CLASS VI PERMIT APPLICATION NARRATIVE

40 CFR 146.82(a)

Sutter Decarbonization Project, Northern California

1.0 Project Background and Contact Information

[redacted]

The Sutter Decarbonization Project ("Project") will geologically store the carbon dioxide (CO_2) captured from the SEC, in strata of the Late Cretaceous Starkey sandstones of the Sacramento Basin (Storage Facility) The proposed Storage Facility is located in Sutter County, approximately [redacted] from the SEC.

This application is for [redacted] UIC Class VI CO_2 injection wells [redacted] associated with the Project.

Using a conservative estimate of the total available pore space acreage, the proposed Storage Facility has the capability of storing over [redacted] of CO_2. The current Project is designed to inject over a [redacted]-year period. Based in part on the results of the Sutter Decarbonization Project, additional field development work may be considered. CO_2 captured by the Project will be delivered to the Storage Facility via a regulated pipeline extending approximately [redacted] from the [redacted] to the Storage Site.

The Project construction schedule is currently pending, but the Commercial Operation Date anticipates the Project will be completed and operational in [redacted].

[redacted] will hold the permits and authorizations necessary for the SEC carbon capture facility and the pipeline. [redacted], a parent company of [redacted], is the applicant for the UIC Class VI CO_2 injection well, CCS1. [redacted] will own and operate the proposed Storage Facility.

Contact for the Applicant is:

[redacted]

[redacted] will be responsible for compliance and implementation of the permit(s) and authorizations necessary for the carbon capture and transport facilities. [redacted], is the applicant for the UIC Class VI CO_2 injection well [redacted] will be responsible for operating the Storage Facility in compliance with all the applicable terms and conditions included in the requested UIC Class VI CO_2 injection well permit. [redacted] is also the owner of the pore space comprising the subsurface of the proposed Storage Facility. Stanford University will also be part of the project team and will develop a state-of-the-art monitoring system that will be ready for implementation once CO_2 injection commences. The plan is to develop a platform (system) that includes both spatial and temporal approaches and analysis. Lawrence Livermore National Laboratory will contribute to the project by supporting community outreach and education and developing a community benefits tracking database and geospatial dashboard.

The documentation included in this UIC Class VI Permit application was prepared in accordance with the U.S. Environmental Protection Agency's (US EPA's) *UIC Control Program for Carbon Dioxide Geologic Sequestration Wells* (The Geological Sequestration [GS] Rule, codified in Title 40 of the Code of Federal Regulations [40 CFR 146.81 et seq.]).

Neither an injection depth waiver nor an aquifer exemption expansion is being requested.

There are no federally recognized Native American tribal lands or territories within the proposed Area of Review (AoR). The proposed area of review (AoR) has no known critical cultural sites or sites of archaeological significance. There is one known place of worship and one known cemetery within a 1-mile buffer zone surrounding the AoR. There are no known schools, hospitals, or nursing homes within the AoR or buffer zone surrounding the AoR.

In the early stages of project development, [redacted] will apply for necessary and applicable permits for federally regulated and state regulated activities as necessary. These permits will cover activities related to transport, storage, and construction for the project. Currently, the project has applied for a state permit from the California Energy Commission as an amendment to existing CEC license 97-AFC-2 as well as an amendment to the existin Title V Permit and Permit to Operate from the Feather River Air Quality Management District.

GSDT Submission - Project Background and Contact Information
GSDT Module: Project Information Tracking ***Tab(s):*** General Information tab; Facility Information and Owner/Operator Information tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Required project and facility details ***[40 CFR 146.82(a)(1)]***

2.0 Site Characterization

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

2.1.1 Starkey storage complex

The term "subsurface storage complex" refers to the geologic storage site that is targeted to safely and permanently store injected CO_2 underground within a storage formation with at least one, or usually multiple, regionally continuous sealing formations called caprocks or seals (NETL 2023). The Sutter Decarbonization Project is proposing storage into the Starkey Storage Complex consisting of the Winters Formation and the Sacramento Shale, a base restrictive interval for CO_2 injection, the injection reservoir, the Starkey Formation which rests unconformably beneath the Capay Formation, a prominent regional stratigraphic marker and upper the seal of the Starkey Storage Complex. The complex consists of a basal confining interval, an injection reservoir, and an upper seal. The stratigraphic relation of these formations is shown in Figure 1.

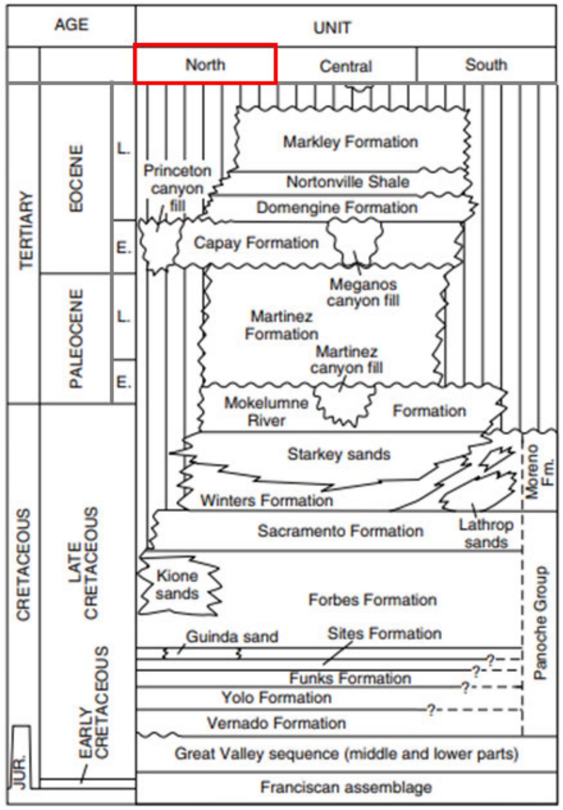

Figure 1. Stratigraphic classification of the Upper Jurassic, Cretaceous, and Tertiary Systems in the Sacramento Basin, California. The Starkey Storage Complex comprises the basal Sacramento Shale, the Winters Formation, upper Starkey Sandstone combined with the storage reservoir, Starkey Clean Sandstone, and Capay Formation as the primary confining zone. The basal contact for lowermost USDW is the Capay Formation (modified from Magoon, 1995).

A well cross-section located one township north of the project area (Figure 2) illustrates the project area, located on the downthrown side of the Willows Fault, and the lateral continuity of the Starkey Storage Complex and the underlying Kione Storage Complex which is without a lateral seal. The Cretaceous Kione Storage Complex, a potential future target for injection operations, (Figure 1) consists of the basal Forbes Formation, a shale with interbedded sandstone lenses, the overlying Kione Sandstone injection zone, and the upper Sacramento Shale, a regional shale and primary upper seal.

[redacted]

Figure 2. Cross-section A to A' shows the stratigraphic sequence from the upper Tertiary deposits to the basement strata transecting the Willows Fault north of the proposed project area. The purple star on the site map is the proposed location of the stratigraphic test well. Source: Harwood, D. S., & Helley, E. J. (1987).

Regional mapping and computational modeling outputs have projected the stratigraphic tops for the Starkey Storage Complex at the proposed stratigraphic test location, shown in Figure 2. The projected stratigraphic tops for the stratigraphic test well are presented below in Table 1.

Table 1. Top depths (in Measured Depth) and thicknesses are taken from the location of the proposed stratigraphic test well.

Formation	Top Depth MD (ft)	Thickness (ft)	Element	Lithology
[redacted]	[redacted]	[redacted]		[redacted]
[redacted]	[redacted]	[redacted]		[redacted]
[redacted]	[redacted]	[redacted]		[redacted]
[redacted]	[redacted]	[redacted]		[redacted]
[redacted]	[redacted]	[redacted]		[redacted]

2.2 Regional characterization

2.2.1 Injection reservoir

The Starkey Formation occurs throughout much of the southern Sacramento Basin, angular unconformities truncate the formation in the subsurface to the north, east, and west (Downey 2010). The Starkey Formation consists of a series of fluvial-deltaic sediments sourced from the Sierra Nevada during the late Cretaceous. The delta depositional system prograded basinwards directed from the East and Northeast towards the South and Southwest. In the literature, three distinct facies are identified: (1) delta front, (2) lower delta plain, and (3) upper delta plain/fluvial. Formation heterogeneity may reduce reservoir quality but improve the likelihood of vertical and lateral trapping of CO_2. The Richter #8-4 well situated west of the Willows Fault zone, identified with a red circle on the west end of the C-C' cross section, (Figure 3a) has a log signature in the Starkey Formation consistent with a coarsening-upward channel facies (Figure 3b) in a progradational setting of the delta front. Table 2 is a compilation of the stratigraphic tops for the Starkey Storage Complex within the Richter #8-4.

[redacted]

Figure 3. (a) Left - Map displays three west to east cross sections transecting the Willows Fault overlying the structure map of the Starkey Clean Sandstone. (b) Right - The geophysical log acquired from the Ricther #8-4 well illustrates the log characteristics from the base of the Kione Sandstone to the upper Capay Shale (not identified on the log).

Table 2. Top depths (in Measured Depth) and thicknesses are taken from the Richter #8-4 well.

Formation	Top Depth MD (ft)	Thickness (ft)	Element	Lithology
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The Starkey Formation is separated into the upper Starkey and the Starkey Clean Sand (shown in the Richter #8-4 geophysical log traces and reflected in stratigraphic tops). The upper Starkey Formation (Figure 4) has been inferred to be a distributary channel environment with overbank thin sands and shales (Edmondson, 1977).

[redacted]

Figure 4. Isochore map of the upper Starkey. [redacted]

The Starkey Clean Sand (Figure 5) or Starkey sand occurs as shallow as [redacted] feet in southern Sutter County, and dips basinward to over [redacted] deep in south-central Solano County; porosities of [redacted] are typical in the Starkey Clean Sand shallower than [redacted] (Downey, 2010). The Starkey Clean Sand is a sequence of deltaic sands and intertonguing shales that conformably overly, and prograde westward over the underlying formations. The Starkey Formation and Winters Formation are different facies of the same depositional system and were contemporaneously deposited. (Johnson, 1990).

[redacted]

Figure 5. Isochore map of the Starkey Clean Sand. [redacted]

The Starkey Formation is located below [redacted] [redacted] on the downthrown side of the Willows fault zone, which implies that CO_2 should be in the required super-critical dense phase.

2.2.2 Confining zones

The Sacramento Shale (Figure 6) is a regional shale below the Winters Formation. On petrophysical logs, the Sacramento Shale is characterized by low density and slow velocities on the sonic log. The Sacramento Shale is also a source rock in the Delta depocenter to the south of the project area (Magoon, 1995). The Sacramento Shale outcrops in the southern Coast Ranges south of the Rumsey-Capay Hills and in the northeastern Diablo Range (Nilsen, 1990).

[redacted]

Figure 6. Isochore map of the Sacramento Shale. [redacted]

The Winters Formation (Figure 7) is mostly shale in the project area, it was deposited in a silt and shale-rich slope environment often referred to as the "Delta Shale" (Nilsen, 1990). The Delta Shale is nearly all clays and fine clastics, most of the coarse clastics from the shelf were distributed through channels to the basin floor (Drummond, 1976); the Winters sand deposition starts in the southwest of the study area. The Delta shale is continuous with the Winters shale in areas where the Winters sand was not deposited (Johnson, 1990). The maximum thickness of the Winters Formation occurs along the axis of the basin. The Winters Formation and Sacramento Shale may appear as one thick shale on geophysical logs; however, these are two separate shales, identified with low density/slow velocity in the Sacramento Shale, which the Winters Shale lacks. The Winters acts as a base seal for CO_2 injection into the overlying Starkey Clean Sand.

[redacted]

Figure 7. Isochore map of the Winters. [redacted]

The Capay Formation (Figure 8) is the upper sealing unit to the Starkey Storage Complex. The Capay Formation is a prominent regional stratigraphic marker due in part to abundant fossil assemblages which are indicative of deposition in the early Eocene. Micropaleontologic data indicate that the lower portion of the Capay was deposited in an outer-neritic environment whereas the upper portion was deposited in an inner-neritic to brackish-water environment (Johnson, 1990). This shale deposition represents the last major transgression in the Lower Eocene; the Capay Formation rests unconformably on top of the Starkey Formation.

[redacted]

Figure 8. Isochore map of the Capay Shale. The [redacted]

2.2.3 General geologic history of the region

The Sacramento Basin represents the northern extent of the Great Valley forearc basin of California. The forearc basin existed for 80 million years of the Mesozoic (Williams and Graham, 2013) between magmatic arc rocks of the Sierra Nevada and Klamath Range to the east and the Franciscan accretionary prism complex of the California Coast Ranges to the west (Figure 9) (Ingersoll, 1979). Siliciclastic fill of this elongate, asymmetric basin is comprised of the Upper Jurassic or Lower Cretaceous (Surpless et al., 2006) to Paleogene Great Valley Group. The Great Valley Group was deposited on the Jurassic age Coast Range Ophiolite in the west and to the east on igneous and metamorphic rocks of accreted Paleozoic terranes (Dickinson and Seely, 1979). The Great Valley Group consists of predominately deep-marine sediments sourced from continental magmatic arc rocks to the east and north (Figure 9). Subduction related tectonism is interpreted to control tilting and subsidence of the basin, which subsequently influenced submarine canyons, channels and associated turbidite-dominated sediments in the forearc basin (Williams and Graham, 2013).

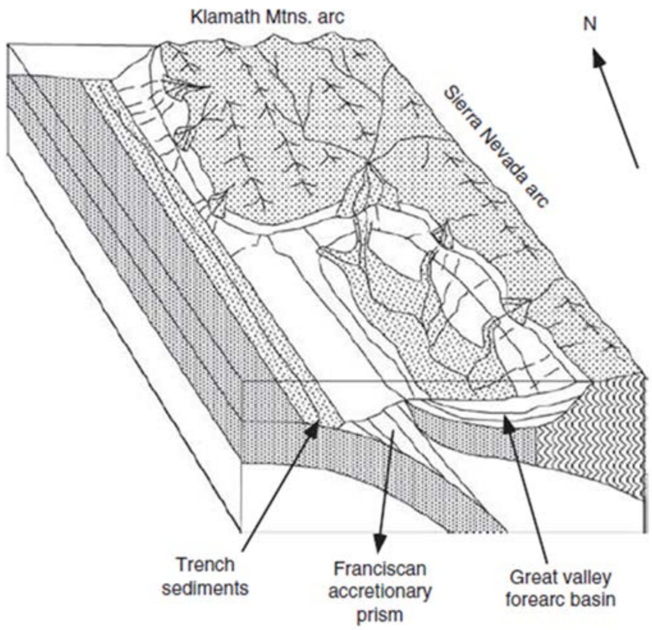

Figure 9. Schematic block diagram of the Late Cretaceous Sacramento Basin. From Williams and Graham, 2013.

Conversion of the California plate margin from convergent to transform during the Cenozoic allowed for preservation of the forearc basin strata (Dickinson and Seely, 1979). Subsequent uplift and deformation of the basin along its western margin is represented by homoclinal folding, uplift, and erosion of the Mesozoic forearc basin fill. Cenozoic deformation of the forearc basin strata is attributed to lateral convergence, transpression, across the San Andreas fault system (Dickinson, 1979; Harwood and Helley, 1987).

The late Cenozoic structural setting of the Sacramento Basin represents a distinct tectonic regime between the Coast Ranges province to the west and the Basin and Range province to the east. Late Cenozoic deformation in the Sacramento Basin has occurred in a stress regime with the maximum component of compressive stress oriented roughly east-west and the minimum compressive stress oriented north-south (Harwood and Helley, 1987). This stress regime has resulted in strain patterns that have developed high-angle reverse faults and folds that trend north-northwest through the Sacramento Basin. This style of deformation is in direct contrast to east-west oriented thrust faults, northwest trending folds and pull-apart basins related to right-lateral displacement along the San Andreas fault system to the west and pervasive east-west extension and volcanism of the Basin and Range province to the east.

[redacted]

Figure 10. Regional shaded relief map including major faults and geographic features relative to the AOR.

2.2.4 Major Geologic Features

Major geologic and structural features local to the AOR include the following:

- The Sutter Buttes
- Willows-Corning fault zone
- Coast Ranges-Sierran Block Boundary Zone (CRSBZ)
- Sierra Nevada Frontal fault system

The Sutter Buttes represent a late Cenozoic volcanic center that is located over the tectonic boundary between oceanic basement rocks comprised of Jurassic ophiolites to the west against metamorphic and plutonic rocks of the Sierran basement (Figure 10). This tectonic boundary between basement terranes is interpreted to roughly coincide with the location of the Willows fault zone to the southeast of Sutter Buttes (Harwood, 1984; Harwood and Helley, 1987). Volcanism occurred between 2.4 and 1.4 Ma and uplifted and deformed the surrounding sedimentary rocks into a dome 8 miles across (Williams and Curtis, 1977).

The Willows-Corning fault zone is part of a N-NW-trending, W-vergent, high-angle basement-involved reverse fault system that is penetrated by wells and imaged on seismic reflection data (Figure 11-Figure 12 and Table 3-Table 4) (Harwood and Helley, 1987, Williams and Graham, 2013). The Willows fault zone extends from the NW corner of the Sacramento Basin, west of Red Bluff, for ~135 miles to the S-SE edge of the basin south of the town of Rosemont (Figure 10). Displacement along the Willows fault and related folding postdates deposition of Upper Cretaceous forearc sediments and precede deposition of the Capay Formation, occurring between 60 and 53 Ma (Harwood and Helley, 1987). Williams and Graham (2013) interpret a component of dextral strike-slip displacement along the Willows-Corning fault zone in addition to previously documented reverse displacement. The Willows-Corning fault zone is not thought to have any Pliocene to Quaternary deformation associated with it and is discussed further in the Faults and Fractures section.

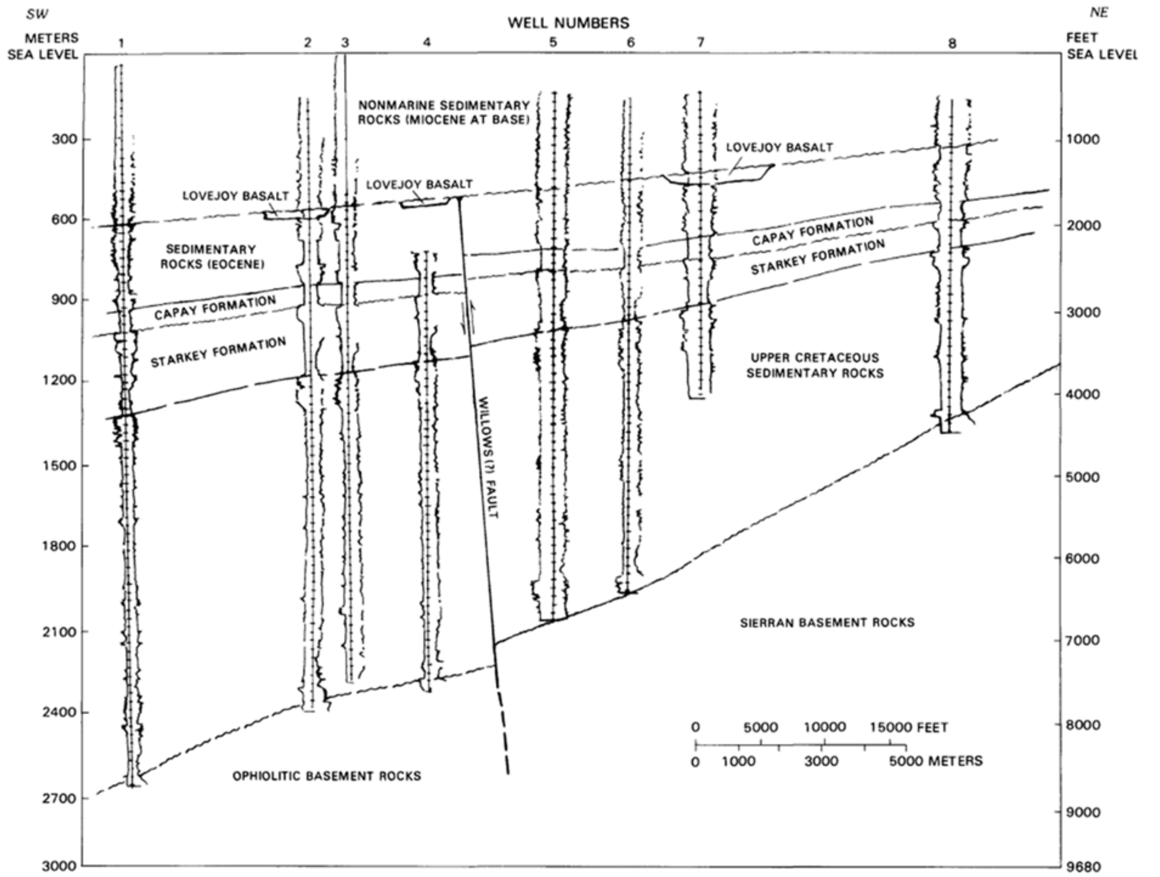

Figure 11. Northern well cross-section showing stratigraphic and structural relationships across the Willows-Corning Fault Zone north of the AOR. See Figure 10 for cross-section location. From Harwood and Helley, 1987. See Table 3 for well information.

Table 3. Well name, operator and locations for northern well cross-section (Figure 11). From Harwood and Helley, 1983.

Well No.	Operator	Well Name	Sec. -T.-R.	Latitude	Longitude
1	Occidental	Zumwalt K-2	12-13N.-1E.	38°59'31.45"N	121°49'4.33"W
2	Shell	Strat test well	31-14N.-2E.	39° 1'10.70"N	121°47'33.86"W
3	G.E. Kadane & Sons	Lamb No. 1	30-14N.-2E.	39° 2'4.38"N	121°47'36.28"W
4	Atlantic	AMKH et al	28-14N.-2E.	39° 2'2.47"N	121°45'35.64"W
5	Atlantic	Continental Stent No. 1	15-14N.-2E.	39° 3'31.28"N	121°43'49.26"W
6	Kenneth L. Sperry	Shannon No. 1	10-14N.-2E.	39° 4'40.80"N	121°44'13.56"W
7	Exxon	Shannon No. 1	14-14N.-2E.	39° 3'53.25"N	121°43'6.53"W
8	Pearson Sibert	Tom No. 1	5-14N.-3E.	39° 5'30.70"N	121°39'50.04"W

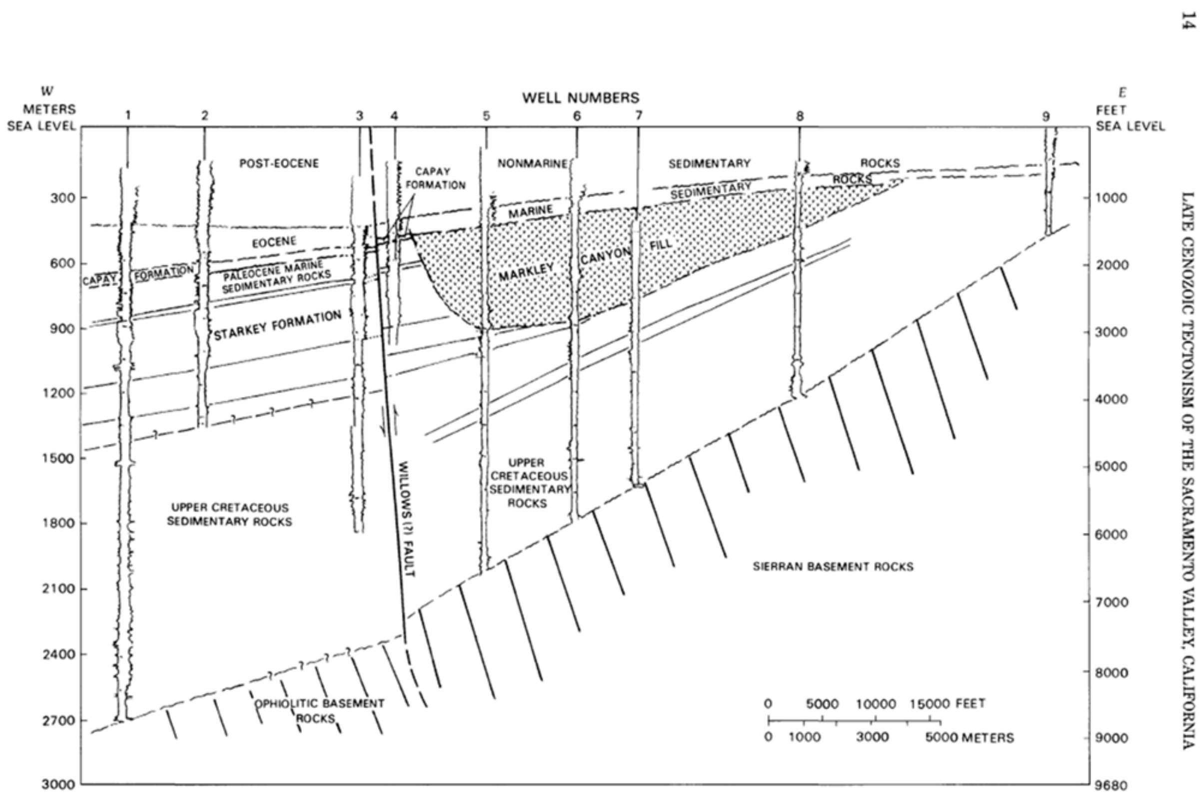

Figure 12. Southern well cross-section showing stratigraphic and structural relationships across the Willows-Corning Fault Zone south of the AOR. See Figure 9 for cross-section location. From Harwood and Helley, 1987. See Table 3 for well information.

Table 4. Well name, operator and locations for southern well cross-section (Figure 12). From Harwood and Helley, 1983.

Well No.	Operator	Well Name	Sec. -T.-R.	Latitude	Longitude
1	Sun Oil Co.	SMC Cameron Dougherty No. 1	31-12N.-3E.	38°50'38.94"N	121°40'57.72"W
2	McCulloch Oil & Gas Crop.	McCulloch-Magoon et al. No. 1	32-12N.-3E.	38°50'40.85"N	121°39'52.20"W
3	Davis Oil Co.	Aileen Marty No. 1	35-12N.-3E.	38°50'42.79"N	121°36'32.00"W
4	Davis Oil Co.	Van Dyke No. 1	35-12N.-3E.	38°50'45.67"N	121°36'2.34"W
5	Decalta Int. Corp	Osterli No. 3	31-12N.-4E.	38°50'44.70"N	121°34'18.52"W
6	Sun Oil Co.	Lenert No. 55-29	29-12N.-4E.	38°51'36.68"N	121°33'10.51"W
7	Kenneth L. Sperry	Davis No. 1	21-12N.-4E.	38°52'29.60"N	121°32'3.77"W
8	Plateau Oil & Gas Co.	Van Dyke No. 1	24-12N.-4E.	38°52'34.43"N	121°28'41.09"W
9	Exxon	Bonnefeld No.1	10-12N.-5E.	38°54'16.42"N	121°24'15.37"W

The western margin of the Sacramento Basin is marked by the Coast Ranges-Sierran Block Boundary Zone (CRSBZ), a zone of compressional reverse/thrust and strike slip faulting between the Coast Ranges and the Sierran Block (Figure 10). This zone is characterized by seismically active blind thrusts associated with tectonic wedging. One such structure is interpreted beneath the Dunnigan Hills region directly to the west of the AoR and is discussed in further detail in the historical seismicity section (Figure 10).

The Sacramento Basin is bordered to the east by the Sierra Nevada foothills (Figure 10). The Sierra Nevada Frontal fault system, or Foothills fault system, separates Paleozoic and Mesozoic metamorphosed volcanic and sedimentary rocks which have been intruded by granitic plutons of Jurassic to Cretaceous age from the Great Valley sequence of the forearc basin (Clark, 1960, Wong, 1992). The Foothills fault system is characterized by Clark (1960) as steeply east-dipping to near vertical faults that are complex zones of sheared, catalastic rocks that tectonically separate Paleozoic and Mesozoic rocks of the Sierra Nevada to the east from forearc sediments of the Sacramento Valley.

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2.3 Maps and cross-sections of the AoR [40 CFR 146.82(a)(2), 146.82(a)(3)(i)]

2.3.1 Wells in the AoR

The Sutter Decarbonization Project Aor contains a total of [redacted] water wells and [redacted] oil and Gas wells (Figure 13, Figure 14, Table). Of these wells, [redacted] penetrate the Starkey Injection complex.

[redacted]

Figure 13. Map of AoR with Main Infrastructure and the end of project plume outlines, proposed injection well locations (red), water wells (blue), protected areas (orange), and major rivers (blue lines).

[redacted]

Figure 14. Map of AoR with proposed surface locations for the injection and monitoring wells (red), oil and Gas wells (green), and water wells (blue) in the AoR.

Table 5. Table of water wells in the AoR. T=Township, R=Range, S=Section, Perf.=Perforation.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.3.2 Injection complex in the AoR

The upper confining unit, the Capay Formation, is laterally continuous across the AoR in both North-South and West-East directions and there are no indications from the geophysical well sections (Figure 15 and Figure 16) of lateral pinch-outs. The Capay Formation is thinnest in the northern section of the AoR and thickens to the south. This relationship will be confirmed upon the interpretation of the 3D seismic acquisition as part of the PhaseII Carbon Safe stratigraphic test well evaluation. The Capay Formation marks the base of the lowest USDW and is an average of [redacted] in the modeled area.

The full injection complex, the Starkey Formation, has been separated into two distinct intervals: the upper Starkey, which has a higher volume of shale in the interval and more variability in the facies and petrophysical parameters. The upper Starkey interval is continuous throughout the AoR and has a fairly consistent thickness ([redacted]). The target injection zone is the Starkey Clean Sand, it is laterally continuous with little variability in facies or thickness throughout the AoR ([redacted]). The Petrophysical properties of the Starkey Clean Sand are also consistently better than the upper Starkey interval. Both Starkey Formation intervals follow the regional trend of thickening to the south.

Further discussion of the regional geology, primary seal thicknesses, and lateral extent, injection zone thickness, and other site-specific geologic characteristics is discussed in the Regional Geology and the Injection and Confining Zone Details sections of this document. Information concerning the faults and fractures and their spatial relation to the injection wells is further discussed in the Faults and Fractures section of this document.

2.3.4 *Cross-sections of the AoR*

[redacted]

Figure 15. West-East geophysical well log cross section with the following tracks (in order from left to right) volume shale log, depth TVDSS, Deep resistivity, Effective porosity, Calculated Permeability. Please note that between the [redacted] well and the [redacted] well is the Willow's Fault.

[redacted]

Figure 16. North-South geophysical well log cross section with the following tracks (in order from left to right) volume shale log, depth TVDSS, Deep resistivity, Effective porosity, Calculated Permeability.

2.4 Faults and fractures [40 CFR 146.82(a)(3)(ii)]

2.4.1 Willows-Corning Fault Zone

The Willows-Corning fault zone extends from the NW corner of the Sacramento basin for ~135 mi to the SE corner of the basin, passing through the NE corner of the AoR (Figure 10). The fault zone is imaged by seismic reflection data and observed on well cross-sections. In the northern portion of the Sacramento Basin the fault zone splays into several disparate fault strands, including the Corning fault, whereas it is delineated as a single fault strand through the central and southern portions of the basin (Figure 10). The Willows-Corning fault zone is a basement involved structure that displays reverse offset and was active throughout the Paleogene and Neogene (Harwood and Helley, 1987). Based on stratigraphic relationships reminiscent of structural inversion in the northern Sacramento Basin, Williams and Graham (2013) infer a component of dextral strike-slip displacement on the Willows-Corning fault system in addition to previously documented reverse displacement.

The Willows-Corning fault zone transects the confining zone intervals of the lower Maastrichtian to upper Campanian Starkey Formation and the lower Campanian Kione Formation. North of the AoR the main strand of the Willows fault zone displaces ophiolitic basement rocks by ~550 ft and the Eocene Capay formation by ~330 ft with eastside up reverse motion (Figure 11)(Harwood and Helley, 1987). South of the AoR the Willows fault zone displaces the Capay Formation by ~100 ft, the Starkey Formation by ~150 ft, and ophiolitic basement rocks by ~500 ft (Figure 12)(Harwood and Helley, 1987).

Further delineation and characterization of the Willows-Corning fault zone is required to address uncertainty around the fault system's stability and sealing capacity. 3D seismic reflection data as part of the CarbonSAFE PhaseII program will help to better understand stratigraphic and structural relationships both across and along the fault zone. The proposed seismic program will additionally allow for characterization of any additional faults and related structures in the AOR. The stratigraphic test well and associated coring program proposed as part of the CarbonSAFE PhaseII project will provide critical rock property, pore pressure, and geomechanical data that will allow for fault zone stability and fluid flow properties to be analyzed. The stratigraphic test well will additionally provide the data necessary to determine fracture presence, density, and orientation within the AoR.

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

2.5.1 Depth, areal extent, and thickness of the injection and confining zones

[redacted] Further data collection in the AoR including the Phase II CarbonSAFE stratigraphic test well and associated tests summarized in the Pre-Operational Testing section will be used to better constrain subsurface uncertainties. Isopachs and a Stratigraphic Column for the Starkey Storage Complex are in the Regional Geology, Hydro, and Local Structure section of this Permit (Figure 1 and Figure 4-Figure 8).

2.5.2 Starkey Formation

The Upper Cretaceous Starkey Formation is a part of a series of deltas sourced from the Sierran arc that prograded to the west and southwest (Cherven, 1983; Downey, 2005; Garcia, 1981). These delta cycles provided sand-rich submarine fan, slope, and basin plain sediment to the shelf edge feeding the Lathrop, Winters, Blewett, and Tracy Formations (Downey, 2005; Garcia, 1981). The cyclical nature of the Starkey delta system and its evolution from a cuspate wave-dominated system with upward coarsening delta facies to a highly lobate system with moderately developed delta plain facies resulted in a high degree of variability to both the lateral and interbedded depositional facies of the Starkey Formation (Cherven, 1983).

Regionally, sandstones of the Starkey Formation can range from a few feet to a few hundreds of feet in thickness with maximum thicknesses upwards of 1500 feet. Porosities for sandstones at the depths below 2900 feet (ft), deeper than the required depth to retain injected CO_2 in the supercritical phase (2600 ft), range from [redacted], while shallower sandstones can have average porosities of [redacted]. There is a single study of permeability data for sandstones in the Starkey Formation in the Sacramento Basin, where values of [redacted] were reported (California Department of Conservation, 1983).

Geophysical logs show that the Starkey Formation has two distinct zones in the AoR. They have been separated as the Starkey (upper) and the Starkey Clean Sand (lower). The Starkey (upper) is on average [redacted] thick in the AoR and the Starkey Clean Sand averages [redacted] in thickness. Porosity and permeability data for each zone is discussed below. The Starkey Clean Sand is located below 2600 feet of depth on the downthrown side of the Willows fault, which suggests that CO_2 can be stored in the super-critical dense phase.

2.5.3 Capay Formation

The Capay Formation, which lies unconformably above the Starkey Formation, is the uppermost sealing unit and a prominent regional stratigraphic marker in well logs. South of the AoR at Bunker Gas Field, Solano County, CA, the Capay shale is described as claystone, interbedded with shale and siltstone (Shariff, 1983). North of the AoR in the Sutter Buttes area, the Capay Formation is described as greenish-gray shale and claystone with buff-colored sandstone interbeds and ranges from [redacted] in thickness (Hausback and Nilsen, 1999). Forams and ostrocods from the Capay Formation indicate deposition in a shallow marine environment and are of Early Eocene Age (Hausback and Nilsen, 1999). Within the AoR, the Capay Formation ranges from [redacted] thick, averaging [redacted], and generally thickening to the southwest. This episode of shale deposition represents the last major transgression in the lower Eocene within the Sacramento Basin (Safonov, 1968). The Capay Formation is the top seal of the Starkey Storage Complex and is the barrier between the proposed CO_2 injection zone and the base of the lowest USDW.

2.5.4 Winters Formation

The Winters Formation rests conformably below the Starkey Formation. The Winters Formation is described as a shale dominated lithofacies within the AoR and is described as shale-rich slope deposits that are fed from a prograding Starkey deltaic system (Downey, 2005; Garcia, 1981; Nilsen, 1990). Distal to the slope shale facies, the Winters Formation is characterized as a turbiditic system down dip of the Starkey Deltas and is noted as a possible source rock to gas accumulations in the area (Garcia, 1981; Magoon, 1995). At the Union Island gas field, lithofacies within the Winters Formation are highly variable and include thick basal sandstone, interbedded sandstones and shales, and laminated shales (Williamson and Hill, 1981). For this reason, the Winters Formation acts as the primary base seal for proposed CO_2 injection into the overlying Starkey Clean Sand.

2.5.5 Sacramento Shale

The Upper Cretaceous Sacramento Shale is a regional shale below the Winters Formation and acts as a secondary base seal for CO_2 injection into the Starkey Clean Sand. It was deposited during a late Campanian transgression in the Sacramento Basin (Cherven, 1983; Downey, 2005). The Sacramento Shale has historically been identified as a regional seal for hydrocarbon exploration and as a source rock in the deltaic depocenter to the south of the AoR (Magoon, 1995; Scheirer, 2007). Regionally, the Sacramento Shale has been noted to be upwards of [redacted] thick and in the area of interest, it averages [redacted] thick. On petrophysical logs, the Sacramento shale is characterized by a low density and slow velocity signature on the sonic log. Mudlogs describe the Sacramento Shale as soft, slightly soluble, with hydrated lumpy organic material (which may cause the low density log signature). Acquiring rotary sidewall cores may be difficult due to the materials softness.

2.5.6 AoR thickness variability of the injection and confining zone

Petrophysical logs indicate that all zones are present in the AoR, and generally thicken to the south-southwest. The total thickness of the Starkey Storage Complex, including the Capay Formation top seal, the Starkey Formation injection zone, and the Winters Formation and Sacramento Shale base seals, ranges from [redacted], with an average thickness of [redacted]. The cross sections shown in Figure 15 and Figure 16 of the Maps and Cross Sections of the AoR section show the lateral continuity of each of the zones of interest across the AoR. 3D seismic data acquisition and interpretation, planned for Phase II of this CarbonSAFE project, will be used to confirm the lateral continuity and stratigraphic relationships of the confining zones prior to well construction and injection.

2.5.7 Mineralogy of the injection and confining zones

No direct mineralogy data was available within the AoR for analysis at the time of this report. Provenance studies of the Capay Formation (N=9) by Baker (1975) and the Great Valley Sequence - K.P Helmhold data (N=15) (Dickinson et al, 1982; Mertz and Nilsen, 1990) provide the framework mineralogy and source terrane interpretation for the late Cretaceous and Eocene stratigraphic intervals. Mineralogy for the Sacramento Shale was not available.

In both the Capay and the Starkey/Winters/Kione/Forbes Formations, the framework mineralogy classifies the intervals as Lithic Arkose (Q-F-R) and is identified as having a dissected arc provenance (Q-F-L), falling within the Circum-Pacific Volcanic-Plutonic suites of the Qm-P-K diagram (Figure 17)

(Dickinson, 1985). These classifications are further supported by paleo current data from Baker (1975), which indicate provenance from the N-NE, with lithics being dominated by plutonic and volcaniclastic detritus (Baker, 1975; Cherven, 1983; Dickinson, 1985; Ingersoll, 1983; Mertz and Nilsen, 1990, Mertz, 1990).

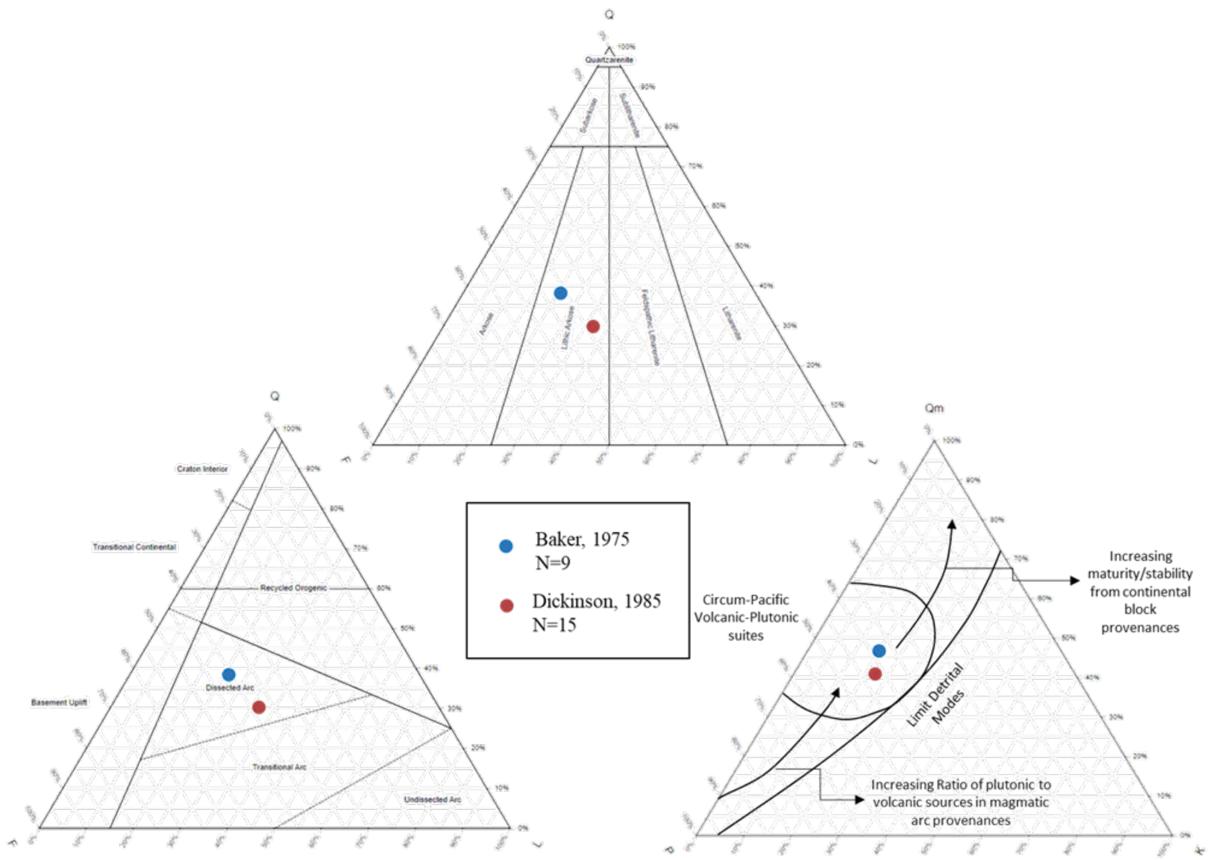

Figure 17. Ternary diagrams showing provenance fields defined by total quartz (Q), total feldspar (F), and lithic (L) sand(stone) composition (Lower Left); and Total monocrystalline Quartz (Qm), Plagioclase Feldspar (P), and Potassium Feldspar (K) (Lower Right) (after Dickinson, 1985); Sandstone identification from Folk, 1970 (Upper).

Additionally, XRD data of the Starkey Formation is available from the analog WESTCARB study 50 miles to south of the AoR (Citizen Green #1 well (API07720688) and further support the framework mineralogical classifications of the Upper Cretaceous Starkey Formation. XRD data averaged 41% Quartz, 7.6% Potassium Feldspars, 33% Andesine, 6% detrital Mica, and approximately 12% authigenic minerals and clays (Ajo-Franklin et al., 2022). These mineral constituents are consistent with derivation from a Sierran arc/Klamath source and subsequent framework mineralogy studies (Barth, 2011; Dickinson, 1985; Hotz,1971; Ingersoll, 1983).

2.5.8 Injection and confining zone geochemical sensitivity

Given the arkosic nature of the Starkey Formation Clean Sand, it is possible that reactions similar to those observed in the Mt. Simon sandstone, which include dissolution of feldspars leading to increased porosity and permeability, and changes to the rock's mechanical strength, may be possible (Harbert et al, 2020). These geochemical changes, however, cannot be modeled accurately without information on the formation fluids and detailed mineralogic data for the injection and confining zones. Geochemical modelling to address these questions is proposed as part of the Stratigraphic test well for the PhaseII

CarbonSAFE Project. The proposed CO_2 stream will be greater than 95% pure prior to injection after dehydration and compression. Expected geochemical reactions with brine and injection/confining zone rocks are discussed in the Geochemistry section.

2.6 Porosities and Permeabilities

Porosities and permeabilities from geophysical logs of 22 wells were used to characterize the pore space of the injection and confining zones in the AoR and surrounding area. These data were used to inform the storage capacity estimates discussed below and the simulation model discussed in the AoR and Corrective Action Plan. Effective porosity (XPORE) for each of the intervals was derived from historical wireline logs within the model area (Figure 18). The calculation for this measurement was:

XPORE = PHIT – VSH*SHPHI

where PHIT was the total porosity, and VSH*SHPHI was representative of volume of clay-bound water in the shale. Notably, because XPORE accounted for clay-bound water, the addition of a net to gross cutoff was not necessary with the given dataset.

Permeabilities (XPERM) were calculated using a modified Timur equation (Timur, 1968); which links permeability with the porosity and irreducible water saturation in sandstones. These data were then constrained by the reported values in the literature by ensuring that the P50 calculated average permeabilities by well were less than 100mD (California Department of Conservation, 1983). Table 7 in the Geomechanical and Petrophysical Information section gives the average values for the thicknesses and petrophysical properties calculated for the wells.

For the simulation model, the porosities and permeabilities at the 22 wells in the model area were averaged over each of the layers in each of the zones. Figure 19a and Figure 19b show the distribution of the well logs within the modeling domain. The model contained two zones: the Starkey upper and the Starkey Clean Sand. [redacted] Petrophysical properties for each layer are outlined in table 4 in the AoR and Corrective Action Plan. This methodology was chosen to better reflect the vertical variability of the petrophysical parameters observed in deltaic systems of comparable size in the absence of a lithofacies model.

[redacted]

Figure 18. Map of wells with petrophysical log evaluation used to characterize the injection and confining zones and build the property model in the simulation described in the AoR and Corrective Action Plan. Blue line is the W-E cross section and green line is the N-S in the Maps and Cross Sections of the AoR section of the permit.

[redacted]

Figure 19. Spatial distribution of the XPORE (19a – Left) and XPERM (19b – Right) logs used to characterize the Starkey Injection complex and build the 3D simulation model (further discussed in the AoR and Corrective Action Plan).

2.6.1 Citizen Green well

The nearest available core data from the Starkey Clean Sand was collected from the Citizen Green Well #1 (API 07720688). This well was drilled in the King Island Field, San Joaquin Valley, CA as part of the WESTCARB partnership basin characterization effort and lies approximately 50 miles to the south of the AoR. The four rotary sidewall cores from the Starkey Clean Sand, report porosity measurements between [redacted] and air permeability measurements from [redacted] (Ajo-Franklin, 2022). These rotary sidewall cores show a greater range of variability, and overall, the permeability measurements are higher than what we calculate from well logs within the AoR. This data suggests that while the presented model may oversimplify the subsurface variability, it is conservative when considering flowability of the reservoir.

2.7 Storage capacity and injectivity

The estimated storage capacity of the proposed injection zone assumes CO_2 injection into the sandstone dominated facies of the Starkey Formation and is based on rock formation data from the nearby Richter #8-4 well. Based on the Richter #8-4 well that demonstrates a net sandstone thickness of [redacted] ft and a total porosity value of [redacted] the Starkey Formation sandstones have an estimated storage capacity of [redacted] per square mile, assuming a storage efficiency of [redacted]. The total estimated p50 storage capacity within the proposed AoR, constituting an area of [redacted], is approximately [redacted]. This suggests that the Starkey Formation should provide more than adequate storage capacity to meet the [redacted] goal of the CarbonSAFE program.

Single well CO_2 injectivity into the sandstones of the Starkey Formation are modeled using the EasiTool from University of Texas GCCC - Gulf Coast Carbon Center. Assumptions for single well injectivity include the following (Table 6):

- Injection over [redacted] years.
- A fracture gradient of [redacted].
- Maximum injection pressure is [redacted] of the fracture gradient.
- Injection into clean sandstone of the Starkey Formation.

The estimated single vertical well injectivity given the above assumptions is [redacted] for the Starkey Storage Complex. Simulation modeling parameters and results are further discussed in AoR and Corrective Action Plan.

Table 6. Summary of the input parameters, efficiency factors and storage capacity for the EasiTool from University of Texas GCCC - Gulf Coast Carbon Center (Hosseini, 2018).

Region	Formation Name	Pressure	Temp	Net Thickness	Total Porosity	CO_2 Density	Storage Efficiency Factor			Rock Type	GCO2=Resource Estimate Potential Mt/mi2		
		psi	°F	ft	%	Lbs/ft^3	P10	P50	P90		P10	P50	P90
[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]		[redacted]			[redacted]		

Limited data are currently available to assess the integrity of the Capay Formation confining zone which lies above the Starkey Formation storage target. The 3D seismic program of the CarbonSAFE PhaseII project will help to delineate the lateral extent and thickness of the Capay Formation as well as map the presence and amount of displacement due to late Cenozoic faulting (see discussion in Faults and Fractures section). Critical rock property and capillary pressure measurements will be made available through the proposed stratigraphic test well and associated logging and coring programs of the CarbonSAFE PhaseII project. Data from the stratigraphic test well will allow for the collection of rock property information and geomechanical studies within the AoR necessary to address the integrity of the confining zone.

2.8 Uncertainties and further testing

Injection and confining zone characterization within the AoR will be further studied with the collection of data at the Phase II CarbonSAFE stratigraphic well and the data outlined in the Pre-Operational Testing section of this permit. Wireline logs, in-situ fluid and pressure testing, rotary sidewall cores, and whole cores will be collected at the injection well site during construction. 3D seismic data will be acquired to determine the lateral extent, depth, thickness, and structural integrity of the injection and confining zones and integrated with core and wireline logs. Core collected from the Starkey Clean Sand injection interval and the Capay Formation top seal and Winters/Sacramento bottom seal will be run through a suite of laboratory measurements to better address the uncertainties outlined herein. Please refer to the Pre-Injection Operational Testing section for the summary of data to be collected pre-injection.

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2.9 Geomechanical and petrophysical information [40 CFR 146.82(a)(3)(iv)]

2.9.1 Petrophysics

Petrophysical calculation methods from geophysical wells for the injection and confining zone are discussed in the Injection and Confining Zone Characteristics section and are summarized in Table 7. Petrophysical well log sections can be found in the Maps and Cross sections of the AoR section of the report.

Table 7. Average, median, maximum, and minimum thicknesses and XPORE and XPERM values calculated from geophysical well logs in the AoR and surrounding modeled area.

Zone Averages						
Measurement Type		**Capay Shale**	**Starkey**	**Starkey Clean Sand**	**Winters**	**Sacramento Shale**
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

2.9.2 Geomechanics

A geomechanical study, as proposed by the CarbonSAFE PhaseII project, is required to address key questions regarding the confining zone interval. Cores collected from the stratigraphic test well proposed for this program will provide measurements of rock strength and ductility for the confining zone. The stratigraphic test well will also allow for detailed fracture analysis (see discussion in Faults and Fractures section). Pore pressure of the confining zone and in situ stress measurements will also be made available with the proposed stratigraphic test well and will allow for analysis of the stability of nearby faults (see discussion of the Willows-Corning fault zone in the Faults and Fractures section).

Regional observations of the in situ stress field orientation and mode are available from the World Stress Map. Borehole breakout measurements approximately [redacted] miles south of the AoR, and from depths between 3,166 to 5,768 feet, show a maximum compressive stress (SHmax) azimuth of 47° (B quality, to within ±20°), the mode is undefined (Table 8) (Heidbach et al., 2018). Focal mechanism analysis from within the Sacramento Basin place the basin in the thrust faulting (TF) regime and show SHmax azimuth orientations 99-105° (D quality, to within ±40°) or roughly east-west (Table 8) (Heidbach et al., 2018). None of the available in situ stress observations are within the AoR of the project.

Observations from the World Stress Map that place the orientation of SHmax at roughly northeast-southwest to east-west in a thrust fault regime suggest that the northwest-southeast trending Willows-

Corning fault zone (see discussion in Faults and Fractures section) may be optimally orientated for possible reactivation. Detailed geomechanical analysis of the in situ pore pressure and the critical pressure threshold for reactivation of this fault system is required to understand the stability of this fault system and any others that are identified from subsequent seismic surveys as part of the CarbonSAFE PhaseII project.

Table 8. World Stress Map observations of SHmax orientation and mode. Quality is ranked from A-E. Regime: U = Undefined, TF = Thrust Fault. Type: BO = Borehole Breakout, FMA = Focal Mechanism Average. (Heidbach et al., 2018).

[redacted]

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

2.10.1 Regional Seismicity

The USGS ANSS (Advanced National Seismic System) Comprehensive Earthquake Catalog which includes the CGS (California Geologic Society) network is used to provide the historical seismicity record for the AoR locally and regionally (USGS, 2017). Regional historical seismicity was considered for a 100 mi radius around the approximate center of the AoR for a 40-year time period (extending from May 2023 to May 1983) with a magnitude greater than M2.5 (Figure 20) and M4.0 (Figure 21) (USGS, 2023).

[redacted]

Figure 20. Regional seismicity within a 100-mile radius of the AOR with magnitude > 2.5 for a 40-year interval (USGS, 2023). Note that sesimicity is concentrated around the basin margins in the Coast Ranges, Klamath Mountains and Sierra Nevada.

[redacted]

Figure 21. Regional sesimicty within 100-mile radius of the AOR with magnitude > 4.0 for a 40-year interval (USGS, 2023). Note that there is no seismicity of this magnitude within the Sacramento Basin.

Regional seismicity is broadly distributed throughout the Sacramento Valley with increasing density and frequency towards the basin margins, this includes the Coast Ranges along the southwestern border of the basin and the Sierra Nevada to the northeast (Figure 20). During the 40-year interval from May 2023 to May 1983 there have been 7169 earthquakes of magnitude 2.5 or greater (Figure 20), of these, 25 earthquakes have been of magnitude 4.0 or greater (Figure 21). None of the magnitude 4.0 or greater earthquakes have occurred within the Sacramento Basin as these earthquakes represent deformation in tectonic regimes separate from that observed in the Sacramento Basin (see Regional Geology for further discussion). This relationship of a relatively seismically stable basin surrounded by regions of active deformation and seismicity is also demonstrated on the USGS Geologic Hazard Map for California (Figure 22) (USGS, 2014).

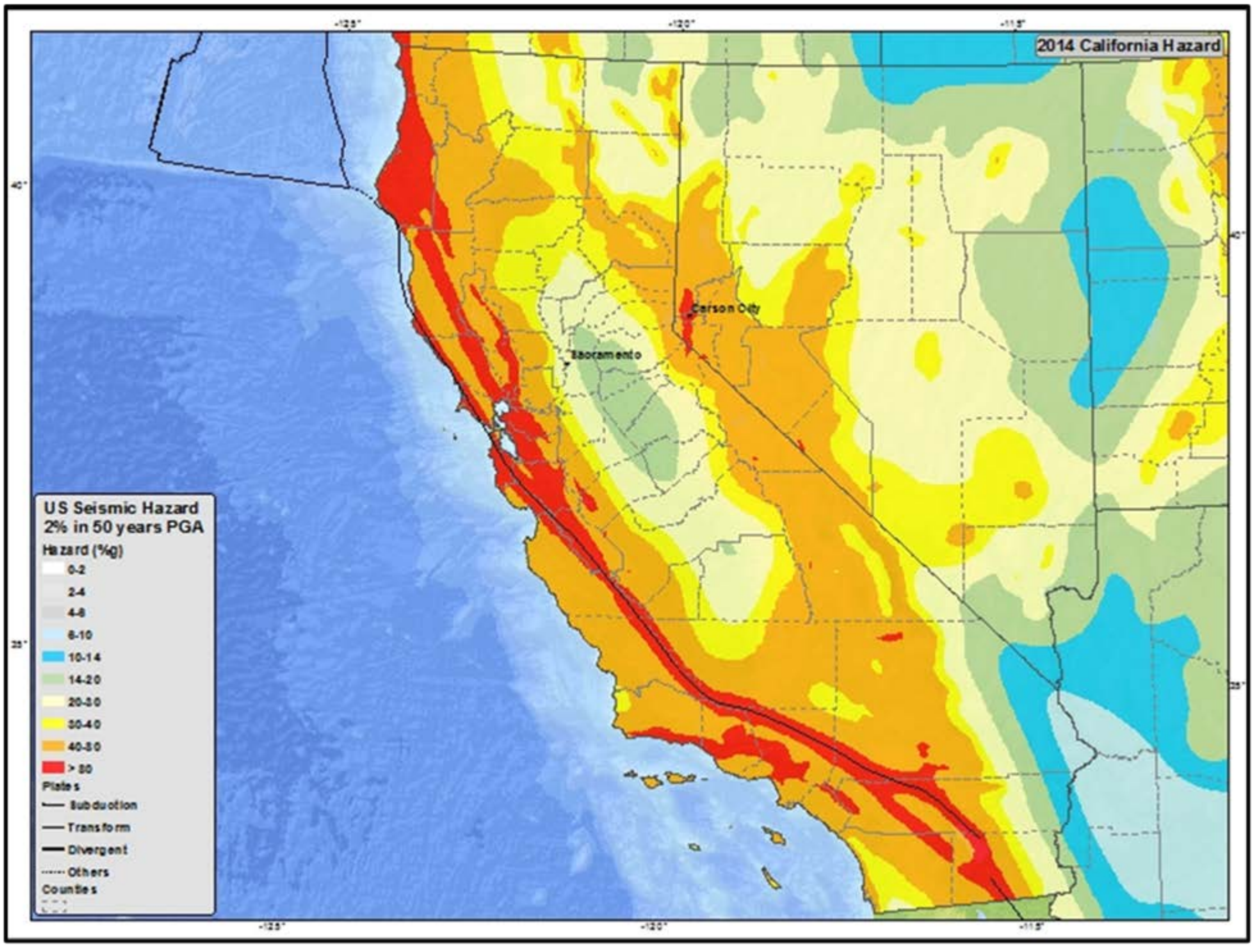

Figure 22. USGS Geologic Hazard Map, 2014.

The Coast Ranges-Sierran Block Boundary Zone (CRSBZ; Wong and Ely, 1983) is the most proximal zone of notable seismicity to the AoR and is located along the western margin of the Great Valley (Unruh, et al., 2019). The CRSBZ is also referred to as the Great Valley thrust fault system by the Working Group of Northern California Earthquake Potential (WGNCEP, 1996) and is used by Uniform California Earthquake Rupture Forecast 2 (UCERF2; WGCEP, 2007, Wills et al., 2008) and 3 (UCERF3; Dawson, 2013) statewide models. Deformation along the CRSBZ in the Southern Sacramento Valley area is expressed by en echelon west-dipping blind thrust faults (O'Connell et al., 2001) and locally by growth anticlines in the Rumsey and Dunnigan Hills area (Unruh and Morres, 1992).
In the Dunnigan Hills area, discrete clusters of small earthquakes occur below ~ 23,000 ft (7 km) on what are interpreted as basement faults beneath imaged thrust faults and tectonic wedging of the eastern CRSBZ (Figure 23, nDUNH) (Unruh, et al., 2019). These structures represent the most proximal sources of Quaternary deformation to the proposed storage AoR.

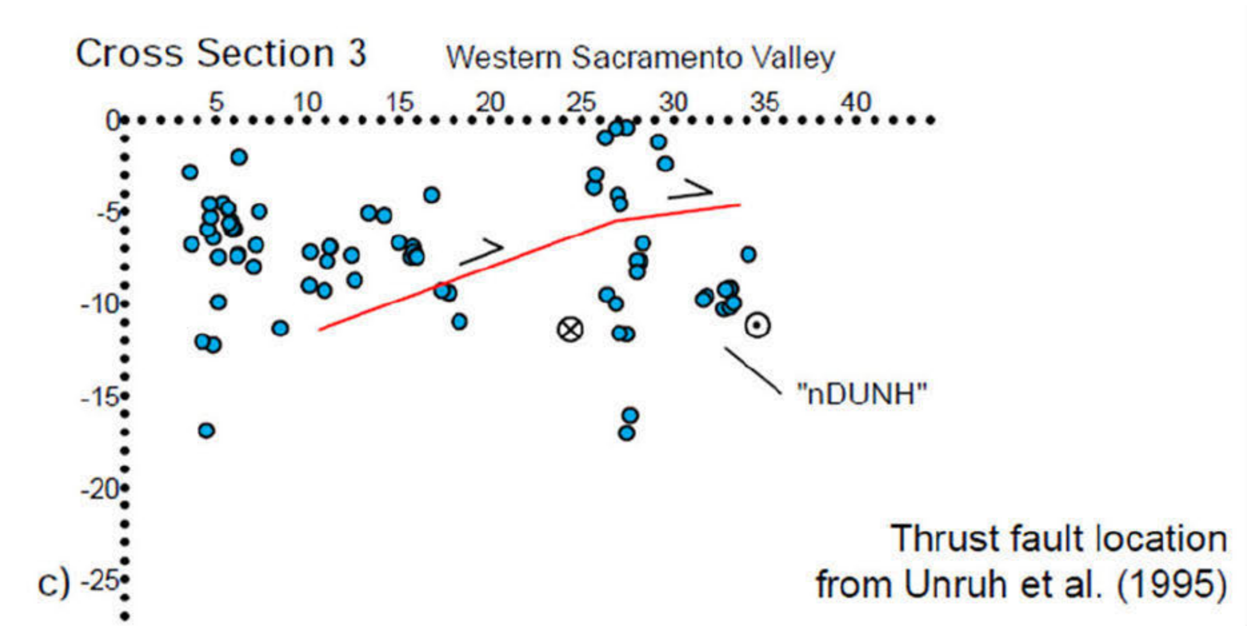

Figure 23. NW-SE oriented cross section of the Dunnigan Hills area showing the location of earthquakes (blue circles) and interpreted blind thrust fault (red). For the location of cross-section see Figure 10.

2.10.2 Local seismicity

Over the 40-year period from May 2023 to May 1983 a total of 19 earthquakes have occurred within [redacted] miles of the AOR, with a magnitude greater than 0 (Table 9 and Figure 24). Of these 19 earthquakes only two of them are greater than magnitude 2.5, both of these earthquakes, one of M 2.56 and the other of M 2.93, occurred in 1995 at significant depth in basement rocks (Table 1). Most of the 19 earthquakes have occurred deep within the Sacramento Basin or in basement rocks, only two shallower earthquakes were recorded, one a M 1.52 at 3,297' and one a M 1.6 at 6,998' (Table 9).

Overall, the historical seismicity record suggests that the proposed storage location is not in a seismically hazardous location. Fault stability and induced-seismicity potential are discussed in the Geomechanics section.

Table 9. Historic local seismicity from May 1983 to May 2023 within a [redacted] radius of the center of the AOR.

[redacted]

[redacted]

[redacted]

Figure 24. Local seismicity within a [redacted] radius of the AOR with magnitude > 0 for a 40-year interval (USGS, 2023).

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2.11 Hydrologic and hydrogeologic information [40 CFR 146.82(a)(3)(vi), 146.82(a)(5)]

2.11.1 Hydrogeologic description

The following discussion about the local freshwater aquifers, which comprise the Underground Sources of Drinking Water (USDW) is described from youngest to oldest (shallowest to deepest). This section describes a generalized stratigraphic section to the top of the bottom of the Ione Formation/ top of Capay Formation, considered the base of freshwater and the deepest point of any USDWs. The definition of a base of fresh water for the State of California differs from what is Federally considered a base of fresh water, which in this permit application is the deepest source of USDWs. The limit for freshwater in California is 3,000 μMhos (equivalent to 3,000 μS/cm), which is about 1,923 ppm of total dissolved solids (TDS). The federal USDW limit is 10,000 ppm TDS. TDS data within the AoR were from wells that were relatively shallow and therefore not near the USDW limit, or from significantly deeper oil and gas wells, beyond the depth at which the USDWs are no longer present. [redacted] The proposed project, therefore, will protect all water above the top of the Capay Formation as a USDW.
Holocene Alluvium

The uppermost geologic unit in the Sutter County area of the Sacramento Basin is the Holocene Alluvium, composed of unconsolidated sediments deposited during the Holocene epoch. These fluvially deposited sediments include silt, sand, and gravel, with occasional clay layers, and were deposited primarily from the Feather and the Sacramento rivers (Helley and Harwood, 1985). The Holocene alluvium is a source of shallow groundwater. The following description is from the 2016 Sutter Subbasin Alternative Plan:
"Deposits further from the river beds thin in thickness and also become finer gained. These sediments are highly permeable and provide areas where groundwater can be recharged and wells can yield from 2,000 to 4,000 gpm (DWR, Bulletin 118 – 2006 Update)."

2.11.2 Late Pleistocene alluvium

Underlying the Holocene Alluvium is the Late Pleistocene Alluvium (Older Alluvium), which consists of alluvial deposits from the last glacial period. Similar to the Holocene Alluvium, these sediments are also composed of unconsolidated silt, sand, and gravel with occasional clay layers (Helley and Harwood, 1985). The Late Pleistocene Alluvium is generally more compact and less permeable than the overlying Holocene Alluvium but still contributes to the overall groundwater system in the region. The following description is from the 2016 Sutter Subbasin Alternative Plan:
"The Older Alluvium consists of the Modesto and Riverbank Formations, and the Victor Formation. These sediments are fairly similar and grouped together in the cross sections.
In the study area, the Modesto Formation is characterized mostly by gravels, cobbles, and sand with some silt and clay. It was encountered from the ground surface to about 70 to 120 feet bgs just to the west of Yuba City near SEWD Well #1. The formation is thicker to the south and thins to the north, with beds that are generally flat-lying (GEI, 2008).
In the study area, the Riverbank Formation underlies the Modesto Formation, and is also sedimentary in origin, and is composed of silts and clays with 10- to 20-foot thick sand and gravel layers. The sand and gravel beds of the Riverbank Formation are thinner and less laterally extensive than those of the overlying Modesto Formation and are therefore more difficult to predict where they may occur. Similar to the Modesto Formation, the Riverbank Formation is thicker to the south, and thins closer to the Sutter Buttes, with beds that are generally flat-lying (GEI, 2008).

The Victor Formation is approximately 100 feet of Sierran alluvial fan deposits consisting of loosely compacted silt, sand, and gravel with lesser amounts of clay deposits. The deposit thins with distance to the west of the Yuba River and the foothills and wells can yield up to 1,000 gpm."

2.11.3 Laguna Formation

Below the Late Pleistocene Alluvium is the Laguna Formation, which was deposited in the Pliocene epoch. This unit is characterized by marine and non-marine sedimentary deposits, including sandstone, siltstone, claystone, and conglomerate (Bartow, 1984). The sediments within the Laguna Formation are primarily derived from the erosion of the Sierra Nevada and are associated with a fluctuating sea level during the Pliocene. The Laguna Formation typically has lower permeability than the overlying alluvial units, which results in a less significant contribution to groundwater resources. The following description is from the 2016 Sutter Subbasin Alternative Plan:
"The formation occurs above the Sutter Buttes Rampart and is unconformably overlain by the Riverbank Formation. The formation consists of two alluvial units and the Nomlaki Tuff Member which is a regional tuff that is a time correlative marker. The Nomlaki Tuff is also present in the Tuscan Formation which is part of the Sutter formation in the study area. Each of the two units create fining upward packages with basal gravels fining up through sand, silt and clay (Busacca, others. 1989). The Laguna Formation in the study area is thinner to the north and thickens to the south with the thickness ranging from about 80-feet in the north to almost 700-feet to the south."

2.11.4 Sutter formation

The Sutter formation is an informal stratigraphic designation for several regionally extensive units. These units are highly spatially variable and have different facies depending on the proximity to their sources. From Springhorn, 2008:
"Transportation of these sediments from their source areas, largely by fluvial processes has produced a large thickness of reworked volcaniclastic and epiclastic strata in the subsurface of the Central Sacramento Valley. This overlap and mixture of formal and informal stratigraphic units, has created complications and confusion in subsurface studies due to the lack of distinguishing characteristics of these deposits. To avoid further confusion, the various nomenclatures of these units have been grouped together as a single informal stratigraphic unit in this study for the purpose of subsurface correlation."
The following description is from the 2016 Sutter Subbasin Alternative Plan:
"The Sutter formation is generally characterized by black, blue, gray and greenish gray, angular to sub-rounded sand gravel. The Sutter formation is an informal unit and consists of sediments interpreted to be the distal portion of the upper Princeton Valley Fill, Mehrten Formation, Nomlaki Tuff, and Tuscan Formation (Springhorn, 2008). The presence of either of these units varies with the relative location of the Sutter Formation with the Sutter Buttes.

The upper Princeton Valley Fill is in the lower portion of the Sutter Formation and lies unconformably above the Lovejoy Basalt (Williams and Curtis, 1977). It consists of fluvially derived sands, conglomerates, and shales up to 1,400 feet thick (Redwine, 1972). The Valley Springs Formation of the Sierra Nevada, located greater than 2,000 feet deep in the Sacramento Valley or found shallower near the eastern margin of the valley, consists of tan, white, and green rhyolitic fragments and is the equivalent to the Princeton Valley Fill (Springhorn, 2008).

The Mehrten Formation consists of fluvial deposits, cobble tuff breccia deposits, tuff deposits, and tuff breccia deposits from the Sierra Nevada (Moses, 1985). The deposits primarily consist of clastic and pyroclastic andesitic fragments that have been deposited as sandstone, siltstone, conglomerate, and tuff breccia.

The Nomlaki Tuff, found in the lower to middle portion of the Sutter formation, consists of white to light gray dacitic pumice tuff dated at 3.4 Ma (Harwood, 1981). The Nomlaki Tuff is near the bottom of the Tuscan Formation.

The Tuscan Formation, a primary aquifer in the northeastern Sacramento Valley, is composed of volcanic sediments derived from Mount Yana located south of Lassen Peak (Lydon, 1968). The Tuscan Formation is subdivided into Unit A through Unit D and mostly consists of interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone with slightly varying mineral compositions and a couple notable tuff members (Harwood, 1981)."

2.11.5 Ione Formation

The Ione Formation is Eocene in age and comprised of non-marine sedimentary deposits. The primary constituents of the Ione Formation include claystone, siltstone, sandstone, and locally developed conglomerate layers, which were deposited in lacustrine and fluvial environments (Bartow and McDougall, 1984).

The sediments in the Ione Formation are largely derived from the weathering and erosion of the Sierra Nevada. The unit records a time of significant tectonic activity, with associated changes in regional drainage patterns and sediment supply (Bartow and McDougall, 1984). The Ione Formation generally has moderate to low permeability, depending on the lithology and degree of cementation. This often limits its contribution to groundwater resources, although more permeable sandstone layers can locally provide water-bearing potential. The Ione overlies the Capay Formation, which is considered the base of freshwater, within which no USDW is present, and the caprock for the storage reservoir, which is described in the regional geology portion of this application.

2.11.6 Groundwater flow direction in principal aquifer zones

The following Figure 25 shows the general groundwater surface elevation contours and flow direction for the Aquifer Zone-1 (AZ-1) as defined in the Sutter Subbasin Water Year 2022 Annual Report. The general flow direction is from northwest to southeast. The general flow direction for AZ-2 and AZ-3 is also from northwest to southeast. The aquifer zones in the subbasin are defined as follows:

- Shallow Aquifer Zone, up to 50 feet bgs
- AZ-1 between 50 and 150 feet bgs and includes the Modesto Formation and Riverbank Formation
- AZ-2, between 150 and 400 feet bgs and includes the Sutter Buttes Rampart and Laguna Formation
- AZ-3, deeper than 400 feet bgs includes the Laguna Formation, Sutter Buttes Rampart and Sutter Formation. Each of these aquifer zones is identified as a principal aquifer within the Sutter Subbasin. These are the primary zones where USDW is produced.

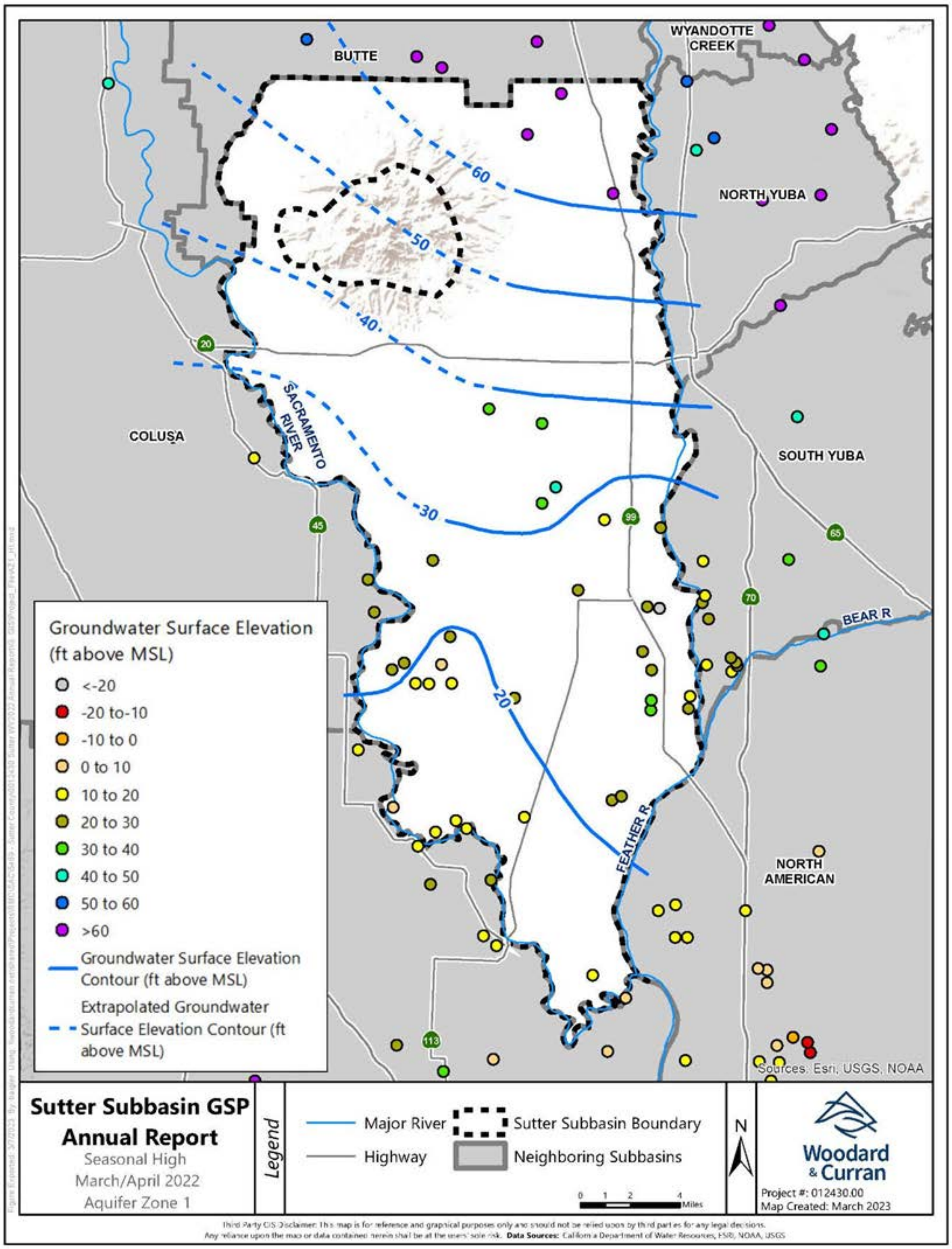

Figure 25. Seasonal High Groundwater Levels in AZ-1, March and April 2022 (From Sutter Subbasin Water Year 2022 Annual Report to the Groundwater Sustainability Plan)

2.11.7 Drinking water wells within AoR

There were approximately 100 well completion reports located in the California Department of Water Resources Well Completion Report database. The wells ranged from a 19-ft deep well drilled in 1942 (WCR1942-000117) to a 1,000-ft deep exploratory borehole that was completed into a 360-ft deep well (WCR2012-004355) in 2012.

2.11.8 Water quality in principal aquifer zones

The Sutter Subbasin Groundwater Sustainability Plan (GSP - Figure 26) has a representative monitoring network for groundwater quality in the aquifers that are used for drinking water and agricultural uses. The network consists of wells distributed both spatially throughout the subbasin and vertically through the different aquifer zones (Shallow, AZ-1, AZ-2 and AZ-3). The following figure shows the location of the groundwater quality wells and the tables provide the well construction details along with the aquifers monitored and the water quality results. The GSP was completed in 2022 and the water quality data presented in the tables below from the GSP are the most recent water quality data for the subbasins monitoring well network and are from 2009 to 2012. In 2024 the annual report update will provide water quality data from 2023.

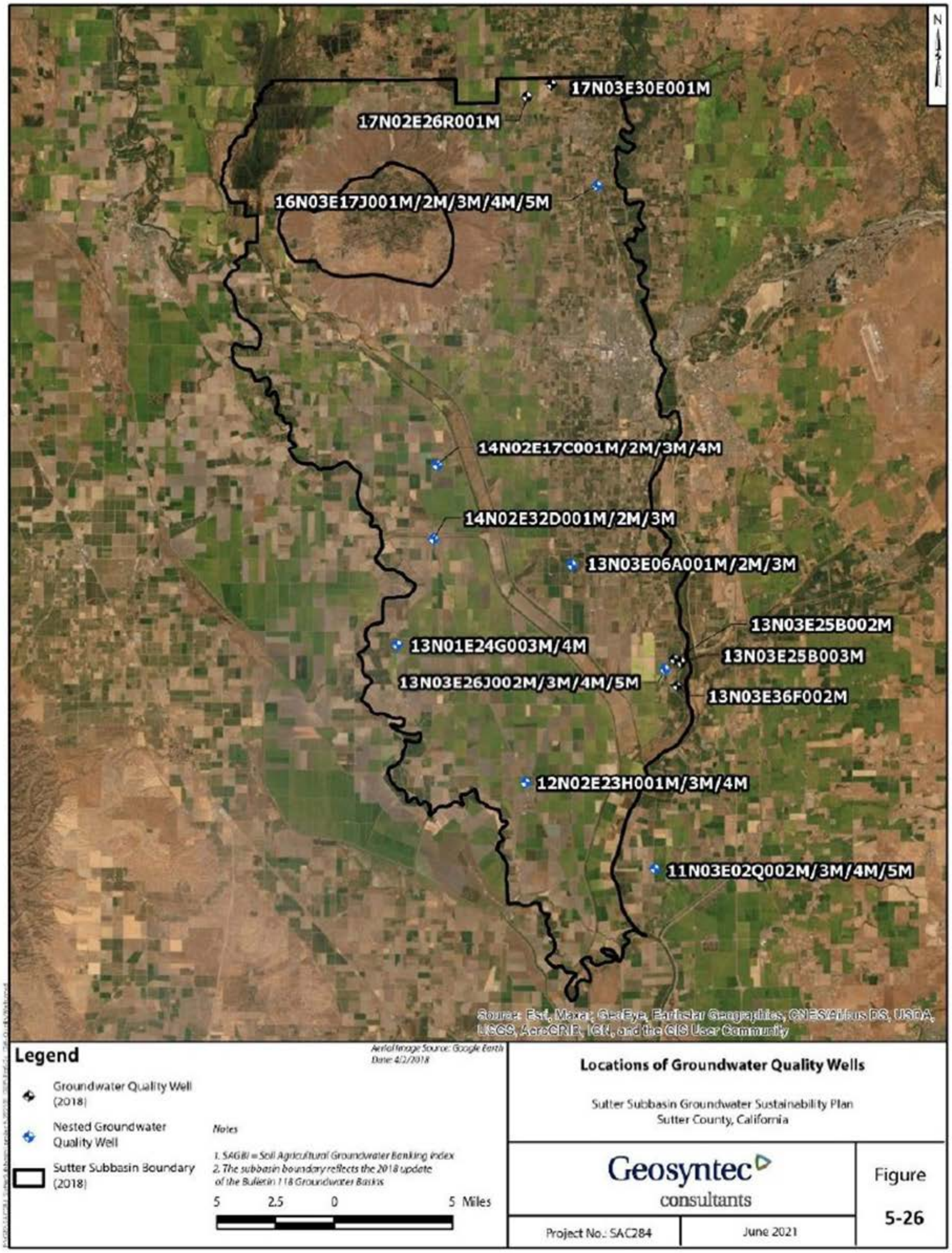

Figure 26. Location of Groundwater Quality Wells (from Sutter Subbasin GSP, 2022)

The following Table 10 from the Sutter Subbasin GSP presents the well construction details for the wells with water quality information.

Table 10. Well construction details for wells with water quality information.

Well ID	Latitude	Longitude	Total Depth	Screen Interval	Aquifer Zone
12N02E23H001M	38.8761	-121.709	150	120-140	1
12N02E23H003M	38.8761	-121.709	600	570-590	3
12N02E23H004M	38.8761	-121.709	705	655-695	3
16N03E17J001M	39.2394	-121.651	85	65-75	1
16N03E17J004M	39.2394	-121.651	615	595-605	3
16N03E17J005M	39.2394	-121.651	785	765-775	3
16N03E17J002M	39.2394	-121.651	315	285-305	2
16N03E17J003M	39.2394	-121.651	430	400-420	2
13N03E26J002M	38.945159	-121.599	175	145-165	1
13N03E26J003M	38.945159	-121.599	445	425-435	2
13N03E26J004M	38.945159	-121.599	610	590-600	3
13N03E26J005M	38.945159	-121.599	1005	985-995	3
11N03E02Q002M	38.823236	-121.6076	170	130-160	1
11N03E02Q003M	38.823236	-121.6076	675	655-675	3
11N03E02Q004M	38.823236	-121.6076	930	910-920	3
11N03E02Q005M	38.823236	-121.6076	1225	1205-1215	3
13N01E24G003M	38.9605	-121.81	160	130-160	1
13N01E24G004M	38.9605	-121.81	100	70-90	1
14N02E32D001M	39.024429	-121.781	64	34-54	1
14N02E32D002M	39.024429	-121.781	210	170-200	1
14N02E32D003M	39.024429	-121.781	500	460-490	3
13N03E06A001M	39.008641	-121.672	65	45-55	1
13N03E06A002M	39.008641	-121.672	175	155-165	1
13N03E06A003M	39.008641	-121.672	265	245-255	2
14N02E17C001M	39.0696	-121.778	60	30-50	1
14N02E17C002M	39.0696	-121.778	245	205-235	2
14N02E17C003M	39.0696	-121.778	425	395-415	2
14N02E17C004M	39.0696	-121.778	755	725-745	3
17N02E26R001M	39.2935	-121.706	601	279-601	2 and 3
17N03E30E001M	39.3012	-121.687	610	263-610	2 and 3
13N03E25B002M	38.951044	-121.5913	248	148-168	1
13N03E36F002M	38.934758	-121.5896	365	160-170	1
13N03E25B003M	38.9494	-121.5863	200	115-200	1

The following table (Table 11) from the Sutter Subbasin GSP provides the summary of water quality data used for the general chemical analysis of the wells in the subbasin monitoring network. The data indicate a TDS range of 151 mg/L to 2,290 mg/L within the subbasin's monitoring network. The highest TDS measurement of 2,290 mg/L was from a well (13N03E06A003M) screened from 245-255 feet bgs in AZ-2 which is the zone from between 150 – 400 feet bgs. There was one other well (14N02E17C0004M) which is screened from 725-745 feet bgs (AZ-3) with a measured TDS of 2,100 mg/L. AZ-3 is the deepest zone and consists of wells deeper than 400 feet bgs.

Table 11. Summary of water quality data used for general chemical analysis.

Well ID	Sample Date	Boron (mg/L)	Total Alkalinity (mg/L)	Arsenic (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Specific Conductance (µS/cm)	Iron (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Nitrate (mg/L)	Potassium (mg/L)	Sodium (mg/L)	TDS (mg/L)	Sulfate (mg/L)	pH	Temperature (Degrees C)
12N02E23H001M	5/18/2010	0.8	198	0.021	44	517	1938	0.008	37	0.154	<0.1	3.7	290	1060	2	7.54	18.80
12N02E23H003M	5/18/2010	0.8	209	0.048	13	151	922	0.021	5	0.073	<0.1	4.2	173	596	26	8.23	21.50
12N02E23H004M	5/18/2010	0.9	194	0.084	15	191	1004	0.032	7	0.088	<0.1	6.1	185	585	20	8.05	20.60
16N03E17J004M	8/12/2010	0.5	134	0.09	19	111	625	0.038	9	0.191	<0.1	5.5	81	386	4	7.69	20.84
16N03E17J005M	8/12/2010	1.8	108	0.013	65	488	1801	0.036	14	0.194	<0.1	12	309	1060	24	7.64	20.42
13N03E26J002M	8/12/2010	0.9	120	0.006	63	472	1728	<0.005	22	0.155	<0.1	26.2	256	951	5	8.91	20.25
13N03E26J003M	8/12/2010	0.7	157	0.008	88	355	1528	0.01	28	0.178	0.3	9.2	178	901	23	7.77	20.22
13N03E26J004M	8/12/2010	1.4	141	0.007	10	116	691	0.01	3	0.042	<0.1	3	126	403	8	8.39	20.90
13N03E26J005M	8/12/2010	2.4	109	0.012	70	920	3229	0.038	22	0.16	<0.2	11.9	483	1850	8	7.38	20.67
16N03E17J001M	8/12/2010	<0.1	70	0.002	13	2	150	<0.005	11	<0.005	3.8	<0.5	4	115	3	7.37	19.75
16N03E17J002M	8/12/2010	0.3	132	0.201	12	9	278	<0.005	11	0.329	<0.1	3.7	35	210	<1	7.39	20.04
16N03E17J003M	8/12/2010	0.3	143	0.101	17	13	310	0.039	8	0.145	<0.1	4	41	225	1	7.78	20.47
11N03E02Q002M	3/9/2011	0.3	327	0.02	55	198	1262	0.18	23	0.242	<0.1	3.1	163	716	9	8.05	18.40
11N03E02Q003M	3/9/2011	0.4	112	0.014	125	951	3279	0.062	30	0.289	<0.1	7.3	416	1880	15	8.07	19.40
11N03E02Q004M	3/9/2011	0.5	95	0.012	129	1040	3515	0.029	28	0.151	<0.1	9.2	473	2160	14	8.03	19.20
11N03E02Q005M	3/9/2011	0.5	124	0.014	38	369	1508	0.075	10	0.198	<0.1	4.6	218	866	9	8.02	18.50
13N01E24G003M	9/12/2012	0.1	112	0.011	7	4	250	0.047	8	0.07	<0.1	1.3	37	189	6	7.28	18.64
13N01E24G004M	9/12/2012	0.3	341	0.013	42	12	692	0.974	39	0.039	0.1	2.1	60	428	22	7.15	18.66
14N02E32D003M	6/20/2012	0.5	169	0.022	49	355	1502	0.021	25	0.254	0.1	11.3	221	874	32	7.67	22.13
14N02E32D002M	6/20/2012	0.3	245	0.008	20	84	784	0.184	12	0.161	<0.1	5.1	139	496	26	7.21	21.90
14N02E32D001M	6/20/2012	<0.1	276	0.006	46	11	566	<0.005	41	0.271	<0.1	2.1	20	318	15	7.18	23.87
13N03E06A001M	3/9/2011	0.3	260	0.009	117	606	2461	0.06	85	0.775	<0.1	2.6	186	1370	2	7.27	18.10
13N03E06A002M	3/9/2011	0.5	134	0.01	154	1000	3501	0.082	106	1.17	<0.1	7.6	286	2200	<1	7.18	18.40
13N03E06A003M	3/9/2011	0.7	130	0.023	148	1110	3803	0.137	99	1.42	<0.1	15.4	386	2290	<1	7.28	19.10
14N02E17C001M	3/17/2010	<0.1	408	0.011	57	16	797	<0.005	60	0.125	7	2.1	36	492	26	7.27	19.50
14N02E17C002M	3/17/2010	0.1	143	0.026	18	7	328	<0.005	9	0.074	<0.1	3.1	41	231	17	6.99	20.30
14N02E17C003M	3/17/2010	0.2	122	0.03	18	36	380	<0.005	7	0.029	0.1	3.8	51	228	12	6.78	20.30
14N02E17C004M	3/17/2010	0.7	142	0.017	127	994	3337	0.026	53	0.573	<0.333	27.7	431	2100	9	5.86	20.70
17N02E26R001M	6/17/2009	0.2	119	0.127	12	14	264	0.0161	11	0.228	1.1	4.4	30	201	<1	7.10	21.50
17N02E26R001M	9/23/2009	0.2	118	0.134	12	16	278	0.06	10	0.00022	1.1	4.2	35	202	<1	7.02	22.10
17N03E30E001M	6/17/2009	0.2	121	0.0681	10	9	250	0.0064	9	0.212	0.4	4.4	33	191	<1	7.20	21.50
17N03E30E001M	9/23/2009	0.3	120	0.0686	10	11	265	0.0318	9	0.192	0.4	4.3	38	197	<1	7.30	21.80
13N03E25B002M	8/26/2009	2.2	120	0.007	78	673	2519	0.064	17	0.574	<0.1	7.5	369	1510	<1	7.65	19.80
13N03E36F002M	8/26/2009	2.2	148	0.01	64	632	2246	0.078	17	0.451	<0.1	6.3	344	1290	<1	7.59	20.50
13N03E25B003M	8/26/2009	1.4	146	0.005	9	98	606	0.05	2	0.074	<0.1	2.1	107	361	<1	8.17	19.00

µS/cm – micro-Siemens per centimeter
Degrees C – Degrees Celsius
mg/L – milligrams per liter
TDS – Total dissolved solids
See Table 5-4 for well construction details

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

The proposed CO_2 stream will be greater than 95% pure. Expected reactions with brine and injection/confining zone rocks are discussed below.

2.12.1 Characteristics of injection zone formation water

There was no available formation water sample in the target injection zone at or near the proposed storage site. [redacted] The data was then plotted using the P50 average from the calculated salinities. Collection and testing of specific formation water samples from the injection zone are planned as described in the Pre-Operational Testing program section.

2.12.2 Mineral composition of the injection zone

The Upper Cretaceous Starkey sandstones are the target CO_2 sequestration storage zones with the overlying Capay Formation acting as the confining seal. The Starkey consists of a series of fluvial-deltaic sediments, which are sourced from the Sierra Nevada and the delta depositional system coming from the east and northeast. Core fragments and grab samples were collected in the Starkey Formation in the Citizen Green #1 well as part of the WESTCARB work performed to characterize the southern Sacramento Basin. The Starkey Clean Sand is predominantly an arkosic sandstone with minor clays and trace minerals. Thin-section samples indicate minimal cementation and angular grains.

2.12.3 Mineral composition of the confining zone

The Eocene Capay Formation consists of greenish-gray mudstone with a glauconite-rich base deposited in a transgressive marine environment (Johnson, 1990). Specific references to its mineral composition are sparse in the literature but it is known to function regionally as a seal.

2.12.4 Geochemical data and modeling

Although some potentially reactive minerals are present in the Starkey Sandstone, the pressure and temperature of the injection zone suggest that any changes in fluid or solid geochemistry as a result of CO_2 injection will only occur over time horizons much longer than the project duration (thousands of years).

As detailed in the Testing and Monitoring plan, formation fluid samples and core samples will be obtained in the injection and confining zones. These samples will be used to characterize the geochemistry of the injection and sealing formations and the compatibility with the CO_2 injection fluid.

References

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

There is no additional information that is needed to be communicated at the time of this report.

3.0 Site Suitability [40 CFR 146.83]

Based on all available data and research presented in this report, the selected site meets the suitability requirement outlined in the regulations. The Starkey Storage Complex comprises the basal Sacramento Shale, the Winters Formation, upper Starkey combined with the storage reservoir, Starkey Clean Sand, and Capay Formation as the primary confining zone. The basal contact for lowermost USDW is the top of the Capay Formation.

The Starkey Formation is a series of deltaic facies with high variability. In the literature, three distinct facies are identified: (1) delta front, (2) lower delta plain, and (3) upper delta plain/fluvial. Formation heterogeneity might reduce reservoir quality but also improve vertical and lateral trapping of CO_2. The target injection zone, the Starkey Clean Sand has an average porosity of [redacted] and an average permeability of [redacted]. It is laterally continuous across the basin and in the AoR the average thickness is [redacted]. Overlying the injection zone is the upper Starkey unit. It has an average porosity of [redacted] and an average permeability of [redacted] and it average thickness in the AoR is [redacted].

The upper confining unit, the Capay Formation, is a laterally continuous shale bed throughout the basin and is an average of [redacted] thick in the AoR. Limited data is currently available to assess the integrity of the Capay Formation. The 3D seismic program of the CarbonSAFE PhaseII project will help to delineate the lateral extent and thickness of the Capay Formation as well as map the presence and amount of displacement due to late Cenozoic faulting (see discussion in Faults and Fractures section) along the Willow's Fault zone. Data from the stratigraphic test well will allow for the collection of rock property information and geomechanical studies within the AoR necessary to address the integrity of the confining zone.

The lower confining units are the Winters Formation and the Sacramento Shale. While regionally, there are variable facies in the Winters Formation, it is characterized as a shale within the AoR and is an average of [redacted] thick. The Sacramento Shale is a laterally continuous shale with an average thickness of [redacted] in the AoR and will act as the secondary basal confining unit to the Starkey Storage Complex. There are no concerns as to the integrity of the lower confining units, but this will be confirmed with the subsurface data collected for the CarbonSAFE PhaseII Stratigraphic well.

Though the proposed CO_2 stream is dry ([redacted]), and the well and infrastructure design is using proven techniques and CO_2 compatible materials, corrosion testing prior to construction will take place to confirm no adverse interactions.

Given the arkosic nature of the Starkey Formation, it is possible that reactions like those seen in the Mt. Simon sandstone, like dissolution if feldspars leading to increases in porosity, permeability and changes in the rock's mechanical behavior, are possible (Harbert et al, 2020). These changes, however, cannot be modeled accurately without the formation fluid and detailed mineralogic data for the injection and confining zones. This modelling, along with corrosion m will take place after the collection of data at the Stratigraphic test well for the PhaseII CarbonSAFE Project* and updated with the data collected during the well construction.

Single well CO2 injectivity into the sandstones of the Starkey Formation are modeled using the EasiTool from University of Texas GCCC - Gulf Coast Carbon Center. Assumptions for single well injectivity include the following:

- Injection over [redacted] years.
- A fracture gradient of [redacted].
- Maximum injection pressure is [redacted] of the fracture gradient.
- Injection into clean sandstone of the Starkey Formation.

The estimated storage capacity of the proposed injection zone assumes CO_2 injection into the sandstone dominated facies of the Starkey Clean Sand and is based on rock formation data from the nearby Richter #8-4 well. The Richter #8-4 well demonstrates a net sandstone thickness of [redacted] and a total porosity value of [redacted]. From these values, the Starkey Formation sandstones have an estimated storage capacity of [redacted] per square mile, assuming a storage efficiency of [redacted]. The total estimated p50 storage capacity within the proposed AOR, constituting an area of [redacted] square miles, is approximately [redacted]. This suggests that the Starkey Formation should provide more than adequate storage capacity to meet the [redacted] million metric ton goal of the CarbonSAFE program.

4.0 AoR and Corrective Action

The Sutter Decarbonization Project has submitted the AoR and Corrective Action Plan (40 CFR 146.82(a)(13) and 40 CFR 146.84(b). Detailed documentation regarding the computational modeling (40 CFR 146.84(c)) has been submitted into the GSDT AoR and Corrective Action Module. This includes:

- Model domain
- Processes modeled
- Rock properties
- Boundary conditions
- Initial conditions
- Operational information
- Model output, and
- AoR pressure front delineation

The lateral extent of the CO_2 plume was defined by the vertically integrated mass of CO_2 per area (Zhang, 2015). To ensure that Sutter Decarbonization Project CO_2 injection activities protect groundwater resources: (1) the AoR was delineated by the CO_2 plume at the end of the injection period with a doubling in perimeter area to account for plume expansion during the post-injection period (Figure 1) and (2) a comprehensive groundwater monitoring is planned (See TESTING and MONITORING PLAN).

[redacted]

Figure 1. Sutter Decarbonization Project delineated Area of Review (black line), CO2 plumes after twelve years of injection (red line), and proposed well locations (red circles).

The AoR and Corrective Action Plan submittal also includes a tabulation of wells that penetrate the confining zone within the AoR. A total of seven legacy oil/gas wells were identified that penetrate the seals and storage zone in or near the AoR. Three wells penetrate the injection zone within the [redacted] plume area; an additional four wells penetrate the confining zone within the AoR. Well records for each of those wells were examined to establish depths, well conditions, and determine the risk of leakage. These wells will be further evaluated during the pre-injection design, characterization and construction phase and remediated as necessary. If corrective action is required for legacy wells that exist in the AoR that were not identified at the time of writing, the Sutter Decarbonization Project shall secure agreements to access, enter, and implement corrective action as needed.

The AoR will be re-evaluated every five years during the injection and post-injection phases unless an event occurs that triggers an AoR re-evaluation sooner. If the results of testing and monitoring and/or AoR re-evaluation throughout the project lifecycle indicate potential interference with any wells penetrating the confining zone, an amended corrective action plan will be implemented and submitted to the EPA (40 CFR 146.84(e)(4)).

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)]***

5.0 Financial Responsibility

The financial responsibility plan was uploaded to the GSDT. The plan includes a description of potential financial mechanisms for each phase. As required by 40 CFR 146.82(a)(14) and 40 CFR 146.85. The financial responsibility plan includes cost estimates for each phase. A cost summary is provided in Table 12. Detailed cost support is provided in the Financial Responsibility documentation in GSDT.
The estimated costs of each of these activities include:

Table 12. Estimated costs for site activities

[redacted]

[redacted], the parent company to [redacted], will provide financial assurance for the Sutton Decarbonization Project.

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]***

6.0 Injection Well Construction

The injection wells will be constructed new to meet the requirements of 40 CFR 146.82.a.12 and 40 CFR 146.86. Proposed specifications and procedures for injection wells [redacted] are detailed in the corresponding documents for Injection Well Design Plan for the Sutter Decarbonization Project [CONSTRUCTION DETAILS (40 CFR 146.86(a))].
Each I Injection Well Design Plan document provides details on:

- Injection Well Operating Conditions
- Formation Conditions
- Open Hole Parameters
- Casing and Completion Tubing Specifications
- Minimum Logging Specifications for Well Construction
- Cement Specifications
- Wellhead Design Parameters
- Proposed Stimulation Program [40 CFR 146.82(a)(9)]

Selected elements of the Injection Well Design Plan, including the stimulation program and well construction elements are summarized below.

6.1 Proposed stimulation program [40 CFR 146.82(a)(9)]

Stimulation is anticipated to clean the perforated interval of any fines, charge residue, and cement or casing debris, as well as remove any drilling mud or dissolved minerals that may be in the formation. This is essential as if untreated, these can contribute to higher downhole injection pressures and lower injectivity. More details on the proposed stimulation program are presented along with the Injection Well Construction Plan for each injection well.

6.2 Construction procedures [40 CFR 146.82(a)(12)]

The injection wells will be constructed new to meet the requirements of 40 CFR 146.82.a.12 and 40 CFR 146.86. Proposed specifications and procedures for injection wells are described in the corresponding documents for Injection Well Design Plan for the Sutter Decarbonization Project [CONSTRUCTION DETAILS (40 CFR 146.86(a))].

Each INJECTION WELL PLAN document provides details on:

- Injection Well Operating Conditions
- Formation Conditions
- Open Hole Parameters
- Casing and Completion Tubing Specifications
- Minimum Logging Specifications for Well Construction
- Cement Specifications
- Wellhead Design Parameters
- Proposed Stimulation Program [40 CFR 146.82(a)(9)]

6.3 Casing and Completion Tubing Specifications

Using the design for CCS 1 as an example, the proposed open hole parameters are provided in Table 1. Proposed casing and tubing completion string specifications are provided in Table 13. The wellbore schematic is presented in the Well Construction Plan. Packer specifications are presented in Table 14.

Table 13. Open hole parameters for the CCS1 Well (provided as an example).

[redacted]

Table 14. Well Casing and Tubing Specifications for the CCS1 Well (provided as an example).

[redacted]

The wellhead specifications have not yet been designed and will be assigned following data collection, testing, and analysis from the CarbonSAFE Phase II work has been completed at this site.

7.0 Pre-Operational Logging and Testing

A series of three injection wells are proposed for the project site. The pre-operational formation testing program will be implemented at each injection well to verify the chemical and physical characteristics of the injection zone and confining zone(s).

The program is developed to meet the testing requirements of 40 CFR 146.87 and well construction requirements of 40 CFR 146.86. The pre-operational testing program will include a combination of wireline logging and side-wall coring. In addition, formation geohydrologic testing will be completed to verify injectivity of the storage formation. A step rate test will provide a site-specific determination of the fracture gradient.

The pre-operational testing program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the Winters Shale (basal confining zone), the Starkey Storage Complex (CO_2 injection zone), the overlying Capay Formation (upper confining zone), and other relevant geologic formations. In addition, formation fluid characteristics will be obtained from the Starkey Clean Sand to establish baseline data against which future measurements may be compared. The results of the testing activities will be documented in a "Pre-operational Testing Narrative" report and submitted to the EPA after the well drilling and testing activities have been completed, and before the start of CO_2 injection operations.

After completing the characterization and testing, the borehole will be completed as an injection well. Mechanical integrity tests (e.g., wireline and pressure tests) will verify well construction and integrity.

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]***

8.0 Well Operation

The injection operations will be implemented by [redacted], the permit OWNER. Under the permit, the OWNER will develop the Sutter Decarbonization Project.
Upon issuance of the UIC permits, the OWNER will begin the process of installing three injection wells and other project infrastructure as described in the permit application. Injection operations will begin once US EPA authorizes permission to operate, and the CO_2 delivery system is commissioned. [redacted] Injection will be distributed across the three permitted injection wells, in accordance with the permit operating conditions for each respective well. [redacted] Well operations, and a description of the proposed CO_2 injectate and its properties (Table 1) are described below.

8.1 Volume of injection fluid generated daily and annually

The proposed injection rate for the project is [redacted] in each of [redacted]. Injection rates in each well are to be determined based on pre-operational testing results. Planned annual CO_2 injection for all wells could be up to [redacted]. At full operating capacity, the expected daily injection, per well will ramp up to [redacted] depending on site geology and injectivity at each well location, and CO_2 availability. A flow meter will be installed to produce a direct reading of total volume per time of CO_2 being injected. Location will be after compression, but prior to the well head.

8.2 Injection operations and procedures

The Sutter Decarbonization Project proposed injection procedures for the project injection wells incorporates maintenance and inspection of the wells and surface equipment that the waste contacts, along with long-term monitoring and contingency planning for safe, responsible operations. The Sutter Decarbonization Project is committed to operating the wells to meet all applicable United States Environmental Protection Agency (US EPA) regulations for CO_2 injection wells. A detailed review of the monitoring program for the wells and surface equipment is provided in the Testing and Monitoring Plan. The operation of all site wells includes recording of various parameters such as the injection flow rate, pressure, and annulus pressure which are continuously monitored and recorded on digital drives and/or backup charts. Since the injection facility will operate 24 hours per day, seven days a week, it will be continuously manned by trained operators in injection well operations.

A maximum wellhead pressure of [redacted] was used for the well design. The maximum surface injection pressure will be based on actual site conditions but will not exceed [redacted] of the fracture pressure.

A mechanical integrity testing program for each injection well will be implemented in accordance with the Testing and Monitoring Plan.

8.3 Operational constraints – maximum allowable surface pressure

The primary operational constraint would be imposed by potential limitation of permitted injection volumes and maximum allowable injection pressure. Once each injection well is drilled and pre-operational testing is complete, this upper bound to injectivity for that well will be established. However, the maximum (surface) injection pressure will not exceed [redacted] of the fracture pressure. Table 2 includes a summary of proposed operational constraints.

8.4 Operational contingency plans

Contingency plans will be in place to identify situations where potential plant and/or process upset conditions may occur and take appropriate measures which are protective to the local area and the environment by shutting in the wells and monitoring their pressure falloff. Operational contingency plans for all the Sutter Decarbonization Project injection wells include potential downtime periods when annual injection well testing, maintenance, well service, and stimulation occur. These plans include the following:

- Annual testing
- Monitoring downhole and on surface

With three permitted injection wells, two wells would normally be operational while one well is tested or serviced for maintenance.

The availability of multiple wells and adhering to proper operations practices, including regular well maintenance and service, will reduce most injection well down-time and should eliminate the unlikely occurrence of one or more wells being simultaneously unavailable for use. In the unlikely event that all wells are temporarily unavailable or are out of commission, CO_2 may be vented to the atmosphere for that limited period until operations and injectivity is re-established. Additional detailed monitoring, and other contingency planning for potential events that may occur during well injection operations are provided in the Testing and Monitoring Plan and in the Emergency and Remedial Response Plan.

8.5 Proposed carbon dioxide stream [40 CFR 146.82(a)(7)(iii) and (iv)]

[redacted]

CO_2 for the Sutter Decarbonization project will be sourced from the nearby [redacted], and transported via pipeline to the storage location. Exact specifications of the CO_2 stream will be determined during project planning stages. However, the CO_2 is expected to be similar to the specifications in Table 18. Corrosiveness of the CO_2 stream will be ascertained during pre-project testing. Technical documentation has been prepared assuming minimal corrosion and incorporating a large safety margin in pipe and tubing design. As data for the CO_2 injection stream are available, these designs and specifications will be updated.

Table 16. Proposed operational constraints.

[redacted]

8.6 Operational procedures [40 CFR 146.82(a)(10)]

8.6.1 Injection well and reporting conditions

Injection well operating conditions are described in more detail in the Narrative section "Well Operation." Reports will be provided as described in the Testing and Monitoring Plan and other Plans (e.g., Emergency and Remedial Response Plan).

Table 7 Injection well operating conditions

[redacted]

The maximum injection pressure, which serves to prevent confining-formation fracturing, was determined: using the local fracture gradient of [redacted], per 40 CFR 146.88(a). The fracture gradient for the Sutter Decarbonization Project will be determined via step rate testing during the pre-operational testing program.

8.6.2 Routine shutdown procedure

For injection shutdowns occurring under routine conditions (e.g., for well workovers), the permittee will reduce CO_2 injection rates in coordination with the compression and pipeline operator. The purpose is to ensure protection of health, safety, and the environment, and prevent sudden changes in the injection system. For routine shutdowns, the normal injection rate will be reduced by 25% and then allowed to stabilize for a minimum of one hour. This will be followed by similar reductions of 50%, 75%, and then 100% of normal injection. (Procedures that address immediately shutting in the well are in the Emergency and Remedial Response Plan of this permit.)

9.0 Testing and Monitoring

This Testing and Monitoring Plan describes how [redacted] will monitor the Sutter Decarbonization Project pursuant to 40 CFR 146.90. In addition to demonstrating that the well is operating as planned, the carbon dioxide plume and pressure front are moving as predicted, and that there is no endangerment to USDWs. Additionally, the monitoring and testing data will be used to validate and refine geological models and simulations used to forecast the distribution of the CO_2 within the storage zone, support AoR re-evaluations, and to demonstrate non-endangerment. Results of the testing and monitoring activities described in the Plan may trigger action according to the Emergency and Remedial Response Plan. The objectives of the plan are:

The Testing and Monitoring Plan will utilize direct and indirect monitoring technologies that will monitor:

- Injectate composition to demonstrate that it is consistent with the permit 40 CFR 146.90(a)
- Corrosion of well materials and components (40 CFR 146.90(c))
- To determine whether CO_2 or brine has migrated Above the Confining Zone (ACZ) (40 CFR 146.90(d))
- USDW groundwater quality (40 CFR 146.95(f)(3)(i))
- Well integrity over the injection phase of the project (40 CFR 146.89(c) and 146.90)
- Near well-bore environment using pressure fall-off testing (40 CFR 146.90(f))
- Development of the CO_2 plume and pressure front in the storage formation over time (40 CFR 146.90(g))
-

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]***

10.0 Injection Well Plugging

The Injection Well Plugging Plan includes schematics and describes how the Sutter Decarbonization Project will plug the injection wells in accordance with the requirements of 40 CFR 146.92. The plugging procedure and materials are designed to prevent unwanted fluid movement, to resist the corrosive aspects of carbon dioxide/water mixtures, and to protect any USDWs.

All casing placed and used in the injection well will be cemented to surface and will not be retrievable at abandonment post-injection. After injection is complete and well pressure has stabilized, and upon approval and concurrence from US EPA, the well will be flushed with brine or fresh water to displace the injectate into the formation. The injection tubing and injection packer will be the only injection equipment remaining in the cased hole. Attempts will be made to remove the injection tubing and packer, however, if the packer cannot be released and/or removed from the cased hole, a wireline tubing cutter will be used to cutoff the tubing above the single packer. A series of balanced cement plugs will be used to fill the entire well with cement for final abandonment.

In order to address newly acquired information following pre-operational testing [40 CFR 146.82(c)(9)], the Sutter Decarbonization Project will submit amendments to US EPA, as needed, for the approved Injection Well Plugging Plan. The revised plan will highlight and explain changes that are needed to address modifications to the well's construction, as documented in the construction specifications or new information about subsurface geochemistry based on the results of pre-operational formation testing and the compatibility of well materials with subsurface fluids and the injectate.

Pending the granting of all approvals for the final plugging program, the Sutter Decarbonization Project will provide, in advance, a completed contact list for reporting to US EPA as part of process to plug and abandon the well and allow US EPA to either witness or oversee operations as needed to ensure compliance.

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)]***

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

This Post-Injection Site Care and Site Closure (PISC) plan describes the activities that the Sutter Decarbonization Project will utilize to meet the requirements of 40 CFR 146.93. The Sutter Decarbonization Project will monitor ground water quality and track the position of the carbon dioxide plume and pressure front after the end of injection operations. The project OWNER [redacted] may not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). Following approval for site closure, the OWNER will plug all monitoring wells, restore the site to its original condition, and submit a site closure report and associated documentation.

The PISC plan includes groundwater quality monitoring and plume and pressure front tracking during the post-injection phase. These, along with other activities described in the plan will meet the requirements of 40 CFR 146.93(b)(1). The results of all post-injection phase testing and monitoring will be submitted annually, within 60 days after the anniversary of the date on which injection ceased, as described under "Schedule for Submitting Post-Injection Monitoring Results," in the PISC plan.

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities during the injection and post injection phases is provided in the Appendix to the Testing and Monitoring Plan.

Alternative Post-injection Site Care Timeframe

No alternative PISC time frame is requested at this time.

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)]***

12.0 Emergency and Remedial Response

The Emergency and Remedial Response Plan (ERRP) is provided to meet the requirements of 40 CFR 146.94. The ERRP describes actions that the OWNER [redacted] shall take to address movement of the injection fluid or formation fluid in a manner that may endanger an underground source of drinking water (USDW) during the construction, operation, or post-injection site care periods. The plan also describes actions the OWNER will take in the unlikely event of an emergency within the project Area of Review (AoR) during construction, operation, or post-injection site care. Unexpected events may include unplanned CO_2 release or detection of unexpected CO_2 movement or associated fluids in or from

the injection zone. This plan demonstrates how the OWNER will comply with 40 CFR 146.94. The site includes [redacted] injection wells: [redacted]
If the OWNER obtains evidence that the injected CO_2 stream and/or associated pressure front may cause an endangerment to a USDW, the OWNER must perform the following actions:

1. Initiate shutdown plan for the injection well(s).
2. Take all steps reasonably necessary to identify and characterize any release.
3. Notify the permitting agency (UIC Program Director) of the emergency event within 24 hours.
4. Implement applicable portions of the approved ERRP.

Where the phrase "initiate shutdown plan" is used, the following protocol will be employed: the OWNER will immediately cease injection. However, in some circumstances, the OWNER will, in consultation with the UIC Program Director, determine whether gradual cessation of injection (using the parameters set forth in the Summary of Requirements of the Class VI permit) is appropriate.

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)]***

13.0 Injection Depth Waiver and Aquifer Exemption Expansion

No injection depth waivers or aquifer exception expansions will be requested in relation to the Sutter Decarbonization Project.

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)]***

14.0 Optional Additional Project Information [40 CFR 144.4]

At present, none of the following impact development of the Sutter Decarbonization Project. The project OWNER, [redacted] will follow California requirements for environmental monitoring as described above in the Narrative section "*Other Information (Including Surface Air and/or Soil Gas Data, if Applicable)*".

- The Wild and Scenic Rivers Act, 16 U.S.C. 1273 et seq. Identify any national wild and scenic river that may be impacted by the activities associated with the proposed project.
- The National Historic Preservation Act of 1966, 16 U.S.C. 470 et seq. Identify properties listed or eligible for listing in the National Register of Historic Places that may be affected by the activities associated with the proposed project. If previous historic and cultural resource survey(s) have been conducted, provide the results of the survey(s).

- The Endangered Species Act, 16 U.S.C. 1531 et seq. Identify any endangered or threatened species that may be affected by the activities associated with the proposed project. If a previous endangered or threatened species survey has been conducted, provide the results of the survey.
- The Coastal Zone Management Act, 16 U.S.C. 1451 et seq. Identify any coastal zones that may be affected by the activities associated with the proposed project.]

Other Information

No other information is included in the permit application at this time.
However, the OWNER will provide any other information requested by the UIC Program Director, or new or updated information that is not specifically requested/required but may be useful for the permit application. This section fulfills the requirement at 40 CFR 146.82(a)(21).