CLASS VI PERMIT APPLICATION NARRATIVE

40 CFR 146.82(a)

GULF COAST SEQUESTRATION
PROJECT MINERVA

1.0 PROJECT BACKGROUND

1.1 Project goals

Gulf Coast Sequestration ("GCS") seeks to build and operate the United States premier saline sequestration asset, Project Minerva, in the Louisiana Gulf Coast. Once completed, the GCS "hub" is expected to be the largest geologic carbon capture sequestration project in the United States and one of the largest in the world, designed to permanently store more than 80 million tons of carbon in a saline aquifer. With the capacity to sequester 2,700,000 tons of CO_2 annually, Project Minerva will have the same carbon offset impact as more than 600 utility-scale solar facilities or some half a million-household rooftop solar panels.

Project Minerva envisions sourcing CO_2 volumes from industrial producers of CO_2 in the Eastern Texas and Southwestern Louisiana industrial corridors. Project Minerva desires to enable the United States manufacturing and industrial base in the Texas and Louisiana Gulf Coast to continue to provide jobs and economic opportunity while minimizing the amount of CO_2 which would have been emitted into the earth's atmosphere. GCS maintains that both economic and environmental stewardship can advance in unison with an asset such as Project Minerva. GCS intends to see this vision become a reality.

1.2 Ownership

GCS is a wholly owned subsidiary of the Stream family, a multi-generational single-family office, based in Lake Charles, Louisiana. In addition to other investments, the Stream family are long-term landowners in Southwestern Louisiana, owning and operating land assets for well over a century in and near Lake Charles. The Stream family have protected and restored tens of thousands of acres of wetlands and sustainably managed thousands of acres of timber assets. The GCS sequestration "hub" is a natural fit for the Stream family.

1.3 Proposed injection mass/volume and CO_2 source

Project Minerva is designed for four wells which are spread into two project areas – "North Site" located in southwestern Calcasieu Parish and "South Site" located in northwestern Cameron Parish. Each of North Site and South Site project areas will contain four injection wells emanating from a single surface location per project area. [The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

CO_2 is anticipated to be sourced from industrial facilities in Southwestern Louisiana and Southeastern Texas, primarily from the Lake Charles and Beaumont industrial corridors. According to Environmental Protection Agency ("EPA") Facility Level Information on Greenhouse Gases Tool ("FLIGHT") the total CO_2 emissions from the four counties/parishes adjacent to Project Minerva emitted nearly 57 million metric tons of CO_2 in 2018 (EPA FLIGHT database at https://ghgdata.epa.gov/ghgp/). The two counties in Texas are Jefferson and Orange and the two parishes in Louisiana are Cameron and Calcasieu. Project Minerva does not have a dedicated source of CO_2 under contract, however, is in advanced stage discussion on offtake arrangements with several counterparties with assets in the four county/parish area discussed above.

1.4 Land Data

Please note that Gulf Coast Sequestration uses the Bureau of Land Management township-range-section land data in its analysis of Project Minerva. See APPDX A – Land.

2.0 GEOLOGY

2.1 Regional Geology

The Gulf of Mexico is a relatively small ocean basin covering an area of more than 579,000 square miles (1.5 million kilometers) (Ocean Exploration and Research Website, 2018 https://oceanexplorer.noaa.gov/). It began to form via rifting during the Triassic/Jurassic period (Figure 2.1). Sediment input has been particularly voluminous since the start of the Paleogene and is responsible for extensive deformation of underlying salt and the resulting abundance of prolific hydrocarbon systems along the Gulf Coast of Louisiana and Texas (Foote et al., 1984). For this project, the proposed site is comprised of more than 8,000 ft of regionally extensive clastic strata. A regional geologic stratigraphic column is provided in Figure 2.2a and Figure 2.3a.

The earliest record of sedimentation in the Gulf of Mexico Basin occurred during the Late Triassic to Early Jurassic period, between 160 and 140 million years ago. Repeated cycles of seawater flooding and evaporation resulted in the formation of extensive salt accumulations that locally reached thicknesses of 10,000 ft to 15,000 ft thick. Subsequent, buoyancy-driven flow created the diapirs, pillows and massifs which characterize the Gulf Coast structure today (Foote et al., 1984). At this time, the early phases of continental rifting resulted in the deposition of non-marine red bed and deltaic sediments (shale, siltstone, sandstone, and conglomerate) of the Eagle Mills Formation in a series of restricted, graben fault-block basins (Figure 2.4). This thick sequence of anhydrite and salt beds (Werner Anhydrite and Louann Salt) are regionally extensive across coastal Louisiana and Texas.

The deposition of the Louann Salt beds was localized within major basins that were defined by the major structural elements in the Gulf Coast Basin. The clastic Norphlet Formation (sandstones and conglomerates) overlies the Louann Salt and is more than 1,000 ft thick in Mississippi but thins westward to a sandstone and siltstone in Texas. Norphlet conglomerates were deposited in coalescing alluvial fans near Appalachian sources and grade downdip into dune and interdune sandstone deposited on a broad desert plain (Mancini et al., 1985). Although the Norphlet Formation is unfossiliferous, based on dating of the overlying and underlying sequences, the Norphlet Formation is probably late Middle Jurassic or Callovian in age (Todd and Mitchum, 1977) (Figure 2.2a).

The depositional environment rapidly changed from continental and evaporitic to shallow marine, with localized areas of deep marine (Foote et al., 1984). Broad carbonate banks composed of limestones, dolomites, and interbedded anhydrites developed along the edges of the basin, with fine carbonate muds deposited in deeper water areas (Foote et al., 1984). Reef construction and sedimentation kept pace with regional subsidence, which allowed thick carbonate sequences to accumulate (Foote et al., 1984). These shallow-water carbonates and clastic rocks make up the Smackover, Buckner, Haynesville formations and the Cotton Valley Group, and were deposited over the Norphlet Formation from the Upper Jurassic into the Lower Cretaceous. Jurassic, nonskeletal, carbonate sands and muds accumulated on a ramp-type shelf with reefal buildups developed on subtle topographic highs (Baria et al., 1982).

A high terrigenous clastic influx in eastern Louisiana and Mississippi occurred during deposition of the Haynesville and diminished westward where the Haynesville Formation grades into the Gilmer Limestone in East Texas. The top of the Jurassic occurs within the Cotton Valley Group, with the Knowles Limestone dated as Lower Cretaceous (Berrasian) (Todd and Mitchum, 1977). The middle Cretaceous was a period of prolonged stability, permitting the development of extensive, shelf-edge reef complexes (Baria et al., 1982).

During the Upper Cretaceous, a large tectonic uplift formed the Rocky Mountains, while the Gulf of Mexico basin subsided. Large volumes of clastic sediments from the uplift were deposited as wedges into the basin. This effectively shut off the production of carbonates, except in the Florida and Yucatan regions. Since the Cretaceous, the rate of terrigenous sediment influx has been greater than the rate of basin subsidence, resulting in significant progradation of the continental shelf margin (Figure 2.5).

Sediment supplies during Cenozoic time overwhelmed the general rate of subsidence, causing the margins to prograde up to 240 miles from the edges of Cretaceous carbonate banks to the current position of the continental slopes off Texas and Louisiana (Foote et al., 1984). The geometry of Cenozoic deposition in the Gulf Coast Basin was primarily controlled by the interaction of the following factors:

- Changes in the location and rates of sediment input, significantly shifting the areas of maximum sedimentation
- Changes in the relative position of sea level, developing a series of large-scale depositional cycles throughout Cenozoic time
- Diapiric intrusion of salt and shale in response to sediment loading
- Flexures and growth faults due to sediment loading and gravitational instability

Early Tertiary sediments are thickest in the Rio Grande Embayment of southern Texas, reflecting the role of the ancestral Rio Grande and Nueces Rivers as sediment sources to the Gulf of Mexico basin (Figure 2.6). By Oligocene time, deposition had increased to the northeast, suggesting that the ancestral Colorado, Brazos, Sabine, and Mississippi Rivers were increasing in importance. Miocene time is marked by an abrupt decrease in the amount of sediment entering the Rio Grande Embayment, with a coincident increase in the rate of sediment supply in southeast Texas, Louisiana, and Mississippi. Throughout the Pliocene and Pleistocene Epochs, the maximum depocenters of sedimentation were controlled by the Mississippi River and are located offshore of Louisiana and Texas.

Tertiary sediments accumulated to great thickness where the continental platform began to build toward the Gulf of Mexico, beyond the underlying Mesozoic shelf margin and onto transitional oceanic crust. Rapid loading of sand on water-saturated prodelta and continental slope muds resulted in contemporaneous growth faulting (Loucks et al., 1986). The effect of this syndepositional faulting was a significant expansion of the sedimentary section on the downthrown side of the faults. Sediment loading also led to salt diapirism, with its associated faulting and formation of large salt withdrawal basins (Galloway et al., 1982a).

Sediments of the Tertiary progradational wedges were deposited in continental, marginal marine, nearshore marine, shelf, and basinal environments and present a complex depositional system along the Texas Gulf Coast.

Overlying the Tertiary progradational wedges along the Texas Gulf Coast are the Pleistocene and Holocene sediments of the Quaternary Period. The voluminous infilling of the Gulf basin during Tertiary time was followed by sediment influx of similar proportions due to the profound effects of continental Pleistocene glaciation (Foote et al., 1984). Pleistocene sedimentation occurred during a period of complex glacial activity and corresponding sea level changes. As the glaciers made their final retreat, Holocene sediments were deposited under the influence of a fluctuating, but overall rising, sea level. Quaternary sedimentation along the Louisianan Gulf Coast occurred in fluvial, marginal marine and marine environments.

2.1.1 ***Regional Stratigraphy***

The intervals of interest at Project Minerva are the Oligocene and Miocene. During these epochs, four sediment-dispersal axes dominated the Gulf margin (Figure 2.6). The Houston and central Mississippi deltas provided a source of coarse-grained sediment for SW Louisiana and SE Texas (Swanson and Karlsen, 2009). Oligocene- and Miocene-age sediments were deposited as major progradational wedges along the margin of the Gulf Coast Tertiary basin (Houston Embayment and South Louisiana Salt Basin sub-basins) (Swanson et al., 2013). The Gulf Coastal Plain was characterized by rapid subsidence in areas of high sediment loading through multiple cyclic depositional episodes. These cycles represented various transgressive and regressive stages and were caused by variations in sediment supply and subsidence.

Major progradational wedges are typically characterized by an up-dip section of interbedded continental and marginal marine sediments underlain by a thick marine section composed of under compacted slope and basin claystone. The instability caused by the direct and rapid loading of water saturated, unconsolidated sediments resulted in the development of large scale, syndepositional, down-to-the-basin faults and intraformational deformation (Galloway et al., 1982a).

Oligocene and Miocene deposits are subdivided according to depositional cycles and paleontological zones (Foote et al., 1984 and Swanson et al., 2013) (Figure 2.7).

1. Vicksburg Group: Lower Oligocene-aged. Represents a transgressive phase (mainly shale and some sandstone lenses)
2. Frio Formation: Middle Oligocene-aged. Represents a dominantly regressive phase. (Mixture of marginal marine and deltaic sandstones and shales, with localized deep marine shales and turbidite sandstones) Downdip equivalent of the continental Catahoula Formation (Swanson et al., 2013)
3. Anahuac Formation: Upper Oligocene-aged. Represents transgression (marine shales and thin sandstones)
4. Fleming Formation: Miocene-aged. Represents a very high number of alternating regressive and transgressive phases (progradational sandstones and retrogradational shales)

2.1.1.1 Vicksburg Formation

The Vicksburg Formation lies within the Tertiary depositional wedge of the Gulf Coastal Plain and is regionally extensive across the Texas and Louisiana Gulf Coast. Alluvial sands were funneled through broad valleys and grade seaward into deltaic sands and shales, and then into prodelta silts and clays. These sediments were deposited during periods of marine transgression, separated by thicker sections deposited during a period of regression in the early Oligocene. The shoreline advanced and retreated in response to both changes in the rates of subsidence and sediment supply. Rapid down dip thickening occurs along the syndepositional Vicksburg Flexure fault zone, where there may be as much as a ten-fold increase in formation thickness. The Vicksburg Flexure marks the shelf margin during early Oligocene time.

In southeast Texas and western Louisiana, the early Oligocene-aged Vicksburg Formation comprises mainly shales with some interbedded sands. In the Houston Embayment and western South Louisiana Salt Basin (Figure 2.6), Vicksburg sediments were deposited in a series of stacked deltas through Vicksburg time (Coleman and Galloway, 1990). Productive fields in the Houston Embayment are generally separated into three distinct trends, which are notated after their associated characteristic fossil. The shallowest and furthest up-dip trend, up-dip of the Vicksburg Flexure, is identified as the Textularia warreni producing trend (Gregory, 1966). Sands in this trend were deposited in proximal deltaic environments in inner neritic depths. The second trend, the Clavulina byramensis producing trend, lies in fault blocks down-thrown to the first and second Vicksburg growth faults. These sands were deposited in an upper Vicksburg delta complex. The lower Vicksburg is primarily a prodelta front environment in this area. The third trend, the Loxostoma B delicate trend, lies seaward of the second trend, and occurs in deeper waters. Sands in this area were deposited in delta front or prodelta environments, preferentially located in paleotopographic lows (Coleman and Galloway, 1990).

2.1.1.2 Frio Formation

The Middle Oligocene Frio Formation is a thick sequence of mainly regressive sediments that were deposited rapidly in alluvial, lagoonal, marginal marine and deep marine environments, forming a major progradational wedge along the Gulf. Frio thickness and depth increases southwards, with localized variations occurring around salt diapirs and major faults (Figures 2.8 and 2.9). Non-marine sands were deposited in constantly shifting deltas and are interbedded with marine shales that were deposited during periods of local transgression. In areas between major delta systems (e.g. Mississippi Embayment, Figure 2.6) shoreface and shallow marine environments deposited broad sandstone units interbedded with marine silts/shales during transgressive periods. Deposition of the progradational Frio wedge was initiated by a major global fall in sea level, with subsequent Frio sediments being deposited under the influence of a slowly rising sea (Galloway et al., 1982b).

On a regional scale, the Frio Formation and Catahoula Formation (up-dip equivalent) can be divided into a number of distinct depositional systems that are related spatially and in time. Three major progradational delta complexes, designated the Central Mississippi, Houston and Norias delta systems, identified by Galloway et al., (1982b), were centered in the South Louisiana Salt Basin, Houston Embayment and Rio Grande Embayment, respectively (Figure 2.6). Three fluvial systems, the ancestral Mississippi, Chita/Corrigan, the Gueydan, supplied sediment to the delta complexes.

The Houston delta system of Texas and southwestern Louisiana is centered in southern Harris County, Texas. The system is composed of several minor, laterally coalescent, and frequently shifting delta lobes (Galloway et al., 1982b). The Chita/Corrigan fluvial systems supplied sediment. Up-dip deltas exhibited wave-dominated, arcuate geometries, while lobate delta geometries characterized episodes of maximum progradation or an area where high subsidence rates were associated with salt withdrawal basins (Galloway et al., 1982b). Due to constant switching of delta lobes, the rate of coastal progradation was slow for the Houston delta system (Galloway et al., 1982b).

A major global sea level rise occurred during the late Cretaceous, creating the Mississippi Embayment and allowing the farthest inland transgression of a shallow epicontinental sea (Vail et al., 1977). This embayment is part of the Mississippi Alluvial plain and supplied sediment to the southwestern portion of Louisiana. By Oligocene time, deposition had increased from the northeast, suggesting that the ancestral Colorado, Brazos, Sabine, and Mississippi Rivers were increasing in importance. Miocene time is marked by an abrupt decrease in the amount of sediment entering the Rio Grande Embayment, with a coincident increase in the rate of sediment supply in southeast Texas, Louisiana, and Mississippi. This continued through the Pliocene and Pleistocene epochs, with the major depocenters of sedimentation controlled by the Mississippi River and these are located offshore of Louisiana and Texas.

The Norias delta system of South Texas constitutes the main Frio Formation depocenter in the South Texas Coastal Plain. Typical sand content ranges from 25% to 40% for a total Frio Formation section that can be more than 12,000 ft thick. The lateral boundaries of the Norias delta system remained fairly fixed through time, centering on Kennedy County, Texas. Deposition of the system prograded the continental margin more than 60 miles basin ward, primarily during deposition of the lower and middle Frio Formation sections. This major off lapping episode was terminated by the shale-rich Anahuac Formation transgression, but the rate of sediment supply to the Norias system was sufficient to severely limit up-dip incursion of transgressive marine shelf facies. The upper Frio Heterostegina-Marginulina delta complexes continued to prograde locally across the Frio platform in the face of regional on lap (Galloway et al., 1982b). Individual deltas of the Norias system exhibit wave-modified, lobate geometries to wave-dominated, cuspate geometries (Galloway et al., 1982b).

Separating the delta complexes was a broad, strike-parallel barrier island/strandplain system along the south-central Texas coast called Greta/Carancahua. It comprises a linear sandstone belt, separating marine from brackish-water (back-barrier lagoon) shales. Shoreline conditions remained fairly constant during Frio Formation deposition. This, coupled with aggregational processes, developed a thick, narrow, homogenous sand section (Galloway et al., 1982b). Strike-parallel growth faults accentuated the coast-parallel geometry of the Greta/Carancahua barrier island/strandplain system. A similar but smaller barrier strandplain system (Buna) was developed by longshore currents off the eastern flank of the Houston delta system in east Texas/southwest Louisiana (Galloway et al., 1982b).

Within Louisiana the upper Frio Formation transitions into fine-grained, mix-load dominated fluvial sediments up-dip, north of Beauregard Parish, ultimately pinching out in central Louisiana, ~80 miles north of the Project Minerva area. To the south (offshore Gulf of Mexico) the downdip limit of the upper Frio Formation is defined by large-scale fault-related juxtaposition against thick, fine-grained formations in the overlying Neogene (Swanson et al., 2013). Local structural highs are the result of salt diapirism, and associated faulting, in combination with the regional structural fabric of major faults dipping dominantly southwards, parallel with the Gulf coastline.

2.1.1.3 Hackberry Trend

A transgressive, deep-water shale and sandstone unit referred to as the "Hackberry Trend" occurs in the middle to lower part of the Frio Formation and is localized to southwest Louisiana and eastern Texas (Figure 2.6 and Figure 2.10). Shales and sandstones of the Hackberry Trend pinch out to the north along the "Hartburg" flexure and formed a southward-thickening wedge (Swanson et al., 2013). The "Hartburg" flexure represents a zone of Oligocene-aged growth faulting which likely generated an area of deep marine environment.

In up-dip areas (north of Project Minerva area), submarine canyons up to 800 ft deep were incised through pre-Hackberry sediments (Figure 2.11) (Swanson et al., 2013). Here, the Hackberry Trend is characterized by thick shales punctuated by sand-rich channel-fill facies deposited in submarine canyons. Further downdip (across the Project Minerva area, and south), basin floor turbidite fan systems and isolated slope channel-fill sandstones typically appear encased in thick shale sequences (Swanson et al., 2013).

2.1.1.4 Anahuac Formation

As sea level continued to rise during the late Oligocene, the underlying Frio Formation progradational platform flooded. Wave reworking of sediment along the encroaching shoreline produced thick, time transgressive blanket sands at the top of the Frio Formation and base of the Anahuac Formation section. The transgressive marine shale-rich Anahuac Formation deposited conformably on top of the blanket sands throughout the Texas and Louisiana coastal region. The Anahuac Formation was deposited in an inner-shelf, shallow marine, proximal deltaic, distal deltaic, and slope environments (Swanson et al., 2013). It is typically composed of calcareous, marine shales with localized, lenticular, micritic limestone units. See Figure 2.12 and Figure 2.13 for structure and isopach maps. In western and central parts of Louisiana (Project Minerva area) the interval mostly comprises shales with lesser sandstones. Limestones and calcareous clastics dominate in eastern Louisiana and the eastern Gulf of Mexico, where clastic influx was minimal (Swanson et al., 2013).

The Anahuac Formation dips towards the Gulf of Mexico and thickens regionally from its inshore margin to nearly 2,000 ft offshore (Galloway et al., 1982b) (Figure 2.13). In southwestern Louisiana, the Anahuac Formation reaches a thickness of more than 1,300 ft (Figure 2.12). An erosional unconformity marks the top of the Anahuac Formation, and the start of a regressive period in the basal Miocene interval. Local variations in gross thickness are likely the result of this unconformity combined with variable fault movement along regional faults, and around salt diapirs.

2.1.1.5 Fleming Formation

The Miocene strata of the Gulf Coastal Plain contain more transgressive-regressive cycles than any other epoch. Rainwater (1968) has interpreted the middle Miocene as a major delta-forming interval comparable to the present-day Mississippi Delta system. The middle Miocene is representative of much of the entire Miocene interval, with only the site of deposition changing in response to various transgressions and regressions. The result is a complex of interbedded shallow neritic clays; restricted marine clays, silts, sands; and deltaic deposits of sands, silts, and clays. If a composite were made of the thickest Miocene intervals around the Gulf Basin, more than 40,000 ft of accumulated sediment would be obtained, of which about 20,000 ft were deposited in southern Louisiana (Rainwater, 1968).

The Oakville Formation and the Lagarto Formation form the major units of the thick Miocene Fleming Formation that were deposited throughout the Gulf Coast region. The Miocene sediments of the Fleming Formation of Louisiana are equivalent to the Oakville and Lagarto Formations of Texas and the Catahoula, Hattiesburg, and Pascagoula Formations of Mississippi (Figure 2.14).

Deposition of the Fleming Formation occurred in relatively shallow water across a broad, submerged, shelf platform constructed during Frio and Anahuac deposition. Three major depositional regimes characterize the Fleming Formation. Figure 2.15 shows the distribution of the lower Miocene depositional systems across the Texas Coastal Plain.

A major fluvial system (Santa Cruz fluvial system) extended across South Texas and supplied sediment to the North Padre delta system (Figure 2.15). The Hebbronville and George West fluvial axes are interpreted as two principal depositional loci of a single major river that shifted southward through Miocene time (Galloway et al., 1982a). The high sand content and internal structures of the fluvial system indicate low-sinuosity, braided, bed-load channel deposition (Galloway et al., 1982a). The Santa Cruz fluvial system grades basinward into delta-plain deposits of the North Padre delta system. The delta system is generally coincident in geographic distribution with the underlying Oligocene Norias delta system of the Frio Formation. The North Padre delta system is characterized by sand-rich, strike-parallel, delta-margin, facies tracts typical of coastal-barrier and beach-ridge facies, characteristic of highly destructive, wave-dominated deltas (Galloway, 1985).

Along the Texas-Louisiana border, the Newton fluvial system supplied sediment to the Calcasieu delta system of southeast Texas and southwest Louisiana (Figure 2.15). Sands of the Newton fluvial system are fine to medium-grained, with thick, vertically, and laterally amalgamated sand lithosome geometries typical of meander belt fluvial systems (Galloway, 1985). Depositional patterns within the Oakville Formation (lower Fleming) of southeast Texas show facies assemblages typical of a delta-fringing strandplain system (Galloway, 1985). The Calcasieu delta system is best developed in southeast Texas in the Lagarto Formation of the upper Fleming. The delta system consists of stacked delta-front, coastal-barrier, and interbedded delta/shoreline sandstones that compose the main body of the delta system, with interbedded prodelta mudstones and progradational sandy sequences deposited along the distal margin of the delta (Galloway, 1985).

Along the south-central Texas Coast, flanking the two Miocene delta systems, is a broad, strike-parallel barrier island/strandplain system. The Matagorda barrier/strandplain system is cored by a prominent strike-parallel belt of sandstone, bounded both up-dip and downdip by mud rich bays and lagoons, and marine shales, respectively (Galloway, 1985). The shore-zone complex has been interpreted by Galloway (1985) to consist of a mix of microtidal barrier-island and sand-rich strandplain deposits. Where streams of the Moulton/Point Blank stream plain infilled the back-barrier bays and lagoons, fluvial channel deposits merge directly with shore-zone sands (Galloway, 1985).

2.1.1.6 Pliocene-aged Formations

Conformably overlying the Fleming Formation is the Pliocene-aged Goliad Formation. The sedimentary sequence of the Goliad Formation is similar in character to underlying Upper Miocene units, having been deposited in a fluvial, deltaic, and marginal marine setting. The section thickens gradually to the south and is approximately 700 to 750 ft thick at the Project Minerva site where it is composed of interbedded fluvial and deltaic sandstones plus local minor conglomerates. Sandstones of the Goliad Formation are the lowermost units containing fresh to slightly saline water, and form the upper Evangeline aquifer in Harris County, Texas (Wesselman and Aronow, 1971). However, at the Project Minerva site, the Goliad is significantly deeper than the base of the defined lowermost USDW.

2.1.1.7 Pleistocene-aged Formations

Lying conformably above the Goliad are the Pleistocene-aged sediments of the Willis Formation that were deposited under the influence of the complex glacial and interglacial climatic sea level changes of the Pleistocene. The Willis Formation was deposited in both fluvial and deltaic environments and thickens in a southeastward dip direction as well as southwest along strike toward the southwest. Pleistocene sediments thicken along the Texas/Louisiana border and in a dip direction where there was significant deposition along growth faults during Pleistocene sea level lowstands (Wesselman and Aronow, 1971). Willis Formation sediments grade conformably into the overlying Holocene depositional units. Pleistocene and Holocene units contain fresh water and comprise the Chicot aquifer.

2.1.1.8 Holocene-aged Formation

With the retreat of the Pleistocene glaciers, sea level began a final irregular rise to its present-day level. As sea level rose, the lower reaches of coastal plain river valleys slowly filled with brackish-to-marine water and subsequently began filling with fluvial sediments. In southeastern Louisiana and eastern Texas, Holocene sediments were deposited in river valley meander belts and are primarily composed of point bar sandstones with interbedded, fine-grained over bank deposits.

The slow rise of the Holocene sea level marked the beginning of the recent geologic processes that have created the present Louisiana/Texas coastal zone. During recent times, sediment compaction, slow basin subsidence, and minor glacial fluctuations have resulted in insignificant, relative sea level changes. The coastal zone in southwest Louisiana/southeast Texas has evolved to its present condition through the continuing processes of erosion, deposition, compaction, and subsidence periods. Recent alluvial deposition in the area is restricted to the geomorphic flood plain of the present-day San Jacinto River system and to the entrenched valleys of the ancestral San Jacinto River system, which had down-cut into the underlying Pleistocene deposits during sea level lowstands (Wesselman and Aronow, 1971).

2.1.2 Regional Structural Geology

The Gulf of Mexico continental margins and deep ocean basin regions are relatively stable areas (Foote et al., 1984). The area is characterized by structural dip towards the Gulf, with frequent Miocene/Oligocene interval normal and growth faults aligned parallel to the contemporaneous shelf edge, stair-stepping down towards the Gulf (Figures 2.16 and 2.17). Tectonism driven in large part by sediment loading and gravity as played a key role in contemporaneous and post-depositional deformation of Tertiary strata (Foote et al., 1984). Deeper fault zones are present at basement level, mirroring the trend of the shallower Oligocene-level faults, but do not appear to be directly linked.

Salt mobilization led to extensive diapirism across the Louisiana and Texas Gulf Coast. This remobilized salt, originating from the deep Louann Salt Formation, may be present in a number of geometrical forms, including diapirs and pillows. In the region of the Project Minerva site, salt features typically occur as diapirs, or "salt domes." Such diapirs buoyantly moved upwards through many thousands of feet of younger strata concurrently with sedimentation during the Oligocene and Miocene. An example can be seen at the Vinton Dome, north of the Project Minerva site (Figure 2.9 and Figure 2.9a). Regional salt features may be deep-rooted and extend vertically for several thousands of feet or may have been totally severed from its deeper source.

Associated faulting is caused either in response to local salt mobilization or evacuation, or on a larger scale where significant volumes of strata have been transported on listric fault surfaces which likely detach along deeper shales and/or salt intervals. Faulting induced by salt evacuation commonly causes an expanded sedimentary section on the downthrown side of the fault (growth fault), usually either down-to-the-coast or down-to-the-basin. Faulting associated with salt movement in the Project Minerva site area includes local radial faulting emanating from Vinton Dome.

A second cause of faulting most common to the Texas/Louisiana Gulf Coast is the cause-and-effect relationship between rapid progradation of sediments and slope failure in the vicinity of the shelf edge or outer platform margin. Sediment accumulated in a series of wedges that thicken and dip gulfward. As a result of rapid progradation and sediment loading, large growth-fault systems formed near the downdip edge of each sediment wedge within the area of maximum deposition. Faulting typically aligned parallel with the contemporary shelf edges in the Gulf Coast region. The greatest displacement of faults and thickest accumulations of Oligocene and Miocene sediments occurred in an area known as the Frio Expanded Zone (Figures 2.16 and 2.17).

Figure 2.9 and Figure 2.13 demonstrate regional structural trends of the Frio and Anahuac formations. Depth increases significantly from north to south and is likely linked to frequent normal and growth faults striking perpendicular to dip, detaching along deep shale or salt intervals. Such faults are only resolvable with 3D seismic data and appear as noise in lower resolution structural maps generated from regional well data. Localized structural highs are commonly associated with salt diapirism. Within the broad structural regime, synclines may result from the interplay of major regional faults with salt domes and the associated counter-regional faulting. An example of this can be seen at Project Minerva where the Vinton and Black Bayou Domes create a localized syncline.

Figure 2.8 and Figure 2.12 demonstrate the significant increase in Oligocene strata thickness observed as the "Frio Stable Shelf Fault Zone" (north Orange County and Central Calcasieu) trends southeastwards into the "Frio Expanded Fault Zone" (Figures 2.16 and 2.17) (Swanson et al., 2013). While no major growth faulting is observed in the Project Minerva 3D seismic dataset, it is believed that regionally, Oligocene sediments greatly expanded and filled vast amounts of accommodation space created by movement along growth faults within the "Frio Expanded Fault Zone" (Swanson et al., 2013).

The shallower Oligocene-Holocene section thickens basinward, periodically interrupted by low-relief, broad salt domes and anticlines. Some minor fault displacement occurs as well, particularly where the system overlies deep-seated Eocene or Oligocene growth-fault trends (Galloway et al., 1982a). Structural modification is greatest where the Cenozoic sedimentary section is warped upwards along the margins of salt diapers.

2.1.3 ***Regional Cross Sections***

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.1.4 ***Regional Groundwater Flow in the Injection Zone***

The Project Minerva site is located within the Gulf Coast basin in southwestern Calcasieu Parish and northwestern Cameron Parish. It is located on the floodplain of the Sabine River (west of the site) and at the seaward margin of the Gulf Coastal plain physiographic province. Sedimentary strata of the Gulf Coast basin consist of poorly lithified units which strike nearly parallel to the coast and thicken to the south. Hydrostratigraphic units of importance range in age from Miocene to recent and include in ascending order:

- Fleming Formation
- Goliad
- Willis
- Lissie (subdivided into the Montgomery and Bentley formations)
- Beaumont
- Holocene/Recent sediments

Within this stratigraphic section are the two main aquifers of the area, the Chicot and the Evangeline.

The Lower Miocene-aged Fleming Formation is the deepest unit in the ground water section and consists of pro-delta mudstones and deltaic sandstones. The clay-rich section of the Fleming Formation is known as the Burkeville aquiclude, which is the confining layer that separates the Evangeline aquifer from the Jasper aquifer.

The Pliocene-aged Goliad Formation conformably overlies marine sediments of the Fleming Formation, and together, they form the Evangeline aquifer. Sediments of the Goliad Formation are predominately fluvial-deltaic sands, marginal marine sands and occasional conglomerates, with a total thickness in this area of approximately 700 ft.

Lying conformably above the Goliad are Pleistocene sediments of the Willis, Lissie, and Beaumont units which are associated with the Chicot aquifer. These deposits reflect the complex glacial and interglacial climatic and sea level changes of the period. The Willis Formation contains both fluvial and deltaic sediments, whereas the overlying Lissie Formation is primarily fluvial. The younger Beaumont Formation is geologically similar to the Lissie Formation and is less than 100 ft thick in the area. [The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

At the top of the stratigraphic section are Holocene deposits that mark glacial retreat and a corresponding rise in sea level. In the local area, Holocene sediments consist of meander belt point bar sandstones and interbedded finer-grained overbank deposits, coastal marsh, mud flat, and beach deposits. [The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).] The combined Pleistocene-Holocene section comprises the Chicot aquifer. A detailed discussion on the regional and local hydrogeology is contained in Section 2.4.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.1.4.1 Frio Formation Fluid Background Velocity

Many of the studies for flow rates in deep saline aquifers come from the search for nuclear waste isolation sites. These studies show sluggish circulation to nearly static conditions in the deep subsurface (Bethke et al., 1988). Flow rates in the deep saline aquifers (Clark, 1988), were found generally to be on the order of inches per year. A south-southeastern (down-dip) direction of regional flow established for the upper Frio Formation is consistent with the theory of deep basin flows and the physical mechanisms (topographic relief near outcrops and deep basin compaction) identified as contributing to natural formation drift (Bethke et al., 1988; Clark, 1988; Kreitler, 1986).

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.2 Local Geology of the Project Minerva Site

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.3 Seismicity

An earthquake is a motion or trembling that occurs when there is a sudden breaking or shifting of rock material beneath the earth's surface. This breaking or shifting produces elastic waves which travel at the speed of sound in rock. These waves may be felt or produce damage far away from the epicenter-the point on the earth's surface above where the breaking or shifting occurred.

The Texas/Louisiana Gulf Coast is historically an area of low seismicity with naturally occurring earthquakes being rare and of exceptionally low magnitude. Project Minerva is located in one of the areas recognized as having low to the lowest level of seismic risk in the continental United States (USGS, 2018, (https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map), Figure 2.68). Rare instances of fluid injection-induced and fluid withdrawal-induced earthquakes from oil field operations have been documented along the Gulf Coast. However, fluid injection-induced earthquakes are associated with much higher injection pressures and volumes than those anticipated to be encountered in Project Minerva injection operation, while fluid withdrawal-induced earthquakes are most commonly associated with large-scale oil and gas production of magnitudes greater than any past or present production near the site.

The frequency of small and large earthquakes is related in a predictable way, called the "Gutenberg-Richter relation" that states that for every 1,000 magnitude 4 earthquakes there will be approximately 100 magnitude 5 events, 10 magnitude 6 events, and one magnitude 7 event. Thus, the occurrence of two earthquakes with magnitude near 6 in the twentieth century suggests that a magnitude 7 may occur every few hundred years or so.

Faulting in the Gulf Coast Basin is predominantly two types: listric normal growth faulting (Figure 2.69) and radial faulting associated with shale or salt piercement structures (Figure 2.70). Growth faults form contemporaneously with sedimentation so that their throw increases with depth and strata on the downthrown side are thicker than the correlative strata on the upthrown side of the fault (Figure 2.69). The faults form in clastic sequences that build out into unconfined depositional sites that have prograded to the edge of the continental margin, resulting in contemporaneous failure of the prograding sediments (Jackson and Galloway, 1984). Although growth faults may be common throughout the Gulf Coast Basin as a whole, none are present within, or immediately surrounding the Project Minerva AoR. Listric faults are locally present but are restricted to the deeper Jurassic and Upper Cretaceous sedimentary intervals well below the Injection Zone.

In any particular region, the level of earthquake hazard depends on many different factors. These include the size, location, and frequency of earthquakes that may occur, as well as the population density, topography and nature of manmade improvements. For any particular earthquake, the expected intensity also depends on the type of construction and the thickness of surficial and near-surface soil. For any region, the most important factor affecting seismic risk is the historical record of earthquake activity. Regions that have had large earthquakes in the past will likely experience them again. Although hazard estimates include information about mapped faults, in practice, the information is not always influential since many faults are not seismically active and many unmapped faults exist.

*2.3.1 **Seismicity - Louisiana***

The Louisiana-Texas Gulf Coast is historically an area of low seismicity, with naturally occurring earthquakes being rare and of low magnitude (Figures 2.71, 2.72 and 2.73). The natural seismicity of the area is attributed to one or more of the following:

- Faulting along zones of flexure caused by sediment loading
- Earthquakes induced by fluid injection and/or fluid withdrawal from oil field operations
- Events related to salt or shale diapirism

Seismic event data through April 2021, for a 186-mile radius around Project Minerva, is shown in Figures 2.71 and 2.72 and tabulated in Table A.1 Seismic Events, APPDX D - Reg Seis. Earthquake events are grouped by geological regime, with those in the "Gulf Coast" area being analogous to the Project Minerva area. Those events in the "Sabine Uplift" area are less relevant to the area of interest. These data were secured from the National Earthquake Information Center.

The data show that southwestern Louisiana is low risk from a historical perspective, with only one recorded seismic event near Project Minerva. On October 16, 1983, a magnitude 3.8 earthquake occurred west of Lake Charles in southwestern Louisiana (20 miles northeast of Project Minerva). The earthquake was felt over an area of 1,004 square miles and had a maximum Modified Mercalli intensity of V. The focal mechanism of the earthquake was determined based on P-wave first motions from 22 local and regional monitoring stations along a predominantly east-west trending, southeast-dipping normal fault with a small strike-slip component. The depth of this event (3.1 miles) provides significant evidence that normal faulting within the crystalline basement may control shallower growth faults along the Gulf Coast.

The largest earthquake within the Gulf Coast geological regime occurred on October 19, 1930, with the epicenter near Donaldsonville, LA (~159 miles east of Project Minerva). This earthquake measured 4.2 on the Richter scale and was felt over an area of approximately 15,000 square miles (Shake Out website).

2.3.2 Seismicity - Texas

In Texas, the regions at greatest risk for seismicity are in West Texas, where earthquakes of magnitude of about six occurred in 1931 and 1995, and in the Panhandle area, where at least six earthquakes with magnitude above 4 have occurred since 1900. Earthquakes of similar magnitude may occur again in these areas. Geologically, some features of the Panhandle are similar to the Missouri-Tennessee area, however, large continental quakes are extraordinarily rare (occurring less often than once per 500 years in any particular place). Within the twentieth century there have been more than 100 earthquakes large enough to be felt in Texas; their epicenters occur in 40 of Texas's 257 counties. Four of these earthquakes have had magnitudes between 5 and 6, making them large enough to be felt over a wide area and produce significant damage near their epicenters.

In four regions within Texas there have been historical earthquakes that indicate potential earthquake hazard. Two of the regions, near El Paso and in the Panhandle, have had earthquakes with magnitudes of about 5.5-6.0 occurring every 50-100 years, with even larger earthquakes possible. In northeastern Texas, the greatest hazard is from very large earthquakes (magnitude 7 or above), which might occur outside of Texas, particularly in Oklahoma or Missouri-Tennessee. In south-central Texas and along the Gulf Coast the hazard is generally low, however, small earthquakes can occur there, including some that are triggered by oil or gas production. Elsewhere in Texas, earthquakes are exceedingly rare. However, the hazard level is not zero anywhere in Texas; small earthquakes remain possible.

Within a 186-mile radius around Project Minerva, 29 earthquakes have occurred since 1900. All lie outside of the Gulf Coast geological province and were in or along the fringes of the Sabine Uplift area (Figures 2.71 and 2.72 and Table A.1 Seismic Events, APPDX D - Reg Seis). The majority of these earthquakes occurred post-2012 and likely linked to oil and gas drilling activity within the Haynesville Shale area of the Sabine Uplift. The geological regime in this area is significantly different to that at Project Minerva, and thus it is not seen as a good analogue for predicting future earthquakes.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.4 <u>Hydrogeology</u>

The primary regulatory focus of the USEPA injection well program is protection of human health and the environment, including protection of potential underground sources of drinking water ("USDW"). The USDW is defined by the EPA as an aquifer which supplies any public water system and contains fewer than 10,000 mg/l total dissolved solids (TDS). The following sections detail the regional and local hydrogeology and hydrostratigraphy.

2.4.1 Regional Hydrogeology

The regional aquifer system is called the Gulf Coast Aquifer System and stretches from Texas, across Louisiana, Mississippi, and Alabama, and includes the western most portion of Florida. Miocene and younger formations contain usable quality water (<3,000 milligrams per liter (mg/L) TDS) and potentially usable quality water (<10,000 mg/L TDS), which is defined as base of lowermost USDW within this system. These aquifer systems regionally crop out in bands parallel to the coast and consists of units that dip and thicken towards the southeast. Baker (1979) describes four major hydrogeologic units that comprise the Gulf Coast Aquifer System in the Texas and Louisiana region. In ascending order, the four units are:

- Jasper aquifer
- Burkeville confining system
- Evangeline aquifer
- Chicot aquifer

The Burkeville confining system hydrologically separates the Evangeline aquifer from the underlying Jasper aquifer. However, the Chicot and Evangeline aquifers are thought to be hydrologically connected. A hydrogeologic stratigraphic column for southwestern Louisiana is contained in Figure 2.75. The following sections provide details on the regional expanse and parameters pertaining the hydrostratigraphy for the defined systems from deepest to shallowest intervals. A regional stratigraphic section (A-A') parallel to dip from Baker (1979) depicting the aquifers in the regional area of Southeast, Texas is contained in Figure 2.76.

2.4.1.1 Hydrostratigraphy

2.4.1.1.1 Jasper Aquifer

The Jasper Aquifer is a hydrostratigraphic unit contained within the Miocene sands in the southwestern portion of Louisiana and Texas. The base of the aquifer coincides with the stratigraphic lower boundary of the Miocene-aged Fleming Formation. In parts of Texas, this also includes the Oakville sands. However, in the project site are this geologic interval is not present. The Jasper aquifer is separated from the deeper saline formation waters of the upper Frio Formation by the shale-rich Anahuac Formation and is a is a confined system overlain by the Burkeville confining unit (Figure 2.76). The system is laterally extensive throughout the southern portion of Louisiana and along the Gulf Coast of Texas. Regionally, the Jasper aquifer system dips southwards and becomes deeper and increases in salinity towards the Gulf of Mexico.

In Louisiana, the Jasper Aquifer System is only used as a freshwater source in Vernon, Beauregard, Rapides and Allen Parishes, located north of Project Minerva. In the Project Minerva area, the Jasper aquifer contains saline waters, ranges in thickness from 50 ft to 2,400 ft thick regionally and is comprised of medium- to fine-grained sands. It is geologically isolated from other aquifers by laterally extensive overlying and underlying clay strata with recharge to the system north of the project site (up-dip). In the local area, the saline-bearing Jasper aquifer strata is truncated against the West Hackberry salt dome.

2.4.1.1.2 Burkeville Confining System

The Burkeville Confining System separates the Jasper and Evangeline aquifers and retards the interchange of water between the two aquifers. The Burkeville Confining System is comprised of compacted clays and fine-grained silts, with occasional lenses of sands. This system is shown to be an effective confining unit due to the differing hydrostatic pressures within the Jasper (underlying) and Evangeline (overlying) aquifers. A typical thickness of the Burkeville is 300 ft (Baker, 1979). However, the unit thickness can vary from 100 to 1,000 ft within the Gulf Coast area. The regional cross section presented in Figure 2.76 depicts the confining system dipping down towards the Gulf.

The system Is comprised of fine-grained silts and clays and is evident across the well logs for the area. The Burkeville contains some sand lenses that may act a as perched aquifers up dip and providing freshwater in localized areas.

2.4.1.1.3 Evangeline Aquifer

Within southwestern Louisiana, the Evangeline aquifer is situated within sands associated with the Pliocene-aged Goliad Formation. These sands underlie the Chicot Aquifer System and are comprised of sands that range from loosely consolidated sands and gravels, with interbeds of silts and clays. The sands are moderately well sorted and overlay the confining Burkeville Confining unit, retarding flow from between the aquifer systems. The upper portion of the Evangeline is separated from the Chicot by thin clay beds, but in some areas, these confining strata are missing. This puts the deeper Evangeline sands in contact with basal sands of the Chicot.

Recharge to the Evangeline aquifer occurs via rainfall inland from the Gulf of Mexico, and minimally, by leakage downwards from other shallow aquifers. The hydraulic conductivity of the Evangeline aquifer varies between 20 to 100 ft/day (DEQ of Louisiana, 2009). The freshwater interval thickness ranges from 50 to 1,900 ft depth in the Evangeline.

2.4.1.1.4 Chicot Aquifer

The Chicot Aquifer System is the main regional aquifer system that provides usable groundwater for southwestern Louisiana. The Chicot Aquifer System is largely comprised of one, major undifferentiated sand, that splits down dip. These Pleistocene-aged sands are predominately comprised of unconsolidated to loosely consolidated gravels and coarse graded sands. They dip and thicken towards the Gulf Coast and thin to the west (towards Texas) and slightly thicken towards the east (towards Mississippi). The aquifer system thickens and deepens to the south at a rate of about 30 ft/mile (Nyman et al., 1990). The upper sand section contains freshwater underlain by saltwater in Cameron Parish (Nyman, 1984), except along the southeastern coast where no freshwater is present (Smoot, 1988). A freshwater to saline interface is driven northwards from the coast by water production for public supply, rice irrigation, and aquaculture. The southern limit of freshwater in the upper aquifer occurs near the coastline (Nyman et al., 1990).

Recharge to the system in Louisiana occurs where the Chicot outcrops in southern Rapides and Vernon Parishes, and in northern Allen, Beauregard, and Evangeline Parishes. There is also minimal recharge to the system via vertical leakage from the shallow overlying alluvial deposits.

2.4.1.2 Regional Groundwater Usage

Groundwater withdrawals from aquifers within Louisiana in 2015 are presented in Figure 2.77 (from USGS and Louisiana Department of Transportation (DOTD)). The primary focus of this assessment is on the Jasper, Evangeline, and Chicot aquifers in the southwestern portion of the state.

The Jasper aquifer is not a major source for regional freshwater use in along the Gulf Coast, except in Beauregard, Rapides and Vernon Parishes (Figure 2.78). As the aquifer dips downwards towards the south (towards the coast), the groundwater increases in chlorides and is less commercially ideal to produce in comparison to the overlying Chicot and Evangeline aquifers. In Louisiana, the Jasper aquifer is primarily used as source only near its recharge areas. Its primary uses are for public water supply and industry with approximately 47.95 million gallons per day (Mgal/d).

Groundwater withdrawal from the Evangeline aquifer in Louisiana is almost half of that then from the Jasper aquifer. The Evangeline is used most heavily used in Evangeline Parish, as well as Allen, Avoyelles, and Beauregard Parishes for public supply and industry (Figure 2.79). It has also been used as a power supply source for the local areas. Approximately 28.56 Mgal/d were withdrawn from the aquifer in 2015.

The Chicot aquifer yields the highest amount of groundwater for the State of Louisiana. It is the primary source of water for Acadia, Calcasieu, Cameron, and Jefferson Davis Parises (Figure 2.80). As the aquifer nears the coast, the lower units become saline and only the upper portions of the aquifer are used as a source of groundwater. Approximately 849.90 Mgal/d are produced from the entire aquifer. The largest contributor for withdrawal is for rice irrigation and aquaculture (crawfish harvesting), which are seasonal. As a result, during the off-peak irrigation season, the aquifer recharges, with the water level rebounding back to normal levels. The Chicot is also the largest supplier of public supply at 95.60 Mgal/day for the region and supports large cities such as Lake Charles.

Overall, regional groundwater withdrawals within the Chicot aquifer have declined since 1985. Since the water levels are stabilized, withdrawal from the aquifers is not expected to have an effect on either the safety of the injection site (non-endangerment of USDWs) or injection operations. The upper Frio Formation Injection Zone at Project Minerva is separated by over 7,000 ft of geologic section (>1,100 ft net impermeable shale) from the shallow USDWs (<10,000 mg/L TDS) (Figure 2.26). Multiple additional saline “buffer aquifers” also exist between the top of the Confining Zone and base of the lowermost USDW, mitigating the vertical transmission of fluids upwards.

Regional aquifer data on the characteristic for the systems is contained in Table 2.4 (from Wesselman and Arrow, 1971) for the aquifers in the Beaumont and Orange, Texas. These data are regional and applicable across the Sabine River into southwestern Louisiana.

2.4.1.3 Regional Groundwater Flow

Groundwater moves through aquifer systems from areas of high hydraulic head to areas of lower hydraulic head. Regional uses from industry and the public water systems have some impacts on diverting the direction of flow.

The Chicot regional flow is in the direction of development. Major development of groundwater occurs around the Lake Charles area. In Cameron Parish, due to aquifer development, the direction of groundwater flow is primarily north and northeast (Lovelace et al., 2004).

A map of the potentiometric surface for the Chicot aquifer (Figure 2.81) shows the direction of groundwater flow. Lovelace et al. (2004) indicated that the flow direction is towards major pumping areas such as Lake Charles in Calcasieu Parish and the northern part of Acadia Parish and south Evangeline Parish, where there is heavy pumping for industrial and irrigation uses. Control points and wells in the analysis are located on Figure 2.81. The direction of flow of groundwater is downgradient at 90 degrees to the potentiometric contours at right angles. An additional issue from pumping and heavy groundwater usage is the upwards coning of saltwater that can occur as response to freshwater withdrawal. The result is higher salinity waters being pulled upwards as pumping increases in aquifers that are hydraulically connected. Along the coast in the southwestern and southern portion of Louisiana, saltwater is being slowly pulled inland (northwards) due to over pumping of groundwater aquifers for industry and agriculture, especially during the peak rice irrigation and aquaculture harvesting seasons. Two regional cross sections (Figure 2.82) extending across Calcasieu Parish show that the southern portion of the parish is impacted by saltwater encroachment in the Chicot aquifer (and by default the Evangeline) from the Gulf of Mexico. Increasing chloride concentrations between 1968 and 1984 indicated that a northwards or upward movement of the freshwater-saltwater interface in areas east and south of Lake Charles.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

2.5 Geochemistry

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

2.6 History of Economic Development

The Frio Formation, including the Anahuac Formation, is the largest producer of hydrocarbons from the Paleogene on the Gulf of Mexico shelf (Swanson and Karlsen, 2013). Hundreds of millions of barrels of hydrocarbons have been produced in the history of Gulf Coast development and Project Minera sits within a highly productive and extensively developed Frio-Anahuac hydrocarbon play (Figure 2.94) As such, the project benefits from a substantial dataset including geophysical well logs, core samples, production data, regional studies, and seismic surveys.

History of exploration at Project Minerva site:

1. 1920's: Early wells targeted the crest and flanks of Vinton Dome and Black Bayou salt domes; Relatively few shallow, Miocene wells drilled
2. 1930's – 1950's: Big increase in drilling (hundreds of wells); salt dome flanks targeted, with wildcat wells extending further afield; large, less structurally complex fault block traps targeted in Miocene reservoir
3. 1960's-1980's: Increasing use of 2D seismic encouraged the expansion of drilling into deeper reservoirs (Miocene and Frio Formation) and more structurally complex areas of the salt dome flanks (e.g. Southern flank of Vinton Dome); peak of Miocene drilling in the 70's before decreasing in the 80's
4. 1990's: Early 90's saw a dramatic drop in drilling in the area before the advent of 3D seismic in the late 90's allowed imaging of deeper Hackberry sandstone reservoirs and a clearer understanding of structural traps. Exploration moved into a new phase of drilling of deeper, over pressured wells. This is important to Project Minerva as it provides a modern, analogous data set for the area of interest (Frio and Anahuac Formations).
5. Early 2000's saw a huge increase in Miocene/Oligocene drilling across the flanks of Vinton Dome and Black Bayou; deep wells targeting Hackberry sandstone channels were drilled away from salt dome structures, notably in the structural low targeted by Project Minerva. The deeper wells targeting the Hackberry were enabled by the extensive 3D seismic shoots

which began in the late 90's and continued through the 2000's. modern log suites were acquired in these wells and provide a critical data source for the Project Minerva analysis.

6. Mid 2000's – present: More recently drilling has continued at a much-reduced rate, mainly targeting previously overlooked accumulations in fault blocks around Vinton Dome, Black Bayou and Phoenix with vertical and directional wells; some older wells drilled across dome crests recompleted to target previously overlooked reserves.

Historic development has provided a wealth of information and knowledge about the regional upper Frio Formation Injection Zone and Anahuac Formation Confining Zone. Nearby production has predominately been from the shallower Miocene or deeper Hackberry (mid-lower Frio Formation). Both targeted intervals are separated from the planned Injection Zone by substantial thicknesses of extensive sealing shales, and as such, there are no depletion issues.

*2.6.1 **Regional Pressure Sources and Sinks***

In order to identify all critical activities in the Injection and Confining Zones, including pressure sources and sinks, a Reveal reservoir simulation model of the project area was built.

1. All available production data (including hydrocarbons and water) were acquired from the Enverus DrillingInfo database, dating from 1950 to August 2020. Data were pulled in August 2020
2. Production was assigned to geological intervals – Hackberry, Frio, Anahuac, Miocene and other
3. Water production and re-injection is available post-1970; the data were allocated to each geological interval
4. The production of oil and gas and the re-injection of produced water were modelled in three regions: Phoenix Lake, Black Bayou and Vinton Dome

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

2.7 Geologic Summary

The analysis of regional and local geology near the proposed Project Minerva Site demonstrates the study area is geologically ideal for CO_2 injection and storage. The massive fluvial-deltaic sandstones of the Oligocene-aged upper Frio Formation provide effective injection reservoirs in terms of their lateral extent, mineralogical composition, and petrophysical characteristics. The geologic assessment has also identified that the reservoirs the permeability, porosity, thickness, and lateral continuity to accept and contain injected material. The overlying aquiclude layers in the upper Frio Formation are sufficiently thick, impermeable, and laterally continuous to contain the injected fluids in the Injection Zone. Shales of the overlying Anahuac Formation and Miocene-age Fleming Formation possess the necessary Confining Zone criteria to be effective barriers to upward movement. The thick Anahuac and Fleming Formation shales extend laterally across the region and are well over 1,000 times less permeable than the underlying injection reservoirs. The existence of multiple sand/shale layers between the top of the Injection Zone and the base of the lowermost USDW insures additional protection from contamination of a USDW.

3.0 SITE CHARACTERISATION

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

3.1.2 Well Data

A substantial amount of time was dedicated to building a comprehensive database. Figure 3.13 illustrates the key inputs built into the primary subsurface database in Petra. Well logs come from proprietary Stream Family records, ENVERUS DrillingInfo data subscription, LDNR SONRIS database and the Texas Railroad Commission database. A large part of the data-mining process involved digitizing proprietary hardcopy well data acquired from the Stream family as well as regional, publicly available tiff logs. ArcGIS was also extensively used for spatial analysis of wells vs data such as infrastructure, and terrain. Petrel was used to combine well and seismic data analysis for use in geostatistical and reservoir simulation modeling.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

4.0 SITE SUITABILITY

4.1 Existing well penetrations in the Injection Zone

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

A full review of well construction and plugging (well integrity) was conducted on all artificial penetrations drilled to the depth of the Upper Frio Formation Injection Zone. This well integrity review followed a protocol outlined in the Area of Review and Corrective Action Plan 40 CFR 146.84(B) document, submitted separately. It was determined that all wells are adequately isolated and pose no risk to the USDW. A full hydrogeological study to characterize and catalogue all water wells within five miles of the AoR was also completed.

Analysis of historical production determined that there are no issues with depletion of the upper Frio Formation. Additionally, there is no current production from the targeted Injection Zone within the AoR – see Section 2.6.1 Regional Pressure Sources and Sinks.

4.2 Model assumptions and conclusion

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(9).]

4.3 Check list of requirements

Analysis of the regional and local geology near Project Minerva demonstrates that the subsurface system is geologically ideal for injection. The massive sandstones of the Oligocene-aged Frio Formation provide effective injection reservoirs in terms of their lateral extent, mineralogical composition, and petrophysical characteristics. Initial studies show that the Injection Zone has the permeability, porosity, thickness, and lateral continuity to accept and contain waste. Shales of the overlying Anahuac Formation possess the necessary confining zone criteria to be effective barriers to upward movement. Additionally, the >7,000 ft overlying, shale-rich Miocene section providing secondary confining.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

5.0 DESCRIPTION OF AoR AND CORRECTIVE ACTION PLAN

5.1 Description of the files submitted for the AoR and the Corrective Action plan

The fully completed AoR and Corrective Action Plan Report has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT.

The report covers in detail the computational modelling approach to the delineation of the Area of Review (AoR), the Corrective Action Plan relating to existing well penetrations within the AoR and the Reevaluation Schedule for AoR delineation once operations commence. A thorough review of the hydrogeology is also supplied, along with a comprehensive bibliography of references utilized during the AoR modelling execution and reporting phase.

The AoR and Corrective Action Plan Report satisfies rule requirements *40 CFR 146.82(a)(13), 146.84(b) and 146.84(c).*

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)]***

6.0 DESCRIPTION OF FINANCIAL RESPONSIBILITY

6.1 Description of the files submitted for the financial responsibility

The fully completed Financial Responsibility Demonstration Report 40 CFR 146.85 has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT.

The Financial Responsibility Demonstration submission will satisfy rule requirements *40 CFR 146.82(a)(14) and 146.85.*

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]***

7.0 DESCRIPTION OF WELL CONSTRUCTION PLAN

7.1 Well Construction Overview

Well construction will create four permanent barriers between underground sources of drinking water (USDW) and injection activities (two casings and two cement sheaths). Two additional barriers will act in unison to separate injection fluids from USDW (tubing metal wall and pressurized annular fluid). There will be a total of six man-made barriers and one natural barrier (Confining Zone/Anahuac Formation) to prevent fluids moving to USDW.

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]

8.0 DESCRIPTION OF PRE-OPERATIONAL LOGGING AND TESTING PLAN

8.1 Description of the documents that are submitted to the GSDT

The fully completed Pre-Operational Logging and Testing Plan ("Data Acquisition Plan 40 CFR 146.87") has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT.

The Data Acquisition Plan 40 CFR 146.87 submission satisfies rule requirements. *40 CFR 146.82(a)(8) and 146.87*

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

9.0 DESCRIPTION OF WELL OPERATION PLAN

The Well Operation Plan submission will be submitted when the CO_2 streams have been identified for the nameplate capacity of Project Minerva.

9.1 Operational Procedures

The Operational Procedures [40 CFR 146.82(a)(10)] submission is currently being prepared and an update to this report will be filed via the GSDT when it is complete.

9.2 Description of the proposed Carbon Dioxide Stream

The Description of the proposed Carbon Dioxide Stream [40 CFR 146.82(a)(7)(iii) and (iv)] submission is currently being prepared and will be filed via the GSDT when it is complete.

10.0 DESCRIPTION OF TESTING AND MONITORING PLAN

10.1 Description of the documents that are submitted to the GSDT

The Testing and Monitoring Plan Report has been submitted via the GSDT in 'Confidential Business Information' form. All tabs that require input data within the module have also been completed and submitted via the GSDT. A 'Confidential Business Information' version has been submitted to Region VI of EPA as well.

The report covers in detail the overall strategy and approach for testing and monitoring, carbon dioxide stream analysis, continuous recording of operational parameters, corrosion monitoring, above confining zone monitoring, external mechanical integrity testing, pressure fall off testing, carbon dioxide plume and pressure front tracking, environmental monitoring at the surface, sampling/analytical procedures. A Class IV well Quality Assurance and Surveillance Plan (QASP) was submitted as an appendix along with additional information relation to project management, data generation and acquisition, assessment and oversight and data validation and usability.

The Testing and Monitoring Plan Report satisfies rule requirements 40 CFR 146.82(a)(15) and 146.90.

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]***

11.0 DESCRIPTION OF INJECTION AND WELL PLUGGING PLAN

11.1 Description of the documents that are submitted to the GSDT

The Injection and Well Plugging Plan has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT. A 'Confidential Business Information' version has been submitted to Region VI of EPA as well.

The report covers in detail the planned tests and measurements to determine the bottom hole reservoir pressure, Planned External Mechanical Integrity Test, Information on Plugs, methods used for volume calculations, notifications, permits and inspections required, plugging procedures and contingency procedures/measures.

The Injection and Well Plugging Plan satisfies rule requirements 40 CFR 146.82(a)(16) and 146.92(b).

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)]***

12.0 DESCRIPTION OF POST-INJECTION SITE CARE AND SITE CLOSURE PLAN

12.1 Description of the documents that are submitted to the GSDT

The Post Injection Site Care and Site Closure Plan (PISC) Plan has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT. A 'Confidential Business Information' version has been submitted to Region VI of EPA as well.

The report covers in detail the pre and post injection pressure differential, post-injection monitoring plan, alternative post-injection site care timeframe, non-endangerment demonstration criteria, site closure plan and QASP.

An Alternative PISC timeframe has been proposed as part of the GSDT submission. GCS has indicated an alternative PISC timeframe of 10 years instead of the default 50 years.

The Post Injection Site Care and Site Closure Plan satisfies rule requirements 40 CFR 146.82(a)(17) and 146.93(a) and the Alternative PISC submission satisfies rule requirements 40 CFR 146.82(a)(18) and 146.93(c).

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)]***

13.0 DESCRIPTION OF EMERGENCY AND REMEDIAL RESPONSE PLAN

13.1 Description of the documents that are submitted to the GSDT

The Emergency and Remedial Response Plan has been submitted via the GSDT in 'Confidential Business Information' form. All Tabs that require input data within the module have also been completed and submitted via the GSDT. A 'Confidential Business Information' version has been submitted to Region VI of EPA as well.

The report covers in detail the local resources and infrastructure, potential risk scenarios, response personnel and equipment, emergency communications plan, a plan review and staff training and exercise procedures.

The Emergency and Remedial Response Plan Report satisfies rule requirements 40 CFR 146.82(a)(19) and 146.94(a).

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)]***

14.0 INJECTION DEPTH WAIVER AND ACQUIFER EXEPMTION EXPANSION

Not applicable as GCS is not seeking a waiver or exemption.

15.0 DESCRIPTION OF ANY ADDITIONAL INFORMATION REQUESTED

15.1 Description of the documents that has been requested by the UIC Program Director

No documents have been requested by the UIC Program Director.

15.2 Optional Additional Project Information [40 CFR 144.4]

*15.2.1 **Wild and Scenic Rivers Act, 16 U.S.C. 1273 et seq***

The National Wild and Scenic Rivers System was created by Congress in 1968 (Public Law 90-542; 16 U.S.C. 1271 et seq.) to preserve certain rivers with outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations. The Act is notable for safeguarding the special character of these rivers, while also recognizing the potential for their appropriate use and development. It encourages river management that crosses political boundaries and promotes public participation in developing goals for river protection. Scenic River Areas are those rivers or sections of rivers that are free of impoundments, with shorelines or watersheds still largely primitive and shorelines largely undeveloped, but accessible in places by roads.

There are no scenic rivers within the project area.

*15.2.2 **National Historic Preservation Act of 1966, 16 U.S.C. 470 et seq***

The National Historic Preservation Act (NHPA) ensures that Federal agencies consider historic properties—defined as any prehistoric or historic site, district, building, structure, or object eligible for inclusion on the National Register of Historic Places (NRHP)—in their proposed programs, projects, and actions before initiation. There are no sites located within the project area that will be impacted.

*15.2.3 **Endangered Species Act, 16 U.S.C. 1531 et seq***

Federally listed species under the protection of the ESA in the vicinity of the Project were identified by a review of publicly available databases. A search using the USFWS Environmental Conservation Online System Information, Planning, and Conservation (IPaC) System consultation tool (Accessed in 2022) for the Project lease area was used to generate an official species list to fulfill the requirements of Section 7 of the ESA.

Based on the results of the IPaC consultation tool no species will be impacted for the proposed project. Species identified included: manatee (no suitable habitat), red-cockaded woodpecker (no suitable habitat), and the eastern black rail (critical habitat not defined). Additionally, according to IPac, there are no critical habitats at this location.

*15.2.4 **Coastal Zone Management Act, 16 U.S.C. 1451 et seq***

The Coastal Zone Management Act (CZMA) defines the coastal zones wherein development must be managed to protect areas of natural resources unique to coastal regions. States are required to define the area that will comprise their coastal zone and develop management plans that will protect these unique resources through enforceable policies of state coastal zone management (CZM) programs. Federal as well as local actions must be determined to be consistent with the CZM plans and policies before they can proceed. As defined in the Act, the coastal zone includes coastal waters extending to the outer limit of state submerged land title and ownership, adjacent shorelines, and land extending inward to the extent necessary to control shorelines. While this is a federal law, it is administered by the State of Louisiana.

The Permits/Mitigation Division of the Louisiana Department of Natural Resources is charged with implementing the Louisiana Coastal Resources Program (LCRP) under authority of the State and Local Coastal Resources Management Act, as amended (Act 361, La. R.S. 49:214.21 et seq). This law seeks to protect, develop, and, where feasible, restore or enhance the resources of the state's coastal zone. Its broad intent is to encourage multiple uses of resources and adequate economic growth while minimizing adverse effects of one resource use upon another without imposing undue restrictions on any user. Besides striving to balance conservation and resources, the guidelines, and policies of the LCRP also help to resolve user conflicts, encourage coastal zone recreational values, and determine the future course of coastal development and conservation. The guidelines are designed so that development in the Coastal Zone can be accomplished with the greatest benefit and the least amount of damage. The LCRP is an effort among Louisiana citizens, as well as state, federal and local advisory and regulatory agencies. The Permits/Mitigation Division regulates development activities and manages the resources of the Coastal Zone. A Coastal Use Permit (CUP) Program has been established by the Act as part of the LCRP to help ensure the management and reasonable use of the state's coastal wetlands. The project area is in the Louisiana coastal zone and will require a CUP.

16.0 REFERENCES – See A.4.1 References

[The information is Confidential Business Information per 5 U.S.C. § 552 (b)(4) and (b)(9).]