# 3.6:
# GEOLOGY, SOILS AND MINERAL RESOURCES

## Introduction

This section describes the geologic character of the landscape and the applicable regulations pertaining to geologic resources in the proposed project area. This section also discusses potential impacts to geologic resources associated with the proposed project. Measures to mitigate any potentially significant impacts are described.

## Environmental Setting

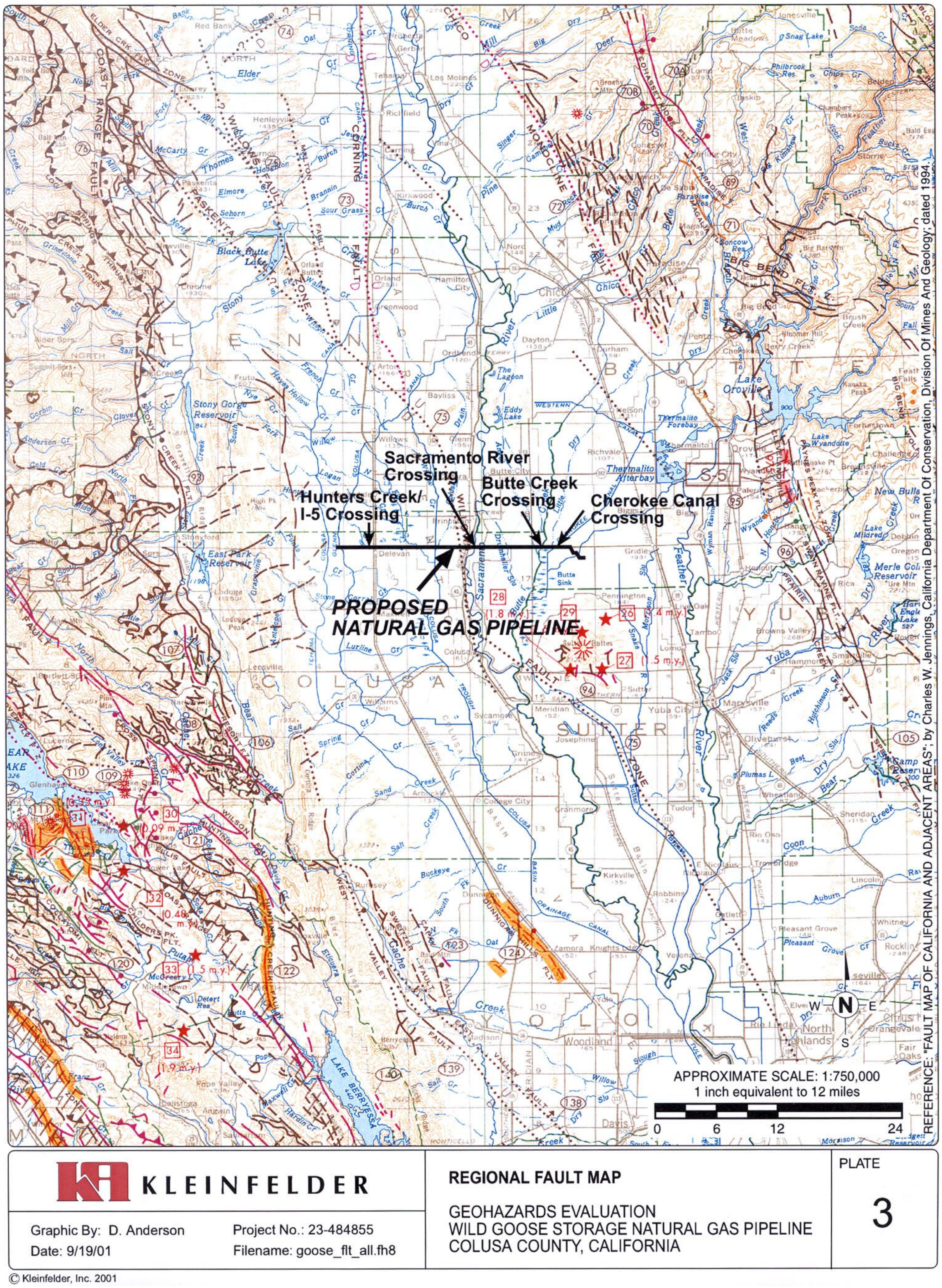
### REGIONAL

The topography of the project study area is relatively flat, with increasing elevation and gradient moving east and west away from the Sacramento River. In Colusa County elevations range from 55 feet above sea level at the Butte/Colusa County line to 150 feet above sea level at the Delevan Compressor Station. In Butte County elevations range from approximately 67 feet above sea level at the Remote Facility Site to 55 feet above sea level at the Butte/Colusa County line.

#### Stratigraphy

The WGSI project lies in the Sacramento Valley portion of the Great Valley Geomorphic Province of California. The Sacramento Valley is filled with about 30,000 feet of marine and non-marine sedimentary deposits, which are underlain by the Sierra Nevada granitic basement rock to the east and ultramafic basement rocks to the west. These two basement complexes are separated by the Coast Ranges-Sierran Block Boundary Zone (CRSBBZ). The CRSBBZ trends roughly north to south and passes beneath the project area west of the Sacramento River (Figure 3.6-1). It appears to coincide with portions of the Willows fault south of the project site and the active Chico Monocline fault north of the project site (Kleinfelder 2001e; Helley and Harwood 1985; URS 2001).

**Figure 3.6-1:** Regional Fault Map




SOURCE: Kleinfelder September 2001

Sacramento Valley fill consists (from the basement rock to the surface) of Cretaceous formations (about 140 to 65 million years before the present [mybp]), Tertiary formations (about 65 to 2 mybp), and Quaternary formations (the last 2 mybp). Cretaceous formations (up to approximately 20,000 feet thick) are predominantly well-consolidated marine sandstones and shales; one of these formations (the Kione Formation) comprises the existing and proposed gas storage zones of WGSI. Tertiary formations (up to approximately 10,000 feet thick) consist of interbedded marine and non-marine sandstones and shales, non-marine conglomerates, and a few volcanic flows, tuff layers and diatomaceous rocks. Quaternary sedimentary deposits (up to approximately 1,000 feet thick) typically consist of alluvial and lacustrine sediments that are semi-consolidated to unconsolidated (Kleinfelder, 2001e). Tertiary and Quaternary formations form a cap over the proposed gas storage zones and contain groundwater used for agricultural, commercial, and drinking purposes.

An inactive volcanic structure, called Sutter Buttes, is located about 10 miles southeast of the project area. The volcanic dome (andesite porphory and rhyolite surrounded by volcaniclastic sediments and pyroclastic mudflow deposits) pushed through the Cretaceous and Tertiary sedimentary rocks (Kleinfelder 2001e; Helley and Harwood 1985). The volcanic activity that created the Sutter Buttes appears to have occurred in the Early to Middle Pleistocene (between 2.4 and 1.6 million years ago) and the youngest volcanic domes were emplaced by 1.6 to 1.4 million years ago (Sutter County 1995).

**Tectonics**

The Great Valley was formed as a synclinal trough (a down-warped fold structure) bounded to the west by the Coast Range-Great Valley Thrust fault system and to the east by the depositional contact with the Sierra Nevada Mountains. Blind thrust faults beneath the western margin of the valley are pushing (thrusting up) the Coast Ranges over the granitic basement rock and Great Valley sediments (Wakabayashi and Smith 1994). This east-west compression across the Sacramento Valley has been active in Tertiary and Quaternary periods, and created north to northwest trending upward and downward shaped folds (anticlines and syncline, respectively) and underlying blind reverse faults. These geologic structures formed traps for economic natural gas fields throughout the Sacramento Valley (Kleinfelder 2001e).

**Faulting**. An active fault is one that has offset of Holocene materials (deposited less than 11,000 years ago) or that has significant seismic activity. Potentially active faults have demonstrated movement within Pleistocene time (approximately 1.6 million years before present). According to the California Department of Conservation, California Geological Survey (formerly Division of Mines and Geology), active and potentially active faults must be considered as potential sources of fault rupture.

There are no known "historically active" faults, or active faults with clear evidence of Holocene displacement (last 10,000 to 12,000 years) crossing the project area (WGSI 2001; Kleinfelder 2001; Colusa County 1989; Butte County 1977). Such faults would be classified as Alquist-Priolo Earthquake Fault Zones (AP Zones) under the 1975 Act as amended in 1994. One historically active fault is the Cleveland Hill fault (part of the Foothills Fault System), located approximately 24 miles northwest of the project area, which produced the Richter magnitude (M) 5.7 Oroville earthquake in 1975. Holocene ground rupture has occurred on the Dunnigan Hills fault (Zamora fault of Harwood and Helley [1987] and part of the Great Valley fault system), located about 40 miles south of the project area (Kleinfelder 2001).

Other faults that are near or crossing the project area are classified as potentially active, conditionally active (potential activity unknown), or inactive. Small, unnamed faults on the southern side of the Sutter Buttes, approximately 6 miles southeast of the Well Pad Site, are classified as potentially active. They could produce a maximum earthquake of M 5.8. A northeast-southwest trending fault traverses the project area (in Butte County), crosses the Cherokee Canal approximately 4,000 feet south of the Well Pad Site and passes near or beneath the Remote Facility Site. This unnamed fault is classified as Pre-Quaternary, meaning there is no evidence of displacement during the last five million years.

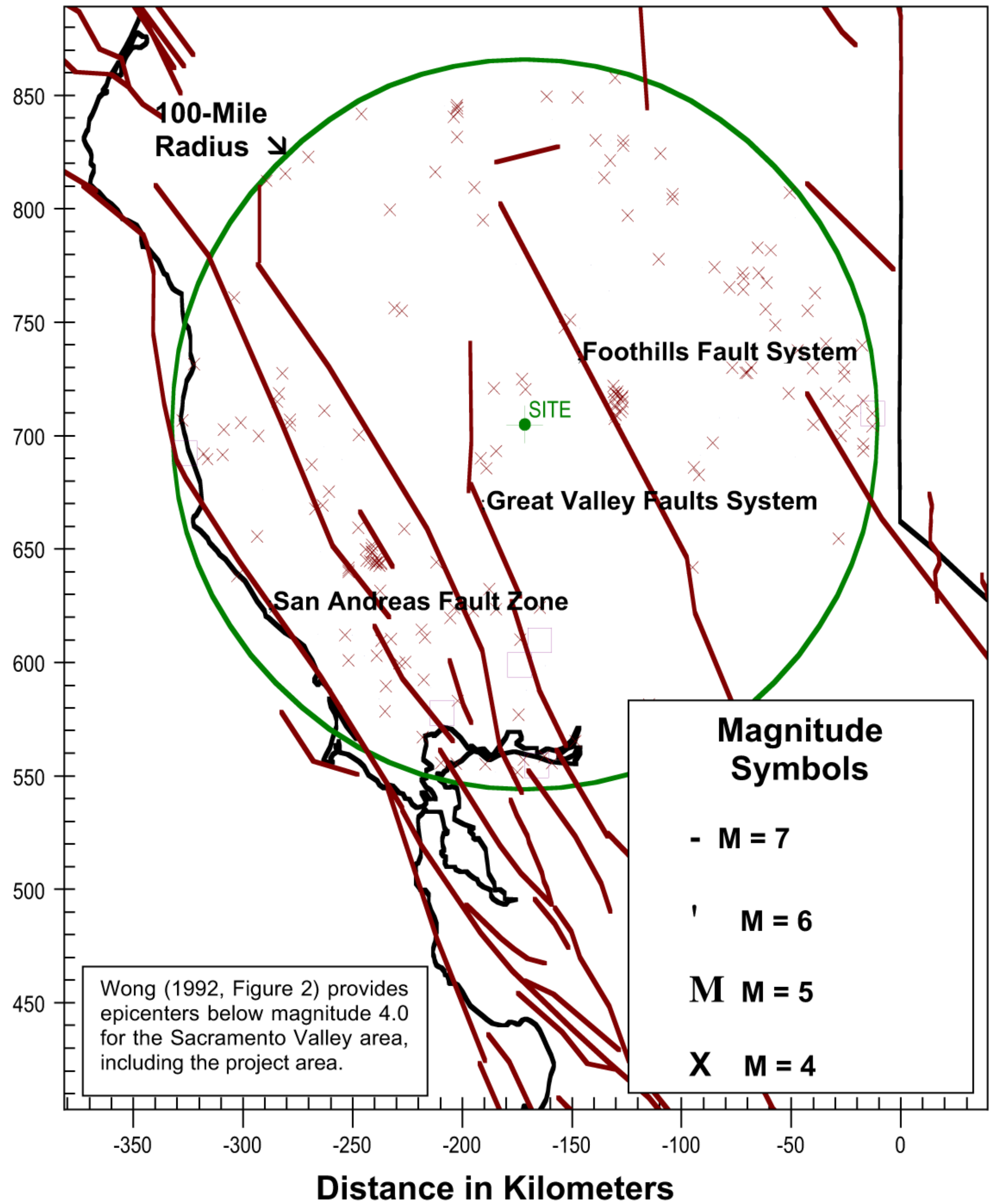
The Willows fault trends in a roughly north-northwest direction, through Colusa and south of the Sutter Buttes, approximately 9 miles southwest of the Well Pad Site. Regionally, the Willows fault is characterized as a steeply (74 degrees) east-dipping plane, with movement upward on the east side. Fault offset decreases towards the surface. The Willows fault is believed to form the Coast Ranges-Sierran Block Boundary Zone (CRSBBZ) and is classified by the State as pre-Quaternary. Faults in this category are not necessarily inactive. The Willows fault is considered “potentially active” (Butte County 1977) due to the historical seismic events in the vicinity of the fault. The nature and activity level of the Willows fault and a related fold have not been extensively studied. The main fault and the fold bound the west and east sides of the Sacramento River where Line 400 crosses the river. Harwood and Helley (1987) present evidence to suggest this fault may be active rather than inactive. Active folding should also be considered.

**Seismicity**. Kleinfelder (2001) identified several earthquakes within about 100 kilometers (62 miles) of the pipeline crossing of the Sacramento River.

- 1881 - An estimated M5.6 occurred east of Red Bluff, about 65 kilometers (40 miles) north of the alignment
- 1892 and 1893 - Three earthquakes M6.8, M6.4 and M5.6 occurred in the Vacaville-Winters area, about 90 to 100 kilometers (56 to 62 miles) south of the alignment, on the Great Valley fault system Segment 6
- 1909 - A M5.9 occurred within the Sierra, near the town of Strawberry Valley, about 70 kilometers (43 miles) northeast of the eastern end of the alignment.
- 1928 - A M5.5 earthquake occurred in the Newville area, about 75 kilometers (47 miles) northwest of the pipeline alignment
- 1975 - The M5.9 Oroville earthquake (Cleveland Hill)
- 1985 - Four minor quakes on an unknown fault in the Coastal Range foothills, the largest registering M3.7

The program EQSEARCH (Blake 1989-2000) was run for the site to search for all historic felt or recorded earthquakes within a distance of 100 kilometers (62 miles) (Figure 3.6-2). The results of that search are presented in Table 3.6-1. Differences between the Kleinfelder reports and Table 3.6-1 are not significant with regard to project impacts.

**Figure 3.6-2:** Earthquake Center Map




SOURCE: Blake, 1989-2000

**Table 3.6-1:** Earthquakes Greater Than Magnitude 5.0 Within 100 Kilometers (62 Miles) of the Project Area (Intersection of the Pipeline and the Sacramento River)

| Date[1] | Distance Miles (Kilometer) | Approx. Latitude (N) | Approx. Longitude (W) | Measured Depth (Km) | Measured Or Estimated Earthquake Magnitude | Estimated Peak Horizontal Acceleration (G) | Estimated Modified Mercalli Intensity |
|---|---|---|---|---|---|---|---|
| 08/02/75 | 28.5 (45.8) | 39.4330 | 121.4750 | 5.1 | 5.20 | 0.056 | VI |
| 08/02/75 | 28.8 (46.3) | 39.4490 | 121.4730 | 4.1 | 5.20 | 0.056 | VI |
| 08/01/75 | 26.0 (41.8) | 39.4360 | 121.5230 | 8.8 | 5.70 | 0.078 | VII |
| 04/20/45 | 32.8 (52.7) | 39.7500 | 121.6500 | n.m.a. | 5.00 | 0.045 | VI |
| 11/18/42 | 45.8 (73.7) | 39.9000 | 121.5000 | n.m.a. | 5.00 | 0.035 | V |
| 11/18/42 | 45.8 (73.7) | 39.9000 | 121.5000 | n.m.a. | 5.00 | 0.035 | V |
| 02/08/40 | 49.0 (78.9) | 40.0000 | 121.6000 | n.m.a. | 5.70 | 0.048 | VI |
| 11/15/38 | 53.9 (86.8) | 39.2500 | 123.0000 | n.m.a. | 5.00 | 0.031 | V |
| 03/03/09 | 58.8 (94.6) | 39.4000 | 120.9000 | n.m.a. | 5.00 | 0.029 | V |
| 05/07/06 | 49.3 (79.4) | 39.2000 | 122.9000 | n.m.a. | 5.30 | 0.039 | V |
| 04/21/92 | 59.6 (95.9) | 38.5000 | 121.9000 | n.m.a. | 6.20 | 0.054 | VI |
| 01/07/81 | 44.2 (71.1) | 40.0000 | 122.0000 | n.m.a. | 5.00 | 0.036 | V |
| 10/08/69 | 61.5 (98.9) | 39.1000 | 123.1000 | n.m.a. | 5.00 | 0.028 | V |
| 12/01/67 | 54.0 (86.9) | 39.2500 | 121.0000 | n.m.a. | 5.00 | 0.031 | V |
| 07/03/62 | 57.4 (92.4) | 39.6700 | 121.0000 | n.m.a. | 5.00 | 0.029 | V |

NOTES: (1) The information presented for all events prior to 1975 is estimated based on relatively poor instrumentation or "felt" reports.
n.m.a. = no measurement available for the early events

SOURCE: Blake 1989-2000

### Natural Gas and Surface Mineral Resources

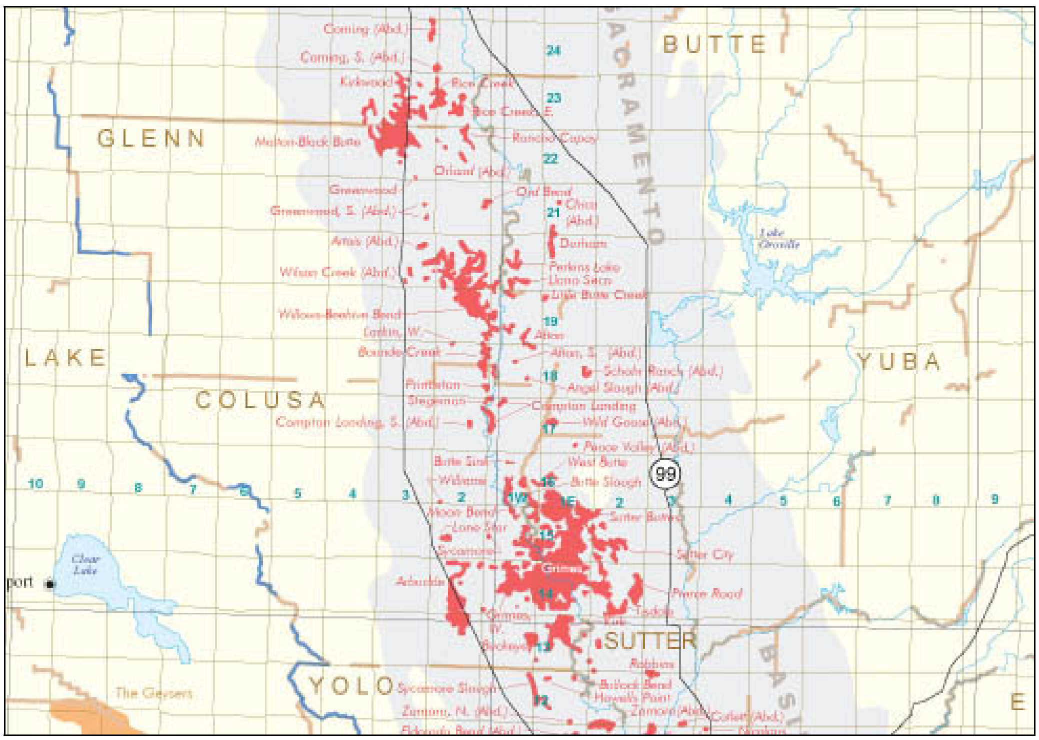
The Central Valley of California (Sacramento and San Joaquin Valleys) is rich in several mineral resources of economic interest. These mineral resources include: petroleum reserves (oil and gas), precious metals (gold, silver and platinum), construction aggregate (sand and gravel), clay, gypsum, and other deposits. Hart (1966) describes mineral resources of the Central Valley. Within the Sacramento Valley and in the project vicinity, the most important mineral resources are natural gas and construction aggregate.

**Natural Gas Resources.** The Sacramento Valley of northern California is a natural gas province. Numerous gas fields are located throughout the valley. Oil and gas exploration in the Central Valley began in the mid 1800s. By the 1890s, natural gas was commercially supplied to local cities. Most fields in the Sacramento Valley produce "dry" gas, with minimal heavier gas components or petroleum liquids. Methane (from about 80 to over 95 percent) is the primary component in the Sacramento Valley, along with minor amounts or other gases (ethane, propane, nitrogen, carbon dioxide, oxygen).

Sacramento Valley natural gas fields are found primarily in Cretaceous and Tertiary age sedimentary deposits. Hydrocarbons are contained within structural traps where channel sands cross over geologic structural highs (domes and anticlines). Sea levels fluctuated during deposition, creating an alternating sequence of marine and non-marine sands and shales forming the reservoirs and cap rock present today.

Natural gas fields are located in the western part of Butte County and throughout the eastern portion of Colusa County, concentrated mainly along the Sacramento River (Figure 3.6-3).

**Figure 3.6-3:** Natural Gas Fields




SOURCE: DOGGR

**Sand and Gravel Resources**. In the Sacramento Valley, sand and gravel represent major economic natural resources. Sand and gravel used as construction aggregate are extracted from young stream deposits associated with present rivers and creeks. In addition, deposits are found along riverbanks, on flood plains and in alluvial fans from former channels. Aggregate is also extracted from old gold dredge tailings (Hart 1966).

In the project vicinity, the Sacramento River and its tributaries represent potentially commercial economic sand and gravel resources. The former California Division of Mines and Geology (formerly CDMG, now the California Geological Survey [CGS]) is the agency responsible for designating potential sand and gravel resource area. Under the 1975 State Mining and Reclamation Act (SMARA), areas of economic interests are designated. In the immediate project vicinity, no specific sand and gravel resources are currently designated under SMARA. No active surface mineral resources would be crossed or affected by the proposed project in either Butte or Colusa County. The active gravel extraction operations are located along the east bank of the Sacramento River. The sand and gravel extraction area nearest proposed project components (pipeline) are in the vicinity of Moulton Weir (WGSI, 2001).

### LOCAL

Appendix I contains supplementary details to support the information contained in this section describing local geologic conditions. Section 3.7, Hazards and Hazardous Materials provides additional discussion of storage field and pipeline issues related to geology. Section 3.8, Hydrology contains additional hydrology information related to geologic hazards, which is summarized below.

#### Surficial Geologic Formations

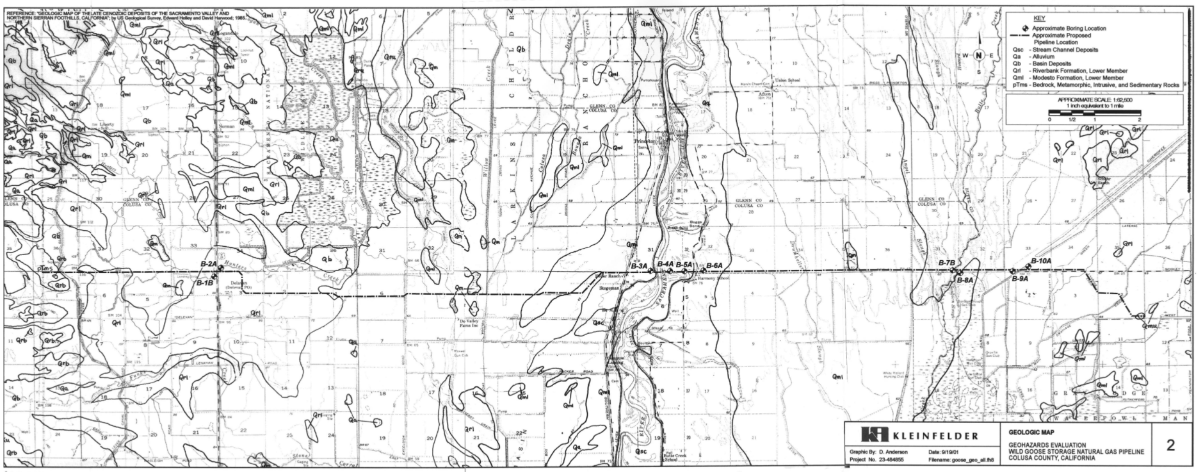
**Soils**. Soils in the project study area are a byproduct of weathered alluvial deposits. Erosion and transport of bedrock material from the bordering mountain ranges provide the source of these alluvial deposits. Most valley soils are alluvial silt loams, clays, and sands deposited by the Sacramento River, Butte Creek, and other tributaries. Project area soils are characteristically fine-textured, poorly drained, with erosion potential rated slight to none (WGSI 2000).

The majority of the alluvial soils on the valley floor have high agricultural productivity and are largely designated as Prime Agricultural soils   Some soils are limited in their ability to support many forms of agriculture because of alkali problems and/or drainage problems caused by the presence of a cemented hardpan layer. These poorly drained soils are particularly well suited for growing rice (see 3.2 Agriculture for rice production in the area).

**Quaternary Basin Deposits**. Kleinfelder (2001e) summarize the local project area surface geology based on previous work by Harwood and Helley (1985), Saucedo and Wagner (1992), Wahrhaftig et al (1993), and Jennings and Strand (1960). Kleinfelder drilled several geotechnical borings along the pipeline alignment adjacent to significant drainage crossings, characterizing materials down to depths of nearly 122 feet (adjacent to the Sacramento River). Figure 3.6-4 is a geologic map reproduced by Kleinfelder from the more detailed map of Harwood and Helley (1985). This map depicts the relationship of the proposed project surface facilities to the youngest Quaternary formations and subunits. These surface facilities would not encounter the Tertiary and older geologic formations mentioned above. Deeper subsurface geology is summarized in the following section.

It is important to understand and properly characterize the geologic materials that would be affected by construction activities, since construction safety, construction techniques, and operational performance depend upon proper engineering consideration during planning and design phases. Geologic mapping and subsurface stratigraphic interpretation within the project area defined the Quaternary alluvium, which is subdivided into several units by relative age and physical characteristics (see Appendix I for additional details). These Quaternary formations overlie the Pliocene Tehama

**Figure 3.6-4:** Geologic Map




SOURCE: Kleinfelder 2001

This Page Intentionally Left Blank

Formation (Tt), and are listed below from oldest to youngest (generally from the flanks of the valley to the river).

- Red Bluff Formation (Qrb)
- Riverbank Formation (Qr)
- Modesto Formation (Qm)
- Holocene alluvium (basin deposits—Qb)
- Natural levee and active channel deposits (Qa and Qsc)

**Storage Field.** Cretaceous bedrock of the Great Valley Sequence is exposed at the surface within the westernmost 0.4-mile of the project alignment. This bedrock consists of interbedded deep marine sandstone and shale. These rocks are representative of bedrock materials that form the reservoir storage zone and horizons immediately above. Bedrock formations comprising the storage zone, caprock layers, and other regionally continuous "regional seal" formations are summarized below (WGSI 2001).

Geologic formations lying stratigraphically between the Red Bluff Formation (described above) and the Capay Formation (described below) consist of Pliocene- through Eocene-age units. They are predominantly volcanic rocks (basalt, tuff, tuff breccia, lahar, etc.) and terrestrial sedimentary deposits (sandstone, conglomerate, siltstone). These formations do not impact the project surface facilities or the proposed storage zone and caprocks; therefore, they are not discussed further (see Appendix I for additional details). Potential considerations related to deep well performance and shallow gas occurrences in these units would be addressed on a case-by-case basis.

**Soil Engineering Characteristics**

The "surface" facilities associated with the project would be constructed within the zone of the ground surface to about 10 feet deep. Where horizontal directional drilling (HDD) is necessary for the pipeline at river/drainage crossings, the planned depth below ground surface (bgs) is between approximately 40 and 120 feet bgs. Geotechnical reports were prepared (Kleinfelder, 2001a, b, c, d, and e) to describe conditions at the four planned HDD sites. From west to east these are: Hunters Creek, the Sacramento River, Butte Creek and Cherokee Canal. Geotechnical studies for the proposed Colusa Power Plant (URS, 2001) coincide with the western terminus of the pipeline near the proposed interconnect site. Anderson Consulting Group (1997) prepared a geotechnical study for the original storage project facilities covering the remote facility site, the Well Pad Site, and the Storage Loop Pipeline. Table 3.6-2 shows the project components discussed below (left column) and the geologic units discussed above along the top. Interior cells show either the length (in miles) of each unit underlying the Line 400 Pipeline route, or the percent of area underlying each individual facility site.

**Table 3.6-2:** Length In Miles Along Line 400/401 Connection Pipeline And Percent Area For Facilities

| Project Component | Pipeline Length | Bedrock | Riverbank | Modesto | Basin Deposits | Stream Channel | Alluvium |
|---|---|---|---|---|---|---|---|
| Interconnect Facility (IF) | | 100% | | | | | |
| Line 400 Pipeline | | | | | | | |
| IF to Hunters Creek (HC) | 3.9 | 0.4 | 1.5 | | 2.0 | | |
| HC to Sacramento River (SR) | 11.3 | | 2.7 | 2.1 | 5.0 | 0.8 | 0.7 |
| SR to Butte Creek (BC) | 5.7 | | | 4.5 | 0.8 | | 0.7 |
| BC to Cherokee Canal (CC) to RFS | 4.7 | | | 0.6 | 4.1 | | |
| Total Pipeline Miles (%) | 25.5 (100%) | 0.4 (1.5%) | 4.2 16.5%) | 7.2 (28%) | 11.9 (47%) | 0.8 (3%) | 1.1 (4%) |
| Remote Facility Site (RFS) | | | | | 100% | | |
| Storage Loop Pipeline (SLP) | | | | | 100% | | |
| Well Pad Site (WPS) | | | | | 100% | | |

SOURCE: Estimated by MHA for this study using the preferred pipeline route and the geology map (Figure 3.6-4)

As summarized in Table 3.6-2, roughly 90 percent of the construction would be in three geologic units. Basin Deposits are about 50 percent, the Modesto Formation about 25 percent, and the Riverbank Formation about 15 percent (see Appendix I for additional details).

## Groundwater

Water is generally shallow throughout the project area, but particularly in the areas between the Sacramento River, and the low hills and alluvial fans. This condition is due to the surface infiltration of precipitation and irrigation water, the subsurface lateral flow of water in shallow porous layers, and the presence of clay-rich or hard layers restricting downward flow of water to the deeper aquifers. Because shallow groundwater affects the properties of earth materials, creating potential geologic hazards, it is important to understand its distribution in the project area. Hazards may be long-term, potentially affecting operations of project components (i.e. liquefaction, buoyancy) or short-term affecting construction related. See Appendix I and Section 3.8 for additional details.

### Mineral Resources

Mineral resources are present in the project vicinity. The following sections discuss the sand and gravel, and natural gas resources in the project area. See Appendix I and Section 3.7 (natural gas) for additional details.

**Sand and Gravel**. The nearest active gravel extraction operation in Butte County is located on the north edge of the Sutter Buttes near Pennington, approximately 6 miles to the southeast of the Remote Facility Site. The other nearby gravel operation is located on West Butte Road, approximately 19 miles south of the Well Pad Site in Sutter County.

**Natural Gas.** Natural gas reserves in Wild Goose Field were depleted in the late 1980s. Small pockets of untapped original gas may remain within some of the more complex reservoir intervals or in shallower zones (Tertiary age). In the Sacramento Valley, natural gas is also present in shallower zones (Tertiary age). In some areas, shallow zones have produced commercial quantities of natural gas. Although these shallow deposits (below about 1,600 feet) are present above Wild Goose Field, they are not productive.

Data collected from shallow zones penetrated during drilling indicates the presence of some natural gas above the deeper Wild Goose (Kione Formation) Sands. Evaluation of these shallow zones indicates that they are "wet" (containing water with gas), and therefore, non-commercial gas occurrences. It is unlikely that any attempt would be made to develop shallow gas bearing zones overlying Wild Goose Field.

### Faulting and Other Tectonic Features

The regional tectonic setting for the central portion of the Sacramento Valley, including faults and historic earthquakes, was discussed above. It is important to understand the character of the faults, and potentially related active tectonic features, in the project area to determine if they may have an adverse impact on proposed project components. There are two faults and an anticlinal fold structure mapped in the project study area. First, the buried Willows fault trends slightly west of north where it enters Colusa County from the north (as an extension of the Corning fault) and crosses the Line 400 alignment about 1.2 miles west of the Sacramento River (Harwood and Helley 1987). From roughly the Glenn County line to Colusa, the trend of the Sacramento River follows the trace of the Willows fault. The doubly-plunging anticlinal fold is subparallel to the fault on the east side of the river. The Willows fault continues on this trend to a location level with (west of) Sutter Buttes where is bifurcates and the main fault trends to the southeast. Second, an unnamed fault extends to the northeast from the just north of this branch point and passes very near the Well Pad Site and the Remote Facility Site. An easterly dipping blind thrust fault may exist in the west side of the Central Valley between theWillows fault and the Cretaceous-age terrain west of the Willows fault.

Each of these structural features has the potential to impact the project components. The Willows fault could produce a significant earthquake, possibly produce surface ground rupture, and cause uplift of the ground surface along the anticline. The unnamed fault could intersect the storage field zones and provide a conduit for the release of storage gas. These tectonic features are discussed in more detail in Appendix I .

### Local Historic Seismicity and Potential Earthquake Sources

The historic seismicity for the region (for earthquakes greater than magnitude 5) within 100 kilometers (62 miles) of the proposed pipeline crossing at the Sacramento River is presented in Table 3.6-1. The nearest earthquake over magnitude 4.9 was 28.5 miles to the northeast (Wong 1992). An additional 69 earthquakes of magnitude 4.0 to 4.9 were found within this same distance. Seven of these events are within 16.5 miles of the river crossing, and two are north and north-northwest of the crossing and could be associated with either a blind thrust, the Willows fault, or random seismicity. Wong (1992) shows several hundred earthquakes (through 1990) within 100 kilometers (62 miles) of the site, ranging in magnitude down to 2.0. Many of these cluster in a north-south grouping east of (not directly on) the Willows fault, suggesting some location error and/or the eastward dip of the fault. The earthquake motions are consistent with the documented sense of movement on the Willows fault.

The faults considered as potential earthquake sources are those used by the California Division of Mines and Geology (DMG) (Petersen et. al 1996) to develop the probabilistic seismic hazard maps for the State. Table 3.6-3 lists these faults and their seismic parameters. The potential for an earthquake that may be associated with the Willows fault is also considered. The earthquake scenarios and groundshaking predictions are discussed in the Groundshaking Hazards section below.

**Table 3.6-3:** Distance From Significant Faults (km)

| Fault Name | Western End | Hunters Creek | Sacramento River Crossing | Butte Creek Crossing | Cherokee Canal Crossing | Eastern End |
|---|---|---|---|---|---|---|
| Great Valley 1 | 2.4 | 8 | 24 | 34 | 36 | 44 |
| Great Valley 2 | 9.5 | 12 | 25 | 35 | 37 | 44 |
| Great Valley 3 | 27 | 28 | 36 | 43 | 45 | 50 |
| Foothills Fault System | 59 | 54 | 41 | 32 | 30 | 24 |
| Bartlett Springs | 43 | 47 | 60 | 69 | 71 | 77 |
| Hunting Creek Berryessa | 52 | 55 | 62 | 68 | 70 | 74 |
| Collayomi | 65 | 69 | 79 | 80 | 81 | 81 |
| Great Valley 4 | 80 | 81 | 82 | 90 | 92 | 99 |

SOURCE: Kleinfelder 2001e, Tables 7 and 8.

See Appendix I for additional information.

### Geology, Soils, and Groundwater Hazards

Most of the topography within the project area is gently sloping except near the Sacramento River. The likelihood of slope-related hazards such as landslides, slumps, and severe erosion in the gently sloping areas is minimal assuming standard engineering and construction practices are followed. River bank slopes at the Sacramento River crossing area are 20 to 30 feet high above the river level on the west and about 10 feet on the east. See Appendix I, Section 3.7, Hazards and Hazardous Materials, and Section 3.8, Hydrology for additional details on related hazards.

**Subsidence**. Subsidence is the settling of the ground surface due to compaction of underlying unconsolidated sediments. Subsidence is most common in uncompacted soil, thick unconsolidated alluvial material due to groundwater, or oil withdrawal, and improperly constructed (poorly compacted) artificial fill. Subsidence in Sacramento Valley has occurred in areas of agricultural development, areas of over-pumped artesian basins, and places compacted through the wetting of moisture-deficient soils by irrigation (WGSI 2001).

Areas in the western portion of Butte County (Butte County 1977) and the eastern portion of Colusa County (Colusa County 1989) have been cited as areas of greatest concern for subsidence. The specific cause of subsidence within these areas has not been identified, but in Colusa County groundwater withdrawal is suspected. Although gas extraction in extreme cases can cause subsidence, subsidence related to gas withdrawal alone does not reach magnitudes comparable to oil or groundwater withdrawal (WGSI 2001). At present, with insufficient information to predict subsidence occurrence, it is assumed that it could occur almost anywhere where groundwater withdrawal is significant.

**Unstable Soils.** Most of the soils in the area are susceptible to expansion, consolidation, chemical reactivity, and settlement. Data are insufficient to provide specific quantitative conditions for each geologic unit; however, Basin Deposits are the most widespread unit and moderate to very high expansion indices indicate that there is a substantial amount of clay in these surficial deposits. Consolidation (and long-term settlement) is most prominent in clay-rich and silt-rich soils. This consolidation and settlement can be much more dramatic under severe seismic shaking (dynamic settlement). The structure, chemistry and particle size of clay materials give them unique properties including high action exchange capacity, catalytic properties, high sorption affinities, and plastic behavior when moist. In general this increases their potential for chemical reactivity and potentially adverse physical properties.

**Landslides**. The classification of the geologic units relative to their potential for natural slope instability depends upon the materials properties and topographic slope. Only the area along the Sacramento River has relatively steep slopes. The materials on the valley floor are devoid of reported landslides and therefore have a very low potential for slope instability. Built-up levees in the low-relief areas offer a higher potential for local slope instability if disturbed by construction. Natural slope instability in the project vicinity is limited to surficial and rotational failures in the Modesto Formation and uplifted, dissected alluvium along the river on slopes greater with a gradient greater than 10%.

**Shallow Groundwater**. It is likely that shallow water is present in most of the project area. Water level fluctuations are common, with depths varying between a few feet and over 10 feet below the surface at a single location.

**Deep Geology (Storage Field).** The possibility of natural gas leaking from a storage field is a primary concern for storage gas operations. If leaking gas reaches the surface and accumulates inside structures, the risk of fire or explosion would result. Storage gas leaks have been documented at other fields with different geologic conditions. These risks and hazards are discussed in Section 3.7, Hazards and Hazardous Materials of this document.

Three types of subsurface gas may be present within geologic and soil units underlying the Project area: (1) processed natural gas (storage gas), (2) biogenic (or swamp) gas, and (3) thermogenic (field) gas. Potential pathways for leaking storage gas are (a) existing wells and dry holes, (b) caprock layers over the storage zones, and (c) faults and fractures that penetrate the storage zones. Information presented in Appendix I deals with geologic conditions related to storage field containment.

### Earthquakes and Faults

**Strong Groundshaking.** Kleinfelder (2001e) used a seismic source model as a basis for determining the probable groundshaking levels that would be experienced within the project area. The model is based on the seismic source model used in developing probabilistic seismic hazard maps by the Division of Mines and Geology (DMG) for the State of California (Petersen et. at 1996). Table 3.6-3 lists these faults and their seismic distances to various locations within the project area. The earthquake probabilities for the faults and their segments were developed by the State using a magnitude-frequency relationship derived from the seismicity catalogs and the fault activity based on their slip rates. The details are discussed in the two aforementioned references, and in Appendix I.

**Dynamic Compaction.** Dry to partially saturated sediments that may not be susceptible to liquefaction may be susceptible to dynamic consolidation and local ground subsidence during strong earthquake shaking. This consolidation or densification occurs in loose cohesionless sediments as the void spaces are diminished due to intense seismic shaking. Hazard maps are not normally created for this condition, and there are no specific analyses available covering any of the project areas.

**Liquefaction.** Liquefaction occurs when saturated, cohesionless (low relative density) materials (usually sand or silty sand) are transformed from a solid to a near liquid state due to the increase in pore-water pressure that can be caused by moderate to severe seismic ground shaking. The Colusa County Seismic Safety Element indicates that liquefaction potential in the area of the Well Pad Site expansion is considered “generally high” because the area is located in a region of recent sediments bordering river alluvium and has a high groundwater level – within ten feet of the surface in some areas. However, the Seismic Safety Element cautions that this designation is based on limited soil and geologic data and should not be the only source used for the direct determination of liquefaction potential (WGSI 2001).

**Lateral Spreading.** Liquefaction potential does exist at the Sacramento River crossing area. Lateral spreading landslides (lateral displacement of soil and underlying alluvium) can occur on relatively shallow slopes due to liquefaction of shallow layers causing a loss of shear strength. Within the project area, this is most likely adjacent to the drainages where slopes are steepest and water may be more likely to accumulate (e.g., adjacent to the Sacramento River). It is not possible to map specific areas based on the current data, although the steeper slopes and the alluvial areas behind these slopes are the most susceptible.

### Mineral and Groundwater Resources

**Surface and In-Stream Mining.** Sand and gravel are mined from alluvial deposits, specifically active river channels and channel floodplains. At the present time there are no known mining operations that would affect the project components, and none that would be negatively impacted by the project. However, it is possible that future mining activities could be undertaken in the Sacramento River up stream or down stream of the pipeline

HDD location. In this case it is possible that scour could have an impact at this location. Considerations are discussed in the impacts section below and Appendix I.

**Shallow Groundwater.** Three potential concerns exist for the presence of shallow groundwater. These relate to 1) water seepage that may collect within, around or on a structure (e.g., foundations, slabs, cut/fill slopes, and utility trenches), 2) water that may be intercepted in excavations causing potential dewatering and safety problems, and 3) liquefaction potential (discussed in a previous section). The first instance could cause damage and/or nuisance with regard to the long-term care and maintenance of facilities. The second instance could cause safety problems for workers, as well as the aforementioned problems. The third concern is for water quality impacts that may affect local farming and biological resources. Water quality impacts are discussed in Section 3.9, Hydrology.

**Oil and Gas Exploration and Recovery.** There are no oil reserves in this part (and most) of the Sacramento Valley. Natural gas reserves in Wild Goose Field were depleted in the late 1980s. Small pockets of untapped original gas may remain within some of the more complex reservoir intervals or in shallower zones (Tertiary age). These gas occurrences would be of limited extent and extremely difficult to find. It is unlikely that any attempt would be made to develop gas-bearing zones overlying Wild Goose Storage Field. It would not be economical to pursue them.

## Regulatory Setting

### STATE

#### California Division of Oil, Gas, and Geothermal Resources

California Division of Oil, Gas, and Geothermal Resources (DOGGR) regulates drilling, production, injection, and gas storage operations in accordance with California Code of Regulations (CCR) Title 14, Chapter 4, Subchapter 1. Onshore Well Requirements, Section 1727.7, Project Data Requirements. Approval must be obtained from DOGGR before any subsurface injection or disposal project can begin. The operator must provide data that are pertinent and necessary for the proper evaluation of the proposed project. The data required include, but are not limited to:

- An engineering study that includes the reservoir characteristics for each injection zone; reservoir fluid data; well casing diagrams; and a well, drilling, plugging, and abandonment plan;
- A geologic study that includes a structural contour map; a map of each injection zone; a geologic cross-section; characteristics of the cap rock; gas reserves of the storage zones before the start of injection; and a representative electric log identifying all geologic units, formations, freshwater aquifers, and oil or gas zones; and
- An injection plan that includes a map of the facilities; maximum surface injection pressure; daily rate of injection per well; monitoring system or method to be used to ensure that no damage is occurring and that injection fluid is confined to the intended zone or zones of injection; method of injection; proposed cathodic protection measures for plant, lines, and wells; proposed surface and subsurface safety devices, tests, and precautions taken to ensure safety of the project; treatment of water injected; and source and analysis of injection fluid.

Reservoir characteristics that must be defined include: porosity, permeability, average thickness, areal extent, fracture gradient, original and present temperature and pressure, and original and residual oil, gas and water saturations.

**California Geological Survey: Alquist-Priolo Earthquake Fault Zoning Act**

In the 1960s and 1970s the State of California recognized the hazards of constructing structures for human occupation across traces of active faults. As a result, the Alquist-Priolo Earthquake Fault Zoning Act (1972) was enacted. The Act directs the State Geologist to delineate special studies zones along active faults within the state. According to the Alquist-Priolo Earthquake Fault Zoning Act, an active fault is one that has ruptured in the last 11,000 years (California Department of Conservation 1972). Structures for human occupancy cannot be placed over the trace of the fault and must be set back from the fault (generally 50 feet).

**California Department of Industrial Relations, Occupational Safety and Health Regulations (CAL/OSHA)**

Worker safety on construction projects, in particular where grading, trenching, and earthmoving are involved, is the responsibility of CAL/OSHA. They establish and enforce regulations for excavation and trenching permits (TITLE 8, Division 1, Chapter 3.2, Subchapter 2, Article 2 [Permits--Excavations, Trenches, Construction and Demolition and the Underground Use of Diesel Engines in Work in Mines and Tunnels]), and for worker safety (Chapter 4, Subchapter 4, Article 6 [Excavations]).

**COUNTY**

**Butte County**

The Land Use (2000), Seismic Safety (1977), and Conservation (1971) Elements of the Butte County General Plan contain geology-related policies (Butte County 1971, 1977,2000). The Land Use Element states:

- Consider the most recent information on seismic hazards on all zoning and subdivision decisions,
- Restrict development along known active fault areas,
- Correlate allowable density of development to potential for landslides, erosion, and other types of land instability,
- Encourage extraction and processing of identified deposits of building materials and other valued mineral resources,
- Encourage the reclamation of lands subject to mineral extraction, and
- Encourage the development of natural gas fields and other fossil fuel resources

The Seismic Safety Element states:

- Inform the public of current estimates of seismic hazards in all parts of the County
- Take into account all known seismic information in making land use decisions. Avoid locating schools, hospitals, public buildings, and similar uses in known active fault areas.

- Follow the policies and criteria established by the State Geology and Mining Board within the Special Studies Zones, and
- Consider liquefaction potential in making land use decisions.

The Conservation Element states:

- Deposits of sand, gravel, and building stone should be identified and development of these products carefully regulated to prevent depletion of these natural resources through improper methods of removal.

### Colusa County

The Colusa County General Plan contains geology-related objectives for Land Use (LU). The following objectives are relevant to the proposed project and project alternatives relative to geology issues. The objectives shall be:

- To permit rural development contingent upon a range of natural factors, including environmental impact, safety hazards, and the availability of water. [Land Use]
- To promote the management of minerals and reduce the impacts of mineral extraction on the environment. [Resource Conservation]
- To encourage water use methods which minimize subsidence. [Resource Conservation]
- To minimize the threats to life and property from seismic and geologic hazards [Public Health and Safety]

Specific applicable Safety policies under the Geologic Hazard Protection section of the Safety Element include:

- **SAFE-6:** No development shall take place on or immediately adjacent to an existing landslide unless a geotechnical investigation has been performed. This investigation shall define slide activity and slide limits, and contain specific recommendations regarding avoidance, removal, or repair. The County Planning Department should maintain a map showing the general location of existing landslides for reference by development sponsors. The determination of the location of a landslide relative to a proposed development and the preparation of any geotechnical report shall be the responsibility of the development sponsor.
- **SAFE-7:** A geotechnical investigation should be performed for any development proposal in an area of known subsidence in order to determine whether engineering modifications should be made to the design to eliminate or mitigate the adverse impacts. The county may also require a geotechnical investigation for any development proposed on highly expansive soils.
- **SAFE-23:** The County Planning Department and the Office of Emergency Services should maintain hazard maps to aid in the review of development proposals and in the development of emergency response plans. Such maps shall illustrate potential flooding, dam inundation, landslides, subsidence, and wildfire threats.
- **SAFE-26:** Development proposals in potential hazard areas should be referred to appropriate agencies for review and recommendations.
- **SAFE-27:** The County should encourage the State Department of Mines and Geology and the State Department of Water Resources to further investigate the cause of

subsidence in eastern Colusa County in order to develop a plant to prevent further subsidence and correct existing problems, if possible.

- **SAFE-28:** The County should support State investigations of earthquake faults and other seismic hazards in the Sacramento Valley and Coast Range. Earthquake preparedness should remain an active part of the county's Emergency Response Program.

Specific applicable Safety policies under the Mineral Resource Policies section of the Conservation Element include:

- **CO-5:** [Partial] Extraction of gravel and other minerals along rivers should be permitted, subject to CEQA and other applicable laws.
- **CO-6:** Development within and adjacent to Resource Conservation lands shall be regulated so that proposed future land uses will not be incompatible with mineral extraction operations, where existing or future mineral extraction operations are likely. Regulations shall be responsive to the type/intensity of the mining operation and the nature of the adjacent land use. Regulations may include but are not limited to: (1) development siting (setback requirements, clustering); (2) land use buffer requirements; (3) hours of operation for mining activities; and (4) dust and noise controls on mining activities and operation.

# Impact Analysis

## AREAS OF POTENTIAL ENVIRONMENTAL CONCERN

Criteria for determining the significance of impacts to geology, seismic, soils, and mineral resources were developed based on questions contained in the environmental checklist form in Appendix G of the State CEQA Guidelines. Based on the checklist questions, a project may have a significant effect on the environment if it would:

### Geology, Seismic, and Soils

The proposed project would have a significant effect if it would:

- Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
  - Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault (refer to Division of Mines and Geology Special Publication 42)
  - Cause or be affected by strong seismic ground shaking
  - Cause or be affected by strong seismic-related ground failure, including liquefaction
  - Cause or be affected by landslides
- Result in substantial soil erosion or the loss of topsoil
- Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse

- Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property
- Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water

**Mineral Resources**

The proposed project would have a significant effect if it would:

- Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?
- Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?

In addition, if the project would be in conflict with the policies and objectives of the County General Plans listed above, this would constitute a significant impact.

Section 15064(h) of the State CEQA Guidelines states that a change in the environment is not a significant effect if the change complies with a standard that is a quantitative, qualitative, or a performance requirement found in a statute, ordinance, resolution, rule, regulation, order, or other standard of general application. Technical conditions may exist for which there is no clear cut legal or performance standard, other than a site-specific determination of the means and methods necessary to reduce potential impacts to a level acceptable to the governing bodies involved with the project approval. In these cases specific performance-based mitigation measures are necessary.

In summary, for the purposes of assessing the significance of geologic, seismic, soils, and mineral resources impacts associated with the proposed project and project alternatives, an impact would be considered significant if:

(1) The proposed project or project alternatives would result in a conflict with the goals, policies, and/or objectives of the Colusa or Butte County General Plans; and

(2) The impacts associated with significant geologic, seismic, soil, and mineral resources technical conditions require mitigation beyond clearly defined legal and performance standards. These standards are generally embodied in the environmental checklist items provided in the State CEQA Guidelines, presented above.

## THRESHOLDS OF SIGNIFICANCE

The following areas of potential environmental concern are discussed and the correlation with the thresholds are noted.

Fault and Earthquake Risk

- Surface Faulting and Uplift [i]
- Strong Groundshaking [ii]
- Liquefaction [iii]
- Lateral Spread Landslides [iv]

Surficial Geology, Unstable Soils, and Shallow Groundwater [b), c), d), and e)]

- Erosion [b]

- Unstable Surficial Deposits, Subsidence, and Shallow Groundwater [c]
- Expansive Soils [d]
- Waste Water Disposal [e]

Mineral Resources and Gas Storage Field Geology [a) and b)]

- Gas Storage Field Caprock, Formation Pressures, and Fractures and Faults

## IMPACT DISCUSSION: EARTHQUAKES AND FAULTING

### Impact 3.6-1.1: Potential for Effects from Faulting or Uplift.

The project would expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving fault movement or ground uplift at the surface on potential geologic features associated with the Willows fault zone.

The nature of the geographic coincidence of the Willows fault with the Sacramento River and presence of the doubly-plunging anticline (a dome structure) present in the subsurface east of the river at the same general location, is suggestive of active or potentially active fault conditions within the project area, due to the apparent very youthful (Holocene-age) influence on surface drainages. The Willows and Corning faults may well be connected in the subsurface. Application to the Willows fault of the conclusions by Unruh (1997) that the Corning fault is active and the rate of movement appears to be very low (about 0.02 to 0.04 mm/year), should be assumed for the Willows fault. A large, local earthquake centered on the Willows fault, or presently poorly understood blind thrust faults, could cause ground movement within the Line 400 pipeline corridor. Therefore, design considerations must be to account for this potential movement.

It is recognized that the probability is very low that a large, local earthquake centered on the Willows fault, or presently poorly understood blind thrust faults, would cause significant ground movement (uplift or rupture exceeding several feet over a relatively short distance) within the Line 400 pipeline corridor. Kleinfelder (2001e, Appendix A) has estimated that a fault displacement of approximately 0.7 meter (2.3 feet) could theoretically occur on the Willows fault. For the case analyzed in Kleinfelder's Appendix A, the pipeline characteristics used may not represent the final design characteristics and the analysis was done by analogy using project work performed for another site or sites. The evaluation is limited to consideration of the amount of fault displacement required to reach the failure (loss of pressure integrity) limit state with no consideration of damage limit states (e.g., incipient wrinkling; SSD. 2002). Without mitigation a potentially significant impact on pipeline performance remains.

**Level of Significance Without Mitigation.** Ground movement on the Willows fault or surface uplift on the associated anticlinal fold would cause a significant effect if the pipeline ruptured and gas were released.

### Mitigation Measures

**Mitigation Measure 3.6-1.** The Applicant shall assess the pipeline response to surface faulting using a detailed nonlinear pipe-soil interaction analysis model for a case-specific evaluation of the Willows fault crossing. The model shall consider different possible fault offsets (or local uplifts) and slip vectors, different fault crossing geometries, different wall thickness and different steel grades for the selected pipeline diameter. The analysis shall consider both the fault offset required to reach the failure (loss of pressure integrity) limit state and to reach the damage limit states (i.e., incipient wrinkling) as a measure of the fault crossing design performance. A detailed plan for the analysis shall be prepared for review by the CPUC (or its designated consultants) and the analysis methodology shall be approved by the CPUC prior to the Applicant preparing the analysis. Results of the analysis shall be used in the design of the pipeline section within a reasonable distance (to be reviewed and approved by the CPUC or its designated consultants) of the projected location of the Willows fault and the mapped anticlinal feature adjacent to the Sacramento River.

**Impact 3.6-1.2: Potential for Effects from Strong Seismic Ground Shaking.**

Project construction and the expanded operations would not affect existing geologic features and would not expose additional people to existing geologic hazards; however, should a significant seismic event occur near the project study area, existing and proposed project facilities could be affected. Kleinfelder (2001e) applied probabilistic and deterministic seismic hazard analysis techniques to estimate the peak ground accelerations for several locations within the project area. Four earthquake scenarios were considered (magnitudes [M] varied from M6.0 to M6.7 for deterministic analyses), including events located at 2 to 34 kilometers (1.2 to 21 miles) from the selected locations. This analysis involved selecting predictive attenuation relationships to estimate the ground motion parameters, and, through probabilistic methods, determining peak accelerations.

Based on these analyses the range of peak horizontal ground acceleration (PHGA) is 0.22g to 0.31g for probabilistic methods and 0.20g to 0.68g for deterministic methods. Any groundshaking over 0.20g is considered significant; however, current (UBC 1997) building code construction can accommodate substantially higher levels of shaking without structural collapse. In general, modern, recently constructed buried steel pipelines within stable geologic formations perform well even when exposed to high levels of seismic shaking, although extensive damage has occurred in past earthquakes due to seismic wave propagation (O'Rourke and Liu 1999). WGSI (2001, page 3.4-8) proposes that construction of all phases of the project would be in accordance with all applicable state and county building and construction codes and ordinances, and that safety vibration sensors shall be installed in all equipment buildings at the Remote Facility Site to shut down operations should a moderate or large earthquake occur.

During project design, geotechnical soil borings shall be performed at the Well Pad Site and Remote Facility Site expansion areas and the Delevan Interconnect Site to the extent necessary to determine the seismic structural design and construction requirements prescribed in the Uniform Building Code Seismic Zone Criteria. WGSI also states that the 6.7-magnitude Northridge earthquake in January 1994, centered within nine miles of Southern California Gas Company's Aliso Canyon Gas Storage, reportedly caused some minor structural damage to aboveground facilities and crushed one well casing approximately 3,000 feet below the surface, but without other serious incident.

**Level of Significance Without Mitigation.** While seismic design guidelines exist for natural gas pipelines, design earthquake values (or a specific methodology to determine them) are not mandated. It is the responsibility of the owner and the regulator (the CPUC) to determine the acceptable risks based on the importance of the supply, the potential impacts to the environment, and the future safety of the public. Therefore, state and county building codes are not adequate to judge the adequacy of the pipeline design. Without specific consideration of the interaction between unique geologic conditions along the pipeline routes (Line 400/401 Connection Pipeline and the Storage Loop Pipeline) and the conservative levels of groundshaking determined by Kleinfelder, the potential exists for a potentially significant impact due to pipeline failure or incipient wrinkling during a large earthquake event.

> **Mitigation Measure 3.6-2.** The Applicant shall provide the CPUC with a plan to analyze pipeline response to ground shaking and traveling wave effects based on the unique geologic conditions along the pipeline routes (Line 400/401 Connection and the Storage Loop Pipeline) and the conservative levels of groundshaking determined by Kleinfelder. The CPUC shall review and approve a final analysis plan prior to final design.

**Impact 3.6-1.3: Potential to Expose People or Structures to Effects from Liquefaction and Dynamic Compaction**

Liquefaction can cause overlying structures (e.g., bridges, buildings, storage tanks) to settle non-uniformly, and buried structures (e.g., fuel tanks, pipelines) to float. In either situation, severe damage to the structure is highly likely. Dynamic compaction can cause non-uniform settlement of several inches to over a foot depending upon sediment thickness and density. Estimates of liquefaction and dynamic compaction potential require specific data from geotechnical borings and groundwater level monitoring. The Holocene basin deposits (Qb), stream channel deposits (Qsc), and the alluvium (Qa) have the highest liquefaction potential and cover about 55 percent of the pipeline route and underlie Remote Facility and Well Pad Sites. Previous geotechnical studies at the latter two sites (Anderson Consulting Group 1997) and Kleinfelder's (2001a, b, and d) studies at the four pipeline drainage crossings (HDD sites) concluded that the liquefaction potential is "extremely remote" and "not considered an issue", respectively, due to the presence of stiff to hard and dense to very dense basin deposits.

Due to the lack of geotechnical data and knowledge of the a potential for low density sand layers to exist in the basin deposits (Qb), Kleinfelder indicates liquefaction potential cannot be entirely dismissed in the unit. Kleinfelder (2001f) conducted a geotechnical study at Drumheller Slough near the pipeline alignment encountered least 3-feet of medium-dense fine sand. This type of layer might be susceptible to liquefaction in other areas.

At the Sacramento River site and along the river in the stream channel and alluvial deposits (Kleinfelder (2001c and e) liquefaction potential does exist. Kleinfelder calculated, at the river crossing, that 11 inches of settlement could occur in the stream channel deposits. These calculations require several types of data, but one very important element is the field measurements of sampler blow counts using the Standard Penetration Test (SPT) method. Two aspects of the SPT blow counts are not explained.

First, if a SPT sampler was used that is designed to hold a liner, it is important to ensure that a liner was installed, because a correction of up to about 20% may apply if a liner is not used (Martin and Lew 1999). Second, gravel was encountered in the potentially liquefiable sand deposits. Kleinfelder discussed the possible effects of gravel on the number of blow counts mainly based on visual observation of the samples and engineering judgment. Erroneous high blow counts (due to hard gravel in a loose sand) could increase the calculated thickness of the potentially liquefiable soils, and increase the estimated earthquake-induced settlements. The drilling and sampling techniques recommended by Martin and Lew (1999) in gravel deposits would have allowed corrections to be made to the calculations (Hushmand Associates 2002). In summary, the liquefaction induced settlement values obtained by Kleinfelder may not be sufficiently conservative for final design due to the drilling and sampling techniques used.

**Level of Significance Without Mitigation.** The potential for earthquake of sufficient severity to cause liquefaction may be low; however the risk of damage to the pipeline in the river area should be minimized to the greatest extent practicable. Kleinfelder (2001e, Appendix A) has estimated that liquefaction settlement has a likely upper bound of 1.25 meters (4.1 feet). The case analyzed may have used pipeline characteristics that may not be preferred for final design and the analysis was done by using an "upper bound value" approach. Without the consideration of corrections in the liquefaction estimates for the SPT sampler and the gravel content, it is not clear that this upper bound is reasonable. In addition, the evaluation is limited to consideration of the amount of liquefaction settlement required to reach the failure (loss of pressure integrity) limit state with no consideration of damage limit states (e.g., incipient wrinkling; SSD 2002). Without mitigation a potentially significant impact on pipeline performance could occur if liquefaction occurred and the pipeline either failed or was severely damaged

**Mitigation Measures.** The mitigation measures described below are designed to avoid potentially significant impacts.

> **Mitigation Measure 3.6-3.** The Applicant shall drill new borings at the final Sacramento River crossing site, using the drilling and sampling techniques recommended by Martin and Lew (1999). These borings shall be performed at the locations with possibly the thickest liquefiable soil deposits, to confirm the SPT blow counts measured (with or without sample rings and considering gravel) and the estimates of liquefaction-induced settlements and lateral deformations. It is possible that the additional field investigation scope may be reduced if a parametric/sensitivity analysis can be performed to investigate the effects of possible lower blow counts and thicker liquefiable soil layers on the liquefaction-induced hazards discussed in Appendix A (Kleinfelder, 2001e). A detailed plan for the drilling, sampling, and analysis shall be prepared for review by the CPUC (or its designated consultants) and the analysis methodology shall be approved by the CPUC prior to the Applicant preparing the analysis. Results of the analysis shall be used in the design of the pipeline section within a reasonable distance (to be reviewed and approved by the CPUC or its designated consultants) of the Sacramento River crossing.

> **Mitigation Measure 3.6-4**. The Applicant shall compile data in City, State, or County files, and to obtain new data on shallow water levels and the density of shallow geologic materials so that a broad-area assessment of areas with potential for liquefaction along the pipeline alignment can be made. Results of the analysis shall be used in the design of the pipeline section crossing identified potentially liquefaction-prone areas (to be reviewed and approved by the CPUC).

Construction mitigation measures exist for development in liquefaction-prone areas. These measures are included below and each shall be considered by the Applicant in the final pipeline and facilities design:

- Excavation and removal or recompaction of liquefiable soils;
- In-situ ground densification;
- Ground modification and improvement;
- Deep foundations;

- Reinforced shallow foundations; and
- Reinforced structures to resist deformation during liquefaction.

**Impact 3.6-1.4: Potential to Expose People or Structures to Adverse Effects from Liquefaction and Cause Lateral Spread Landslides**

When seismic groundshaking and liquefaction also cause permanent ground displacements (PGD) that affect the pipeline alignment or other facility location, damage can occur. At the present time, no definitive mapping has been performed across the entire project area with regard to predicting potential PGD (see Mitigation Measure 3.6-4). The area of primary concern is adjacent to the Sacramento River, where a preliminary site-specific assessment was made (Kleinfelder 2001e, Appendix A). Holocene basin deposits (Qb), stream channel deposits (Qsc), and the alluvium (Qa) have the highest liquefaction potential and are found adjacent to the Sacramento River where surface slopes along the river form “free-faces” that may be susceptible to lateral spread landslides. Kleinfelder’s (2001d and e) studies at the Sacramento River crossing (HDD site) did not rule out these landslides. The Sacramento River crossing has the highest potential for these effects.

Lateral spread landslide potential was assumed for the Sacramento River crossing and an empirical calculation to define the amount of lateral movement of the landslide mass was performed (Kleinfelder 2001e, Appendix A). The analysis was based on the liquefaction assessment described above and assumptions about the extent and thickness of loose soils west of the riverbank. The analysis concluded that the lateral spread displacement would be 0.9 meter (3 feet), and that for this condition (or less) and a 1060 feet long landslide mass sliding parallel to the pipeline, the pipeline pressure integrity would be maintained. A similar analysis for movement perpendicular to the pipeline was also made.

The lateral spread displacement analysis in Appendix A (Kleinfelder, 2001e) has numerous assumptions, only some of which are supported by actual site-specific data. The estimate may have used pipeline characteristics that may not be preferred for final design and the analysis was done by using an empirical approach, without the consideration of corrections in the liquefaction estimates for the SPT sampler and the gravel content. In addition, the evaluation is limited to consideration of the amount of lateral displacement that may cause a failure (loss of pressure integrity) limit state with no consideration of damage limit states (e.g., incipient wrinkling; SSD 2002). Without mitigation a potentially significant impact on pipeline performance could occur.

**Level of Significance Without Mitigation.** If permanent ground displacement were to occur along the Line 400/401 Connection Pipeline adjacent to the Sacramento River, the pipeline may either be damaged to the point of failure and an unplanned release of gas, or to a point of “incipient wrinkling” where weakness induced into the pipeline could lead to future failure.

Mitigation Measures. The Applicant shall complete Mitigation Measure 3.6-3 above, including drilling new borings in areas adjacent to the final Sacramento River crossing site, where lateral spreading landslides are most likely to occur based on topography.

**Level of Significance After Mitigation.** The effects would be less than significant if Mitigation Measure 3.6-3 is implemented.

## IMPACT DISCUSSION: SURFICIAL GEOLOGIC AND SOILS CONDITIONS

### Impact 3.6-2: Potential for Soil Erosion or the Loss of Topsoil

The project-affected slopes with the potential for erosion would be the new fill and landscaped berm at the Well Pad Site expansion, the slopes bordering the Sacramento River pipeline crossing, and cut slopes along the trench alignments. The flat gradient along the non-trench portions of the pipeline ROWs and at the Remote Facility Site would not be prone to erosion. Disturbance of the slopes may promote surface water infiltration that can lead to severe erosion and the promotion of surficial or rotational slope failures in the generally massive deposits.

While the erosion potential for the project would be considered less than significant, more than five acres would be disturbed by construction activities, requiring compliance with the Construction Storm Water General Permit issued by the Regional Water Quality Control Board. The Storm Water Pollution Prevention Plan (SWPPP) prepared for initial project development would be revised to include the proposed project components. By implementing the SWPPP during construction, WGSI would ensure that project erosion would be minimal and any potential impacts will be less than significant.

**Level of Significance Without Mitigation.** If required regulations are adhered to, and if the measures employed during initial project development and the supplemental measures described above for project pipeline construction and maintenance activities are implemented, potential soil erosion would be less than significant.

**Mitigation Measure.** No mitigation required.

### Impact 3.6-3: Potential for Impacts due to Unstable Soils or Subsidence

**Unstable Soils.** As described in previous sections and depicted in Table 3.6-2, the project components are underlain by six of the seven predominant geologic units exposed within the project area. The Line 400 pipeline is predominantly (23.3 miles or about 91.5 percent) in three units, the Modesto Formation, basin deposits, and alluvium. These geology/soil units have varying degrees of stability relative to the proposed project activities. Currently documented geotechnical information is available at widely spaced locations along the pipeline (at four HDD crossings) and at the Remote Facility and Well Pad Sites.

Available data are sufficient to conclude that the surface facilities (including the Remote Facility, Well Pad, Delevan Connector, all pipeline valve locations, concrete thrust blocks) could be safely built if the latest California Uniform Building Code (CUBC 1997 and updates; ICBO 1997), and other requirements of the Colusa and Butte County Building Departments relative to geotechnical analysis for foundations, slopes, etc., are satisfied.

The four presently planned pipeline HDD crossings have been studied by Kleinfelder (2001a, b, c, and d) with regard to the recommended drilling depth, and the resultant potentials for inadvertent loss of drilling fluid to the formation (including the surface water and shallow groundwater systems) due to “frac-out”. It will be necessary to satisfy State and Federal permit requirements relative to drilling fluids, drilling pressures, and depth of cover.

**Subsidence.** The operation of the expanded storage field would not exceed the original natural gas capacity of the field prior to initial development and extraction. Natural gas withdrawal from the reservoir would be accompanied by produced water and gas reinjection, thereby minimizing any risk of subsidence (WGSI 2001). Consequently, no subsidence impacts from the injection and withdrawal of natural gas are anticipated.

Areas in the western portion of Butte County and the eastern portion of Colusa County have been cited as areas of greatest concern for subsidence, although the specific causes of subsidence within these areas has not been identified. Groundwater withdrawal is suspected to be the cause of the local subsidence. In other sediment-rich groundwater basins, subsidence and structure settlement may reach a meter (3+ feet) or more over thick poorly consolidated alluvium. However, settlements of 5 to 30 centimeters (2 to 12 inches) are rather common. Spread over large distances, local effects are generally minor. If differential movement potential along the pipeline is significant over short distances, pipeline deflections are possible. Resultant ground failures can be manifest as ground cracks with relative vertical displacements as indicated above. When structures overlie these local subsidence areas, ground cracking may be translated through foundations and slabs causing structural damage.

**Landslides**. Slope stability evaluations must consider the effects of construction (trench and HDD related excavations) on both natural slopes and newly created cut slopes. These evaluations would be required for pipeline trench excavation and development along the river. Design and construction mitigation measures (e.g., shoring, retaining walls, reduced slope angles, earth reinforcement) in conformance with County and UBC (1997) standards must be employed to prevent slope instability

**Level of Significance Without Mitigation.** WGSI (WGSI 2001, page 3.4-8) has committed that during project design, geotechnical soil borings shall be performed at the Well Pad Site and Remote Facility Site expansion areas and the Delevan Interconnect Site to the extent necessary to determine the seismic structural design and construction requirements prescribed in the Uniform Building Code Seismic Zone CriteriaWGSI also indicates that the Well Pad Site fill material would be compacted to 90 percent relative density ( WGSI page 3.5-11). These project measures, if performed properly, would provide sufficient protection against unstable soil conditions such that no significant adverse impacts are anticipated.

No widespread evidence of subsidence or subsidence-related damage has been reported in the project area. Subsidence effects along the pipeline would be spread over a large distance and local effects should be minor. Due to the relatively small size of the individual facilities, the likelihood of ground cracking passing through the sites and not already being detected would be small. Therefore, the potential impact of subsidence on the project facilities is considered less than significant.

**Mitigation Measures.** No mitigation measures are required.

### Impact 3.6-4: Potential for Effects Related to Expansive Soils

Changes in moisture content cause clay-rich expansive soils to shrink (reduced moisture) or swell (increased moisture). Volume changes can be a few percent to over 50 percent. This process can be cyclical and the associated episodic pressures can damage structures not designed to withstand the forces. The soils in the project area, particularly the basin deposits, demonstrate these characteristics, based on the County General Plan Safety Elements and geotechnical studies available for the project.

Expansive soils could affect the stability of building and equipment foundations at the Remote Facility Site and the Well Pad Site, causing them to settle or crack. This impact would be considered less than significant since the building permit process and compliance with current regulations would ensure adequate engineering for the foundations. These effects would be unlikely to significantly affect the pipeline because it would be surrounded by soil below grade.

WGSI (2001, page 3.4-9) has committed that during project design, geotechnical soil borings would be performed at the Well Pad Site, the Remote Facility Site expansion areas and the Delevan Interconnect Site. The soil borings would be analyzed to determine the applicable structural design and construction requirements prescribed in the 1997 Uniform Building Code to compensate for expansive soil conditions.The fill and foundation areas at the Well Pad Site and Remote Facility Site would be engineered (over-excavated and backfilled with structural fill material) in compliance with Butte County building requirements to account for expansive soil. By implementing the building code requirements, potential effects of expansive soils would be accounted for in project design and construction, and no significant impacts are anticipated.

**Level of Significance Without Mitigation.** If required regulations are adhered to, and if the measures described above are employed during project development, potential expansive soil impacts would be less than significant.

**Mitigation Measure.** No mitigation required.

## IMPACT DISCUSSION: MINERAL RESOURCES

### Impact 3.6-5: Potential for Effects to Extraction of Mineral Resources

In-stream and floodplain mining are not current taking place in the Sacramento River up or down stream in proximity to the project area.  If mining in the active Sacramento River channel were to take place in proximity to the Line 400/401 Connection Pipeline crossing location, the potential exists for the river bottom incision upstream or down stream of the mine. If incision were deep enough to reach the buried pipeline (constructed by the horizontal directional drilling process), it could theoretically undermine the structures or expose them to river bottom current and debris.

Kleinfelder (2001d) proposed that the pipeline be located between roughly elevations plus 20 feet msl and minus 5 msl for the two bore option, and below roughly elevation minus 40 feet msl for the one bore option. These elevations place the pipeline about a minimum of 20 feet and 60 feet, respectively, below the channel bottom. No channel scour/deposition modeling has been performed to justify these depths as being sufficient to prevent future contact with the river bottom, and no pipeline deformation estimates have been presented. Future in-steam mining and floodplain gravel pits could affect the crossing site, although without the proper data gathering an modeling it is not possible to provide an estimate for the potential amount of scour.

**Level of Significance Without Mitigation.** Based on the potential for deep floodplain mining just up or down stream from the site, it is possible that the 20-foot separation offers too little margin or safety and without mitigation a potentially significant impact could occur. The 60-foot separation would appear to offer a sufficient margin of safety, but that cannot be firmly concluded without additional data. Greater depth of cover beneath the river bottom could be necessary.

Without modeling of possible in-steam mining and floodplain mining scenarios, it is not possible to determine the potential impacts to the pipeline for the recommended burial depths. If such a study was completed and the recommendations from that study were implemented, the potential impacts would be less than significant. Therefore, without mitigation a potentially significant impact could exist for the one bore option as well.

**Mitigation Measures 3.6-6.**The Applicant shall undertake and complete a modeling study to define possible in-steam mining and floodplain mining scenarios and the potential impacts of the scenarios on the pipeline at the preferred depths. Based on the modeling study the final depth of burial below the river bottom shall be determined. A plan for the modeling study shall be prepared for review by the CPUC. The analysis methodology shall be approved by the CPUC prior to the Applicant preparing the analysis. Results of the analysis shall be used in the design of the pipeline section crossing the Sacramento River (to be reviewed and approved by the CPUC).

**Impact 3.6-6: Potential to Overcover or Preclude Extraction of Natural Gas or Sand and Gravel Mineral Resources**

Project implementation should not adversely affect known natural gas, sand and gravel, or other energy or mineral resources. Natural gas reserves in Wild Goose Field were depleted in the late 1980s and it was believed shallow deposits present above Wild Goose Field are not productive. It is unlikely that any attempt would be made to develop shallow gas bearing zones overlying Wild Goose Field.

Quaternary alluvium east of the Sacramento River and along the pipeline route may have properties suitable for mining of sand and gravel. None of these areas are known to have been designated by the CGS as potential mineral resource zones, although this does not preclude such designation in the future. If areas along the pipeline were found to be suitable and mining were proposed, mine plans could be developed to assure the stability of the pipeline by using setbacks from the alignment.

In-stream or floodplain sand and gravel mining within certain distances (and to certain depths) may be found to affect the stability of the pipeline at the Sacramento River crossing. This could cause an otherwise feasible mineral extraction project to be cancelled or modified.

**Level of Significance Without Mitigation.** No potentially significant impacts related to future extraction of natural gas or sand and gravel are anticipated based on the project as defined. The potential for some in-stream or floodplain sand and gravel mining within certain distances (and to certain depths) of the Line 400/401 Connection Pipeline crossing to be cancelled or modified is not considered significant due to the abundance of mineable deposits in other areas of the valley.

**Mitigation Measure.** No mitigation measures are required.