3.4 GEOLOGY AND SOILS

The construction and operation of the proposed new or expansion SPR sites could result in impacts related to or affecting the geology and soils of the area where the SPR facilities would be located. These impacts could include erosion, subsidence, seismic activity, **soil liquefaction**, brine and oil seepage into soils, impacts associated with multiple uses of a salt dome, and stability of a salt dome. The following subsections describe the methodology for evaluating the potential impacts, discuss the common impacts for all of the sites, and evaluate the potential impacts for each specific site by considering the affected environments.

3.4.1 Methodology

To form independent conclusions about the likelihood and severity of potential impacts at each potential SPR site, DOE analyzed geology and soils using previous NEPA documents that predicted impacts, existing site reports that evaluated actual impacts, SPR design criteria requirements, and other available references characterizing geological features. The following sections briefly describe the methodology for evaluating each potential impact on geology and soils.

3.4.1.1 Erosion

Site preparation activities would temporarily expose the land surface and could potentially lead to increased soil erosion. The amount of erosion would depend mainly on site-specific characteristics such as soil type, the amount of excavation and filling of soils, the exposed area of soils, and the duration of exposure. To evaluate the potential for erosion, DOE considered its experience at existing SPR sites and the erosion control measures that should be taken.

3.4.1.2 Subsidence

Subsidence is the geological sinking or downward settling of an area on the Earth's surface, resulting in the formation of a depression.

Construction and operation of storage caverns would lead to local surface subsidence directly above the caverns. For this EIS, DOE evaluated the potential for subsidence, due to construction and operation of storage caverns, using two methods. The first method is based on the historical local subsidence data measured at the existing SPR sites from filled caverns that have been actively monitored. Subsidence surveys indicate that local subsidence above caverns at existing SPR sites (Bayou Choctaw, Big Hill, West Hackberry) occurs at annual rates of 0.47 to 3.4 inches (12 to 85 millimeters) corresponding to total cavern volumes between 72 MMB (Bayou Choctaw in 1988) and 219 MMB (West Hackberry in 1988). DOE estimated the subsidence rate at each site by comparing the planned cavern volume with that of the exiting caverns, and then used the estimated subsidence rate to calculate the local subsidence over a period of 30 years. The second method is based on the numerical analysis results and experience on salt caverns used for underground storage (Bauer 1997; Bauer 1999; Neal 1991a; Van Eijs 2000). Experience suggests a general rule that 10 percent of the cavern volume is lost over 30 years (caused by the salt creeping and naturally closing openings) and that 80 percent of this loss leads to subsidence (Neal 1991a). DOE used this general rule, together with the planned cavern capacity at each site, to estimate the subsidence at the surface central area over the caverns. DOE assumed that the subsidence bowl is cone-shaped with a distance between the surface edge and the outer walls of the caverns equal to the maximum depth of the caverns. For the proposed new sites, the methods described above are used to evaluate the possible subsidence. For the proposed expansion sites, the possible subsidence is evaluated based on the site-specific historical subsidence data.

3.4.1.3 Seismic Activity

The DOE SPR Level III Design Criteria require sites to be located in areas falling within seismic zone 0 or 1 in order to minimize seismic risk (DOE 2001a). For this EIS, DOE first evaluated the potential for the candidate sites to experience earthquakes by comparing the known seismic intensity of each site with this seismic criterion. Second, DOE evaluated the potential for the proposed cavern construction and operation activities to induce seismic activity by analyzing the known location of faults and using its experience at the existing SPR sites.

> **Seismic** applies to the activity of naturally or artificially induced earthquakes or earth vibrations, where the seismic waves are the elastic waves produced by these vibrations.

3.4.1.4 Soil Liquefaction

Soil liquefaction is a condition that occurs when loosely packed deposits change from a solid to a liquid state because of increased pressure and reduced stress. This may result from seismic shaking or other events. DOE evaluated the potential of soil liquefaction by comparing the seismic intensity of each site with the minimum intensity required for causing soil liquefaction.

> **Soil liquefaction** is a process that occurs when saturated sediments are shaken by an earthquake. The soil can lose its strength and cause the collapse of structures with foundations in the sediment.

3.4.1.5 Stability of Salt Domes

The geological stability of a salt dome depends mainly on local seismicity, fault formation, and salt evolution. DOE evaluated the geological stability of salt domes in the Gulf Coast region based on these factors. DOE also considered the effect of the construction and operation of caverns on the stability of salt domes.

3.4.1.6 Brine and Oil Seepage from Caverns

Section 3.2 evaluates the potential for brine and oil leaks from pipelines and other proposed surface activities. This section supplements that evaluation by examining the potential for such leaks from the storage caverns themselves. The likelihood of brine and oil seepage from a salt cavern into soils depends on the tightness of salt around the cavern. The DOE SPR Level III Design Criteria (DOE 2001a) specifies the minimum thickness of impervious salt around an SPR cavern to ensure the structural stability and tightness of the cavern (see table 3.4.1-1). For this EIS, DOE used these criteria to evaluate the likelihood of brine and oil seepage by considering the thickness of impervious salt around the cavern at each candidate site.

Table 3.4.1-1: DOE SPR Level III Design Criteria on Cavern Dimensions

Parameter	Allowed Minimum
Cavern center-to-center spacing	750 feet (229 meters)
Thickness of salt between two adjacent caverns (P)	480 feet (146 meters)
Distance between cavern wall and dome edge	300 feet (91 meters)
Distance between cavern wall and adjoining property line	100 feet (30 meters)
Cavern roof apex to top of salt (S)	450 feet (137 meters)
Ratio P/D[a]	1.78
Ratio S/D	1.0

[a] D is the average constructed diameter of the cavern

3.4.1.7 Multiple-Use Impacts

Interactions could occur between various operations in a single salt dome, depending on the distance between two operations. The DOE SPR Level III Design Criteria (DOE 2001a) specifies the minimum distances between two caverns and between a cavern and an adjoining property (see table 3.4.1-1). DOE used these criteria to evaluate the potential multiple-use impacts of the proposed action by considering the distance between the proposed new caverns and the existing operations of caverns (if any) at each site.

3.4.2 Impacts Common to Multiple Sites

This section analyzes the basic kinds of potential impacts caused by geology and soil conditions at each site. Based on the analysis of information that appears in sections 3.4.3 through 3.4.9, and following the methodology described in section 3.4.1, DOE believes some categories of potential impacts warrant more detailed and site-specific evaluation. We based our evaluation on subsidence associated with cavern construction and operation and the potential results caused by multiple uses of the candidate domes.

3.4.2.1 Erosion

Surface construction at the SPR sites, along pipelines, at new RWI sites, and in other new facilities could lead to erosion of soils caused by excavation, filling, and exposure of soils. The amount of erosion would depend mainly on site-specific characteristics that affect the amount of excavation and filling of soils and the exposed area of soils, the types of soils, the duration of exposure, and the local topography. In general, soil erosion could cause temporary and negligible deposits of soil on lands adjacent to construction sites. Implementation of standard erosion control measures such as seeding, sodding, riprapping, installation of sediment retention and detention basins, and **silt** fencing would prevent or reduce erosion of soils caused by construction.

The operation and maintenance of SPR facilities would consist mainly of filling the caverns and transferring the crude oil to oil distribution networks during drawdown. No soil erosion impacts would occur from filling and drawdown activities. Soils would stabilize soon after they are revegetated following construction.

The primary impacts associated with erosion would be to surface waters and biological resources, which are evaluated in sections 3.6 and 3.7, respectively. Because of the limited construction time and the implementation of the standard erosion control measures described above, DOE concludes that erosion impacts on geology and soils would be temporary, cover a small area, and negligible. The following site analyses do not address erosion from site-specific construction or operation and maintenance activities.

3.4.2.2 Subsidence

The construction, operation, and maintenance of RWI facilities, crude oil distribution facilities, brine disposal facilities, and support facilities are expected to result in little to no surface subsidence. This conclusion is based on the soils known to exist at each site (characterized in the site-specific affected environment descriptions below), the engineering precautions that would be integrated into the facility designs, and the past experience of minimal to no subsidence caused by these kinds of facilities at existing SPR sites. DOE believes no adverse subsidence impacts would be expected from such activities, and therefore this issue is not addressed in the analysis of each site.

Activities associated with the construction and operation of the storage caverns would lead to local surface subsidence over the cavern, so this potential impact is evaluated for each site in the site-specific sections. For salt domes, the local subsidence over the caverns is produced mainly through slabbing and cavern creep closure. Slabbing creates loose slabs of salt on the cavern walls and roof in sheared or impure salt with properties that vary with direction. The potential for slabbing at the SPR caverns would be extremely low because of the depth and purity of the salt where the SPR caverns would be constructed. Creep closure is an active process in any salt cavity where stress differentials (the pressure difference between the open cavern and the surrounding solid salt formation) exist. Construction and operation of the SPR caverns would result in stress differentials and thus the cavern creep closure. After an SPR site closes, subsidence would continue at a rate that depends on how well the cavern capacity is backfilled and how high the pressure in the former storage cavern is maintained. DOE plans to take steps during site decommissioning to minimize the extent of continued subsidence after closure.

In addition to a local change in topography, one possible impact of the subsidence would be the formation of ponds over the caverns at upland sites where the land surface has subsided to a level below the groundwater table. Proper engineering design, monitoring, and control, such as surface pavement with drainage systems, would prevent pond formation. Local subsidence at wetland sites like the proposed new Chacahoula site could submerge the platform at the area over the storage caverns. Proper engineering design, monitoring, and controls (e.g., raising the height of the platform) would prevent submergence of the platform.

The local subsidence would be limited to the area overlying the caverns. There would not be one depression for each cavern, but rather a single depression over all of the caverns. Such a localized effect would not contribute to the regional subsidence that occurs throughout the Gulf Coast region. Underground fluid withdrawal (groundwater and petroleum) and natural compaction and drainage of organic soils—not SPR site development and operation—are the main reasons for the regional subsidence (NAS 1991). For example, groundwater withdrawal in Houston, TX, has caused some coastal areas to subside by more than 6.6 feet (2 meters). The Mississippi River delta area of southern Louisiana is subsiding because of natural compaction and loss of sediment transport from the Mississippi River, and the New Orleans, LA, area is one of the principal areas of organic soil subsidence.

3.4.2.3 Seismic Activity

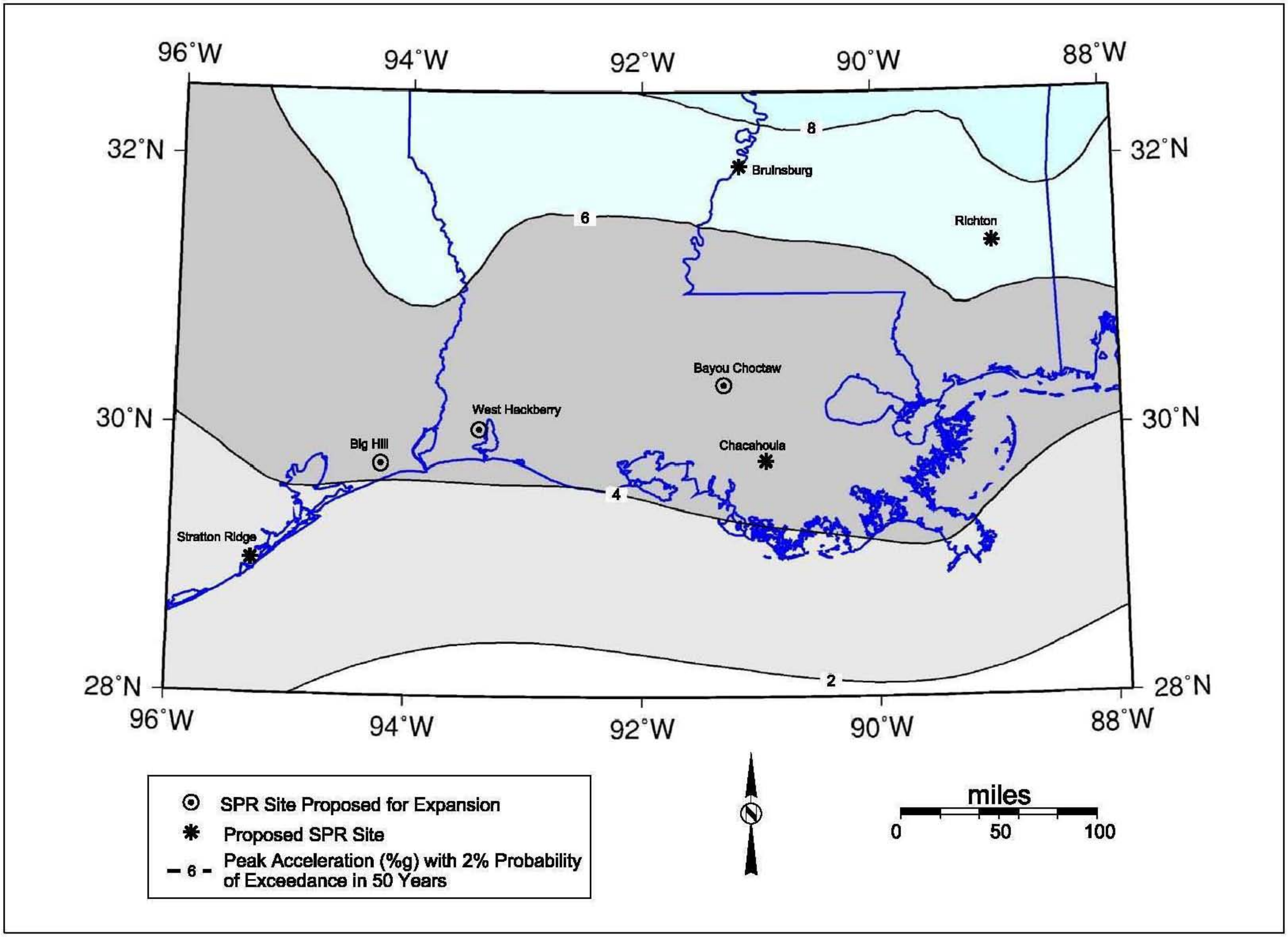
There is very little potential for regional seismic activity (natural earthquakes) at the candidate sites (USGS 2002). According to the Seismic Risk Map for the Uniform Building Code 1994, the gulf coast region is within seismic zone 0 or 1, the lowest risk zone (ICBO 1997). Although the region has a number of active faults, the faulting is not of natural geological origin, which most likely would not induce earthquakes (FEA 1976).

Figure 3.4.2.3-1 shows the peak acceleration with 2 percent probability of exceedance (i.e., annual frequency of exceedance of 0.0004) in the Gulf Coast area (created from http://equint.cv.usgs.gov/eg-men/html/custom2002-06.html). The peak acceleration at all of the SPR sites would be smaller than 7.5 percent *g*, where *g* is the acceleration of gravity. An earthquake with peak acceleration smaller than 7.5 percent *g* (magnitude smaller than 4.7) would not likely result in damages at the existing and proposed SPR sites.

Faults exist locally in the **caprock** and/or around the perimeters of salt domes. The known location of faults around each of the candidate sites is discussed in the site-specific affected environment sections below. The possibility that increased pressure or subsidence from site construction and operation would activate nearby faults and induce seismic activity is very unlikely. As required by the SPR Level III Design Criteria, a detailed subsurface geophysical investigation would be conducted during the detailed design stage to ensure that a

Caprock is a layer of rock that is often found covering some or all of a soft dome

Figure 3.4.2.3-1: Peak Acceleration with 2 Percent Probability of Exceedance in 50 Years in the Gulf Coast Area



salt dome is adequate for cavern development, which would prohibit the construction of new caverns in an area with near-surface faults that might be activated. Therefore, the site-specific sections do not evaluate the potential for proposed construction and operation activities to stimulate earthquakes.

At the new Bruinsburg site and the Bayou Choctaw and West Hackberry expansion sites, brine would be disposed of through underground injection systems. This would include a new injection well field at Bruinsburg and existing or expanded well fields at Bayou Choctaw and West Hackberry. While this injection would increase the pressures in the pore spaces of the receiving formation in areas near the injection wells, such increased pressures would not be expected to increase the potential for seismic activity. While such a risk could be a concern in seismically active regions, where the frictional resistance within faults may be overcome by increased hydrostatic pressure, DOE's SPR Level III Design Criteria require sites to be located in areas of minimal risk. This issue would be examined during the site-specific underground injection permitting process and any risks would be further mitigated; therefore potential impacts associated with induced seismic activity resulting from underground injection of brine at the proposed Bruinsburg, Bayou Choctaw, and West Hackberry sites were not evaluated in this EIS.

3.4.2.4 Soil Liquefaction

Each of the following site-specific affected environment descriptions generally characterizes the types of soils at the candidate expansion sites. While these soils and the landforms at the different sites have the potential to behave in a manner that could result in liquefaction in a seismic shaking, the potential for this impact is very low. The Bruinsburg site is located in seismic zone 1 with design peak horizontal acceleration at the ground surface equal to 0.075 g, and the other sites are located within seismic zone 0 with design peak horizontal acceleration at the ground surface equal to 0 g (ICBO 1997). The peak horizontal acceleration at the ground surface required to induce soil liquefaction is more than 0.1 g (Youd and Idriss 2001). Therefore, soil liquefaction is not discussed in the following site-specific sections.

3.4.2.5 Stability of Salt Domes

The geological stability of salt domes depends mainly on local seismicity, fault formation, and salt evolution. As stated in Section 3.4.2.3, the peak acceleration at all of proposed SPR sites would be smaller than 7.5 percent *g*. An earthquake with peak acceleration smaller than 7.5 percent *g* would not likely endanger the stability of a salt dome. The faults in the region are either non-active or active with movement that is very gradual along the fault. The construction and operation of SPR caverns would be unlikely to activate nearby faults. The "self-healing" property of salt would minimize the formation of discontinuities in the salt dome because salt tends to fill in any cracks that develop. The growth rate of salt domes is extremely slow in the Gulf Coast region, approximately 2.3×10^{-4} inches (5.8×10^{-3} millimeters) per year (DOE 1978b; Jirik and Weaver 1976). Therefore, the salt domes in the Gulf Coast region are geologically stable and there would be no threat to the storage cavern integrity.

Since the construction and operation of caverns would follow the DOE SPR Level III Design Criteria that ensure cavern integrity and stability, the SPR caverns would not endanger the geological stability of the salt domes. The successful construction and operation of storage caverns during the past decades clearly shows the geological stability of the salt domes in the Gulf Coast region. Therefore, the stability of salt domes is not discussed in the following site-specific sections.

3.4.2.6 Brine and Oil Seepage from Caverns

Four mechanisms may lead to leakage of brine or oil from a salt cavern:

- Flow paths of sufficient **permeability** in the salt or associated natural seepage pathways such as faults and joints;
- Flow through hydraulic fractures generated in the walls of the cavern;
- Leakage along the salt-cement interface in the cased wellbore of the wells used to inject and withdraw fluids from the caverns; and
- Upward migration through any wells that were drilled previously into the dome and since have been abandoned.

Each of these mechanisms and their potential to result in leakage from the SPR caverns is discussed in the site-specific sections.

Rock salt is essentially impermeable with a permeability of about 10^{-21} to 10^{-19} square meters, and as shown in table 3.4.1-1, DOE's design criteria would require that at least 300 feet (90 meters) of salt separate the cavern wall from the edge of the dome. In addition, DOE would conduct detailed geophysical surveys for each new site to ensure that the new SPR caverns would not touch any potential seepage pathways. Thus, brine or oil would be very unlikely to leak through the salt itself or associated potential seepage pathways.

Because salt tends to creep but not break, hydraulic fractures are a potential concern only if the crest of the cavern sinks significantly after the storage cavity is formed. The potential for such sinking is minimized by the DOE design criteria that require the top of the salt to be at least 450 feet (140 meters) thick (see table 3.4.1-1). The potential for hydraulic fractures is also minimized by the short time needed to fill the caverns to capacity after construction and by operating the caverns at the highest possible pressure to reduce cavern creep closure and surface subsidence (Neal 1991a; Bauer 1997; Bauer 1999). As a result, any fractures that do form in the top of the dome overlying the caverns would not be expected to propagate through the whole roof salt and reach the caprock. The remaining unfractured roof salt and the caprock would prevent leakage of brine or oil from a salt cavern.

With the borehole and casing sealed according to standard practices, the leakage of brine or oil from a salt cavern along the salt-cement interface in the cased wellbore would be unlikely.

For a site with exploration and production wells previously drilled into the dome (such as the site at Richton), brine and oil could leak from the storage caverns through unknown abandoned wells that intersect the caverns. Proper site selection and detailed geophysical surveys would ensure that any such wells are identified, and then best management practices, such as sealing any unused wells that are located above the storage caverns, would virtually eliminate the potential for such leakages.

To protect against cavern leakage, the cavern would be pressure-tested before oil is injected. The total allowable leakage would be less than 100 barrels of oil per year. DOE anticipates that cavern integrity would surpass this requirement.

For these reasons, the likelihood of oil or brine migrating from the storage caverns is low. In addition, the caverns are thousands of feet below sea level, and the rock aquifers at this depth would contain saline water that would be unusable as a potable source. Because the likelihood of oil or brine migration from a cavern is low and the surrounding aquifers are not potable water sources, potential impacts would be negligible. The potential impacts associated with oil and brine leaking from the caverns is not addressed in the following site-specific sections.

3.4.2.7 Multiple-Use Impacts

Two categories of potential multiple-use impacts are associated with the proposed action. First, multiple uses of a dome such as sulfur production, brine production, and cavern storage of other materials, could lead to accidental releases, increased levels of subsidence, cavern flooding, and possibly even fire or cavern collapse. For a site with previous and existing mining and storage operations, multiple-use impacts would be eliminated by locating the new caverns far from the existing dome operations in accordance with the SPR Level III Design Criteria (DOE 2001a), as shown in table 3.4.1-1. With proper engineering design based on the SPR Level III Design Criteria, the proposed new caverns would have no adverse interaction impacts; nevertheless, each site-specific section discusses the extent to which the candidate domes have been utilized for other activities.

The second category of potential impact would include the loss of access to mineral resources, including salt, caused by the construction and operation of the SPR sites. In chapter 5, this EIS addresses the potential impacts of irreversible and irretrievable commitment of resources.

3.4.3 Bruinsburg Storage Site

3.4.3.1 Affected Environment

The Bruinsburg dome in the Mississippi embayment and a part of the north Louisiana-Mississippi salt dome basin, is characterized by thousands of feet of **fluvial deltaic** and near-shore sediments punctuated by numerous **piercements**. The Bruinsburg salt dome is an irregular shape; its approximate dimensions are 2,600 feet (810 meters) (north-south) by 3,400 feet (1,030 meters) (east-west) at a depth of 2,500 feet (760 meters). The top of the salt dome is at a depth of approximately 2,000 feet (610 meters) with an area of about 240 acres (96 hectares). There is an **overhang** in the western area of the dome (Swann 1989). The north flank of the dome has a minimally overhanging, but near-vertical salt margin (Rautman and Lord 2005, p. 2). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.3-1.[1]

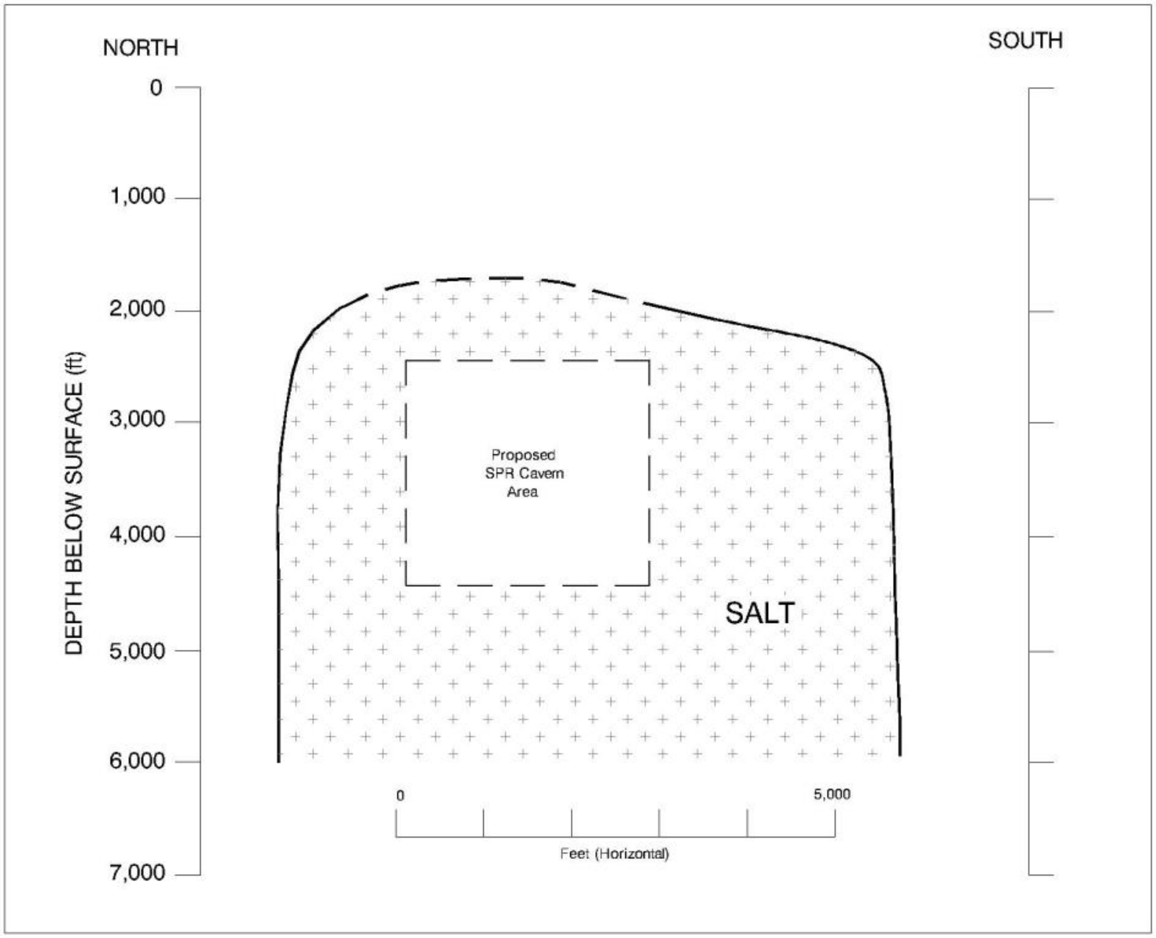
Piercement is a dome or anticlinal fold in which a mobile plastic core (i.e., salt) has ruptured the more brittle overlying rock. Also known as a diapir, dipiric fold, piercement dome, or piercing fold.

On the western side of the caprock, a fault trends mostly northward and tangential to the dome margin (Rautman and Lord 2005). A number of faults also offset sedimentary horizons overlying the caprock (Swann 1989).

---

[1] DOE recently conducted seismic surveys of the Bruinsburg salt dome to measure the size of the dome to determine its capability to provide 160 MMB of oil storage capacity. Analysis of the surveys indicates that the salt dome is smaller than initially thought and would likely be capable of accommodating only 70 MMB, instead of the planned 16 caverns with 10-MMB capacity each in the salt strata above 5,000 feet (1,500 meters) below the surface that would be required under current SPR operating criteria (Rautman et al. 2006). Surveys of salt dome characteristics at depths below 5,000 feet (1,500 meters) indicate that there may be an ability to develop oil storage caverns below 5,000 feet (1,500 meters), but doing so would be more difficult technically and would involve uncertain operational risks. This EIS retains the Bruinsburg site as presented in the draft EIS.

Figure 3.4.3-1: Cross-Section Diagram of the Bruinsburg Dome



No pre-existing leached cavities are in the Bruinsburg salt dome (Rautman and Lord 2005).

The area considered for brine disposal is just south of Highway 552 and north of Alcorn, MS. The area is dominated by cleared and level land of several hundred acres. Two geological formations could be used as the brine disposal reservoir: the Wilcox sand, which is more than 1,300 feet (400 meters) thick and 3,100 feet (950 meters) below surface, and the Sparta sand, which is about 750 feet (230 meters) thick and more than 1,800 feet (550 meters) below surface.

3.4.3.2 Operation and Maintenance Impacts

Subsidence

At the potential new Bruinsburg site, DOE would construct 16 new 10-MMB caverns arranged in four rows of four caverns each, for a total capacity of up to 160 MMB (see figure 2.4.1-2). By comparing the total volume of the new caverns with that of the existing caverns at sites with measured subsidence data, the local subsidence above the caverns can be estimated as 1.05 to 2.44 inches (27 to 62 millimeters) per year, resulting in total subsidence of 2.6 to 6.1 feet (0.80 to 1.9 meters) over 30 years.

With a general rule of 10 percent volume loss over 30 years resulting from salt cavern creep, the total volume loss would be 144 million cubic feet (4.1 million cubic meters); 80 percent would lead to a subsidence volume of 115 million cubic feet (3.3 million cubic meters). Assuming that the subsidence bowl is cone-shaped with the surface edge of 4,450 feet (1,360 meters) (maximum depth of the caverns) from the outer walls of the caverns, the maximum subsidence at the surface central area over the caverns can be calculated as 3.2 feet (1.0 meters) which is in the range of 2.6 to 6.1 feet (0.80 to 1.9 meters) estimated above. The local subsidence would be most likely in the range of 2.6 to 6.1 feet (0.80 to 1.9 meters) over 30 years. Further subsidence after site closure would be reduced by decommissioning methods that would backfill or otherwise help keep the pressure up in the former storage caverns.

Given the groundwater level at the site and the amount of projected subsidence, ponds likely would not form over the caverns; therefore, the main impact would be the formation of a depression over the cavern area, which would tend to capture local drainage at that location.

Multiple-Use Impacts

No multiple-use impacts would be expected at the Bruinsburg site because the site has no pre-existing storage caverns.

3.4.4 Chacahoula Storage Site

3.4.4.1 Affected Environment

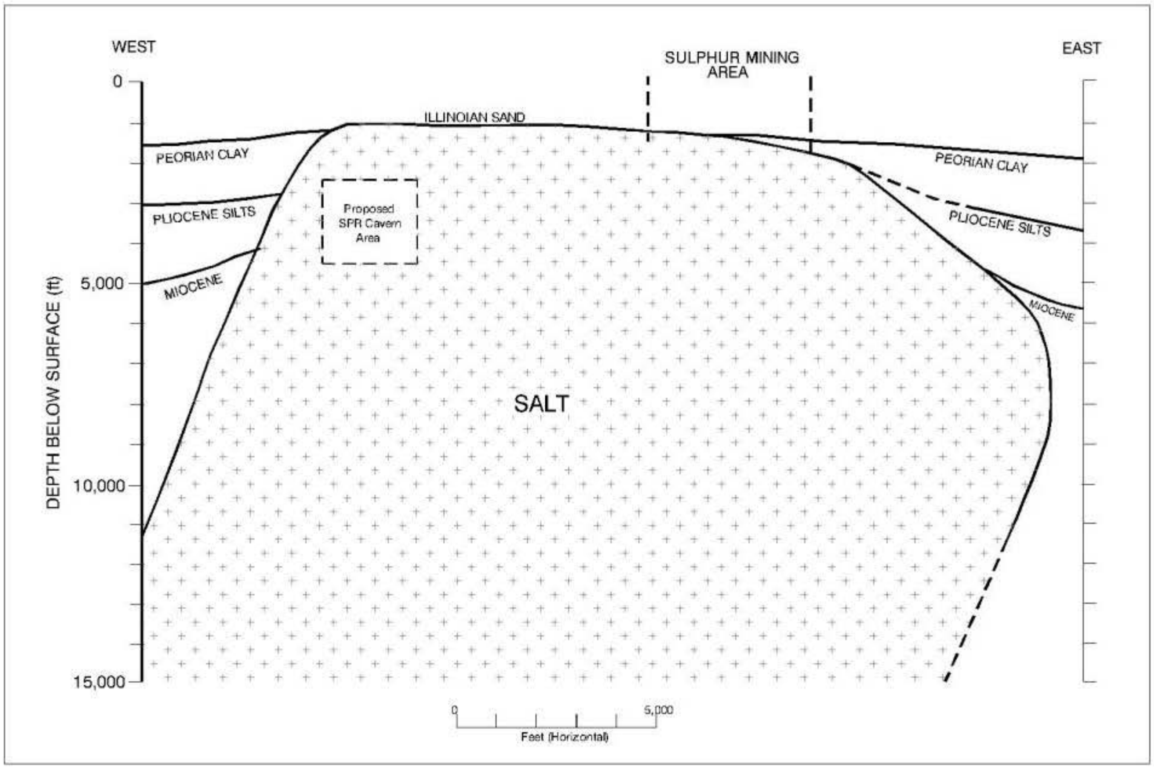
The Chacahoula salt dome is near the center of the Holocene Mississippi Delta, which has created the land in south Louisiana, between the old Lafourche and Teche distributive channels (Magorian and Neal 1990). The distributive channels once drained off the Mississippi River. The dome is an elliptical piercement structure that has a broad rounded top and sloping sides, with depths between 2,000 and 12,000 feet (610 and 3,700 meters). The dome is large enough, about 1,700 acres (690 hectares) at 2,500 feet (760 meters) below ground, to construct a large storage facility with multiple caverns. An overhang occurs approximately between 6,600 and 10,000 feet (2,010 and 3,040 meters) below ground on the east side. There is no indication that the overhang would affect the storage areas of the dome inside the 2,500-foot (760-meter) below ground salt contour (Magorian and Neal 1990; PBE 2004b). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.4-1.

Caprock overlying the dome is primarily composed of anhydrite, with gypsum and calcite probably present. Sulfur is a minor constituent of the caprock. Caprock is thin or absent over much of the dome, but has enough thickness in the northeast corner to have enabled minor sulfur extraction (DOE 1978b; Magorian and Neal 1990).

Up to 1,500 feet (460 meters) of unconsolidated and partially consolidated muds, sands, and shales overlie the central portion of the dome. Unconsolidated and partially consolidated sands and shales underlie the sediments and extend downward to about 7,500 feet (2,300 meters) below sea level. Sand, shale, and limestone are found below 7,500 feet (2,300 meters) underground, probably reaching depths in excess of 22,000 feet (6,700 meters) below ground. The salt piercement has forced these sediments upward in the immediate vicinity of the dome. Faulting within the lower formations adjacent to the dome is extensive and complex (DOE 1978b).

Extracting operations at the dome have produced hydrocarbons, brine, and sulfur. Sun Oil Company made the first discovery of petroleum in 1938 and has produced 50 MMB of oil and one trillion cubic feet (28 billion cubic meters) of gas on the south and northeast sides of the dome, with many oil and gas production wells drilled. Texas Brine Company operates three brine production caverns in the south

Figure 3.4.4-1: Cross-Section Diagram of the Chacahoula Dome



central part of the dome. The area in the northeastern part of the dome was mined for sulfur from 1955 to 1962; because of these operations, the site is subject to ponding. Local surface subsidence of 1.0 feet (0.3 meters) or more has occurred (Magorian and Neal 1990; PBE 2004b).

3.4.4.2 Operation and Maintenance Impacts

Subsidence

The proposed new caverns would result in additional surface subsidence; however, because the new caverns are far from the abandoned sulfur mining area (see figure 3.4.4-1), the new surface subsidence would not result in further sinking of previously affected areas. Based on a general rule of 10 percent initial volume loss over 30 years, similar group patterns observed in the cavern field at the West Hackberry dome, and quantitative analyses, the local subsidence over 30 years was estimated as 5 feet (1.5 meters) (Neal 1991a).

Because the Chacahoula site is in a submerged wetland, the majority of the proposed cavern area is currently under water. Local subsidence in these conditions could result in the platforms over the storage caverns becoming submerged. Proper engineering design, monitoring, and control, such as raising the height of the platforms, should prevent this problem. Thus, the main impact associated with the predicted subsidence at this site would be an increase in the water depth overlying the cavern area.

Multiple-Use Impacts

As previously mentioned, hydrocarbons, brine, and sulfur have been extracted respectively from the south and northeast sides, in the south central part, and in the northeastern part of the salt dome (Magorian and

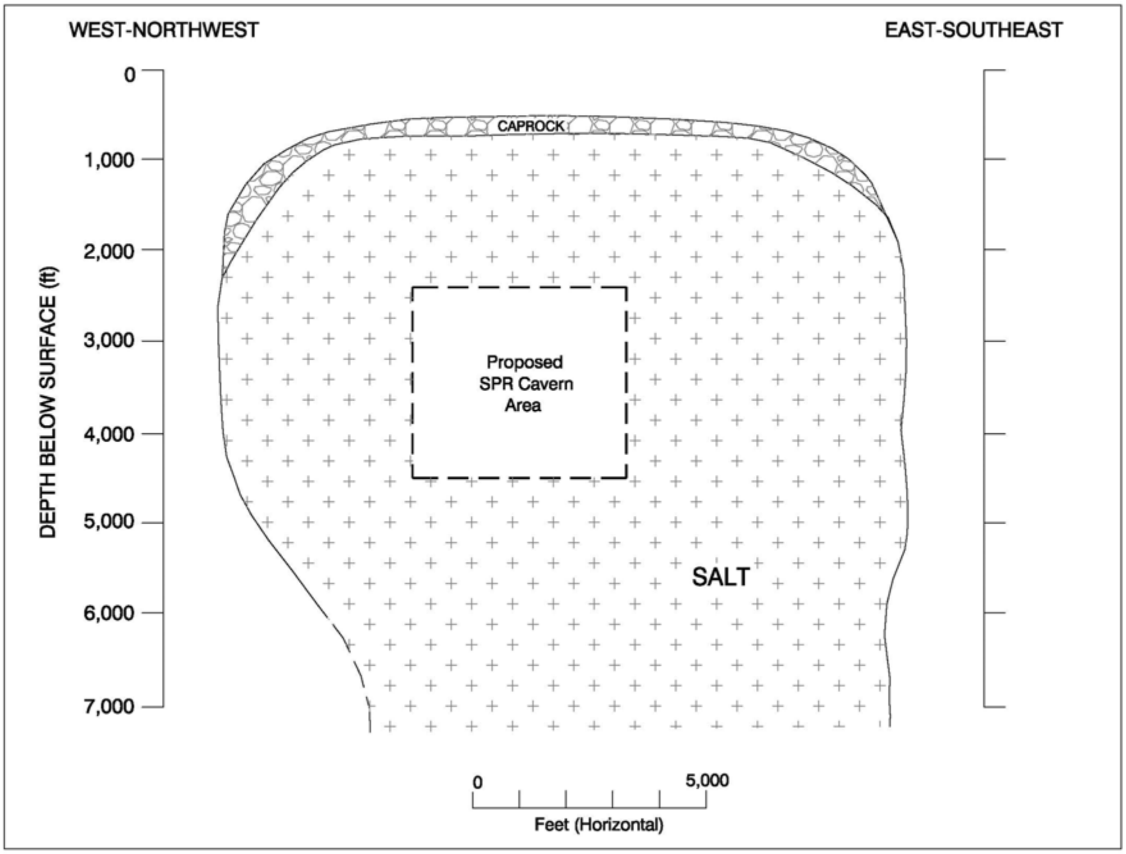
Neal 1990; PBE 2004b). With the proposed new caverns located in the western part of the dome and far from these operations, no adverse multiple-use impacts would be expected.

3.4.5 Richton Storage Site

3.4.5.1 Affected Environment

The Richton salt dome is a large, oblong piercement dome. At the 2,200-foot (670-meter) depth, the dome measures approximately 5 miles (8 kilometers) (northwest-southeast) by 3 miles (4.8 kilometers) (east-west). The dome is mushroom-shaped with a large overhang on the western edge and a somewhat less well-defined overhang on the eastern edge. Sulfur exploration wells indicate that the shallowest salt is found at 720 feet (220 meters) below land surface. About 5,500 acres (2,200 hectares) within the 2,000-foot (600-meter) deep salt contour are potentially suitable for crude oil storage caverns (DOE 1986; Neal 1991b). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.5-1.

Figure 3.4.5-1: Cross-Section Diagram of the Richton Dome



The top of the caprock lies at a depth of approximately 510 feet (160 meters) below land surface. The caprock is approximately 210 feet (65 meters) thick. The caprock has a number of small fractures, which is typical of piercement domes. Most of these fractures are closed at present; however, sulfur exploration drilling and DOE boreholes in the caprock indicate that some of the fractures may be open. Because the roof salt is over 1,000 feet (305 meters) thick, these fractures would have no adverse impact on the storage caverns.

The predominant **stratigraphic** units overlying the dome are sedimentary formations extending to a depth of approximately 660 feet (200 meters) immediately over the caprock of the dome. Alluvium, which consists primarily of fine-grained sand, silt, **clay**, and sandy gravel, is found in the stream valleys around the site. The predominant formation immediately over the salt dome, the Citronelle Formation that dates to the Pliocene age, has a maximum thickness of approximately 220 feet (66 meters), and consists of gravelly, coarse-grained to fine-grained sand with lenses of silt, silty clay, and clay. These same deposits make up the upper stratigraphic units of the edge of the salt dome. Below these deposits are other sedimentary deposits that are of middle Oligocene to Paleocene age and extend to a depth of more than 2,300 feet (700 meters) and a sequence of Cretaceous and Jurassic sedimentary rocks with thickness of 9,800 to 19,000 feet (3,000 to 5,800 meters) (DOE 1986).

Faults are present in the vicinity of the Richton dome. The Phillips fault zone is located north of the dome and parallel to the Wausau salt ridge. It is the only postulated **basement fault** in the area. Most other faults are present only in the Eocene Wilcox Formation, but a few faults are exposed at the surface. A fault that is present at depths below the Paleocene Midway Group, known as F-7, intersects the northwestern edge of the Richton dome. Development of the fault is thought to be the result of salt dome deformation, and movement along the fault is most likely created by the migration of the salt. Evidence for two other possible faults was observed in the Hattiesburg Formation atop the dome, but this movement is minor and may not extend into the salt. None of these faults appears to have been active during the Quaternary period (DOE 1986; PB-KBB Inc. 1992).

3.4.5.2 Operation and Maintenance Impacts

Subsidence

From quantitative analyses using the measured subsidence data at existing sites and detailed analyses based on a general rule of 10 percent initial volume loss over 30 years, DOE estimates that the local subsidence at the surface area over the caverns would be 2.6 to 6.1 feet (0.8 to 1.9 meters) over 30 years. The subsidence would decrease rapidly as it gets far from the area immediately above the cavern field.

Because groundwater can be found just below the land surface at Richton, this depression would become filled with water. DOE proposes to use proper engineering design, monitoring, and control, such as drained paved areas, to prevent the formation of subsidence-induced ponds over the caverns. With such measures, the subsidence is expected to change the local topography immediately over the new cavern area, but local drainage patterns would probably not be significantly altered.

Multiple-Use Impacts

There is no existing activity, historical mining, or oil production at Richton (PB-KBB Inc., 1992, p.9). Many sulfur exploration wells have been drilled into the salt dome. Best management practices would ensure that no existing wells would intersect the caverns and that the wells above the storage caverns would be fully sealed. Although oil and gas fields exist to the north and south within 10 miles (16 kilometers) from the salt dome, no multiple-use impacts would be expected because they are not within the actual salt column of the Richton salt dome. Thus, DOE expects that no multiple-use impacts would occur at this site.

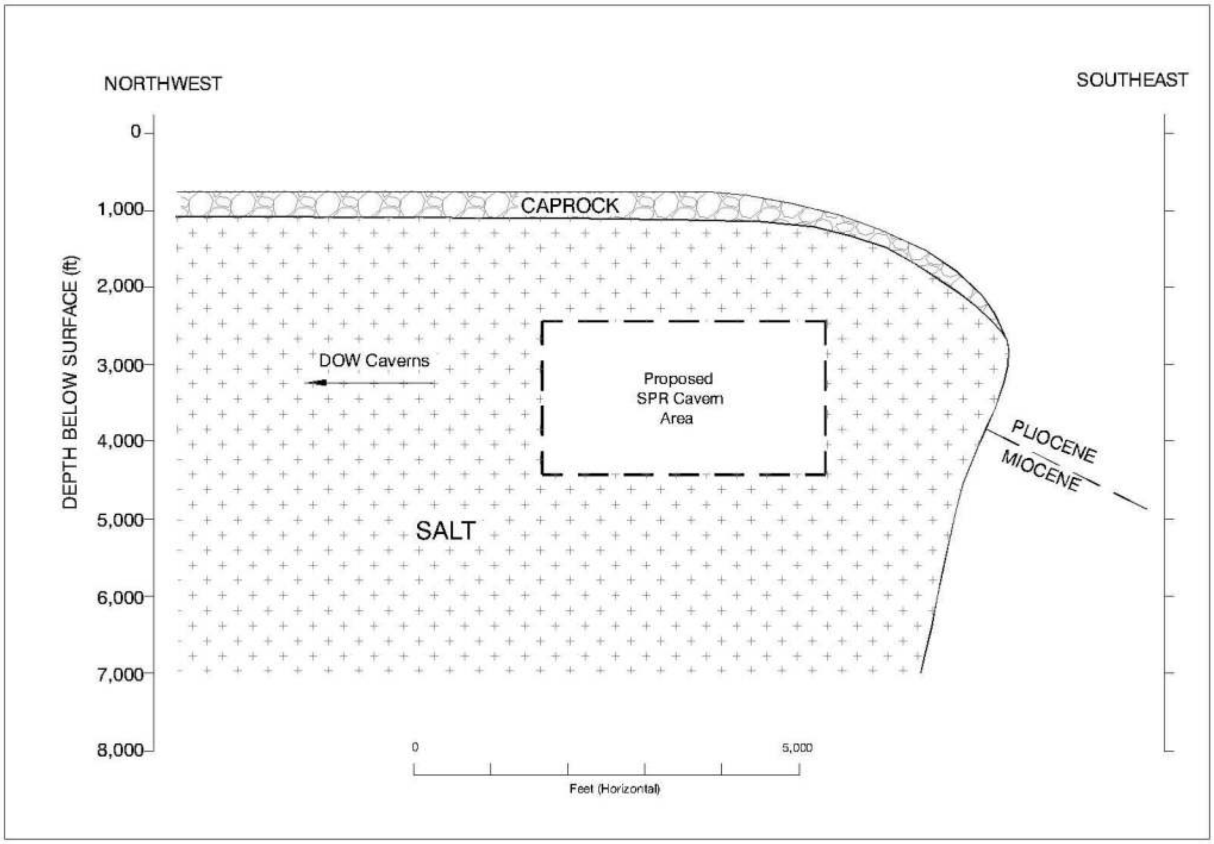
Since the Freeport LNG facility would be more than 2,000 feet from the SPR caverns, the subsidence caused by the SPR caverns in the area of the Freeport LNG facility would be small. The integrity of pipelines on the Stratton Ridge salt dome would be affected by the differential subsidence (ratio of subsidence difference to length between two locations along the LNG pipeline). The differential subsidence due to the construction and operation of the SPR caverns would be small and would not likely damage the integrity of LNG pipelines. Therefore, the multiple-use impacts would be negligible for the SPR caverns and the Freeport LNG facility.

3.4.6 Stratton Ridge Storage Site

3.4.6.1 Affected Environment

The Stratton Ridge candidate site ranges from 9.8 to 13 feet (3 to 4 meters) above sea level with local topography characterized by surrounding marshes, bayous, lakes, and creeks (DOE 1991b). The salt dome is irregular in shape with approximate dimensions of 3 miles (4.8 kilometers) (north-south) by 4 miles (6 kilometers) (east-west). The top of the caprock is at a depth of 870 feet (260 meters), and the top of the salt is at a depth of 1,300 feet (390 meters). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.6-1.

Figure 3.4.6-1: Cross-Section Diagram of the Stratton Ridge Dome



There is a salt overhang on the southeastern corner of the dome, but it would not affect the proposed SPR site because of the distance between the overhang and the proposed storage site location (DOE 1991b). A trough-like depression extends generally in a north-south direction on the east-central part of the dome. This depression is apparently the result of an active slump fault at the site. In addition, caprock shifting and associated casing failures have occurred in the area of this suspected fault, releasing ethane into the caprock in at least one instance. Seismic work performed in December 1990 by Cockrell Oil Company demonstrates that this fault completely cuts off the east side of the dome with a 60 degree dip. There is a definite topographic rise on the upthrown side of the surface projection of this fault, supporting this interpretation; however, there is ample room for the proposed new SPR caverns on the high side of the fault, far enough back so that continuing fault movement would not damage well casings (Neal 1991b).

Radial faulting, typically found around the perimeters of salt domes, exists on the southern edge of the dome. Other faulting has also been identified in the caprock. These caprock faults are of a much smaller displacement than the radial faults (Neal 1991b). The radial faults and the other faults in the caprock would not affect cavern development and operation because they do not extend deep into the salt mass.

The surface soils immediately overlying the Stratton Ridge dome are the Edna fine sandy loam and the Edna-Aris complex. They feature a subsurface clay layer up to 4.9 feet (1.5 meters) thick, and both are poorly drained, with low permeability and slow surface runoff. These soils would not readily permit water to pass into the water table (USDA 1991).

Approximately 57 brine and petroleum product storage caverns with a wide range of sizes are currently in use at the Stratton Ridge dome (DOE 1991b). Subsidence is occurring over the extensive cavern field operated by a number of chemical and petroleum companies such as Dow Chemical, British Petroleum, Conoco, and Occidental, at rates comparable to those experienced at existing SPR sites (USDA 1991; Neal 1991b). The Texas Railroad Commission recently permitted Freeport LNG Development L.P. to drill at least three wells as part of an effort to construct a liquefied natural gas storage facility at the Stratton Ridge dome (Rautman 2005). In addition, corrosion problems have occurred at the existing commercial caverns in the salt dome at Stratton Ridge because of the presence of dissolved hydrogen sulfide in groundwater (Douglas 1979).

3.4.6.2 Operation and Maintenance Impacts

Subsidence

Local subsidence has occurred in the areas of the current cavern operations at Stratton Ridge, and it is causing a saucer-shaped depression to form over the group of caverns owned by Dow Chemical Company, Inc. The data provided by Dow for the period between 1986 and 1990 estimate the rates being experienced at existing SPR sites on other salt domes. The extent of current cavern volume loss resulting from creep closure is such that perennially wet areas could develop at Stratton Ridge even without SPR development (Neal 1991b). During operation and maintenance, local subsidence would continue to increase because of the 16 new SPR caverns with a total capacity of up to 160 MMB. The local subsidence most likely would be in the range of 2.6 to 6.1 feet (0.80 to 1.9 meters) over 30 years. The subsidence would decrease rapidly as it gets farther from the cavern field.

Because wet areas could develop at the Stratton Ridge site even without SPR development (Neal 1991b, p.4), DOE would use proper engineering design, monitoring, and controls, such as drained paved areas, to prevent the formation of subsidence-induced ponds over the caverns. Impacts associated with subsidence would be limited to the area immediately over the dome, including the proposed SPR site. In addition, the hydrogen sulfide present in the groundwater could travel through fissures in the caprock and lead to increased rates of corrosion and casing failures (Neal 1991b). DOE would use proper engineering design and monitoring to limit the erosion caused by the hydrogen sulfide and to monitor the casings.

Multiple-Use Impacts

Dow Chemical, British Petroleum, Conoco, and Occidental currently operate an extensive cavern field at the Stratton Ridge salt dome consisting of approximately 57 brine and petrochemical product storage caverns with a wide range of capacities (DOE 1991b). Thus, multiple-use impacts may be possible from an accidental release of light hydrocarbons traveling through caprock fissures to an SPR site from an industrial storage site (Neal 1991b) and becoming a source of fire and contamination at the SPR site. However, because (1) no adverse effects have occurred at existing SPR sites adjacent to caverns storing light hydrocarbons, and (2) the distance between the new SPR caverns and existing light hydrocarbon storage operations would not be smaller than that at the existing SPR sites, following the SPR Level III Design Criteria, DOE expects negligible multiple-use impacts.

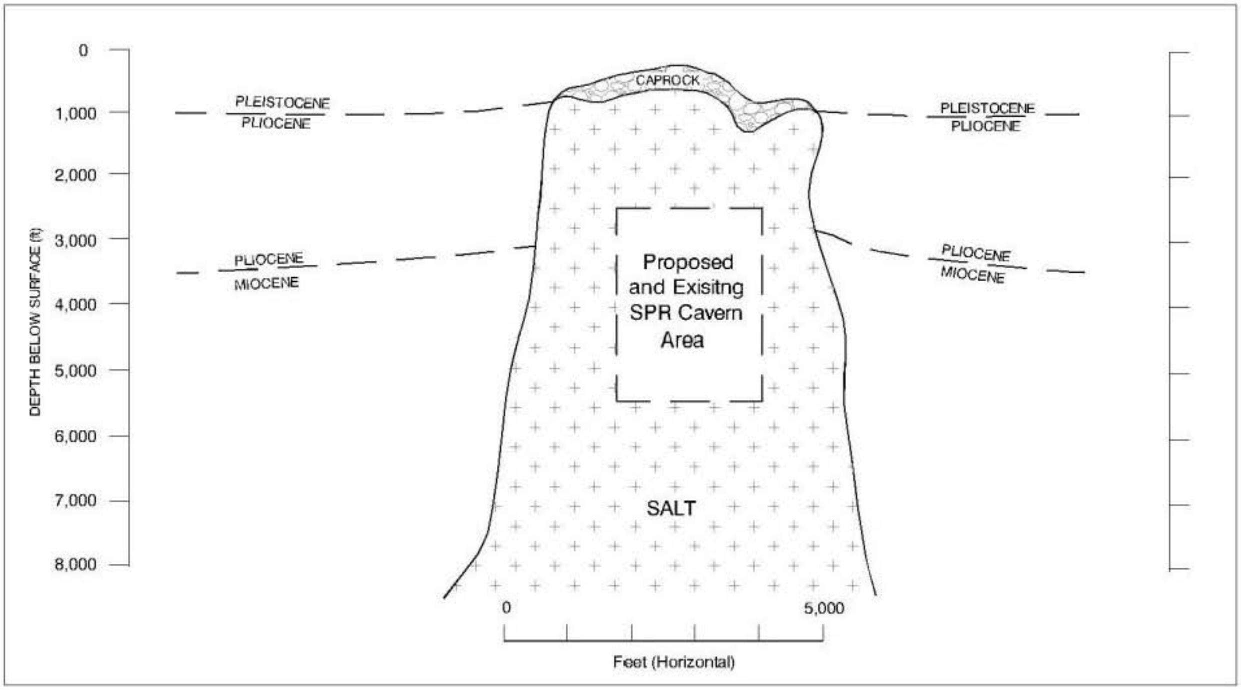
Since the Freeport LNG facility is more than 2,000 feet (610 meters) away from the SPR caverns, the subsidence increment in the area of the Freeport LNG facility would be small. What would affect the integrity of pipelines is the differential subsidence (ratio of subsidence difference to length between two locations). The differential subsidence due to the construction and operation of the SPR caverns would be small and would not likely damage the integrity of LNG pipelines. Therefore, the multiple-use impacts would be negligible for the SPR caverns and the Freeport LNG facility.

3.4.7 Bayou Choctaw Expansion Site

3.4.7.1 Affected Environment

The Bayou Choctaw dome is nearly circular in plain view, having a broad irregular top at a depth of 500 to 1,200 feet (152 to 366 meters) below sea level. The sides of the dome show steeply dipping contours, with the east side dipping at about 79 degrees and gradually increasing to a vertical angle. An overhang on the west side significantly decreases the area available for solution-mined storage cavern construction. The caprock overlying the Bayou Choctaw salt dome is composed of insoluble residues of salt and its alteration products. The caprock has a highly irregular surface and its general thickness varies from 200 to 400 feet (61 to 122 meters) (DOC 1976; DOE 1978b). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.7-1.

Figure 3.4.7-1: Cross-Section Diagram of the Bayou Choctaw Dome



Unconsolidated and partially consolidated muds and sands overlie the dome caprock with a thickness of 240 feet (72 meters) to 840 feet (260 meters). Outside the dome, unconsolidated and partially consolidated sands and shales underlie the sediments and extend downward to about 9,000 feet (2,700 meters) below sea level. These sediments have been forced upward by the salt piercement in the immediate vicinity of the dome (DOC 1976; DOE 1978b).

Oil production has occurred all around the dome with the greatest density of drilling on the southeast and north flanks (DOE 1978b). Currently six storage caverns, each approximately 12.5 MMB, operate at the Bayou Choctaw site (PBE 2004a).

3.4.7.2 Operation and Maintenance Impacts

Subsidence

The 1982 to 1988 survey data show that the site has subsided at a rate of 0.5 to 1.3 inches (12 to 34 millimeters) per year (Neal 1991a). The 1991 survey data show that little subsidence was occurring at the site, probably only 0.1 inches (3.0 millimeters) per year (DOE 1991b). Operation and maintenance of the three new caverns (two would be constructed and one would be acquired) would increase the subsidence rate; but the increment would be small considering the small cavern volume increase (20 MB of two constructed caverns versus 86 MMB of six existing SPR caverns and one acquired cavern). Therefore, potential impacts associated with subsidence at the dome area would be negligible.

Multiple-Use Impacts

By locating the two new caverns far from the six existing operating caverns following the SPR Level III Design Criteria (see figure 2.5.1-2), no adverse interaction impacts would be expected during operation and maintenance.

3.4.8 Big Hill Expansion Site

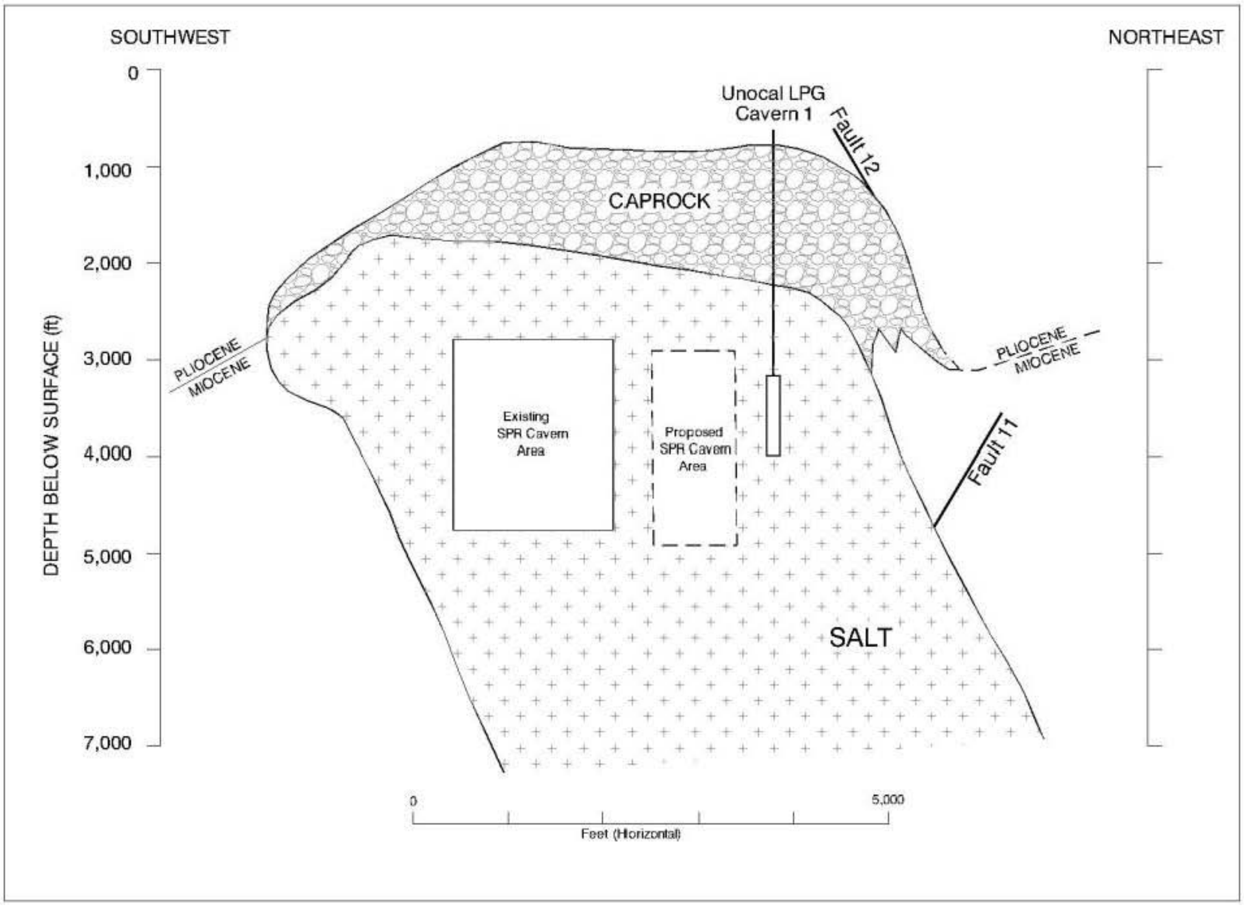
3.4.8.1 Affected Environment

The Big Hill salt dome is a moderately elliptical piercement dome, with a nearly circular horizontal cross section, an irregular top, and steep sides. It is approximately 1.3 miles (2.0 kilometers) (north-south) by 1.0 mile (1.6 kilometers) (east-west).

Beaumont clay and Lafayette gravel in particular have been identified as major sediments overlying the dome. These deposits and other sands and clays have been unevenly deposited by meandering rivers in local floodplains and deltas (DOE 1978d; DOE 1989a). Sediments surround the dome, extending to depths exceeding 9,800 feet (3,000 meters) (DOE 1978d). More shallow sediments from silty loam soils are found at the surface.

A cross-section diagram of the Big Hill dome and surrounding area is shown in figure 3.4.8-1. The salt dome is covered by a roughly circular surface mound that rises to a maximum elevation of about 36 feet (11 meters) above sea level and forms a significant topographic feature in the local area (DOE 1978d; DOE 1989a). The dome has three prominent overhangs, including one minor overhang on the western flank and major overhangs on both the southern and eastern flanks (Neal 1991b; DOE 1991b). The shallowest known salt is found on the west perimeter of the dome at approximately 1,700 feet (530 meters) below sea level. The deepest salt encountered at the site is on the south flank of the dome at 5,700 feet (1,750 meters). An estimated 420 contiguous acres (170 hectares) within the 2,000-foot (600-meter) underground salt contour and extending to 5,900 feet (1,500 meters) deep are potentially

Figure 3.4.8-1: Cross-Section Diagram of the Big Hill Dome



suitable for the development of crude oil storage caverns. The existing cavern depth interval of 2,200 to 4,200 feet (670 to 1,300 meters) could be used for additional cavern development. The total potential storage volume is 270 MMB (DOE 1978d).

The top of the caprock lies at a depth of approximately 330 feet (100 meters) below the surface and covers the majority of the salt mass. The thickness of the caprock varies between 850 and 1,400 feet (260 and 410 meters), making it one of the thickest in the Gulf Coast region (DOE 1991b). The caprock is composed of porous sandstone that overlies dolomitic limestone, gypsum, and anhydrite (DOE 1978d). Because of cavities or large pores in the caprock, previous SPR drilling encountered several zones of lost circulation (loss of drilling mud) (DOE 1991b). Because of the upward pressure exerted by the rising salt, the caprock is severely fractured and faulted. One major surface fault has resulted in 98 feet (30 meters) of displaced caprock and likely extends into the dome. Otherwise, the fault patterns identified by extensive drilling in the Big Hill caprock and in the areas flanking the dome are characteristic of the fault patterns of domes. This pattern generally reflects radial faulting with subsidiary concentric, **normal faults** between the radial faults (DOE 1978d).

Uncertainty remains regarding an apparent north-south trending shearing zone at the site. There is no evidence that this **shear zone** has affected the existing SPR cavern field (Neal et al. 1991c).

3.4.8.2 Operation and Maintenance Impacts

Subsidence

Survey data indicate that the site has subsided 0.24 to 0.60 inches (6 to 15 millimeters) per year between April 1989 and May 1994 and 0.24 to 0.36 inches (6 to 9 millimeters) per year between May 1994 and January 1999 (Bauer 1999). The decrease is probably due to the operational procedure of maintaining the caverns at a relatively high operating pressure and the corresponding decrease in creep closure rate of the caverns with time (Bauer 1999). During operation and maintenance, the site likely would subside at a rate higher than the existing rate of 0.24 to 0.36 inches (6.1 to 9.1 millimeters) per year because of the new caverns. Assuming that the subsidence rate is proportional to total cavern volume and that the total existing cavern volume is 170 MMB, the new subsidence rate can be estimated as follows:

- Approximately 0.35 to 0.53 inches (9.0 to 13 millimeters) per year with total new cavern volume equal to 80 MMB; and

- Approximately 0.38 to 0.56 inches (9.5 to 14 millimeters) per year with total new cavern volume equal to 96 MMB.

At the highest subsidence rate of 0.56 inches (14 millimeters) per year corresponding to the largest total new cavern volume of 96 MMB, the land surface would subside 1.4 feet (0.43 meters) over 30 years. Because the top of the most shallow aquifer at the Big Hill site is approximately 6.6 feet (2 meters) below land surface, no formation of ponds would be expected during the life of the operation. In addition, engineering controls such as surface pavement with drainage systems would prevent the formation of such ponds. Thus, DOE expects no subsidence impacts would occur at this expansion site, even for the 96 MMB storage capacity alternative.

Multiple-Use Impacts

There are two small liquefied petroleum gas storage caverns of 0.5 MMB each owned by Unocal Corporation in addition to the 14 existing SPR caverns in the salt dome. There are also oil fields on the northwest and southwest flanks of the dome, although no commercial oil production has ever occurred from the caprock (DOE 1992a, p. 7-3). With the new caverns located far from the existing operations (see figure 2.5.2-2), DOE expects that no adverse multiple-use impacts would occur.

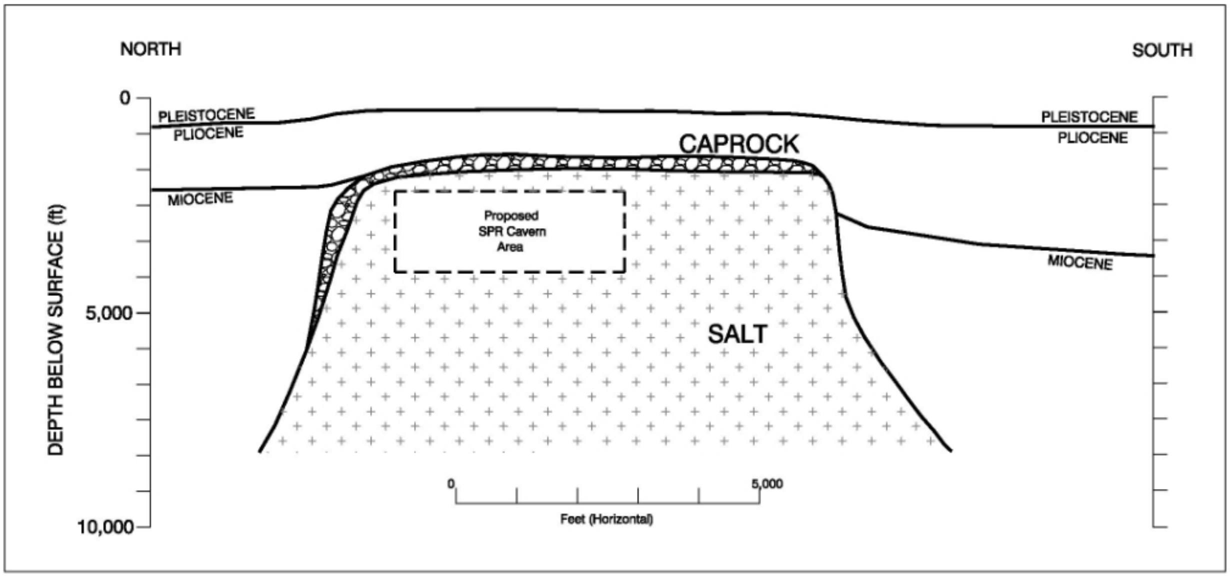
3.4.9 West Hackberry Expansion Site

3.4.9.1 Affected Environment

Unconsolidated and partially consolidated muds, sands, and shales overlie the central portion of the West Hackberry dome, with thicknesses ranging from 1,500 to 2,000 feet (460 to 610 meters). Unconsolidated and partially consolidated sands and shales extend to a depth of 9,500 feet (2,900 meters) on the flanks of the dome. Above the dome, the sediments have been forced upward by the salt, forming a mound with an elevation of 19 feet (5.8 meters) above mean terrain (DOC 1977).

The West Hackberry dome itself is an elliptical piercement structure, having a broad nearly flat top at an average depth of 2,000 feet (610 meters) below sea level. The slope of the dome sides range from slightly less than 60 degrees to steeper than 75 degrees on the north side. The surface area within the 2,000-foot (610-meter) depth contour of the salt stock is about 1,750 acres (710 hectares). An overhang is on the southeast side of the dome (DOC 1977; DOE 1978d). A cross-section diagram of the dome and surrounding area is shown in figure 3.4.9-1.

Figure 3.4.9-1: Cross-Section Diagram of the West Hackberry Dome



Caprock covers the entire salt mass above the 3,000-foot (914-meter) depth contour, with a maximum thickness of 525 feet (160 meters). Caprock depth ranges from less than 1,500 feet (457 meters) in the southwest to more than 4,000 feet (1,220 meters) on the north and south perimeter (DOC 1977). The caprock is intensively fractured, faulted, and broken into fragments resulting from upward pressures exerted by the rising salt stock (DOE 1978d).

Faulting in formations overlying and adjacent to the dome is extensive and complex. Three major northeasterly trending faults may have influenced the orientation of the dome axis. These faults have created a zone of weakness through which the salt may have risen. A secondary series of radial faults is interpreted to occur on the northwest and southeast perimeter of the dome (DOC 1977).

3.4.9.2 Operation and Maintenance Impacts

Subsidence

Data from January 1983 to October 1988 show a subsidence rate of 2 to 3 inches (51 to 76 millimeters) per year at West Hackberry, while data from January 1993 to October 1996 show that the subsidence rate had decreased to 1 to 2 inches (25 to 51 millimeters) per year (Bauer 1997). The decrease is probably resulting from the operational procedure that maintains the caverns at relatively high operating pressure, and the corresponding decrease in creep closure rate of the caverns with time (Bauer 1997). Because no new caverns would be constructed, the future subsidence rate would be expected to be smaller than 3 inches (76 millimeters) per year.

The local subsidence likely would lead to formation of ponds at the area over the caverns. Proper engineering design, monitoring, and controls such as draining paved areas would be used to prevent the formation of subsidence-induced ponds over the caverns. Thus, DOE expects that potential impact of subsidence at West Hackberry would be negligible.

Multiple-Use Impacts

The three caverns to be acquired by DOE at the West Hackberry site are close to each other and likely would coalesce during operation. The caverns are located in a line with 175 feet (53 meters) and 200 feet (61 meters) between the caverns. The coalescence would increase the rate of subsidence and could lead to cavity collapse. The known instances of salt cavern collapse (Bayou Choctaw, LA 1954; Grand Saline, TX 1976; Belle Isle, LA 1973; Eminence, MS 1973) occurred during brine solution mining, and they are believed to have resulted from uncontrolled or accidental leaching of the salt near the top of the dome rather than from structural failure of the cavern roof. Thickness of the cavern roof in each collapse was less than 300 feet (91 meters) (DOE 1978b, p. E-2). With the roof thickness greater than 1,500 feet (460 meters), the occurrence of collapse is very unlikely.

3.4.10 No-Action Alternative

The no-action alternative would limit the impacts from SPR construction and operation to those that have already occurred or that would occur at the existing SPR storage sites at Bayou Choctaw, Big Hill, Bryan Mound, and West Hackberry. Some of the existing environments for the proposed new SPR storage site alternatives would remain undeveloped and it is possible that others would be developed for salt cavern storage or other oil and gas activities. For those sites that are developed for oil and gas activities, a small amount of localized subsidence is possible. Selection of the no-action alternative would eliminate some potential geological impacts such as small long term subsidence over cavern areas and the multiple use impacts unless the caverns or their surfaces were developed for some other purpose.

The Bruinsburg storage site would likely remain in agricultural use because of the lack of development pressure. The Chacahoula storage site could remain undeveloped. However, existing oil and gas activities occur near the Chacahoula storage site, and if the proposed site were developed by a commercial entity for oil and gas purposes some geological subsidence could continue as a result of those activities. The Richton site would likely remain in use as a pine plantation because of the lack of development pressure. Dow, British Petroleum, Conoco, and Occidental energy companies have storage facilities on the Stratton Ridge dome and it is possible that the Stratton Ridge storage site could be developed for cavern storage by a commercial entity, some geological subsidence could occur.