2.0 SITE CHARACTERISTICS[1]

The physical, environmental and demographic features of the GGNS site as they relate to an early site permit application are presented and discussed in this section. These site characteristics form the basis for future comparison (at the COL stage) with design characteristics of the selected plant type, to verify that the site is suitable for that plant type.

2.1 Geography and Demography

2.1.1 Site Location and Description

2.1.1.1 Site Location

Grand Gulf Nuclear Station is located in Claiborne County in southwestern Mississippi. The plant site is on the east side of the Mississippi River about 25 miles south of Vicksburg and 37 miles north-northeast of Natchez. The Grand Gulf Military Park borders a portion of the north side of the plant site property, and the community of Grand Gulf is about l-1/2 miles to the north. The town of Port Gibson is about 6 miles southeast of the plant site.

The Universal Transverse Mercator Grid Coordinates for the center of the area of the proposed location of the new reactor(s) on the site are approximately N3,542,873 meters, and E684,021 meters.

The GGNS site property boundary shown on Figure 2.1-1 encompasses approximately 2100 acres of property. Figure 2.1-1 shows the location of significant plant facilities with respect to the site property boundary, and with respect to the proposed location of a new facility on the site.

2.1.1.2 Site Description

The site and its environs consist primarily of woodlands and farms and are about equally divided between two physiographic regions. The western half of the plant site property is in the alluvial plain of the Mississippi River; the eastern half is in the Loess or Bluff Hills. The elevation of the plant site property varies between 55 and 75 *feet above mean sea level in the alluvial plain region, whereas the Loess Hills portion varies from 80 to more than 200 feet above mean sea level (msl) at the inland of the site. Elevations of about 400 feet above mean sea level occur on the hilltops east and northeast of the site.*

Two lakes, Gin Lake and Hamilton Lake, are located in the western portion of the property. These lakes were once the channel of the Mississippi River and range from about 8 to 10 feet deep. A third lake, created from a borrow pit developed during construction of GGNS Unit 1 is located near the barge slip at the river.

2.1.1.2.1 General Arrangement of Structures and Equipment - GGNS Unit 1

The principal buildings and structures include the containment structure, the turbine building, the auxiliary building, the control building, the diesel generator building, the standby service water cooling towers and basins, the enclosure building, the radwaste building, the natural draft cooling tower and the auxiliary cooling tower. A structure which houses the administration

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[1] This ESP application makes use of material from the GGNS Updated Final Analysis Report (UFSAR) where considered appropriate. When such material (text) is used in this application (verbatim), it is shown in italics. Tables and figures taken from the UFSAR do not use italics but are referenced (by number) on the associated tables and figures of this document.

offices, clean machine shop, and guardhouse is provided. A building is also provided to store the site fire truck, foam chemicals, and miscellaneous fire fighting apparatus. The Energy Services Center (ESC) building, located to the west northwest of the Unit 1 power block, includes engineering and training facilities, and the site visitor's center. (See Figure 2.1-1)

Bulk storage facilities are provided for hydrogen and oxygen in support of the hydrogen water chemistry system on the plant north end of the Unit 2 cooling tower basin. The bulk liquid hydrogen facility includes a 20,000 gallon cryogenic tank, cryogenic pumps, atmospheric vaporizers and gas storage tubes to supply high pressure gas to the hydrogen water chemistry, generator cooling and primary water tank blanket systems.

The bulk liquid oxygen facility includes a 9,000 gallon cryogenic tank and atmospheric vaporizers to supply low pressure gas to the hydrogen water chemistry system.

2.1.2 Exclusion Area Authority and Control

The boundary line of the plant exclusion area (as defined in 10 CFR 100) for GGNS Unit 1 is shown on Figure 2.1-2. The boundary consists of a circle drawn from the center of the Unit 1 containment. *The minimum distance from the Unit 1 reactor to the exclusion area boundary is 696 meters. This is the closest distance from the center of Unit 1 containment to the plant property boundary.* The proposed location of the power block housing the reactor containment structure for the new facility is within the exclusion area for the GGNS Unit 1 plant.

The boundary line of the exclusion area for a new facility (as defined in 10 CFR 100) is also shown on Figure 2.1-2. The exclusion area boundary (EAB) for a new facility consists of a circle of approximately 0.52 miles (841 meters) radial distance from the circumference of a 630 ft. circle encompassing the proposed power block location for a new facility. Thus the minimum distance to the exclusion area boundary from any individual new reactor site within the 630 ft. circle would be 0.52 miles (841 meters). The area within this EAB is wholly contained within the GGNS site property boundary. The exclusion area for a new facility includes a majority of the GGNS Unit 1 exclusion area. Distances from the proposed location of a new facility's reactor site to the nearest plant site property boundary in each of the sixteen sectors are given in Table 2.3-149, which also gives annual average atmospheric dispersion factors.

2.1.2.1 Authority

For all practical purposes, SERI controls the surface rights, and SERI has authorized Entergy Operations to maintain control of ingress to and egress from the exclusion area and provides for evacuation of individuals from the area in the event of an emergency. Furthermore, SERI owns most of the mineral interests within the exclusion area. To the extent that third parties still own mineral interests in the exclusion area, it is extremely unlikely that such third party interests would ever be exercised so as to create an exception to Entergy Operations' control of the exclusion area.

A similar arrangement would be made for exercise of authority over the area within the exclusion area for the new facility on the site property. Because the proposed exclusion area for a new facility is wholly contained within the GGNS site property boundary, SERI would have effective control over the exclusion area for a new facility.

2.1.2.2 Surface Rights

SERI has acquired and will maintain surface ownership of all the land within the GGNS plant site property boundary, with the following exceptions:

1. *SMEPA has a 10 percent undivided interest in the* [GGNS Unit 1] *power block area within the plant exclusion area. This is a 94-acre tract containing the cooling towers, containment buildings, and other major plant structures. SMEPA also owns a 10 percent undivided ownership interest in two very long and narrow strips of land (7 l/2 and 5 acres, respectively) on which the* [GGNS Unit 1] *water supply and discharge piping is located.*

2. *Entergy Mississippi, Inc. owns the 52-acre* [GGNS Unit 1] *plant switchyard area, which is partially located within the plant exclusion area* [and the proposed exclusion area for a new facility]. *However, under a* 1999 *agreement with MP&L (now Entergy Mississippi, Inc.), SERI has authority to exercise complete control and determine all activities on Entergy Mississippi, Inc. property and easements in the exclusion area including exclusion of Entergy Mississippi, Inc. personnel and third parties. SERI has transferred such rights to Entergy Operations.*

   Entergy Operations has unrestricted access to the switchyard area. [For GGNS Unit 1,] *Entergy Operations performs all routine switchyard activities, operates the main generator breakers and 34KV breakers, and maintains the main, ESF, and BOP transformers. Entergy Operations is also responsible for all security functions within Entergy Mississippi, Inc. property at GGNS.*

3. *A two-acre residential property which is totally surrounded by the plant site property boundary in the southwest sector of the site is privately owned. This property is outside the exclusion area* [for GGNS Unit 1 and the proposed exclusion area for a new facility].

There are no railroads or navigable waterways that traverse the exclusion area for the existing GGNS Unit 1 plant or the proposed exclusion area for the ESP Facility. One county road runs through the GGNS plant site property; Bald Hill Road traverses both the exclusion areas. Bald Hill Road cuts through the south-southeast, south, south-southwest, and southwest sectors of the plant site. Two Entergy Mississippi, Inc. transmission lines traverse the GGNS plant site property; neither of them crosses any portion of the exclusion area proposed for a new facility on the ESP Site. The GGNS Unit 1 plant structures and support buildings (with exception of structures at the river), including the Energy Services Center (ESC) building, which includes engineering and training facilities, the site visitor's center, and the EOF, are within the proposed exclusion area for a new facility. There are no other industrial, commercial, institutional, or residential structures in the proposed exclusion area for a new facility on the ESP Site.

Entergy Operations will allow access to parts of the plant site property outside the [GGNS Unit 1] *exclusion area for recreational purposes. Arrangements have been made for control of traffic on the county roads, a part of* [Bald Hill Road] *which is located within the exclusion area. These arrangements are implemented only during a declared emergency and are fully described in the Emergency Plan. The protected area is posted to ensure awareness of access restrictions by individuals.*

Similar arrangements would be implemented for operation of any new plant(s) on the GGNS ESP Site to the extent they do not interfere with operations or emergency planning. Appropriate arrangements with SERI and Entergy Operations, Inc. for control of ingress and egress to the new facility location and its exclusion area would be established.

2.1.2.3 Mineral Rights

The joint owners of Grand Gulf Nuclear Station (GGNS) own or control 89 percent of the mineral rights within the [GGNS Unit 1] *plant exclusion area, and all the mineral rights within the central portion of the exclusion area, including the power block area. This includes all the rights beneath seismic Category I structures. Despite the ownership by third parties of a small portion of the mineral interests within the exclusion area, for all practical purposes Entergy Operations maintains complete control over the* [GGNS Unit 1] *exclusion area in accordance with 10CFR100.ll(a)(1) and 10CFR100.3(a).*

The requirement of 10CFR100.3(a) states that activities unrelated to operation of the reactor may be permitted in the exclusion area under appropriate limitations, provided "...no significant hazards to the public health and safety will result." The outstanding mineral interests will not result in any significant hazard to public health and safety and are, therefore, de minimis.

There is no activity at the GGNS plant site to explore for, drill for, or otherwise extract minerals. Past unsuccessful exploratory activities on or near the GGNS plant site and the geological character of the subsurface structure in the vicinity of the GGNS plant site indicate that commercial mineral production within or near the exclusion area appears unlikely in the foreseeable future. This has been confirmed in a geological appraisal, dated January 1987.

In addition, under Mississippi law, prospective mineral developers have no legal right to use physical force or to create a public disturbance to gain access to a property in order to explore for or to extract minerals. Furthermore, they would be prohibited from drilling any oil or gas well until a permit is issued by the State Oil and Gas Board following a notice and public hearing. Since SERI and SMEPA own, and Entergy Operations controls, substantially all of the minerals located within the exclusion area, SERI and Entergy Operations would attend any hearings and would have the opportunity to object to the drilling and/or the location of any potential well.

As discussed above, Entergy Operations controls all surface rights in the exclusion area [for both GGNS Unit 1, and the proposed exclusion area for a new facility on the ESP Site]. *Entergy Operations has and will continue to have complete control of ingress to or egress from the area. Attempted ingress for the purpose of exercising mineral rights could be prohibited at least until such time as questions regarding the rights of the various parties could be determined.*

As a practical matter, the owner or a lessee (or a potential lessee) of mineral interests would in all likelihood attempt to obtain a written consent and damage waiver from the surface owners of the property before commencing seismic investigations of the GGNS plant site. In addition, the mineral rights holder would also likely attempt to negotiate a well site agreement with the surface owners prior to seeking a permit from the State Oil and Gas Board to drill on the property. Both of these measures would be reasonable and prudent, and would be especially so in the case where the property includes a nuclear power generating station. These factors give SERI, as the owner, an additional, practical measure of control over the exclusion area [for both GGNS Unit 1, and the proposed exclusion area for a new facility on the ESP Site].

Because the outstanding mineral interests are not reasonably likely to mature into activities unrelated to operation of the existing GGNS Unit 1 facility or a new nuclear plant or plants on the site which could affect safe operation, potential health and safety factors are obviated and therefore, the outstanding mineral interests are a de minimis exception to total control of the exclusion areas.

2.1.2.4 Easements

SERI and SMEPA own all the surface rights at GGNS except the plant switchyard, which is owned by Entergy Mississippi, Inc. A number of easements over the GGNS property are in effect.

With respect to easements within the [GGNS Unit 1] *exclusion area, there is one public road which traverses the southern corner of the exclusion area in which Claiborne County maintains an easement or road right of way. In addition, Entergy Mississippi, Inc. has two rights of way or easements for transmission line purposes on the GGNS plant site property which are 200 feet in width.* Neither of these transmission line easements is located within the proposed exclusion area for a new facility. *Furthermore, SMEPA has a general easement within the exclusion area which was obtained from SERI at the time SMEPA obtained an ownership interest in the power block area. SMEPA's easement rights for purposes of exercising its ownership rights in connection with GGNS* [Unit 1] *apply to all property located within the* [Unit 1] *exclusion area owned by SERI in which SMEPA did not acquire a 10 percent undivided ownership interest. SERI and SMEPA also have an easement in and over the switchyard area. There are no rights of way or easements within the exclusion area* [for both GGNS Unit 1, and the proposed exclusion area for a new facility on the ESP Site] *other than those described above.*

[GGNS Unit 1] *Exclusion area control by Entergy Operations is not affected by these easements since (1) SERI and SMEPA are and will continue to be licensees, and (2) the switchyard agreement allows SERI to control future activities in the switchyard area and on the Entergy Mississippi, Inc. transmission easement within the exclusion area (SERI has transferred this right to Entergy Operations), and (3) arrangements have been made for control of traffic on the county road as described in the GGNS* [Unit 1] *Emergency Plan.* Similar arrangements for traffic control through the exclusion area would be made for a new facility, unless it becomes necessary to relocate the road, in which case this becomes a non-issue.

2.1.2.5 Control of Activities Unrelated to Plant Operation

Any permitted activities taking place within a new facility's exclusion area and unrelated to the new facility operation would be restricted while the facility is in operation.

2.1.2.6 Arrangements for Traffic Control

The proposed exclusion area for a new facility is not traversed by a railway or waterway and, therefore, no arrangements would be required for these; however, the exclusion area is traversed by a county road. Agreements would be put in place such that local law enforcement authorities would block the road when notified that such a need exists, or the road relocated out of the exclusion area if required, as discussed below.

2.1.2.7 Abandonment or Relocation of Roads

At the time of construction of the GGNS Unit 1 plant, the decision was made to not relocate the portion of Bald Hill Road which traverses the southern part of the exclusion area. That portion of Bald Hill Road within the proposed exclusion area for a new facility is also located within a potential construction usage area, as shown in Figure 2.1-2. Therefore, it may become necessary for construction of the new facility, to relocate a portion of the road.

2.1.3 Population Distribution[2]

The population data presented in this section were primarily based on the 2000 U.S. Census (Reference 1). The LandView 5[3], software was used to develop demographic data presented in this section of the report. The census data was augmented by information from other agencies and public organizations from the states of Mississippi and Louisiana (References 13 and14)[4]. The area, encompassed by a 50-mile radius from the center of the proposed power block location for a new facility on the site, includes all or a portion of the following 25 counties and parishes in Mississippi and Louisiana:

Mississippi Counties		Louisiana Parishes	
Adams	Lincoln	Caldwell	Madison
Amite	Madison	Catahoula	Richland
Claiborne	Rankin	Concordia	Tensas
Copiah	Sharkey	East Carroll	West Carroll
Franklin	Simpson	Franklin	
Hinds	Warren		
Issaquena	Wilkinson		
Jefferson	Yazoo		

[2] Sources for population data and projections, as well as information on seasonal variations (transient) population in the area around the GGNS, are identified and referenced in this section, as appropriate. The population data and general descriptions of human activity and seasonal variations are provided to comply with Regulatory Guide 1.70 (Section 2.1.3). In general, the GGNS UFSAR was the basis for the information included in this section. This information was updated with data obtained by research, as cited, conducted primarily in 2002. Except for population projections, which provide insight into future population growth, information provided in this section is a description of the current population based on research in 2002.

[3] **LandView®** reflects the collaborative efforts of the U.S. Environmental Protection Agency (EPA), the U.S. Census Bureau, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS) to provide the public readily accessible published federal spatial and demographic data. It is composed of two software programs: the LandView® database manager and the MARPLOT® map viewer. These two programs work in tandem to create a simple computer mapping system that displays individual map layers and the demographic and spatial information associated with them.

[4] This augmented information includes descriptions and data (current for 2002 to the degree practical) for facilities, schools, parks, recreational areas, etc. Population projections are provided in this section by distance and sector. However, no attempt is made to estimate projections for transient populations, school populations, specific community populations, etc. These would be assumed to grow at the same rates consistent with their associated segment's projections.

2.1.3.1 Population within 10 miles

Figure 2.1-3 shows a map of the area within 10 miles of the site. On this map, concentric circles have been drawn, with the site at the center point, at distances of 1, 2, 3, 4, 5, and 10 miles. The circles are then divided into 22.5-degree segments with each segment centered on one of the 16 cardinal compass points (e.g., north, north-northeast). Within each area thus formed by the concentric circles and radial lines, the projected resident population for 2002, 2030 (the projected first year of facility operation) and each decade for five decades through the year 2070 have been estimated and are given in Table 2.1-1. The population data for the area within ten miles of the site was based on census block points from the LandView 5 software program provided by the U.S. Census Bureau.

The projected populations for each segment are based on averages of the population projections obtained from the Louisiana State University Parish population projections and the Mississippi Center of Policy Research and Planning projections for the Louisiana parishes and Mississippi counties, respectively (References 13, 14)[5].

There are no residents within the exclusion area boundary as defined for a new facility (see Section 2.1.2).

2.1.3.2 Population Between 10 and 50 miles

Figure 2.1-4 shows a map of the area within 10 to 50 miles of the site. On this map, concentric circles have been drawn, with the center of the proposed power block location on the site at the center point, at distances of 10, 20, 30, 40 and 50 miles. The circles are then divided into 22.5-degree segments with each segment centered on one of the 16 cardinal compass points (e.g., north, north-northeast). The projected resident population for 2002, and each decade for five decades from the projected first year of plant operation, 2030, through the year 2070 for each area formed by the concentric circles and radial lines is given in Table 2.1-2. The basis of estimating the 2002 and the projected population distributions are the same as those described in Section 2.1.3.1.

2.1.3.3 Transient Population

Transient population, particularly within the low-population zone of the Grand Gulf site, shows both seasonal variations (due to the Grand Gulf Military Park, Warner-Tully YMCA Camp, Lake Claiborne, hunting camps, and fishing) and daily workday variations (due to employment, schools, and other sources of an occasional nature). Descriptions of the seasonal and daily variations in population in the area surrounding the Grand Gulf site are presented below.

The Grand Gulf Military Park is located approximately 1-1/2 miles north of the site and is contiguous to the site property. The park is open daily from 8:00 a.m. to 5:00 p.m. and had over

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[5] Both Mississippi and Louisiana based the population projections on the same methodology, i.e., the Cohort-Component Method. The Louisiana projection also used the Shift-Share method of allocating growth among parishes. The Cohort-Component Method carries each sex/race group in the target population (either state or county/parish) individually forward in time, by five-year intervals and for five-year age categories. This method is widely used for long-range population projections, including the population projection of the United States for the years 1999 – 2100. (For additional detail on this example, see Reference 17).

88,000 visitors who used the facilities and grounds in 2001. There were approximately 31,000 visitors to the park who paid for camping and tours in 2001. School groups, Boy Scouts, YMCA groups and others use Grand Gulf Military Park for field trips and nature studies. Most people visit the park on Sundays, with Saturday second in attendance. The park is most heavily populated during the months of June and July. (Reference 2)

The Warner-Tully YMCA Camp (Mississippi) consists of 108 acres of land located approximately 3-1/2 miles northeast of the site. Approximately 800 campers use the Warner-Tully camp facilities each year. The YMCA camp is open from late May to the end of August. (Reference 3)

Lake Claiborne (Mississippi) is a private development of residential and recreational facilities. It is located approximately 3-1/2 miles east of the site. Lake Claiborne, Inc. has a total of about 450 members; there are 51 families in full-time residence at the development. A maximum of 200 people use these facilities on a summer weekend (References 4 and 19).

Lake Bruin State Park consists of 53 acres located on the shore of Lake Bruin, Louisiana, approximately 9.5 miles southwest of the site. From July 2001 to June 2002, the park had approximately 36,000 visitors. (Reference 6)

There are approximately 150 hunting camps within Claiborne County. These camps are primarily used for deer hunting and other types of hunting, as well as sport fishing. The camps are too numerous to get an accurate number of hunters using the camps. Each camp, depending on the size of the camp, could have up to 20-30 hunters on a weekend day during hunting season. (References 5 and 15)

There are several hunting clubs located across the Mississippi River from the GGNS in Tensas Parish, Louisiana. Approximately 400 hunters are members of these clubs, primarily deer and duck hunters (Reference 17)

Mississippi's deer season traditionally opens early in October for archery and late November for guns. The season continues through early January. The greatest numbers of hunters are present on the first day of gun season, which is early November. Approximately 500-600 hunters are customarily in attendance at the camps for the first day of the first gun season. After the opening weekend, approximately 70% of the hunting population utilize the camps in the area until the end of the season in early January. (Reference 5)

Sport fishing in the area occurs in the months of April through September with Saturday the busiest day of the week. As many as 200-250 fishermen may be within the vicinity on weekends during the months noted above. The number of fishermen may drop to less than 150 during the week and depending on the weather conditions. (Reference 5)

The Kansas City Southern freight train passes north to northeast within 28 miles of the site twice daily. The train runs from Vicksburg to Meridian, MS, and then returns to Vicksburg. The train carries a crew of five. (Reference 7)

The Delta Queen Steamboat Company operates three paddle wheel tour boats on the Mississippi River, the Delta Queen, the Mississippi Queen and the American Queen. The Delta Queen is scheduled to pass the GGNS site a minimum of five times during the 2003 season. She has a full complement of 174 passengers and 75 crew. The Mississippi Queen is scheduled to pass the GGNS site a minimum of 8 times during the 2003 season with a full complement of 416 passengers and 156 crew. The American Queen is scheduled to pass the GGNS site a minimum of 13 times during 2003 with a full complement of 436 passengers and 161 crew. (Reference 8)

There is one primary forest product company, Anderson-Tully, that owns and leases land within the study area. Anderson-Tully has 12 people on logging crews that work in the vicinity. Anderson-Tully is located in Vicksburg, Mississippi. (Reference 9)

There is limited commercial fishing within the study area. Most of this occurs on the Mississippi River, the Big Black River and the Bayou Pierre River, with catfish being the most abundant catch. There are approximately 12 commercial fishermen who fish within the area. (Reference 5)

The GGNS Unit 1 facility has approximately 750 people who work at the plant site. Plant staffing is round the clock, with approximate numbers of personnel on site as indicated below for the normal day crews and night crews (Reference 18).

GGNS Approximate Staffing Levels

	Normal Week Day	Normal Weekend Day	Outage Week Day	Outage Weekend Day
Day	660	70	800*	210
Night	90	60	170*	140

* Outage week day estimated based on difference between outage weekend day and normal weekend plus normal week day staff.

2.1.3.4 Low Population Zone

The definition of a low population zone (LPZ) as stated in 10 CFR 100 is: "the area immediately surrounding the exclusion area which contains residents, the total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident." The LPZ radius is 2.0 miles centered on the reactor for the existing GGNS Unit 1 plant (Reference GGNS UFSAR Section 2.1.3.4). The LPZ for a new facility, a 2 mile radial distance measured from the circumference of a 630 ft. circle encompassing the proposed power block location for a new facility will be essentially the same as for GGNS Unit 1. The center of the 630 ft. circle is approximately 1200 ft. west and 1000 ft. north of the GGNS Unit 1 reactor containment center. Figure 2.1-5 illustrates the approximate LPZ and indicates transportation routes within a 10-mile radius of the site. The number and density of residents in the area immediately surrounding the GGNS site (in both Mississippi and Louisiana) are low, enabling simple and effective evacuation procedures to be followed in the event of a serious accident. The resident population within the LPZ is 51 people (LandView 5). The GGNS Unit 1 daily population of employees is about 750, with the approximate distribution between day and night as indicated above in Section 2.1.3.3. The resident population density within the LPZ radius is about 4.1 persons per sq. mile. The roads within the area will be the primary transportation routes for evacuation. Table 2.1-3 lists facilities and institutions within 5 miles of the site.

Seasonal and peak daily transient population within the low population zone is mainly due to recreational use of the Grand Gulf Military Park, hunting and sport fishing and the work force at the GGNS site. Each of these contributors to the transient population in the LPZ are described in Section 2.1.3.3 above.

2.1.3.5 Population Center

A population center is defined in 10 CFR 100 as a densely populated area where there are about 25,000 inhabitants or more. The closest population center is Vicksburg, Mississippi, located approximately 25 miles north-northeast of the site, with a 2000 population of 26,407. This is the only population center within 50 miles of the site. The nearest major city is Jackson, Mississippi, which lies 55 miles to the northeast of the site, and has a population of 184,256 according to the 2000 census. The southwest portion of Jackson is located within the 50-mile radius. Figure 2.1-6 shows those communities in the area whose populations are over 1,000. Table 2.1-4 displays populations and distances of all communities in the 50-mile radius area with a population of over 1,000. (Reference 1)

2.1.3.6 Population Density

The cumulative resident population for 2000 was calculated using the data from LandView 5 software provided by the U.S. Census Bureau. The population density for Claiborne County, in which the site is located, is 24.3 persons per sq. mile; for the state of Mississippi, it is 60.6 persons per sq. mile. The projected population within a 30-mile radius for the year 2030, the projected initial year of plant operation, would be 108,628 people and the projected population density, average of all segments in the 30-mile radius, would be 38.2 persons per sq. mile. The projected population within the 30-mile radius for the year 2070 (i.e., the projected end of the initial 40 year plant licensed operating period) would be 119,289 people, and the projected population density, average of all segments in the 30-mile radius, would be 42.2 persons per sq. mile. Table 2.1-5 displays the projected populations within the divided segments. Table 2.1-6 displays the comparison of cumulative population for the initial year of plant operation, 2030, assuming 500 persons/sq. mile, and the year 2070, the projected end of the initial 40 year plant licensed operating period, assuming 1,000 persons/sq. mile. (Reference 1) As shown in Table 2.1-6, the site's projected population density is well below the value specified in Regulatory Guide 4.7, Position C.4 (i.e., 500 persons/sq. mi.).

2.1.3.7 Public Facilities and Institutions

A summary of the schools, hospitals and public parks in the area within about 10 miles from the site is given in Table 2.1-7.

During the 2000-2001 school year, the enrollment population for schools within the vicinity of the site can be found below. (Reference 10)

	Institution Population	
School Name	Students	Faculty
Port Gibson High School	565	33
Port Gibson Middle School	453	31
Arthur W. Watson Elementary	993	52
Chamberlain-Hunt Academy	111	16
Claiborne Educational Foundation	77	7
Alcorn State University	3,100	~194 (Reference 16)

Claiborne County Hospital has 32 beds. The staff consists of five doctors, ten registered nurses, six nurses' aides, and three X-ray technicians. (Reference 11)

The Claiborne County Courthouse houses the offices of the Circuit Clerk, Chancery Clerk, County Tax Assessor, County Superintendent of Education, and a courtroom. The county jail, located behind the courtroom, has one prison cell and can accommodate 25 inmates; yet, it generally has less than five inmates. (Reference 12)

Grand Gulf Military Park occupies about 150 acres, is located approximately 1-1/2 miles north of the site, and is contiguous to the site property. Lake Bruin State Park consists of 53 acres located on the shore of Lake Bruin. See Section 2.1.3.3 for additional discussion.

2.1.4 References

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2.2 Nearby Industrial, Military and Transportation Facilities and Routes

The Grand Gulf Nuclear Station site is located in Claiborne County, Mississippi. Figure 2.2-1 shows the county is bordered on the west by the Mississippi River (and Louisiana Parishes of Tensas and Madison), on the north by Warren County, on the east by Hinds and Copiah Counties, and on the south by Jefferson County.

The GGNS site area is accessible by both river and road. U. S. Highway 61 and State Highway 18 connect Port Gibson (5 miles southeast of the site) with Natchez, Jackson, and Vicksburg. There are no ferry boat services within a 50-mile radius of the GGNS site.

The economy of the area is agricultural, with the largest acreage in timber. The greatest part of the manufacturing in the area is based on lumber products.

This section of the report provides information regarding the potential effects on the safe operation of a new nuclear facility from industrial, transportation, mining, and military installations in the GGNS site area.

2.2.1 Locations and Routes

There are no military installations located near the GGNS site area, and no missile sites in either Mississippi or Louisiana. The nearest military facility was England Air Force Base in Alexandria, Louisiana, approximately 100 miles to the southwest; however; it was officially closed in 1993. (Reference 3)

Figure 2.2-2 shows the location of oil and gas pipelines within vicinity of the site. The nearest pipeline carries natural gas and is 4.75 miles east of the site. There are no mining operations within the vicinity of the GGNS site.

Figures 2.2-3 and 2.2-6 show the locations of all airports, federal highways, and railroads in the area. The Mississippi River, which passes 1.1 miles west of the location of the proposed site (river mile 406) for a new facility, provides an important means of transportation for industry. The nearest river port facility, Port Claiborne, is located at river mile 404.8, as shown in Figure 2.2-4. (References 1, 2, and 5) A larger river port facility is located at river mile 437, north of the site in Vicksburg, Mississippi. The Vicksburg port is a United States Customs port of entry. (Reference 5).

The nearest airport is Tensas Parish airport located in St. Joseph, Louisiana, approximately 11 miles southwest of the GGNS site across the Mississippi River (Figure 2.2-3). It is a small public airstrip, which serves the town of St. Joseph and Tensas Parish. The paved runway extends for 3,500 feet. The Newellton airport, serving the town of Newellton and Tensas Parish, is approximately 12 miles west of the site. The paved runway extends for 2,750 feet. (Reference 17)

The nearest commercial airport is Jackson International, located in Jackson, Mississippi, approximately 65 miles northeast of the site. Jackson International airport has two 8,500 ft. runways with 45 daily direct outgoing flights and 104 other connecting flights from this airport. Major airlines serving the airport are Delta Airlines, American Eagle, Southwest, Northwest, Continental Express, ASA, U.S. Airways Express, ComAir and four cargo carriers. (Reference 13)

The nearest general aviation airport is Vicksburg Municipal Airport, located south of Vicksburg, Mississippi, and which lies 18 miles north-northeast of the site (Figure 2.2-3). The length of the hard surface runway is 5,000 feet. There are two other general aviation airports serving the

Vicksburg area. Vicksburg/Tallulah Regional Airport lies 8 miles west of Vicksburg and 22 miles north of the site. This airport has one hard surface runway that extends to 5,002 feet. Lying 8 miles north-northwest from the Vicksburg/Tallulah airport, is Scott Airport. Scott Airport maintains two runways; one is turf, with a length of 2,400 feet and the other is a hard surface runway extending to 3,014 feet. Scott Airport lies 28 miles north-northwest of the site. Another general aviation airport is the Natchez-Adams County airport, located 30 miles south-southwest of the site. It has two runways, one that extends to 6,500 feet and one to 5,000 feet. (References 5, 6, and 17)

The GGNS site is located between two major air routes used mainly by commercial aircraft. One air route (V245), approximately 10 miles southeast of the GGNS site, extends from Natchez to Jackson, Mississippi. The other air route (V417), about 30 miles north of the site, extends from Jackson, Mississippi to Monroe, Louisiana. Commercial aircraft flying by instrument flight rules, as well as smaller private aircraft flying by visual flight rules, use these routes. There is some private air traffic between Vicksburg and Natchez, Mississippi, the majority using U. S. Highway 61 or the Mississippi River for flight reference. An air route map for the vicinity is provided in Figure 2.2-5. (References 5, 6, and 7)

U. S. Highway 61 parallels the Mississippi River from New Orleans, Louisiana to St. Louis, Missouri, and passes approximately 4.5 miles east-southeast of the GGNS site at its closest point. Mississippi Route 18 connects Port Gibson to Jackson. A section of the Natchez Trace Parkway passes approximately 6 miles southeast of the GGNS site running southwest towards Natchez, Mississippi, and to the northeast to Jackson, Mississippi (Figure 2.2-6).

Several motor truck lines such as Delta Freight, Saia Motor Freight, Roadway Express and Consolidated Freightways provide freight delivery service to the Port Gibson area. There is no railroad freight service within the vicinity. The nearest railroad is the Kansas City Southern freight train which passes approximately 28 miles north-northeast of the GGNS site in Vicksburg, Mississippi. (Reference 8).

2.2.2 Descriptions

2.2.2.1 Descriptions of Facilities

The industries within the immediate GGNS site area are located in Port Gibson (Figure 2.2-7). Information about these industries with the number of employees and the products stored or manufactured is summarized in Table 2.2-1. These industries lie approximately 6 miles southeast of the site and are considered to have the largest employment within the immediate area of the site. Information about the larger manufacturers in the counties surrounding the GGNS site can be found in Table 2.2-2. (Reference 9)

2.2.2.2 Description of Products and Materials

A section of U. S. Highway 61 passes within 5 miles east-southeast of the GGNS site, and is 4.5 miles to the east-southeast at its closest point. Table 2.2-3 lists the hazardous chemicals transported in Claiborne County from October 2001 to October 2002. There are other hazardous materials such as gasoline and diesel fuel that are delivered throughout the county to service stations within Claiborne County, as well as to the GGNS site.

GGNS Unit 1 also receives shipments of up to 17, 000 gallons of liquefied hydrogen every two to four weeks, and up to 9,000 gallons of liquid oxygen once per month. The hydrogen and oxygen are stored on site in 20,000 and 9,000 gallon cryogenic bulk liquid tanks, respectively.

The hydrogen and oxygen are delivered by truck. Once on the GGNS property the trucks travel a specific route to the storage tanks. (Reference 15)

The Mississippi River flows within 1.1 miles of the site at its closest point. Table 2.2-4 lists the types and amounts of hazardous cargo shipped by barge on the Mississippi River between the mouth of the Ohio River, river mile 954 to Baton Rouge, Louisiana, river mile 236 for the year 2000. (Reference 11).

Regarding the river transportation of chlorine, the Chlorine Institute estimated that, on average, chlorine shipments were made four times a year on the Mississippi River. The amount and frequency of shipments has decreased since 1982. The typical quantity of chlorine shipped by barge was 600-1200 tons per barge. (Reference 12)

The Claiborne County Port Commission built a small port on the Mississippi River at river mile 404.8 in Claiborne County (Figure 2.2-4). The mean depth of channel and berth is 14 ft. Services provided at this port are mooring assistance, stevedore, dryage and deepwater berths. Port cargo includes forest products, pulpwood, feed grains, and agricultural products. (References 1, and 5)

In the past the Port Gibson Oil Works operated in Claiborne County. This company maintained two 12,000 gallon underground storage tanks of N-hexane. The company has ceased operations and according to the Port Gibson Chamber of Commerce the property lies vacant. (Reference 14)

Various potentially hazardous chemicals are stored and used at Unit One at GGNS. Table 2.2-5 lists the type and estimated quantity of these chemicals. Figure 2.2-8 shows the storage location on GGNS. (References 20, and 26)

2.2.2.3 Pipelines

The nearest gas-transmission pipeline is 4.75 miles east of the site. Operating pressure of the 4-inch-diameter pipe is 225 psi. The pipeline was installed in 1955, buried at a minimum of 3 feet beneath the ground. The isolation valves are Rockwell type. The two closest isolation valves are located at 5.5 miles east and 7.5 miles east-northeast of the site. The pipeline is presently carrying natural gas, and there is no future plan to carry a different product. This line runs parallel with U.S. Hwy 61 in a north-south direction. (References 18, 22, 27, and 28)

2.2.2.4 Waterways

Figure 2.2-4 shows the proposed location of the intake structure in the Mississippi River for a new facility on the GGNS site. This intake structure will be located near river mile marker 406 where the existing GGNS Unit 1 barge slip is located. Water from the Mississippi River would be withdrawn at this location for use as cooling tower makeup, service water cooling system makeup and other miscellaneous water uses, for a new facility at the GGNS site.

2.2.2.5 Airports

No commercial airport facilities are located within 10 miles of the GGNS site. The nearest commercial airport is located in Jackson, MS, approximately 65 miles northeast of the site. There are 5 general/public aviation airports located within the vicinity of the site. These general/public aviation airports are used only for small planes. See Section 2.2.1 for additional information. There are no airports within the vicinity that have plans of extending their runways. A list of airports showing the number of aircraft based at each, and the average number of flights for that airport can be found in Table 2.2-6. (References 16 and 17)

2.2.2.6 Projections of Industrial Growth

There are no plans for expansion of existing facilities or new industrial development in the vicinity of the GGNS site. There are no definite projections for major expansions of industries manufacturing or handling large quantities of hazardous materials within 50 miles of the site. (References 1 and 19)

2.2.3 Evaluation of Potential Accidents

The design of a new facility to be constructed at the ESP Site is not available at this time. Therefore, this evaluation is based on the analyses of potential accidents which were completed for the GGNS Unit 1 plant. The results of these Unit 1 evaluations were reviewed taking into account the proposed location of a new facility. The results of this approach demonstrate that the conclusions drawn from the analyses for GGNS Unit 1 are appropriate for a new facility located as proposed at the GGNS ESP site. Additional supporting qualitative analysis is provided where necessary, to demonstrate site acceptability where conditions or inputs might have changed from GGNS Unit 1 licensing to the time of this report.

On the basis of the information provided in Subsections 2.2.1 and 2.2.2 [of Reference 26]*, the potential accidents considered as design basis events were determined to be of very low probability. The potential effects of these accidents on the plant were considered, however, in terms of design parameters (e.g., overpressure, missile energies, etc.) or physical phenomena (e.g., concentration of flammable or toxic cloud outside building structures, etc.).*

2.2.3.1 Determination of Design Basis Events

2.2.3.1.1 Explosions and Flammable Vapor Clouds (Delayed Detonation)

Flammable gases in liquid or gaseous state can form a vapor cloud which could drift toward the plant. The drifting cloud's capability of exploding is based on its concentration being above the lower flammable limit concentration for the material being released. The unrestricted vapor cloud is assumed to move downwind toward the plant from the release point originating at U. S. Highway 61 under stable atmospheric conditions and low wind speeds. The effect of overpressure on plant structures caused by delayed detonation of the hazardous material was evaluated to be much less than 1 psi peak reflected pressure due to the distance between the possible detonation points and the plant.

The nearest transportation route to the power plant site is the Mississippi River. Its nearest bank is located 1.34 miles from the site facilities. This distance will preclude any damage to plant facilities resulting from potential accidents involving explosion or fires originating from a ship or barge in the river. The largest probable quantity of explosive material transported by ship is approximately 5,000 tons (equivalent TNT) as listed in Regulatory Guide 1.91. Furthermore, most of the plant structures and all of the safety-related structures are located on top of a bluff approximately 65 feet above the normal river level. The bluff provides an earthen shield against explosions of potential river-traffic cargo. Also, any flammable vapor clouds released by a traffic accident in the river would be partially shielded by the high elevated river bank. Therefore no explosive hazard to the plant located 1.34 miles inland is anticipated due to an ignition of the vapor cloud.

The nearest bank of the river is approximately 1.1 miles from the proposed location for a new facility on the GGNS ESP Site. In addition, a new facility would be located on the bluffs to the east of the river, which are approximately 65 feet above the normal river level. As noted above for the GGNS Unit 1 plant, this bluff would provide an earthen shield against possible explosions originating from river barge traffic. Based on the combination of distance from the river bank and the intervening bluff, this would preclude any damage to the structures of a new facility at the proposed location, resulting from an explosion originating from a ship or barge on the river.

No military installations, chemical or munition plants, stone quarries, or major gasoline-storage areas are located within 5 miles of the plant site. The chemical storage facilities at Port Gibson, described in subsection 2.2.2, store relatively small amounts of chemicals, and the probability of exploding the two 12,000-gallon underground N-hexane tanks is very small. In the last 25 years, no accidents have been reported. Assuming that an accident does take place, the peak reflected pressure on the plant structures which are about 4.5 miles away from detonation of the 34.5 tons equivalent TNT yield, is negligible (e.g., much less than 1.0 psi).

A 4-inch-diameter, 225-psi, gas-transmission pipeline passes 4.75 miles east of the site. Potential explosions, either by immediate or delayed ignition of an unconfirmed natural gas-air mixture, will not endanger the safety of the nuclear station due to the separation distance between the possible detonation points and the plant.

As indicated above for GGNS Unit 1, no military installations, chemical or munitions plants, stone quarries, or major gasoline-storage areas are located within 5 miles of the GGNS site. In Section 2.2.2 above it was noted that the two 12,000-gallon underground N-hexane tanks are no longer in use; therefore, they do not need to be considered as a hazard for a new facility on the GGNS ESP Site.

The 4-inch-diameter, 225-psi, gas-transmission pipeline that passes 4.75 miles east of the site is also a non-hazard for a new facility due to the physical separation distance between the pipeline and the facility location.

Table 2.2-3 lists the hazardous chemicals that were transported on roads within Claiborne County from October 2001 to October 2002. To support analysis of a highway transported explosive, the maximum probable hazardous cargo for a single highway truck was assumed to be approximately 50,000 pounds (equivalent TNT) as presented in Regulatory Guide 1.91 (Reference 24). Per the Regulatory Guide, the distance beyond which an exploding truck will not have an adverse effect on plant operations or will not prevent a safe shutdown of the reactor is conservatively defined by the relationship:

$$R \geq kW^{1/3},$$

where R is the distance in feet from an exploding charge of W pounds of TNT.

When R is in feet and W in pounds, the constant k is equal to 45.

Thus, the safe distance is calculated to be 1,658 feet (0.31 miles). Since the closest point of U. S. Highway 61 to GGNS site is 4.5 miles, no hazard to the plant due to an explosion on Highway 61 would be expected.

Liquefied hydrogen is delivered to the GGNS site by United States Department of Transportation (USDOT) approved truck, with a maximum capacity of 17,000 gallons. Liquefied oxygen is also delivered to the site by USDOT approved trucks. There are no regulations specifying a minimum distance between a liquefied-hydrogen delivery truck and a safety-related structure. However, the intent conveyed by Regulatory Guide 1.91 (Reference 24) and the EPRI guidelines (Reference 30) concerning evaluation of explosions occurring on transportation routes near nuclear power plants is that considerable distance be provided, if possible, to mitigate damage that could occur from an explosion of a liquefied-hydrogen truck. The current truck route on the GGNS site results in about 400 ft. separation from the outer boundary of the proposed location for the power block of a new facility, which is less than the minimum separation distance of 1285 ft calculated per Regulatory Guide 1.91 in Reference 15. However, the probability of an accident resulting in a hydrogen explosion calculated (in Reference 15) per the Regulatory Guide 1.91 methodology is 4.1×10^{-7} per year. Therefore, according to the guidelines presented in Regulatory Guide 1.91 (criteria is less than 10^{-6} per year when conservative assumptions are used), the truck explosion event need not be considered a design basis accident for a new facility on the site. However, it is prudent to maintain maximum separation distance between safety-related structures and the truck route.

The presence of the 20,000 gallon liquid-hydrogen storage tank located in the north end of the abandoned Unit 2 cooling tower basin and the liquid-oxygen storage tank (Figure 2.2-4) present the potential hazard of an explosion or a gaseous cloud. The pressure effects resulting from an explosion of the hydrogen tank has the potential of damaging safety-related structures. In addition, a gaseous cloud has the potential of entering a safety-related structure through the air intake of the structure. Hydrogen is an explosion hazard. While an oxygen cloud will not explode, the potential threat from liquid oxygen is the contact of oxygen enriched air with combustible material and the ingestion of oxygen enriched air into safety related intakes. An analysis was performed to determine the safe separation distance between the liquid hydrogen and oxygen storage tanks and any safety-related structure. The following minimum separation distances were calculated. (Reference 15)

	Minimum Separation Distance (ft)	
Type of Hazard	Explosion	Gaseous Cloud
Liquid hydrogen storage tank	737	NA
Liquid hydrogen pipe break; pipe size or hole size of ½"; pipe not seismically supported	378	1340
Liquid Oxygen	NA	1060

These calculations are valid for new construction at the GGNS ESP Site, so long as the minimum separation distances stated in the report are maintained, or structures are appropriately designed for the expected blast pressure. The proposed area for construction of a new facility is beyond the minimum separation distance requirements given in the calculation for both blast considerations and gaseous cloud considerations.

2.2.3.1.2 Toxic Chemicals

Potential accidental release of toxic chemicals transported on U. S. Highway 61 will not endanger the safe operation of the station because of the distance by which they are separated, 4.5 miles. As indicated in Table 2.2-3, in 1974 [1979] *the majority of the hazardous materials transported near the site were fuel products moving on the Mississippi River. Fires originating from collision of water surface vehicles are possible. The 3 years onsite wind frequency distribution data (8/72 - 7/74, 1/76 12/76) reported in Section 2.3 shows that the strongest wind was less than 25 mph from sectors, WSW, W, WNW, and NW, which would carry the hot plume from the potential fire toward the plant. An area of spill of* 5.0×10^4 m^2 *was assumed. Due to the tremendous amount of plume rise resulting from the heat generated, a wind speed greater than*

70 mph would be required to bend the plume so its edge would touch the control room normal air intake at an elevation of 50 meters above the river and 1.34 miles inland. Therefore, no toxic hazard to control room personnel is expected.

As stated above, the closest point of U.S. Highway 61 to the GGNS site is 4.5 miles. Therefore, an accidental release of toxic chemicals transported on U. S. Highway 61 would not endanger the safe operation of a new facility at the proposed location on the GGNS ESP Site. As indicated in Table 2.2-4, in 2000 the majority of the hazardous materials transported near the GGNS site were fuel products moving on the Mississippi River as in 1979. The 6-year onsite wind frequency distribution data (1996-2001) reported in Section 2.3 shows that the winds that originated from compass sectors W-SW, W, W-NW and NW, that would carry the hot plume from a fire caused by explosion to the proposed location for the new facility, had speeds generally under 20 mph. The analyses presented in the GGNS UFSAR (Reference 26) above, assumed a spill area of 5.0×10^4 m^2 and concluded that a wind speed greater than 70 mph would be required to direct the plume toward the GGNS Unit 1 control room air intake. The proposed location for a new facility is also on the bluffs above the river, and is about 1.1 miles inland. Since the proposed location for a new facility is similar to that of GGNS Unit 1, no toxic hazard to the facility would be expected.

The type of chemicals listed in Table 2.2-3 were analyzed as to their effect on GGNS control room personnel in the event of a barge accident causing the release of toxic gas. The results of the analyses were provided in a letter to the NRC dated August 24, 1981 (AECM-81/0316) which indicated that the calculated toxic gas concentrations at the control room were below corresponding toxicity limits. (Note: chlorine was evaluated separately.) It was therefore concluded that toxic chemicals and gases transported on the Mississippi River posed no hazard to GGNS control room personnel. Upon subsequent review of the analyses, the NRC requested that a probabilistic analysis for bulk shipments of ammonia be performed to reassess its potential hazard. The results of this later analysis were submitted in a letter dated September 23, 1981 (AECM-81/0352) and the NRC agreed with the conclusion that based on the conservative assumptions used, the risk to control room personnel from a barge accident involving ammonia is acceptably low and falls within the guidelines established in the Standard Review Plan Section 2.2.3.

Table 2.2-4 contains a listing of hazardous materials transported on the Mississippi River and past the GGNS site in the year 2000. The list of materials in Table 2.2-4 is very similar to that in the GGNS UFSAR (Reference 26) Table 2.2-3. This would indicate that due to separation of the site from the river and current wind speeds comparable to that in the original analyses, the risk to control room personnel in a new facility at the proposed location, from a toxic chemical release on the river would be acceptably low.

Chlorine was also found to be transported on the lower Mississippi River (See [Reference 26] *Subsection 2.2.2.2). The most common amount of chlorine in a single shipment was 1100 tons and it was stored in four independent cylindrical tanks. A probabilistic evaluation has been performed. The results conservatively show the probability of a chlorine accident on the Mississippi River in the vicinity of the plant is approximately 1.8×10^{-4} per year. This probability is within NRC acceptance criteria which permit the elimination of the chlorine barge accident as a design basis event.*

Regarding the river transportation of chlorine, the Chlorine Institute estimated that, on average, chlorine shipments were made four times a year on the Mississippi River. The amount and frequency of shipments has decreased since 1982. The typical quantity of chlorine shipped by barge was 600-1200 tons per barge. (Reference 12) Therefore, the above conclusion regarding hazards from chlorine shipments would also be true for a new facility in the proposed location on the GGNS ESP Site.

Toxic gas analyses are performed on potentially hazardous chemicals stored on the plant site, in accordance with the guidelines of Regulatory Guides 1.78 and 1.95, NUREG-0570 and NUREG/CR-1741. Table 2.2-5 *lists refrigerants, Freon, Halon and No. 2 fuel oil stored in the plant and various materials stored in the yard.* Figure 2.2-8 *shows their location. The results of the analyses of these chemicals and the assumptions used in the analyses are listed in Table 2.2-7. Other chemicals stored throughout the plant site that have been determined potentially hazardous are analyzed or administratively controlled.*

The results of the hazards analyses, when compared to the toxicity limits given in Regulatory Guide 1.78, National Air Quality Standards, OSHA standards or other reliable sources show that there is no danger of reaching hazardous concentrations of toxic gases in the control room.

Potentially hazardous chemicals stored on the GGNS site are under administrative controls, including quantities and locations, and are evaluated as necessary to ensure no adverse affect on the safe operation of Unit 1.

As listed in Table 2.2-5*, three chillers of refrigerant R-134a are installed in the auxiliary building at the floor of El. 139'. In case of accidental release of one chiller, there is no direct pathway for the release of gas to diffuse to the control room air intake located in the control building roof El. 206'. Therefore, the gas concentration at the air intake will be minimal. For fire protection in the computer room, there are 12 portable bottles, 174 pounds each, of Halon 1301 installed in the control building, El. 133-0. Since the control room is equipped with breathing apparatus and the personnel are trained in the use of the apparatus, no hazard to the personnel is expected in case of fire or accidental release of the gas.*

Table 2.2-5 (GGNS UFSAR Table 2.2-6) is a listing of the potentially hazardous chemicals stored at the GGNS Unit 1 facility, and Figure 2.2-8 (GGNS UFSAR Figure 2.2-5) shows the storage locations. It would be expected that, in similar fashion to current GGNS Unit 1 practices, hazardous materials stored on the ESP Site at a new facility would be effectively managed by administrative controls, and that the administrative controls in place for the GGNS Unit 1 hazardous materials storage and handling, would preclude adverse impacts to the operation of a new facility on the site.

*In the event of an explosion at the location of the underground fuel oil tank, an open pool fire is assumed with dimensions of 15 by 60 feet and a burning rate of 8 in./hr. (*Reference 31*). Due to the tremendous amount of plume rise resulting from the oil fire, the estimated wind speed required to bend the hot plume to touch the control room air intake 200 feet away is 29 mph. The highest westerly wind recorded onsite for a period of 3 years is less than 25 mph. The estimated concentrations of the products of combustion at the control room air intake are insignificant with the highest recorded wind. Also, the probability of exploding of an underground fuel oil tank is very small, because the vapor mixture inside the tank is too rich to burn while the tank is in use. There is no record of any active underground fuel oil storage tank exploding in the area.*

The above evaluation addresses the possible explosion of the existing GGNS Unit 1 underground diesel fuel oil storage tank located inside the Unit 1 plant protected area as noted. The proposed location for a new facility is approximately 1000 ft. from the location of the diesel fuel tank at Unit 1; therefore, the potential impacts to a new facility in the proposed location on the GGNS ESP Site from a tank explosion and fire are minimal.

In 1997, calculations were performed to evaluate the habitability of the control room for accidental releases of hydrogen or oxygen from the hydrogen water chemistry system (Reference 15). These calculations indicated that control room personnel are not subject to the hazard of breathing air with insufficient oxygen inside the control room due to a release of hydrogen. A new facility would be located farther away from the hydrogen storage tank; thus, these conclusions are also valid for a new facility at the proposed location on the GGNS ESP Site.

2.2.3.1.3 Fires

Fires originating from accidents at any of the facilities or transportation routes discussed previously will not endanger the safe operation of the station because of the distances between potential accident locations and the proposed location of the new facility.

*To predict the consequences of a fire, a line-source model (*Reference 32*) provides a reasonable estimate of ground level pollutant concentration downwind of the fire line. The normal flame temperature for brush fire is 2,000 to 2,500 F. Plume temperature drops to 25 F above ambient air temperature about 250 feet above the fire. The horizontal indraft usually returns temperature to ambient within approximately 500 feet from the fire. Assuming the fire consumes 10 tons of fuel/acre with pollutant emission rates of 150 lb CO/ton, 20 lb HC/ton and 45 lb of particulates/ton, the maximum concentrations resulting from these conditions were found to be well below acceptable toxicity limits at the control room normal air intake. Therefore, fires are not considered to present a credible hazard to the plant.*

Chief James Grey of the Claiborne County Fire Department stated that as of December (2002) the department has had approximately 90 calls in 2002, most of which were car and dumpster fires. These fires were located in the Port Gibson area. No fires have been reported near the vicinity of the plant site (Reference 25). The marsh type character of the forests limits fires in this region. Fires rarely grow out of control in this type of region. The new construction areas would be cleared of trees, further minimizing the potential for forest fires near the new facility. Thus, the above analysis performed for GGNS Unit 1 is applicable for a new facility with regards to potential hazards from fire.

2.2.3.1.4 Collisions with Intake Structure

The proposed intake structure is located east of the river bank, and its embayment would be positioned out of the shipping channel of the river, minimizing the probability of a ship or barge colliding with the structure. Therefore, the collision of a ship or barge in the river with the proposed intake structure is not considered a design basis event.

2.2.3.1.5 Liquid Spills

As illustrated in Table 2.2-4, petroleum products are the predominant chemical transported on the Mississippi River. A majority of these chemicals have a density less than one, which means the chemicals will float on the surface of the river. While it is possible for spilled chemicals to be drawn into the proposed river intake, the severity is minimized since the chemicals tend to float on the surface of the water and the proposed intake screens would be located beneath the surface of the water. In the event of a spill in the vicinity of the intake structure, the river intake system could be shut down to minimize hazards to plant equipment and personnel. Appropriate independent safety-related systems would be in place to assure the safe shutdown of a new facility, in the event of a possible unavailability of raw water makeup from the river.

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2.3 Meteorology

2.3.1 Regional Climatology

The description of the general climate of the region at the time of licensing of Grand Gulf Nuclear Station Unit 1 was based primarily on climatological records for Vicksburg and Jackson, Mississippi. This description utilizes that data as appropriate and is augmented by more recent data from the Vicksburg station and the GGNS site meteorological tower.

Topographical considerations and examination of the records indicate that meteorological conditions at Vicksburg and Jackson are representative of the general climate of the region encompassing the site. Since Vicksburg is the closer of the two stations and borders the Mississippi River, the tables and figures included are based primarily on Vicksburg data when the period of record and observational procedures are considered adequate. Otherwise, Jackson data are presented.

Recent improvements in the National Oceanographic and Atmosphere Administration (NOAA) National Climatic Data Center (NCDC) data systems provide easy access to local meteorological data records since the middle of 1996. GGNS site data is also available for this period. Most of the tabular data in this section are from these recent data sources, but there was also an extensive amount of meteorological data gathered and evaluation that was performed for the licensing of Grand Gulf Unit 1 in the 1970s. In several cases, such as the reoccurrence rate of rare events based on many decades of observation, the original data is preferable. For example, the last few years have been unusually dry in the region, so it would be more accurate and more conservative, in terms of maximizing rainfall predictions, to use the Unit 1 licensing data rather than to draw long term rainfall conclusions on data from the last five years. General discussions of the regional climate dating from the Unit 1 licensing period are also still valid so the existing Unit 1 meteorological discussion and references in the GGNS Unit 1 UFSAR (Reference 4) are still applicable.

2.3.1.1 General Climate

The climate of southwestern Mississippi is humid and subtropical with a short cold season and a relatively long warm season. The predominant air mass over the region during most of the year is maritime tropical with origins over the Gulf of Mexico. In the winter, occasional southward movements of continental polar air from Canada bring colder and drier air into Mississippi. However, cold spells seldom last over 3 or 4 days.

In summer, the region is almost wholly dominated by the west- ward extension of the Bermuda High, a subtropical, semipermanent anticyclone. The prevailing southerly winds provide a generous supply of moisture and this, combined with thermal instability, produces frequent afternoon and evening showers and thundershowers over the region. The convective thundershowers of the summer season are more numerous than frontal type thunderstorms. However, the thunderstorms associated with the occasional polar front activity in late winter and early spring are more severe and sometimes produce tornadoes.

Mississippi is south of the average track of winter cyclones, but occasionally one moves over the state. In some winters a succession of such cyclones will develop in the Gulf of Mexico or in Texas and move over or near the state. Also the state is occasionally in the path of tropical storms or hurricanes (Reference 1).

It is common in wind direction data collection to divide the directions of the compass into sixteen 22.5 degree sectors centered on true north (N), north-northeast (N-NE), northeast (NE), east-northeast (E-NE), east (E), east-southeast (E-SE), southeast (SE), south-southeast (S-SE), south (S), south-southwest (S-SW), southwest (SW), west-southwest (W-SW), west (W), west-northwest (W-NW), northwest (NW) and north-northwest (N-NW). *The general airflow over the region is from the southerly sectors during much of the year, although the prevailing direction may be from one of the northerly sectors during some months.* The net air movement can be deduced from the annual resultant wind values for the GGNS site shown in Table 2.3-1. The average windspeed at the site has ranged from 3.7 mph to 4.3 mph between 1996 and 2001. The average windspeed at Vicksburg between 1997 and 2001 ranged from 7.0 mph to 7.5 mph as shown in Table 2.3-2.

The temperature regime of the region can be described by the data that are shown in Table 2.3-3. From 1997 to 2001, the maximum dry bulb temperature during the summer months in Vicksburg was 99 ºF while the winter extreme low was 16 ºF. From 2000 to 2001, the maximum dry bulb temperature[1] during the summer at the GGNS site was 98.6 ºF, while the winter extreme low was 17.3 ºF.

Table 2.3-3 presents wet and dry bulb temperatures for Vicksburg and dry bulb temperature for the site. The values from the Grand Gulf UFSAR (Table 2.3-56) date from 1964 and represent data from Jackson, MS. The data collected at Vicksburg over a five year period, and at Grand Gulf over a two year period, are consistent with the GGNS UFSAR data.

Climatic records of humidity in Vicksburg are shown in Table 2.3-4. These data show that relative humidity in the region is high throughout the year. Nighttime relative humidities are highest in summer and fall and lowest in winter. Daytime humidities are highest in winter. Seasonal variations are in the vicinity of 5 to 10 percent. Highest relative humidities occur in the early morning hours (00:00 – 06:00), averaging greater than 80 percent during all months. Lowest relative humidities occur during early and mid afternoon with averages ranging from about the mid-50s to the mid-60s for all months.

Mean annual precipitation in the region ranges from about 50 inches in northwestern Mississippi to 65 inches in the southeastern part of the State. During the freeze-free season, rainfall ranges from about 24 inches in the northwest to about 37 inches in the southeast, but during winter the precipitation maximum is centered in the northwest with the minimum on the coastal counties. The fall months are the driest of the year. Yearly average rainfall at the GGNS site for 2000 and 2001 is approximately 45 inches (Table 2.3-70), and at Vicksburg for the period of 1997 to 2001 was about 50 inches (Table 2.3-71).

While snowfall is not of much economic importance, it is not a rare event in Mississippi. During the 65 years from 1898 through 1957 and 1997 through 2001, measurable snow or sleet fell on some part of the state in all but 3 years. During these 65 years snow or sleet fell in January in 40 years, and in February in 32 years. Along the latitude of the site (about 32° N) snow has fallen in about 30 percent of the years. (References 1 and 3) Vicksburg snow events for the last five years are shown in Table 2.3-76.

Local (site) meteorological conditions are expected to result almost entirely from synoptic-scale atmospheric processes. That is, the local site does not have a unique micro-climate but rather the local meteorology is consistent with the wide area meteorology. There are two exceptions caused by local effects due to the Mississippi River. First, there is higher humidity directly adjacent to the Mississippi River, and so the Vicksburg humidity data is more appropriate for

[1] Reference 2 only includes 2 years of temperature and rainfall data for the GGNS site.

site estimates than the Jackson data. Second, *there is some evidence of channeling of extremely low level (less than 70 feet above grade) winds from the west into a trajectory along the river. This phenomenon has no effect on dispersion of effluents from the plant since the site is east of the area affected.*

2.3.1.2 Regional Meteorological Conditions for Design and Operating Bases

2.3.1.2.1 Severe Weather Phenomena

This section describes severe weather phenomena that may require consideration in design of safety related structures, systems and components. Most recent data is taken from the NCDC Storm Event database that covers the period of 1950 through 2002 (Reference 5), but even longer data periods are used for some phenomena to try to capture the occurrence of rare events.

2.3.1.2.1.1 Hurricanes

During the period 1899 to 2000 there were 117 tropical cyclones which affected the Middle Gulf Coast (Louisiana, Mississippi, Florida, Texas and Alabama). Of these, 39 (33.3 percent) were category 1, 30 (25.6 percent) were category 2, 36 (30.8 percent) were category 3, 10 (8.5 percent) were category 4 and 2 (1.8 percent) were category 5 hurricanes. Table 2.3-5 presents a monthly breakdown of the 117 cyclones and provides a definition of the storm categories.

Tropical cyclones, including hurricanes, lose strength as they move inland from the coast and the greatest concern for an inland site is possible flooding due to excessive rainfall. The extremes for rainfall presented below include possible hurricane effects.

The small diameter, extremely intense Camille hurricane (1969), whose center passed less than 10 miles to the east of Jackson Municipal Airport, generated gusts at Jackson of only 67 mph. The top winds in this hurricane at points on the coast were estimated at over 170 mph (Reference 7).

2.3.1.2.1.2 Tornadoes and Waterspouts

Tornadoes do occur in this area. A highly destructive tornado struck Vicksburg in December 1953. In addition, on April 17, 1978, a tornado struck GGNS. A detailed report of this event was submitted to the NRC via Reference 8. The tornadoes reported during the years 1950 - 2002 in the vicinity of Claiborne, Warren and Hinds Counties in Mississippi and Tensas Parish in Louisiana are shown on Table 2.3-6.

In the period from 1950 to April 2002, a total of 108 tornadoes touched down in these four districts, which have a combined area of 2,545 square miles (Reference 9). References 10 and 11 identify that local tornadoes have a mean path area of 0.43 square miles. The site recurrence frequency of tornadoes can be calculated using the point probability method as follows:

Total area of tornado sightings = 2,545 sq. mi.

Average annual frequency = 108 tornadoes ÷ 52.3 years = 2.07 tornadoes/year

Freq/yr of a tornado striking a particular point P = (0.43) (2.07) ÷ 2545 = 0.00035

Mean recurrence interval = 1/P = 2,860 years.

*Waterspouts are similar to tornadoes but they do not form under the same meteorological conditions; they form over water bodies and do, on occasion, cross the coastline and penetrate several kilometers inland, (*Reference 12*). The water bodies in the vicinity of the Grand Gulf site area not likely to spawn waterspouts.*

2.3.1.2.1.3 Thunderstorms

Table 2.3-7 presents the thunderstorm data for the region from 1955 through 2002. About 62 percent of the thunderstorms in this area occur during the warm months (March-July), indicating that the majority are warm air-mass thunderstorms. From 1955 - 2002, 421 thunderstorms are listed for this area, with Hinds County receiving approximately 40 percent, Claiborne County receiving 12 percent, Warren County receiving 32 percent, and Tensas Parish receiving 16 percent of the thunderstorms. The total of 298 storms shown in the table is less than the sum of the individual totals (421) for each of the three counties and Tensas Parish because some of the individual storms extended into more than one county.

2.3.1.2.1.4 Lightning

Data on lightning stroke density is extremely sparse. Analysis has shown that the density per square mile is approximately one-half of the number of storm days from the isokeraunic map. This was partially confirmed by a two-year count in a region with 27 storm days per year where the average stroke density was approximately 15 strokes per square mile per year (Reference 13).

The annual mean number of thunderstorm days in the site area is estimated to be 66 based on interpolation from the isokeraunic map (Reference 14); *therefore it is estimated that the annual lightning stroke density in the Grand Gulf site area is 33 strokes per square mile.*

2.3.1.2.1.5 Hail

From 1955 - 2002, 279 hailstorms occurred in the region per year, with Hinds County receiving approximately 57 percent, Claiborne County receiving 6 percent, Warren County receiving 19 percent, and Tensas Parish receiving 18 percent of the hailstorms, as shown in Table 2.3-8. For this table, each occurrence of hail was counted as an individual event, even if two counties recorded hail simultaneously. The most probable months of occurrence of hail are March and April. Property damage occurs infrequently, with 6 recorded events in Warren County, 14 in Hinds County, 4 in Claiborne County, and 2 in Tensas Parish in this 47-year period.

2.3.1.2.1.6 High Air Pollution Potential

The atmospheric ventilation rate is numerically equal to the product of the mixing height and the wind speed within the mixing layer. Higher ventilation rates are better for dispersing pollution than lower ventilation rates.

A tabulation of daily mixing heights and mixing layer wind speeds for both morning and afternoon was obtained from the National Climatic Data Center for 1992 through 2000 at the Jackson International Airport in Jackson, Mississippi (Reference 15). This data was used to generate the morning and afternoon ventilation rates in Table 2.3-9.

Morning ventilation is less than 4600 m^2/s throughout the year, and is less than 3100 m^2/s from May through October. Afternoon ventilation is higher than 5600 m^2/s from March through September, but lower than 4900 m^2/s from October through February. Based on this and the tendency of pollutants to collect during the course of a day, the highest daily air pollution potentials exist during the lower afternoon ventilation rates from October through February.

Lowest air pollution potentials occur in the spring due to the relatively high mean ventilation rates.

Other data sources provide independent checks of this conclusion, including the Grand Gulf Unit 1 UFSAR which cites data collected in 1959 through 1962 (Reference 4). *According to Korshover* (Reference 16), *in a 35-year period from 1936 through 1970, there were 36 cases of 4 days or more of atmospheric stagnation over southwest Mississippi, … with maximum probability in October and the minimum in March.*

2.3.1.2.2 Probable Maximum Annual Frequency and Duration of Freezing Rain

An ice storm (also called glaze ice) is the accretion of ice, generally clear and smooth, formed on exposed objects by the freezing of a film of supercooled water deposited by rain, drizzle, or possibly condensed from supercooled water vapor. The weight of this ice is often sufficient to greatly damage telephone and electric power lines and poles. The ice coating on roads frequently slows down, or even completely paralyzes, transportation and makes movement of personnel and equipment extremely difficult.

Most glaze is the result of freezing rain or drizzle falling on surfaces with temperatures between 25 and 32 ° F. The glaze belt of the United States includes all of the area east of the Rocky Mountains. However, in the southeast and Gulf Coast sections of the country, below freezing temperatures seldom last more than a few hours after glaze storms (Reference 17).

The occurrences and durations of recorded ice storms and heavy snow storms in the three counties and one parish around the GGNS site for the 8 year period 1993 through 2001 is shown in Table 2.3-10 (the storm database of Reference 5 contains this type of data for this location starting in 1993). From these data, conservatively including the heavy snowstorm of 1997, the frequency of ice storms in the Grand Gulf area is estimated to be 4 in eight years or 0.5 per yr.

The ice storm reported December 22, 1998 at 8:00 PM through December 25 at 5:00 AM, was the longest lasting storm with a total duration of 57 hours. Property damage was estimated at $16.6 million. It is noted that while the ice storm duration was 57 hours, that period was over an area of 27 counties. The time would have been less at a single location. Vicksburg reported the following history: 2 hours of trace rain (about 0.01 inches), followed by one dry hour, and then 8 hours of rain for a total of 0.4 inches at the start of the storm, then a period of 15 hours with only a trace of precipitation, and then 11 hours of rain totaling 0.85 inches, followed by only a trace of precipitation for the remainder of the storm. A conservative approach would be to neglect the dry/trace precipitation periods and assume this represents a 19 hour ice storm duration. Reference 4 also discussed combining periods of ice storms in this manner and developed a 12-hour maximum based on the ten years 1954 through 1963. Based on the Reference 4 maximum duration of 12 hours in 10 years of data, and this maximum value of 19 hours in 18 years of data, the maximum probable duration in 100 years would be 27 hours assuming a logarithmic extrapolation, i.e., 27 = 12 +(19-12)*log(100-10)/log(18-10).

The total number of glaze storms reported in the broad general area surrounding the plant site, during the period 1917 through 1953 inclusive, ranged from 1 to 7. It is estimated that about 30 percent of these caused ice coatings in excess of 0.5 inches in some portions of the area (Reference 17). As noted above, Vicksburg received about 1.25 inches of precipitation during the 1998 ice storm.

2.3.1.2.3 Probable Maximum Annual Frequency and Duration of Dust Storms

The occurrence of dust, blowing dust, or blowing sand is a comparatively rare phenomenon in the Jackson/Grand Gulf area. Although there are categories for dust and sand in the meteorological data collection system used at Vicksburg, no hours are identified under this category in the period 1997 to 2001. The hourly weather records for the years 1955 through 1964 cited in the Grand Gulf Unit 1 UFSAR do include 33 hours of dust blowing at the Jackson Airport (out of this 87,600 hour period). It is conservative to continue to use these data. These statistics are shown in Tables 2.3-11 through 2.3-14.

The total hours of occurrence are shown for each month of each of the ten years in Table 2.3-11*. April had the largest total. From the yearly totals shown in this table, the probable maximum annual frequency (probability=0.01) of dust storms in the Grand Gulf area is estimated to be 14/8,760 or 0.16 percent.*

Table 2.3-12 *shows the number and duration of discrete occurrences of dust storms by month. A discrete occurrence is defined as one hour, or more than one consecutive hour, during which dust, blowing dust, or blowing sand was reported by the National Weather Service. There were no occurrences of more than one hour during the ten year period.*

Table 2.3-13 *summarizes the monthly statistics on the dust storm occurrences and* Table 2.3-14 *presents a summary of frequency and duration for each of the 10 years. From these data the probable maximum duration (probability = 0.01) of the dust storm in the Grand Gulf area is estimated to be about two hours.*

2.3.1.2.4 Estimated Weight of the 100-Year Return Snowpack

Snowpack, as used in this section, is defined as a layer of snow and/or ice on the ground surface, and is usually reported daily, in inches, by the National Weather Service at all first order weather stations.

The density of the snowpack varies with age and the conditions to which it has been subjected. Thus, the depth of the snow- pack is not a true indication of the pressure which the snow- pack exerts on the surface which it covers. A more useful statistic for estimating the snowpack pressure is the water equivalent (in inches) of the snowpack.

To estimate the weight of the 100-year snowpack at the Grand Gulf site, the maximum reported snow and/or ice depths at Jackson and Vicksburg, Mississippi were reviewed from three sources. The current NCDC storm event database (Reference 5) identifies that the greatest snowfall in its period of data, 1993 to September 2002, occurred on December 14, 1997. That storm deposited 8 inches of snow in certain areas in a snow event that covered Claiborne, Hinds and Warren counties. Reference 29 records that a site in the Vicksburg area saw a total of 10.1 inches of snow fall in January 1919. Reference 25 identifies the maximum 24-hour snowfall at Jackson was 10.6 inches in January 1940. Since this data review covers at least 83 years back to 1919, it is possible to conclude with 83% confidence that the 100-year snowfall maximum is 10.6 inches. This is rounded up to 11 inches for greater conservatism.

Reference 19 *states that freshly fallen snow has a snow density (the ratio of the volume of melted water to the original volume of snow) of 0.07 to 0.15, and glacial ice formed from compacted snow has a maximum density of 0.91.*

In the Jackson/Grand Gulf area, snow melts and/or evaporates quickly, usually within 48 hours, and before additional snow is added; thus, the water equivalent of the snowpack can be considered equal to the water equivalent of the falling snow as reported hourly during the *snowfall. The data during the period studied indicate that the water equivalent of the maximum snowpacks in the Jackson area was between 0.08 and 0.12 inches of water per inch of snow. Hence, it appears that a conservative estimate of the water equivalent of snowpack in the Grand Gulf site area would be 0.20 inches of water per inch of snowpack. Then, the water equivalent of the 100-year return snowpack would be 11 x 0.2 = 2.2 inches of water.*

Since one cubic inch of water is approximately 0.0361 pounds in weight, a one inch water equivalent snowpack would exert a pressure of 5.20 pounds per square foot (0.0361 x 144).

For the 100-year return snowpack, the water equivalent would exert a pressure of 11.44 pounds per square foot (5.2 x 2.2).

2.3.1.2.5 Estimated Weight of the 48 Hour Probable Maximum Winter Precipitation

Rainfall in the recent 5 year period discussed below are from a period of relatively low rainfall (Reference 21). Therefore, it is conservative to use earlier data periods to develop the probable maximum winter precipitation values. Table 2.3-74 shows that the maximum rainfalls at Vicksburg in the 5 year period 1997 through 2001 are well below the 5 year recurrence rate presented in the GGNS UFSAR (Reference 4). This UFSAR data is based on a 15-year period.

The observed maximum precipitation amounts (water equivalent) during any consecutive 48 hour period at Jackson, Mississippi for the indicated winter (November through March) seasons is given in Table 2.3-15 (Reference 20). *The data were analyzed by the Gumbel-Lieblein method described by Thorn in* Reference 18 *with the following results:*

Return Period (Years)	*Max. 48 Hr. Winter Precip. Water Equivalent (inches)*
10	*4.60*
25	*5.50*
50	*6.15*
100	*6.80*
500	*8.20*
1,000	*8.80*

Thus, it is estimated that a value of 7.0 inches (water equivalent) is ultra-conservative for the 48 hour probable maximum winter precipitation at the Grand Gulf site, especially since only one of the above maximum values contained a trace of frozen precipitation.

In the unlikely event that the 7.0 inches maximum were entirely frozen precipitation, i.e. there was no run-off, a weight of 36.4 pounds per square foot (0.0361 lbs/in^3 x 7 in x 144 in^2/ ft^2) would result.

2.3.1.2.6 Weight of Snow and Ice on Safety-Related Structures

Since the plant site is subjected to a subtropical climate with mild winters, prolonged snowfalls or large accumulations of snow or ice on the ground and structures are not anticipated.

The estimated depth of the l00-year return snowpack is 11 inches, 2.2 inches of water equivalent, as discussed in Section 2.3.1.2.1.9.

2.3.1.3 Meteorological Data to be Used in Evaluating the Ultimate Heat Sink

Meteorological data is used in accident analyses and other analyses to determine the effectiveness of safety related heat removal systems; i.e., the ultimate heat sink. This section discusses GGNS site and local area meteorological data which may impact design of safety related heat removal systems.

2.3.1.3.1 Meteorological Parameters

The controlling meteorological parameters required for the analysis of cooling tower performance are the wet bulb temperature and the coincident dry bulb temperature. Table 2.3-3 presents data on these parameters from three data sources: historical data, 1948 – 1975, from the GGNS UFSAR (Reference 4) (see Table 2.3-56 for GGNS UFSAR data); data from Vicksburg, MS., 1997 – 2001 (Reference 3); and data from the GGNS meteorological tower, 2000 – 2001 (Reference 2). The GGNS data relevant to this assessment covers a very limited period. (See discussion of site instrumentation in Section 2.3.3). However, Table 2.3-3 shows that the 99%, 97.5%, and 95% frequency numbers from the recent GGNS data is consistent with the historical data. Therefore, the previous design basis temperatures remain valid for future design basis purposes.

2.3.1.3.2 Worst 1-Day, 5-Day, and 30-Day High Temperature Periods

a. *Worst 1-Day Period*

   The hourly data for the worst 1-day, August 6, 1970, are shown in Table 2.3-16.

b. *Worst 5-Day Period*

   The first 5 daily average values of the wet bulb temperature were summed and divided by five to calculate the first 5-day average. Then the sixth day's data was added to the sum and the first day value was subtracted from the sum. This new sum was divided by five to get the 2nd five day average. This process was repeated until all the observations were exhausted. Each five day period of data was averaged and the maximum average was selected as the worst 5 consecutive days. The daily average wet bulb and coincident dry bulb temperatures for the worst 5-day period are shown in Table 2.3-17*.*

c. *Worst 30-day period*

   The same method of running averages as was used for the worst 5-day period was used to find the worst 30 consecutive days. The daily average wet bulb and coincident dry bulb temperatures for the worst 30 day period are shown in Table 2.3-20

2.3.1.4 Design Basis Tornado Parameters

The Design Basis Tornado characteristics are specific to the site and region of the country in which the site is located. However, rather than conducting site research on tornado characteristics, most sites in the past licensing proceedings have relied on NRC endorsed studies that set conservative values for key design basis tornado characteristics. These characteristics were then used in the design of the subject facility.

Regulatory Guide 1.76 (Reference 41), based on WASH-1300, has been used since the 1970s by the industry to establish the appropriate design basis tornado characteristics, depending on the proposed site location in the country. Since the issuance of this guide, additional tornado data has become available by way of the National Severe Storms Forecast Center. Using this later data and Regulatory Guide 1.76 methodology, the NRC developed an interim position, establishing an update to the design basis tornado characteristics. The NRC's updated criteria were described in its safety evaluation, dated March 25, 1988 (Reference 42). The design basis tornado characteristics defined for this project, as listed below, are based on the NRC's interim position. The below listed characteristics are associated with a Region 1 site. (Per that NRC guidance, the GGNS ESP Site is located in Region 1.)

Maximum wind speed, mph	330
Rotational speed, mph	260
Maximum Translational speed, mph	70
Radius of maximum rotational, speed, ft	150
Pressure drop, psi	2.4
Rate of pressure drop, psi/sec	1.7

2.3.1.5 100-Year Return Period Fastest Mile of Wind

*The records of the National Weather Service for Jackson, Mississippi (*Reference 22*) report the fastest mile of wind to be 68 mph. This occurred in 1952. Other records (*Reference 25*) show that the height of the wind sensor in 1952 was approximately 46 feet above ground level. Reducing 69 mph from 46 feet to the standard 30 foot level gives a value of 64 mph.*

The fastest hourly averaged wind speed recorded by the Grand Gulf meteorological tower at 33 feet in the period from 1996 through 2001 was 31 mph in 1999. The fastest hourly average wind speed recorded at Vicksburg in the period from 1997 through 2001 was 33 mph, also in 1999. This more recent data covers a shorter period than that utilized in the Grand Gulf Unit 1 UFSAR, so the Grand Gulf UFSAR analysis continues to be appropriate for long term return periods for maximum wind speeds.

Reference 23 *indicates a value of approximately 83 mph for the 100-year return period fastest mile of wind in the Grand Gulf area.*

*A Gumbel-Lieblein extreme value analysis (*Reference 18*) of Jackson wind data, corrected for differences in measurement levels for the years 1960 through 1975, gave a value of 61 mph for the 30 foot level 100-year return period fastest mile of wind.*

In Reference 23*, Thom cites the often used power law as a representative estimate of the vertical wind profile. This vertical distribution of the wind velocity is expressed as,*

$$u_z = u_{30}\ (z/30)^{(1/n)}$$

Where z is the height above ground, u_z is the wind speed at height z, u_{30} is the wind speed at 30 feet, and n is a constant depending on surface roughness. For the Grand Gulf site the value of n is approximately 7 since the terrain characteristics can be described as being level or slightly rolling land with some obstructions.

In addition to corrections of the basic 30 feet above ground design wind for height of structures it is also necessary to apply corrections for gusts. This is normally done by means of a gust *factor (gust velocity ÷ the velocity of the fastest mile of wind). A gust factor of 1.3 is used for gusts of approximately 1-second duration that, in a 90 mph basic wind, would have a length downwind of about 130 ft. This is adequate for small structures. A gust factor of 1.1 will allow for gusts of approximately 10-second duration that, in a 90 mph basic wind, would have a length downwind of about 1,300 ft.; this factor is adequate for larger structures having a horizontal dimension, transverse to the wind of about 125 ft. (*Reference 24).

2.3.1.6 Other Regional Meteorological and Air Quality Conditions Considered

Regional meteorological or air quality conditions which need to be considered for design of safety related structures, systems and components of a new facility will be determined and evaluated as required by 10 CFR 52.

2.3.2 Local Meteorology

2.3.2.1 Normal and Extreme Values of Meteorological Parameters

The following sections contain information on wind, air temperature, atmospheric water vapor, precipitation, fog and smog, atmospheric stability, and mixing heights at the GGNS and surrounding area.

2.3.2.1.1 Winds

2.3.2.1.1.1 Wind Distributions (All Meteorological Conditions)

Wind data is available from both the Vicksburg meteorological station and the Grand Gulf meteorological tower. Both sets of data are discussed here to provide a fuller description of winds in the area.

2.3.2.1.1.1.1 Vicksburg Wind Data

Tables 2.3-19 to 2.3-30 present monthly percent joint frequency distributions for wind directions and speeds, based on a 5-year period of record from 1997 through 2001, for Vicksburg. Table 2.3-31 provides an annual summary of the data. On an annual basis, Vicksburg wind data collected in the five years 1997 through 2001 show central N is the most frequent (13.8 percent) wind direction. The wind is from SE through central S 30.8 percent of the time. Westerly (W-SW - W-NW) and easterly (E-NE - E-SE) winds are least frequent, with frequencies of 9.1 and 16.1 percent, respectively (Table 2.3-31). Southerly components prevail in spring, summer, and winter, while northerly components prevail in the fall (Tables 2.3.19 to 2.3.30).

Winds average greater than 8.1 mph from January through April, and 7.7 mph or less from May through December. Mean annual wind speed is 7.4 mph (Table 2.3-31).

The Vicksburg meteorological station winds are presented graphically in Figures 2.3-8 to 2.3-13. These wind roses cover the period from 1997 through 2001 and represent the frequency of winds coming from a particular direction by the length of the line in that direction. Vicksburg records a usual pattern of winds coming from the north or south. At Vicksburg, winds from the west occur as infrequently as winds from the east. However, the year 2001 is seen to be one where most winds come from the eastern half of the rose (Figure 2.3-13).

2.3.2.1.1.1.2 Grand Gulf Wind Data

The same wind data assessment was applied to GGNS site data collected at the Grand Gulf Meteorological Tower for the period from 1996 through 2001 (Reference 2). Monthly relative frequencies of wind direction and speed for the Grand Gulf site are shown in Tables 2.3-32 through 2.3-43, and data for all years is shown in Table 2.3-44.The wind speeds are hourly averages and there are no zero speeds recorded. The minimum site recorded wind speed is 0.309 mph. Winds average greater than 4.2 mph from December through April, and 3.6 mph or less from May through November. Mean annual wind speed is 3.9 mph.

Wind roses are presented for the Grand Gulf site in Figures 2.3-1 to 2.3-7 from the 6-year period 1996 through 2001. The normal wind pattern shows winds primarily from either the north (NW to NE) or south (SW to SE), with the highest frequency originating in the SE. In most years, few winds blew from the east, although 2001 was an exception to this pattern. In general. the wind roses from Vicksburg and Grand Gulf show the same trend towards prevailing winds from the NW to NE and SW to SE.

2.3.2.1.1.1.3 Wind Direction Persistence

Hourly weather observation records from the National Weather Service at Vicksburg, Mississippi for the years 1997 through 2001 were examined for wind direction persistence. The longest persistence periods from a single sector (22.5 degrees), three adjoining sectors (67.5 degrees), and five adjoining sectors (112.5 degrees) were determined for each sector (and calm) during each year. The results are shown in Tables 2.3-45 through 2.3-47. During the period, the single sector persistence was greatest (28 hours) for the central north direction. The average maximum persistence (17.6 hours) was also greatest for the central north direction. For the persistence in three adjoining sectors, the central south sector had the longest period of persistence (109 hours) and the largest average maximum persistence (63.8 hours) as shown in Table 2.3-46. The longest persistence period (105 hours) from five adjoining sectors occurred in the S-SE sector (Table 2.3-47). The central north sector showed the greatest average maximum persistence (57.2 hours).

Wind persistence data similar to the above are shown in Tables 2.3-48 through 2.3-50 for the Grand Gulf site. The statistics shown in these tables cover a six-year period from 1996 through 2001. Table 2.3-48 shows that the longest single sector persistence period was 27 hours from the central north sector. The central north sector also had the greatest average maximum persistence in a single sector. For the longest persistence in three adjoining sectors, the central north sector had the longest period with 91 hours as shown in Table 2.3-49. The central south sector had the greatest average maximum persistence (61.5 hours) in three adjoining sectors. The persistence data for five adjoining sectors (Table 2.3-50) shows the central N-NE sector with the longest persistence period (181 hours) and the greatest average maximum persistence (102.8 hours).

Table 2.3-51 presents a comparison of the maximum persistence period for the GGNS site in hours with historic data from Jackson and Table 2.3-52 presents a comparison of the maximum persistence periods for Vicksburg and GGNS. While there are differences in the preferred sectors, the data demonstrate that it is not likely that any single wind direction would persist for a substantial period of time. Table 2.3-53 is the maximum wind direction persistence period for each sector at Jackson from Reference 4 to provide historic comparison.

2.3.2.1.2 Air Temperature

Table 2.3-54 shows that temperature extremes for Vicksburg have ranged from 107 ºF (August and September 2000) to 16 ºF (January 2001) (Reference 3). Table 2.3-55 shows that temperature extremes for GGNS have ranged from 104.2 ºF (August 2000) to 17.3 º F (January 2001) (Reference 2). The data shows good agreement between the two locations.

Figures 2.3-14 and 2.3-15 present the site hourly temperatures for the years 2000 and 2001 (Reference 2). A comparison of the two years is made in Figure 2.3-16, where the maximum and minimum temperatures measured in 96 hour intervals are plotted against the start date of the interval.

2.3.2.1.3 Atmospheric Water Vapor

Mean relative humidities for four time periods per day at Vicksburg are shown in Table 2.3-4 (Reference 3).

All of Mississippi experiences high humidity during much of the year. At Vicksburg humidities of 90 percent or higher have occurred at any hour of the day. They are most frequent in the early morning hours. In the summer, at times there develops a combination of high temperatures together with high humidities; this usually builds up progressively for several days and becomes oppressive for one or more days. Humidities of less than 50 percent occur on some days each month, usually in the early afternoon hours. Humidities drop under 30 percent on about one-quarter of the October and November days; the number of days with such low humidities diminishes in the other months. In July and August there may be none. (Reference 25).

Table 2.3-3 shows temperature data for the GGNS site and Vicksburg. Maximum one percent exceedance dry bulb of 99 °F and the one percent exceedance maximum wet bulb temperature of 82 °F are shown for Vicksburg. These values are slightly greater than the Grand Gulf Unit 1 maximum temperatures of 98 and 79, respectively, that were based on a 1964 data source (Table 2.3-56).

The saturation deficit tables (Tables 2.3-57 through 2.3-68) were prepared from 5 years (1997-2001) of Vicksburg hourly weather observations (Reference 3). These tables show the total monthly occurrences as a function of windspeed and wind direction segment for the 5 year period. Table 2.3-69 shows the total annual occurrences as a function of windspeed and wind direction segment.

2.3.2.1.4 Precipitation

2.3.2.1.4.1 Rain

The GGNS site rainfall data covers the time period from 2000-2001 and the Vicksburg data covers the time period from 1997-2001 (References 2 and 3). Monthly and annual mean and extreme precipitation amounts for the GGNS site and Vicksburg, Mississippi are presented in Tables 2.3-70 and 2.3-71, respectively. Average monthly precipitation at the GGNS site follows a seasonal trend, reaching a maximum mean in March (10.02 inches) and a minimum mean in November (0.02 inches). Maximum annual mean precipitation has been 46.85 inches. For Vicksburg, the maximum mean precipitation is in December (9.94 inches) and a minimum mean in May (0.38 inches). The maximum annual precipitation in Vicksburg is 59.76 inches.

Table 2.3-72 and Table 2.3-73 provide monthly frequency distribution of rainfall rates at the Grand Gulf site and Vicksburg, respectively.

In general, the Vicksburg data appears to be representative of the Grand Gulf area. The variations between the two locations from month to month, particularly during the summer months, are likely reflective of the occurrence of heavy shower and thunderstorm activity common in the area.

The maximum short period precipitation was determined for the Grand Gulf Unit 1 UFSAR (Reference 4). As discussed previously, that data is still valid and conservative as compared to recent experience. *Maximum point precipitation values are given in* Table 2.3-74. *These were interpolated from the maps of USWB Technical Papers 40 and 49* (References 26 and 27). For comparison purposes, the recent 5-year maximum short period precipitations are listed for Vicksburg, Mississippi in the table.

Table 2.3-75 *was taken from* Reference 28. *It presents maximum observed short period precipitation data for Vicksburg.*

A comparison of the two tables suggests that 100 year amounts may have occurred during the period of record (1893-1961) for precipitation amounts for periods of 3, 6, 12, and 24 hour durations.

A comparison of the more recent data record, the five years from 1997 through 2001, shows that the more recent period has had less heavy rains than expected for a random 5-year period.

2.3.2.1.4.2 Snow

Annual average snowfall in the Grand Gulf area is estimated to be 1 to 2 inches. This estimate is based on 36 years of record (1930 -1966) at Vicksburg (Reference 29) *and 39 years of record (1936-1975) at Jackson (*Reference 25*).* This data is assumed to be more representative of the long term site meteorology due to the relatively dry recent years, although, during 1997 through 2001, the Vicksburg meteorology station reported snow conditions for several hours in November through March as presented in Table 2.3-76.

The maximum monthly amount in Vicksburg was 10 inches in February 1960 and this total fell within a 24 hour period. The maximum annual amount was also 10.0 inches. At another site in the Vicksburg area a total of 10.1 inches of snow fell in January 1919.(Reference 29). The maximum recorded in the current NCDC storm event database is 8 inches in December 14, 1997 (Reference 5). This database coves snowstorms for the period 1993 through September 2002.

The maximum monthly amount at Jackson was 10.6 inches in January 1940 in a 24-hour period. The maximum annual amount was 11.6 inches and occurred in the 1939-1940 season (Reference 25).

2.3.2.1.5 Precipitation Wind Roses

Figure 2.3-17 shows an annual precipitation wind rose for Jackson, Mississippi for 10 years prior to 1972 (Reference 4 Figure 2.3-5). This data shows that rains in Jackson happen most often in the months of December through March, with the most common directions of SE through S and N-NW through NE. *Winds speeds during precipitation average 9.1 mph annually and over 7.9 mph (the average annual wind speed) during fall, winter, and spring.*

Figure 2.3-18 shows an annual precipitation wind rose for the GGNS site based on data from the years 2000 and 2001. This data is also seen in Table 2.3-77, as well as monthly rain totals in Table 2.3-70. This is a shorter data collection period than the Reference 4 precipitation wind rose, and these are relatively dry years, but the same general trends can be seen. The period of greatest rain is still December through March, although two dry February months were recorded in this period. The most frequent wind directions are N-NW to NE and S-SE to SW.

2.3.2.1.6 Fog and Smog

Table 2.3-78 shows that over the period 1997 to 2001, Vicksburg has averaged about 93 hours/year of fog, with October through January having the greatest frequency of fog. Vicksburg records are considered representative of the Grand Gulf site due to its proximity and to its similar location relative to the bank of the Mississippi.

Note that the Grand Gulf Unit 1 UFSAR estimated that moderate fog will occur about 1 percent (88 hours) of the time at Grand Gulf, and heavy fog will occur about 0.6 percent (53 hours) of the time (Reference 4), which is consistent with the Table 2.3-78 data.

The Grand Gulf Unit 1 UFSAR also contains an evaluation of smog based on Jackson data over the years 1955 through 1964. Grand Gulf is well removed from Jackson metropolitan area and Vicksburg, and is, therefore, not prone to heavy smog. Table 2.3-78 shows haze records by month from Vicksburg for the period of 1997 - 2001. There were about 194 hours/yr on average of haze during this period.

2.3.2.1.7 Atmospheric Stability

Atmospheric stability data for the Grand Gulf site were generated as part of a plume behavior study. This stability data was generated in Reference 32 based on five years of surface observations at the Grand Gulf site and the Vicksburg NCDC meteorology station. Hourly observation data were converted into stability classes and frequency by season using the SACTI software code, Reference 31. The resulting stability classes for the Grand Gulf site are presented by season and wind direction in Tables 2.3-80 through 2.3-83, and annual frequency data is presented in Table 2.3-79.

The frequency and strength of inversion layers are also investigated with nine years of weather balloon data collected at the Jackson airport. Weather balloons are released twice daily at 6:00 a.m. and 6:00 p.m., to collect temperatures at increasing elevations. The monthly data are provided in Tables 2.3-84 through 2.3-95, and annual average data in Table 2.3-96, in terms of percentages of mornings and afternoons containing inversions, average inversion layer elevation, and the maximum strength of the inversions. An inversion is defined as any three elevation readings showing temperatures increasing with elevation. The inversion layer height is the point (found by interpolation between readings) at which temperature again starts to decrease with elevation. The maximum inversion strength is the maximum temperature rise divided by elevation difference within the inversion layer. (Reference 15)

The weather balloon data does not address how long inversion layers may persist. For this purpose, the Grand Gulf Unit 1 UFSAR data, based on the period 1955 through 1964, is used in Tables 2.3-97 through 2.3-108. *The tables show the number of discrete periods when inversion conditions existed one hour, or two or more consecutive hours. Short periods contained within a longer period are not considered as discrete occurrences. These tables show the data for each of the 10 years in order to show the variations from year to year. They also show the monthly mean distribution calculated from the 10 years.*

The monthly means are summarized in Tables 2.3-109 and 2.3-110 *and they have been added to give an annual mean.*

Tables 2.3-111 through 2.3-124 *show similar inversion data for the Grand Gulf site. These inversion occurrences were determined from E, F, or G stability classifications resulting from onsite delta-temperature measurements. The period covered by the data is from August 1972 through July 1974 and January 1976 through December 1976.*

2.3.2.1.8 Mixing Heights

Monthly mixing heights for Jackson, Mississippi are shown in Table 2.3-125. These were obtained from the NCDC and are based on the ten-year period 1992 through 2001 (Reference 15). Consistent with the mixing heights presented in the Grand Gulf UFSAR (Reference 4), which are based on a four year record at Jackson, the average mixing heights in the mornings are lowest during the fall, and the average mixing heights in the afternoon are lowest in the winter.

2.3.2.2 Potential Influence of the Plant and Its Facilities on Local Meteorology

Operation of a new facility at the Grand Gulf site will influence the local climatology. A discussion of the expected extent of this influence is presented in this section. The major thrust of this discussion is aimed at an evaluation of cooling tower plume effects. An assessment of the contribution of moisture to the ambient environment from cooling tower blowdown waste heat discharge is included. Finally, a qualitative evaluation of the effects of the cooling system on daily variations of several meteorological parameters is presented.

A number of literature sources were reviewed to determine the nature and extent of studies made of the effects of waste heat disposal systems on the meteorological environment. The literature search revealed a lack of definitive, empirical studies, and validated methods to approach the complex problems involved in quantitatively assessing the extent of the modifications of the atmosphere. Though many theoretical models have been postulated for calculating cooling tower visible plume lengths, none of those models reviewed has been adequately verified by scientific observations

2.3.2.2.1 Cooling Tower Plumes

Cooling systems, which depend on evaporation of water for a major portion of the heat dissipation, may create visible vapor plumes. These vapor plumes cause shadowing of nearby lands, salt deposition, and can cause fogging or icing. An assessment of potential plumes from the addition of a new power production facility with cooling towers at the Grand Gulf site and the cooling tower plume impacts was performed (Reference 32). This assessment was done using the SACTI plume modeling code (Reference 31). Grand Gulf site and Vicksburg meteorology data for the period 1997 through 2001 was used in the model.

Two different options for cooling towers were evaluated for the new facility, and each was addressed in the assessment. The first consisted of four natural draft cooling towers (NDCTs) to provide normal heat sink cooling capability. The second utilized four 20-cell linear mechanical draft cooling towers (LMDCTs) for the same function. In both cases, the total heat rejected to the atmosphere is as defined in Table 1.3-1 (condenser / heat exchangers duty). The heat load used is a bounding value and is the primary conservatism in the study. Reasonable estimates were made for cooling tower dimensions, layout, and airflow rates, since final design of the facility is not known. Maximum drift rate for cooling towers of these types, and average Mississippi River water salt concentration were used to support deposition calculations.

Table 2.3-126 describes the expected plume lengths by season and direction for the NDCT option. Each of the four individual NDCTs have less heat rejection than the existing operating GGNS Unit 1 NDCT, but the four plumes merge and carry farther than for an individual tower.

Table 2.3-127 presents the plume lengths by season and direction for the LMDCT option. These plume lengths are typically shorter, but the plumes would be closer to the ground. This increases salt deposition and the possibility of fogging.

Table 2.3-128 compares the plume lengths by frequency for the NDCT and LMDCT options.

2.3.2.2.2 Blowdown Discharge

*Configuration of surface thermal plumes resulting from the discharge of blowdown water into the Mississippi River were calculated by Pritchard (*Reference 33 *for February and June for both high- and low-water cases).*

*By applying the steam fog index method developed by Currier, et al. (*Reference 34 *for cooling ponds, steam fog occurrence probabilities over the core (+10 F isotherm) of the plume of 38 percent were obtained during extreme February morning conditions. In June, the probability is only five percent.*

Initially, the results for February appear to be extremely significant. However, it must be pointed out that the steam fog index over the ambient river water yields a probability of 13 percent and the core of the thermal plume covers an area of only 0.007 acre. The +5 F isotherm encloses an area of 2.6 acres with a steam fog occurrences probability only a few percent higher than over ambient river water. A separate approach, based on humidity increases due to evaporation, yielded even lower probabilities.

2.3.2.2.3 Cooling System Plume Effects on Ground Level Meteorological Variables

a. Wind

Operation of cooling towers creates a miniconvective cell above the tower. Air surrounding the tower near the surface is drawn into the base of the tower. This air is heated in the tower, rises, and, with the excess moisture picked up while passing through the tower, creates the vapor plume. Therefore, the surface winds in the vicinity of the towers are deflected toward the towers. No quantitative estimate has been made of the horizontal extent of this effect, but it certainly does not extend as far as the site boundaries.

b. Temperature

The vast majority of heat released to the atmosphere by the cooling system will be carried aloft with the cooling tower plumes, thereby warming considerably the air in the plumes. Surface air temperatures near the cooling tower are expected to be slightly cooler than ambient during the day and slightly warmer at night due to weak entrainment of air aloft in the convective circulation. Also, air near the heated blowdown discharge plume in the Mississippi River may be slightly above ambient. These differences are so small and local that they cannot be measured beyond a few hundred feet from the tower or thermal plume.

c. Atmospheric Water Vapor

In the vicinity of the vapor plumes, both the absolute and relative humidity aloft will be increased as evidenced by calculated frequency of visible plume occurrence. Absolute humidity at the surface will be increased only slightly. However, relative humidity near the tower may be increased during the colder months due to relatively low moisture-bearing capacities of cold air. As has been noted, blowdown thermal discharge influences on atmospheric humidity will be insignificant.

d. Precipitation

*Light drizzle and snow occasionally have been noted within a few hundred meters downwind from cooling towers (*Reference 35*), but these phenomena are very localized and should have no effect outside the site boundary. Huff compared the flux* *of water vapor and air from natural draft cooling towers with those occurring in natural convective showers. His results indicate that some enhancement of small rain showers might be expected, as tower fluxes are within an order of magnitude of the shower fluxes. Larger thunderstorms, with their much greater flux values, should not be significantly affected, except that formation may occur somewhat earlier in the day than would otherwise be expected, with the cooling tower plume possibly acting as a triggering mechanism.*

e. Fog and Icing Stability

*Studies conducted by Broehl (*Reference 36*), Zeller (*Reference 37*), and Hosler (*Reference 38*) indicate that surface fogging from natural draft towers does not present a significant problem. Broehl and Zeller found no cases of cooling tower plumes reaching the ground, while Hosler noted only one in a two year study at the Keystone Power Plant, near Shelcota, in western Pennsylvania.*

The plume study performed for a new facility on the site (Reference 32), showed no fogging would occur for the NDCTs option. The LMDCTs are predicted to cause only minimal fogging, on the order of 15 hours per year. It should be noted, however, that that the SACTI code used in the Reference 32 assessment has not been as extensively benchmarked for fogging as it has been for visible plumes and deposition (Reference 50).

It follows that ground-level icing should be considered insignificant at the Grand Gulf site because of the combined low probabilities of ground-level plumes from either type tower and freezing conditions.

f. Stability

No quantitative assessment can be made of the influence of the cooling system on atmospheric stability. It can be reasoned that beneath the cooling tower plumes somewhat more stable conditions might be expected than would otherwise be experienced during the day and slightly less stable at night.

g. Dew

*A study conducted at Plant Bowen, Cartersville, Georgia, (*Reference 39*) indicates that dew formation may be significantly retarded beneath the cooling tower plume, especially during the winter months.*

h. Dispersion of Radioactive Effluents

Although atmospheric ventilation may be reduced beneath the cooling tower plumes, this effect may well be more than compensated for by increases in dispersion due to cooling tower convection. When the winds carry vented effluents toward the towers, a portion of the effluents may be caught up in the influx of air at the base of the towers and carried aloft with the plume.

Based on the above discussion, it is concluded that the new facility's cooling system, i.e., the cooling tower plume (from either the NDCT or LMDCT designs) would have no significant impact on meteorological conditions at ground level at Grand Gulf.

2.3.2.3 Topographical Description

The proposed location for the new facility site lies about 6,300 feet east of the Mississippi River. The town of Port Gibson, Mississippi lies about six miles to the southeast, the town of St. Joseph, Louisiana lies about 13 miles to the southwest, and the Big Black River empties into the Mississippi River about three miles to the north.

The surrounding terrain is generally hilly and wooded to the south and east, with several hilltops over 350 feet above mean sea level to the south. To the north and west, the terrain is generally flat and wooded, lying less than 100 feet above mean sea level. Numerous lakes of various sizes and isolated marshes dot the landscape. There is a rather abrupt (irregular) 100 to 200 foot rise in terrain approximately one mile east of the riverbank. Figures 2.3-19 to 2.3-21 *present topographic cross sections and a site area map.*

According to Regulatory Guide 1.3 (Reference 49), credit for elevated release of contaminants is given only if the release point is at a height of at least 2.5 times the height of the tallest nearby structure that could affect dispersion. Since discussion of effects of topography on diffusion estimates is required only for elevated releases, and the diffusion analyses for the new facility at the Grand Gulf site assume a ground level release, these effects have not been estimated.

2.3.2.4 Local Meteorological Conditions for Design and Operating Bases

Site specific data was used for determination of atmospheric dispersion and diffusion estimates as discussed in Sections 2.3.4 and 2.3.5 of this report.

2.3.3 Onsite Meteorological Measurements Program

The onsite meteorological measurements program has been designed to meet requirements at least as stringent as those required by Regulatory Guide 1.23 (Reference 48).

The onsite meteorological measurement program has evolved over the years from temporary monitoring towers installed prior to construction to a state-of-the-art system installed in late 2000 and early 2001. In March of 1972 two temporary towers were installed, one on the bluff and one in flood plane, near the Mississippi River Bank. A permanent tower was installed in August 1972 approximately 5000 ft N-NW of the center of the Unit 1 reactor, adjacent to the temporary tower. Both temporary towers were removed in March of 1973.

The permanent tower was 162 ft high and supported instrumentation for wind speed and direction and temperature at 33 ft and 162 ft. The instrumentation on this tower was upgraded in 1983 to meet the requirements of NUREG-0654 as part of the initial licensing conditions for GGNS Unit 1. A back-up tower was also installed to provide data on wind speed and direction and sigma-theta.

Data collection since the startup of the system (August 1972) has met Regulatory Guide 1.23 (Rev. 0) requirements except the relative humidity data as discussed in Section 2.3.3.1. A new relative humidity sensor was installed in December 2000 as indicated in Section 2.3.3.2.

2.3.3.1 Onsite Meteorological Measurements Program – Pre-2000 Modifications

The permanent tower is 162 feet high and has the following equipment installed at each of the indicated levels (all heights above grade):

Surface	*Tipping bucket rain gauge* *Delta temperature translator* *(utilizes 33- and 162-foot temperature sensors)*
33 feet	*Wind speed sensor,* *Wind direction sensor,* *Temperature sensor,* *Dew point sensor*
162 feet	*Wind speed sensor,* *Wind direction sensor,* *Temperature sensor*

Table 2.3-129 *shows the specifications of the meteorological equipment at Grand Gulf. All data collected since the starting date of August 2, 1972, have met Regulatory Guide 1.23 requirements except the relative humidity data. Maintenance and operational difficulties were experienced with the relative humidity sensors. The sensors were replaced by two Tech-Ecology Met Set 5-T Dewpoint systems in December 1976.*

….

All parameters are measured by duplicate sensors at each level.

Meteorological data from the permanent tower will be supplemented with information from the backup meteorological system. This system will monitor wind speed, wind direction, and sigma theta. The information from the backup system will be supplied to the control room via a telemetry system. This information will be utilized to ensure data availability should a temporary loss of information from the permanent tower occur. Table 2.3-129 *outlines the specifications for the backup meteorological equipment.*

All information recorded by the meteorological instruments on the permanent tower are stored both in digital and analog forms. The analog traces serve as backup to the digital system. Data from the temporary tower instrumentation were recorded by analog trace only.

The permanent (main) tower serves as a representative observation station (i.e., meteorological conditions at that location are considered to be representative of the site). The 162-foot meteorological tower with base elevation of 156 feet (MSL) is located approximately 5,300 feet northwest of the control building of the station as shown in Figure 2.1-1*. The nearest bluffs are 362 feet to the west of the meteorological tower. There are trees 35 feet high along these bluffs. Approximately 50 feet below the bluffs the flood plain extends 4,500 feet to the west to meet the Mississippi River at an elevation of 65 feet (MSL). To the south and to the east, the nearest trees are 689 feet and 396 feet from the tower, respectively. Tree heights in these directions are between 50 to 60 feet. A country road passes the meteorological tower 400 feet to the north. The meteorological tower is surrounded by a fence which is 7 feet high and 70 feet away from the base of the tower. An instrument shack about 8 feet high is installed near the base of the tower. The immediate vicinity of the tower is covered by Bermuda grass which is mowed as necessary. The soil beneath the grass is loess. ….*

The percentage of data recovery during the first annual cycle … for [the] *combination of sensor systems used in preparation of joint frequency distributions … and used in diffusion analyses …. [50/10 meters (162/33 feet) T, 10 meters (33 feet) wind direction and speed],* [was] *98.73 percent of all possible sets of hourly values from August 1, 1972 through July 31, 1973 …. Data recovery from each of the other sensing systems exceeded 90 percent for the year.*

2.3.3.1.1 Meteorological Data Processing

2.3.3.1.1.1 Introduction

The data processing procedure for Grand Gulf meteorological data involves three basic steps:

- *a. Data collection*
- *b. Data editing and consolidation*
- *c. Data analysis*

Computer software has been developed to process the collected data according to steps b. and c. above. This section includes a summary of the data collection methods and description of the processing and analysis of the data.

2.3.3.1.1.2 Data Collection

The onsite meteorological data are recorded in both analog and digital form.

2.3.3.1.1.2.1 Analog Data

The analog traces are recorded on strip charts which act mainly as a backup and verification for the digital data. The data are recorded continuously on six chart rolls, one for each of the following sets of parameters:

1. *50-meter (162 foot) wind speed and direction (sensor A)*
2. *50-meter (162 foot) wind speed and direction (sensor B)*
3. *10-meter (33 foot) wind speed and direction (sensor A)*
4. *10-meter (33 foot) wind speed and direction (sensor B)*
5. *10-meter (33 foot) temperature and 50-meter (162 foot)/ 10-meter (33 foot) T, surface precipitation, and 10-meter (33 foot) dew point temperature (sensor A)*
6. *10-meter (33 foot) temperature and 50-meter (162 foot)/ 10-meter (33 foot) T, surface precipitation, and 10-meter (33 foot) dew point temperature (sensor B)*

All wind speeds are recorded in miles per hour. Wind directions are recorded on a 0-~~540F~~[360 degrees] *scale. Temperatures are recorded in F (degrees Fahrenheit). The precipitation is a step trace, each step representing 0.01 inches.*

2.3.3.1.1.2.2 Digital Data

The digital data is received by the plant data computer at a rate of one reading per second. It is recorded each time the value varies by a specified deadband. Each piece of data is checked to assure it is between the minimum and maximum instrument limits. This quality indication and the time is recorded with each value.

An average is calculated each hour from the one second readings. The quality of the samples is reflected in the quality of the average. This quality indication and the time the average was calculated is recorded with each hourly value.

The meteorological data are available to the main control room and personnel via the plant computer. A one second reading and an hourly average is available for each of the following parameters:

1. *Wind speed - 10-meter (33 foot) and 50-meter (162 foot) elevations*
2. *Wind direction - 10-meter (33 foot) and 50-meter (162 foot) elevations*
3. *Temperature - 10-meter (33 foot) elevation*
4. *Differential temperature (T) - 10-meter (33 foot) and 50-meter (162 foot) elevations*
5. *Dew point - 10-meter (33 foot) elevation*
6. *Precipitation - ground level*

2.3.3.1.1.3 Data Processing

The meteorological data is gathered from the plant data computer recordings on request. The quality of the hourly averages is used to determine the data reliability. The data is then available for correction or change and reliability is evaluated again.

The hourly readings are used to calculate joint frequency distributions from wind speeds and wind direction data for the 10 meter and 50 meter levels. These frequency distributions are summarized on request for each Pasquill Stability Class.

2.3.3.1.2 Meteorological Instrumentation Inspection and Maintenance

GGNS has established procedures for the inspection and maintenance of the onsite meteorological instrumentation. This responsibility is shared between the Operations and Maintenance Departments.

Routine inspections are made to ensure proper operation of equipment and that no damage to the tower, shack, or any other structure or equipment has occurred. The recording medium are checked for proper operation and changed biweekly. The standby generator is tested for auto start on a routine basis.

Semiannual visual inspections of the tower and equipment are made to determine the conditions of sensors, cabinets, wiring, structures, and individual components. Semi-annual checks for proper instrumentation readings are made at various points. A check for the "As-Found" and "Final" data condition are made to verify proper operation of the equipment. A check on the battery bank and battery charger is made along with the proper operation of the standby generator and its inverter. The tower cables are adjusted for proper tension, and the following instrumentation is calibrated:

1. *2 - Differential temperature sensor, El. 33'-162' (10-50 meters)*
2. *2 - Dew point - El. 33' (10 meters)*
3. *2 - Wind speed - El. 33', 162' (10 meters, 50 meters)*
4. *2 - Wind direction - El. 33', 162' (10 meters, 50 meters)*
5. *Rain gauge – Surface*

2.3.3.2 Onsite Meteorological Measurements Program – Post-2000 Modifications

Both the main 162 ft (50-meter) tower and backup 33 ft (10-meter) tower were replaced around December of 2000, due to obsolescence and increased maintenance costs. The 162 ft (50-

meter) tower has the following equipment installed at each of the indicated levels (all heights above grade):

Surface	*Tipping bucket rain gauge* *Delta temperature (utilizes 33- and 162-foot temperature sensors)*
33 feet	*Wind speed sensor* *Wind direction sensor* *Relative humidity sensor*
162 feet	*Wind speed sensor* *Wind direction sensor* *Temperature sensor*

The specifications for the new instrumentation are provided in Table 2.3-130*.*

The main tower serves as a representative observation station (i.e., meteorological conditions at that location are considered to be representative of the site). The 162-foot meteorological tower with base elevation of 156 feet (MSL) is located approximately 5,300 feet northwest of the control building of the station as shown in Figure 2.1-1*. The nearest bluffs are 362 feet to the west of the meteorological tower. There are trees approximately 50 feet high along these bluffs. Approximately 50 feet below the bluffs, the flood plain extends 4,500 feet to the west to meet the Mississippi River at an elevation of 65 feet (MSL). To the south and to the east, the nearest trees are approximately 489 feet and 396 feet from the tower, respectively. Tree heights in these directions are between 50 to 60 feet. A country road passes the meteorological tower 600 feet to the north. The meteorological tower is surrounded by a fence which is 8 feet high. An instrument shack about 8 feet high is installed approximately 400 feet north of the tower. ….*

Data recovery from the new meteorological tower instrumentation, based on evaluation of data from March 2001 to March 2002, was 98 percent.

2.3.3.2.1 Meteorological Data Processing

The data processing procedure for Grand Gulf meteorological data involves three basic steps:

- *a.* *Data collection*
- *b.* *Data editing and consolidation*
- *c.* *Data analysis*

Computer software has been developed to process the collected data according to steps b. and c. above. This section includes a summary of the data collection methods and description of the processing and analysis of the data.

2.3.3.2.1.1 Data Collection

The onsite meteorological data are recorded in digital form.

All wind speeds are recorded in miles per hour. Wind directions are recorded on a 0-360° scale. Temperatures are recorded in F (degrees Fahrenheit). The precipitation is a step trace, each *step representing 0.01 inches. Relative humidity is recorded on a 0 100% scale. Sigma Theta is calculated and recorded in degrees.*

The digital data package is received by the plant data computer every ≤ ten seconds. It is recorded each time the value varies by a specified deadband. Each piece of data is checked to assure it is between the minimum and maximum instrument limits. This quality indication and the time is recorded with each value.

An average is calculated every fifteen minutes and each hour from the readings. The quality of the samples is reflected in the quality of the average. This quality indication and the time the average was calculated is recorded with each value.

The meteorological data are available to the main control room and personnel via the plant computer. A ≤ ten second reading, a fifteen minute average, and an hourly average is available for each of the following parameters:

1. *Wind speed – 10-meter (33 foot) and 50-meter (162 foot) elevations*
2. *Wind direction – 10-meter (33 foot) and 50-meter (162 foot) elevations*
3. *Temperature – 10-meter (33 foot) and 50-meter (162 foot) elevations*
4. *Differential temperature (T) – 10-meter (33 foot) and 50-meter (162 foot) elevations*
5. *Relative Humidity – 10-meter (33 foot) elevation (ten second and hourly only)*
6. *Precipitation – ground level*
7. *Sigma Theta – 10-meter (33 foot) and 50-meter (162 foot) elevations (fifteen minute and hourly only)*
8. *Aspirator flow – 10-meter (33 foot) and 50-meter (162 foot) elevations (fifteen minute and hourly only)*

2.3.3.2.1.2 Data Processing

The meteorological data is gathered from the plant data computer recordings on request. The data can also be acquired from data storage modules in the MET Shack. The quality of the hourly averages is used to determine the data reliability. The data is then available for correction or change and reliability is evaluated again.

The hourly readings are used to calculate joint frequency distributions from wind speeds and wind direction data for the 10 meter and 50 meter levels. These frequency distributions are summarized on request for each Pasquill Stability Class.

2.3.3.2.2 Meteorological Instrumentation Inspection and Maintenance

GGNS has established procedures for the inspection and maintenance of the onsite meteorological instrumentation. This responsibility is shared between the Operations and Maintenance Departments.

Routine inspections are made to ensure proper operation of equipment and that no damage to the tower, shack or any other structure or equipment has occurred.

Semiannual visual inspections of the tower and equipment are made to determine the conditions of sensors, cabinets, wiring, and individual components. Semi-annual checks for proper instrumentation readings are made at various points. A check for the "As-Found" and "Final" data condition are made to verify proper operation of the equipment. A check on the *batteries and battery charger is made. The tower cables are adjusted for proper tension, and the following instrumentation calibrated on the primary tower:*

1. *2-Temperature sensor, El. 33'-162' (10-50 meters)*
2. *1-Relative Humidity– El, 33' (10 meters)*
3. *1-Wind speed – El, 33', 162' (10 meters, 50 meters)*
4. *1-Wind direction – El, 33', 162' (10 meters, 50 meters)*
5. *Rain gauge – Surface near primary tower*

The following instruments are calibrated on the back-up tower:

1. *1 – Temperature sensor, El. 33' (10 meters)*
2. *1 – Wind speed, El. 33' (10 meters)*
3. *1 – Wind direction, El. 33' (10 meters)*

For this ESP application, calculations to determine diffusion estimates for both short- and long-term conditions were completed using data from the meteorological instrumentation in service prior to the most recent replacement in December 2000, as described in Section 2.3.3.1. Data recovery for the period evaluated in the calculations (Sections 2.3.4 and 2.3.5) is indicated in Table 2.3-131.

2.3.4 Short Term Diffusion Estimates

2.3.4.1 General

The consequence of a design basis accident in terms of personnel exposure is a function of the atmospheric dispersion conditions at the site of the potential release. Atmospheric dispersion consists of two components: 1) atmospheric transport due to organized or mean airflow within the atmosphere and 2) atmospheric diffusion due to disorganized or random air motions. Atmospheric diffusion conditions are represented by relative air concentration (*X*/Q) values (Reference 45).

The efficiency of diffusion is primarily dependent on winds (speed and direction) and atmospheric stability characteristics. Dispersion is rapid within stability Classes A through D and much slower for Classes E through G. That is, atmospheric dispersion capabilities decrease with progression from Classes A to G, with an abrupt reduction from Classes D to E.

Relative concentrations of released gases, X/Q values, as a function of direction for various time periods at the exclusion area boundary (EAB) and the outer boundary of the low population zone (LPZ), were determined by the use of the computer code PAVAN (Reference 43)*. This code implements the guidance provided in Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," August 1979.* The *X*/Q calculations are based on the theory that material released to the atmosphere will be normally distributed (Gaussian) about the plume centerline. A straight-line trajectory is assumed between the point of release and all distances for which *X*/Q values are calculated (References 43, 45).

Using joint frequency distributions of wind direction and wind speed by atmospheric stability, PAVAN provides the X/Q values as functions of direction for various time periods at the exclusion area boundary (EAB) and the low population zone (LPZ). The meteorological data needed for this calculation included wind speed, wind direction, and atmospheric stability. The meteorological data used for this analysis was collected from the on-site monitoring equipment from January 1996 through December 2000. These five years were averaged and are reported in Tables 2.3-132 through 2.3-138. Other plant specific data included tower height at which wind speed was measured (10.0m), and distances to the EAB (841m) and LPZ (3219m).

Within the ground release category, two sets of meteorological conditions are treated differently. During neutral (D) or stable (E, F, or G) atmospheric stability conditions when the wind speed at the 10-meter level is less than 6 meters per second (m/s), horizontal plume meander is considered. X/Q values are determined through the selective use of the following set of equations for ground-level relative concentrations at the plume centerline:

$$X/\mathrm{Q} = \frac{1}{\mathrm{U}_{10}\left(\pi u_y u_z + \mathrm{A}/2\right)} \qquad \text{Equation 1}$$

$$X/\mathrm{Q} = \frac{1}{\mathrm{U}_{10}\left(3\pi u_y u_z\right)} \qquad \text{Equation 2}$$

$$X/\mathrm{Q} = \frac{1}{\mathrm{U}_{10}\pi S_y u_z} \qquad \text{Equation 3}$$

where:

X/Q *is relative concentration, in sec/m³,*

U_{10} *is wind speed at 10 meters above plant grade, in m/sec*

u_y *is lateral plume spread, in meters, a function of atmospheric stability and distance*

u_z *is vertical plume spread, in meters, a function of atmospheric stability and distance*

S_y *is lateral plume spread with meander and building wake effects, in meters, a function of atmospheric stability, wind speed, and distance*

A *is the smallest vertical-plane cross-sectional area of the reactor building, in meters²*

PAVAN calculates X/Q values using Equations 1, 2, and 3. The values from Equations 1 and 2 are compared and the higher value is selected. This value is then compared with the value from Equation 3, and the lower value of these two is selected as the appropriate X/Q value.

During all other meteorological conditions, unstable (A, B, or C) atmospheric stability and/or 10-meter level wind speeds of 6 m/s or more, plume meander is not considered. The higher value calculated from equation 1 or 2 is used as the appropriate X/Q value.

From here, PAVAN constructs a cumulative probability distribution of X/Q values for each of the 16 directional sectors. This distributions is the probability of the given X/Q values being exceeded in that sector during the total time. The sector X/Q values and the maximum sector X/Q value are determined by effectively "plotting" the X/Q versus probability of being exceeded and selecting the X/Q value that is exceeded 0.5% of the total time. This same method is used to determine the 5% overall site X/Q value.

The X/Q value for the EAB or LPZ boundary evaluations will be the maximum sector X/Q or the 5% overall site X/Q, whichever is greater (Reference 45). *All direction-dependent sector values are also calculated.*

2.3.4.2 Calculations and Results

Reference 45 divides release configurations into two modes, ground release and stack release. A ground release includes all release points that are effectively lower than two and one-half times the height of the adjacent solid structures. Since specific building arrangement details (i.e., building height and area) are unknown until a specific plant type is selected, the building area and height were not used in the calculation. This is conservative since the building wake effect will tend to reduce the calculated X/Q. Also, since the release point, or stack height, is unknown until a specific plant type is selected, the release mode was classified as a ground release.

PAVAN requires the meteorological data in the form of joint frequency distributions of wind direction and wind speed by atmospheric stability class. The meteorological data used was obtained from the GGNS meteorological data collected from 1996 through 2000.

The stability classes were based on the classification system given in Table 2 of Regulatory Guide 1.23 (Reference 48), as follows:

Classification of Atmospheric Stability
(Reference 48, Table 2)

STABILITY Classification	Pasquill Categories	σ_θ*	Temperature change with height (°C/100m)
Extremely unstable	A	25.0°	<-1.9
Moderately unstable	B	20.0°	-1.9 to -1.7
Slightly unstable	C	15.0°	-1.7 to -1.5
Neutral	D	10.0°	-1.5 to -0.5
Slightly stable	E	5.0°	-0.5 to 1.5
Moderately stable	F	2.5°	1.5 to 4.0
Extremely stable	G	1.7°	> 4.0

* Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to 1 hour.

Joint frequency distribution tables were developed from the meteorological data with the assumption that if data required as input to the PAVAN program (i.e., lower level wind direction, lower wind speed, and temperature differential) was missing from the hourly data record, all data for that hour was discarded. Also, the data in the joint frequency distribution tables was rounded for input into the PAVAN code.

Building area is defined as the smallest vertical-plane cross-sectional area of the reactor building, in square meters. As stated above, this parameter was not used and the building area was entered as zero.

Building height is the height above plant grade of the containment structure used in the building-wake term for the annual-average calculations. As stated above, this parameter was not used and the building height was entered as zero.

The tower height is the height at which the wind speed was measured. Based on the lower measurement location, the tower height used was 10 meters.

A ground release includes all release points that are effectively lower than two and one-half times the height of adjacent solid structures (Reference 45). Therefore, as stated above, a ground-release analysis was assumed.

The cumulative frequency of *X*/Q at the EAB (841 m) can be found in Table 2.3-139. Table 2.3-140 presents the cumulative frequency at the LPZ (3219 m). A summary of results is provided below. Median (50 percent) values may be used in making realistic estimates of the environmental effects of potential radiological accidents; conservative estimates may be based on calculated 5 percent values.

Tables 2.3-141 and 2.3-142 report the directional-dependent sector *X*/Q values at the EAB and LPZ respectively.

ESP *X*/Q VALUES (sec/m^3)
(Based on 1996-2000 Meteorological Data)

	0 – 2 hrs	0 – 8 hrs	8 – 24 hrs	24 – 96 hrs	96 – 720 hrs
EAB (841 M, SW)	5.13E-04				
LPZ (3219 M, SW)		7.65E-05	5.35E-05	2.46E-05	8.04E-06

2.3.4.3 Relative Concentration Estimates at the Control Room Emergency Intake

A specific plant design has not yet been selected for construction at the GGNS ESP Site for this Early Site Permit application; therefore, determination of dispersion and diffusion coefficients at the Control Room emergency intake has not been done.

2.3.4.4 Ingress/Egress Diffusion Estimates

A specific plant design has not yet been selected for construction at the GGNS ESP Site for this early site permit application; therefore, determination of diffusion estimates for site ingress/egress has not been done.

2.3.4.5 Toxic Chemical Diffusion Estimates

See Section 2.2.3.1.

2.3.5 Long Term Diffusion Estimates

2.3.5.1 General

For a routine release, the concentration of radioactive material in the surrounding region depends on the amount of effluent released, the height of the release, the momentum and buoyancy of the emitted plume, the wind speed, atmospheric stability, airflow patterns of the site, and various effluents removal mechanisms. Annual average relative concentration, X/Q, and annual average relative deposition, D/Q, for gaseous effluent routine releases were, therefore, calculated.

2.3.5.2 Calculation Methodology and Assumptions

The XOQDOQ Computer Program (Reference 44) which implements the assumptions outlined in Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Release from Light-Water-Cooled Reactors" (Reference 47) developed by the USNRC, was used to generate the annual average relative concentration, X/Q, and annual average relative deposition, D/Q. Values of X/Q and D/Q were determined at points of potential maximum concentration, outside the site boundary, at points of maximum individual exposure and at points within a radial grid of sixteen 22 ½° sectors and extending to a distance of 50 miles. Radioactive decay and dry deposition were considered.

Meteorological data for the period from 1996 through 2000 was used, and receptor locations were determined from the locations given in the GGNS 2001 Land Use Census. Hourly meteorological data was used in the development of joint frequency distributions, in hours, of wind direction and wind speed by atmospheric stability class. The wind speed categories used were consistent with the GGNS short-term (accident) diffusion χ/Q calculation discussed above, and the GGNS Offsite Dose Calculation Manual (ODCM) meteorological evaluation (Reference 46). Calms were distributed as the first wind speed class.

Joint frequency distribution tables were developed from the hourly meteorological data with the assumption that if data required as input to the XOQDOQ program (i.e., lower level wind direction and wind speed, and temperature differential as opposed to upper level wind direction and wind speed) was missing from the hourly data record, all data for that hour would be discarded. This assumption maximizes the data being included in the calculation of the χ/Q and D/Q values.

The analysis assumed a combined vent located at the center of the proposed facility location. At ground level locations beyond several miles from the plant, the annual average concentration of effluents are essentially independent of release mode; however, for ground level concentrations within a few miles, the release mode is very important. Gaseous effluents released from tall stacks generally produce peak ground-level air concentrations near or beyond the site boundary. Near ground level releases usually produce concentrations that decrease from the release point to all locations downwind. Guidance for selection of the release mode is provided in Regulatory Guide 1.111 (Reference 47). In general, in order for an elevated release to be assumed, either the release height must be at least twice the height of adjacent buildings or detailed information must be known about the wind speed at the height of the release. For this analysis, routine releases from a new facility were conservatively modeled as ground level releases.

Building cross-sectional area and building height are used in calculation of building wake effects. Regulatory Guide 1.111 (Reference 47) identifies the tallest adjacent building, in many cases the reactor building, as appropriate for use. Several plant types were evaluated for the

GGNS early site permit and building dimensions vary; therefore, for conservatism, building wake effects were not considered.

Consistent with Regulatory Guide 1.111 (Reference 47) guidance regarding radiological impact evaluations, radioactive decay and deposition were considered. For conservative estimates of radioactive decay, an overall half-life of 2.26 days is acceptable for short-lived noble gases and a half-life of 8 days for all iodines released to the atmosphere. At sites where there is not a well-defined rainy season associated with a local grazing season, wet deposition does not have a significant impact. In addition, the dry deposition rate of noble gases is so slow that the depletion is negligible within 50 miles. Therefore, in this analysis only the effects of dry deposition of iodines were considered. The calculation results with and without consideration of dry deposition are identified in the output as "depleted" and "undepleted."

No terrain recirculation factor was applied. This is consistent with the GGNS position on Regulatory Guide 1.111 (Reference 47) as stated in the UFSAR (Section 3A) (Reference 4). This regulatory position states that since the meteorological data does not show any conclusive or systematic up and down or cross valley flow, it would be inappropriate to apply recirculation factors as indicated in Regulatory Guide 1.111 (Reference 47).

Receptor locations for the Grand Gulf site were evaluated as specified in NUREG 1555 which states: "*X*/Q and/or D/Q at points of potential maximum concentration outside the site boundary, at points of maximum individual exposure, and at points within a radial grid of sixteen 22½ degree sectors (centered on true north, north-northeast, northeast, etc.) and extending to a distance of 80 km (50 mi) from the station. A set of data points should be located within each sector at increments of 0.4 km (0.25 mi) to a distance of 1.6 km (1 mi) from the plant, at increments of 0.8 km (0.5 mi) from a distance of 1.6 km (1 mi) to 8 km (5 mi), at increments of 4 km (2.5 mi) from a distance of 8 km (5 mi) to 16 km(10 mi), and at increments of 8 km (5 mi) thereafter to a distance of 80 km (50 mi). Estimates of *X*/Q (undecayed and undepleted; depleted for radioiodines) and D/Q radioiodines and particulates should be provided at each of these grid points."

2.3.5.3 Results

Results of the analysis, based upon 5 years of data collected onsite, are presented in Tables 2.3-143 through 2.3-146.

2.3.6 References

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2.4 Hydrologic Engineering

2.4.1 Hydrologic Description

2.4.1.1 Site and Facilities

The site for the Grand Gulf Nuclear Station is on the east bank of the Mississippi River in the vicinity of river mile 406, approximately 25 miles south of Vicksburg, Mississippi, and 6 miles northwest of Port Gibson, Mississippi. It is bounded on the west by the Mississippi River and on the east by loessial bluffs forming part of the hilly region that extends from Vicksburg to Baton Rouge, Louisiana. The Mississippi River floodplain adjacent to the site is relatively low and flat with elevations ranging from 55 to 75 ft. (All elevations in this report [GGNS UFSAR] *are in feet above mean sea level, datum of 1929.)*

The plant site is in the loessial uplands with a plant yard grade elevation of 132.5 ft. This elevation is well above the water levels in the Mississippi River as summarized below:

Item	*Elevation (ft. msl)*
U. S. Army Corps of Engineers design project flood elevation	102.1 (References 7 and 33) [96.2 ft as reported in Reference 8]
Existing grade of west bank levee (GG Project design flood elevation)	*103*
100-yr flood elevation	*91.4*
Mean annual flood elevation	*76.5*
Low Water Reference Plane for RM 406	37.5 (Reference 1) [34 ft as reported in Reference 8]
Low water elevation (lowest recorded at Vicksburg projected to Grand Gulf)	*28*

The main exterior access route to the site is via the Grand Gulf road. An access road leading from the Grand Gulf road to the site has been constructed. A construction heavy-haul road, about 6800 feet long, connects a barge landing on the Mississippi River to the access road. The barge slip used during construction of GGNS Unit 1 is located at river mile 406.4 (Figure 2.4-1).

The Universal Transverse Mercator (UTM) Grid Coordinates for the center of the location of the power block area for a new facility is approximately N3,542,873 meters and E684,021 meters. The proposed location for the power block area for the new facility is west of the main plant access road (Figure 2.4-1). The grade elevation for a new facility will be established in consideration of requirements to provide flood protection for associated safety-related structures, systems and components.

The plant makeup and service water is supplied by a series of radial collector wells located in the floodplain parallel to the Mississippi River. … During normal operation, plant service water is discharged to the circulating water system to supply the required circulating water system makeup water. The circulating water system blowdown is discharged to the discharge basin and from there is discharged by a single pipeline to the Mississippi River. (Figure 2.4-1)

A number of investigations have been conducted in regards to the radial collector wells (Mississippi River and alluvial aquifer) which supply cooling and makeup water (Plant Service Water (PSW)) for the existing GGNS Unit 1 plant. The studies have dealt primarily with the hydrogeologic setting, aquifer hydraulics, well yields and well conditions. The studies determined that, based upon the total projected PSW demands for the existing GGNS Unit 1 plant, the aquifer which supplies the existing PSW wells is capable of meeting system demands through the design life of the existing plant. However, addition of new facility(ies) to the site, with a (maximum) requirement of approximately 85,000 gpm makeup water (made up of 78,000 gpm maximum blowdown from Table 1.3-1, and about 7,000 gpm for facility miscellaneous makeup requirements) could not be supported by collector wells drawing water from the alluvial aquifer.

Therefore, makeup (cooling tower makeup and other raw water needs) and normal service water for a new facility would be supplied from the Mississippi River via an intake located on the east bank of the river and on the north side of the existing barge slip (Figure 2.1-1).

Effluent from a new facility would be combined with that from the existing GGNS Unit 1 facility, and the combined effluent would be discharged into the river downstream of the intake such that recirculation to the embayment area and intake pipes would be precluded.

Emergency cooling water (ultimate heat sink) for a new facility would be provided by closed-cooling system(s) that utilize enclosed basins with mechanical draft cooling towers or similar heat removal mechanisms. This emergency cooling system would not be reliant on the river intake, with the possible exception of normal (non-emergency operation) makeup water supply.

There are two streams that girdle the plant site as shown in Figure 2.4-1*. Both streams drain into Hamilton Lake. The stream to the south, draining Basin B, was rerouted around the plant site and a 15-foot culvert was placed at its outlet to safely carry local floods and site drainage. This rerouted stream does not cause any significant modification to the natural drainage and is designed to carry the probable maximum flood. The stream to the north, draining Basin A, which receives most of its water from the watershed outside the plant area was not rerouted. However, a 12-foot culvert was placed under the access road to connect it to the flood plain. The plant yard is graded to direct runoff from rainfall on the roofs and the yard away from the buildings to the two streams.*

The plant yard for a new facility would likewise be graded such that runoff is directed away from existing site buildings, and buildings for a new facility. Use of the two streams for directing runoff from new facility areas and buildings, to the maximum extent possible, is anticipated.

2.4.1.2 Hydrosphere

The dominant hydrologic feature in the vicinity of the site is the Mississippi River (Figures 2.4-2, 2.4-3, and 2.4-3a). The site is located in the Lower Mississippi River Region, and the major tributaries, major cities, and other pertinent features of the Mississippi River in the area are shown on Figures 2.4-3 and 2.4-3a*. The streamflow system within the region is composed chiefly of the Mississippi River and its tributary streams between Cairo, Illinois, the Gulf of Mexico and the coastal area streams of southern Louisiana. The total drainage area of the streams within the region is about 102,400 sq mi, 40,740 sq mi of which contribute flow to the Mississippi River.… The subbasins and major rivers of the Mississippi River Basin are shown in* Figure 2.4-4 *and drainage features of these basins are summarized in* Table 2.4-1*.*

At the plant site, the natural floodplain is about 60 miles wide. However, the flow is confined to a width of about two to four miles by high bluffs on the east bank and man-made levees with top *elevations ranging from 101 to 103 ft on the west bank. The river has a width of about* [one-half to] *one mile during dry seasons. The width increases to about four miles during floods.*

Several lakes are in the floodplain in the vicinity of the site. However, their hydrologic characteristics have no influence on the plant site. Of immediate relevance to the plant site are two small and steep streams [Stream A and Stream B]*. The one to the north of the site is perennial, draining Basin A with an area of 2.8 sq miles, and the other to the south and adjacent to the plant facilities is intermittent, draining Basin B with an area of 0.6 sq miles. Both drain into Hamilton Lake in the floodplain of the Mississippi River.*

Rivers of the Mississippi basin have numerous river-control structures ranging from levees and navigational locks to major dams. Details of these structures are described in subsection 2.4.4. In the site region, the U. S. Army Corps of Engineers has built levees on the west bank with top elevations ranging from 101 to 103 ft. The Corps of Engineers has completed revetments along the east and west river banks in the site area, including the east bank that borders the GGNS site, to maintain the river channel (Reference 1, and Figure 2.4-5). There are 1,610 miles of authorized levees on the main stem of the Mississippi River (Reference 2).

2.4.2 Floods

2.4.2.1 Flood History

Floods on the Mississippi River occur primarily as a result of precipitation and snow melt runoff from its major tributaries, the Ohio, Missouri, Arkansas, and Red Rivers (Figure 2.4-4). *The Ohio River contributes 66 to 76 percent of the mean flow of the Mississippi River during the period January to March, while the Missouri contributes 47 to 52 percent during the period June to September* (Table 2.4-1). *Major floods on the Ohio generally occur between mid-January and mid-April, those on the Missouri and the Upper Mississippi generally occur between mid-April and the end of July. The Arkansas and White Rivers experience floods between the beginning of April and the end of June. Thus, the flood season on the Lower Mississippi generally extends from mid-December to July. The number of peaks, duration of near-peak flow, and the flood volumes during a year all vary greatly.*

Flood discharges at Vicksburg during six of the highest recent floods are summarized in Table 2.4-4. A water surface profile for the Mississippi River between river miles 360 and 480 for the 1937 flood, and the low water reference plane profile for the year 1993, are shown in Figure 2.4-6. Based on these flood discharges and the profile for the 1937 flood, the highest recorded water level was about 40 ft below the GGNS Unit 1 plant grade of 132.5 ft. Updated information on floods at Vicksburg (Reference 7) indicates that no flood since the construction of GGNS has exceeded the discharge of the 1973 flood.

Hydrographs for the Mississippi River showing maximum, minimum, and average stages at Vicksburg, Mississippi, (based on data collected from 1932 to 2000) and at Natchez, Mississippi, (based on data collected from 1940 to 2000) are shown in Figures 2.4-7 and 2.4-8. Figure 2.4-9 illustrates the annual maximum instantaneous peak streamflow at Vicksburg from 1858 to 1999.

No historical data exist on the flooding of the two intermittent local streams [Figure 2.4-1]*. An indication of the extremes of rainfall and runoff observed over small areas in Mississippi and Louisiana is given in* Tables 2.4-5 (Reference 34) and 2.4-6 (References 35 and 36). *From these tables it is noted that the maximum observed 24-hr rainfall in the region varies from 7.9 to 21.40 in. and maximum observed stream flow varies from 147 to 1581 cfs/sq mi.*

2.4.2.2 Flood Design Considerations

Safety-related structures, systems, and components for a new facility would be designed to withstand the worst flooding caused by an appropriate combination of several hypothetical events, as required by GDC-2. The events to be considered would include: probable maximum flood (PMF) of the Mississippi River coincident with wind-generated waves (Section 2.4.3.6); seismic failure of upstream dams coincident with the U. S. Army Corps of Engineers design-project flood (DPF) (Section 2.4.4); ice flooding (Section 2.4.7); and PMF of the two small streams adjacent to the plant (Section 2.4.3.3). The elevation of the structures of a new facility would be well above the Mississippi River DPF, eliminating Mississippi River flooding concerns from the design of safety-related structures, systems and components. Therefore, the event which will control the facility flood design is the probable maximum precipitation (PMP) on the watersheds for the site (Section 2.4.2.3).

To establish design flood considerations for the GGNS site in its existing configuration, acceptable methods of estimating the PMF were used. The PMF for the Mississippi River is estimated based upon the flood defined by the U. S. Army Corps of Engineers design-project flood. The PMF for the two local streams was estimated based upon methods recommended in Regulatory Guide 1.59 [Design Basis Floods for Nuclear Power Plants].

The design flood considerations for the site areas are based on the local drainage areas which can be seen on Figure 2.4-10. Relevant material from the GGNS UFSAR which detail the flood design considerations for GGNS Unit 1 is included herein, and discussion is included to show how the evaluations are applicable for a new facility on the site.

All safety-related systems, structures and components (SSCs) for the new facility would be located above maximum flood elevation, or flood protection would be provided such that the requirements of GDC-2 and 10 CFR 100 would be met.

2.4.2.3 Effects of Local Intense Precipitation

The effects of local intense precipitation at the GGNS site have been evaluated in the GGNS UFSAR (Reference 8). This information has been reviewed and is considered to be valid for the determination of maximum floodwater elevation that could reasonably and conservatively be expected for a new facility. The relevant sections of the GGNS UFSAR are included below, with updated information as needed for evaluation of flooding concerns for a new facility. Consistent with the GGNS UFSAR, the position regarding Regulatory Guide 1.59 (as described in UFSAR Appendix 3A) remains unchanged. The PMF for the two local streams close to the plant site has been estimated based on the unit hydrograph method in accordance with Regulatory Guide 1.59 (Reference 8).

The forecast effect of a local probable maximum precipitation (PMP) event on the adjacent drainage areas and site drainage systems is based on the evaluations discussed below through Section 2.4.3.5. The estimated maximum floodwater elevations do not exceed 133.25 feet msl.

The estimated local probable maximum precipitation (PMP) and the resulting maximum floodwater elevation for the existing site configuration was calculated for the drainage areas, Basin A and Basin B (Figure 2.4-10). The footprint of the existing plant and the proposed construction areas for a new facility are shown on Figure 2.4-10. The new facility construction area would be primarily located in Basin A and Basin B drainage areas, except for a small area located on the southwest corner of the proposed construction site. This area drains away from Basin B and thus would not contribute to flooding in Basin B. The proposed location of the power block for a new facility would be in an area drained by both Stream A and Stream B (Figure 2.4-10).

The runoff model in the original GGNS analysis used a very conservative assumption, in that the runoff coefficient (i.e., the percentage of rain that appears as direct runoff) was set at 1.0 (see Section 2.4.2.3.3.2.3, Peak Discharges). This assumption essentially models the drainage basins as if they were covered, such that all rainwater is allowed to run off without benefit of soil infiltration. Therefore, this evaluation is considered valid for a new facility located on the proposed ESP Site.

2.4.2.3.1 Precipitation Distribution

*Distribution of local intense precipitation at GGNS is based upon PMP data obtained from U. S. Weather Bureau Hydrometeorological Report (HMR) No. 33 (*Reference 9*). Per HMR 33, the all season PMP values for a 10 square mile area and various storm durations are:*

Duration (hr)	*6*	*12*	*24*	*48*
PMP (in.)	*30.5*	*36.0*	*40.0*	*43.0*

The drainage basins for streams A and B are shown in Figure 2.4-10*, and have approximate areas of 2.8 and 0.6 square miles, respectively. Because these basins are small, the PMP rainfall values from HMR 33 are of too long a duration for the determination of a PMF (or PMP induced flood). Temporal distribution per the procedures outlined in EM-1110-2-1411* (Reference 10) *yields the PMP distribution given in* Table 2.4-7.

A more recent document, HMR No.53 dated April 1980 (see Figure 22 in Reference 11), shows a 2% increase in the hourly rate of rainfall over that reported in HMR 33. This would result in a relatively small increase in the 6 hr PMP; this small change is not expected to significantly affect the results of the analysis done for the existing GGNS facility. Thus, the analyses for the GGNS Unit 1 facility are considered applicable for a new facility at the ESP Site.

2.4.2.3.2 Runoff Model

The model adopted for determination of the peak discharge for basins A and B is based on the unit hydrograph concept. The approach consists of estimating basin lag, developing a representative dimensionless hydrograph (Reference 12*), and synthesizing a unit hydrograph for any selected rainfall duration.*

The lag in hours is based on the curves given by Chow (Reference 13*). From these curves, it is possible to estimate basin lag based on length and slope of the channel.*

The dimensionless hydrograph adopted is based on observed data and upon curves developed by Hudlow (Reference 12) *and Feddes* (Reference 14) *for small drainage basins varying in size from 0.5 square miles to 75 square miles. Mean dimensionless hydrographs developed by Hudlow* (Reference 12) *for a stream in east central Texas with a drainage area of 0.48 to 9.2 square miles, and by Feddes* (Reference 14) *for a two square mile basin near Bryan, Texas. The watershed characteristics of basin J* (Reference 12) *and Hudson Creek near Bryan, Texas,* (Reference 14*) are similar to those of basins A and B as discussed below.*

The pertinent data for different parameters for basins A and B, at the plant site, along with the characteristics of basin J and Hudson Creek, are as follows:

Basin	*Drainage Area (sq mi)*	*L (mi)*	*Lca (mi)*	*S (ft/mi)*	*Lag (hr)*
A	*2.8*	*3.4*	*1.9*	*48.53*	*1.60*
B	*0.6*	*1.52*	*0.53*	*64.14*	*0.65*
J	*0.48*	*0.96*	*0.33*	*62.80*	
Hudson Creek	*1.98*	*2.18*	*1.15*	*34.32*	

Where:

L = *Length of the longest watercourse from point of interest to the watershed divide*

Lca = *Length of water course from point of interest to the intersection of a line perpendicular to the stream alignment passing through the centroid of basin*

S = *Overall slope of longest watercourse from point of interest to divide*

An average graph as shown in Figure 2.4-11 *has been used as being representative for the site region. On the dimensionless hydrograph, the ordinate is the discharge multiplied by the lag plus one-half the rainfall duration divided by the volume of runoff. The abscissa is time expressed as a percent of lag plus half the duration.*

The lag times obtained above were applied to the dimensionless hydrograph (Figure 2.4-11*) to produce the unit hydrograph given in* Table 2.4-8 *and* Figure 2.4-12*. The unit durations of the unit hydrographs used are 0.5 hr and 0.25 hr for basins A and B, respectively. The precipitation increments used for both basins are given in* Table 2.4-9*. The flood hydrographs obtained for the two basins along with the unit hydrograph and precipitation distribution are shown in* Figure 2.4-12*.*

The Plant area is divided into several drainage subareas shown on Figure 2.4-13 *based upon site features such as roads, abandoned railroad beds, or other features, which would tend to divide flow. The peak discharge for each subarea is calculated using the rational equation:*

$$Q = CIA$$

in which

Q = *peak discharge from the area in cubic feet per second (cfs) due to the assumed storm condition.*

C = *coefficient of runoff.*

I = *intensity of precipitation in in/hr corresponding to the time of concentration (Tc).*

A = *drainage area in acres.*

This hydrograph would not change with the construction of a new facility because the hydrograph drainage areas would remain the same, the length of the longest watercourse would not be altered, and the overall slope would be unchanged. Thus, the runoff model is considered valid for a new facility in the proposed location on the ESP Site.

2.4.2.3.3 Site Drainage System

2.4.2.3.3.1 Basic Design

Finished grade for a new facility would be sloped away from buildings. A storm drainage system for a new facility would be designed to carry the 100-year runoff. Storm runoff for the new facility would be carried away from the plant area by a storm drainage system consisting of appropriate combinations of swales, open channels, subsurface system(s) of catch basins and pipes, and culverts. Runoff from a new facility would then be routed toward streams A and B, and would subsequently drain to either Lake Hamilton or Lake Gin, as appropriate. Consideration of key culvert blockage is included in the runoff analyses for GGNS Unit 1, as described in the following sections.

2.4.2.3.3.2 Drainage of Local Intense Precipitation

The following sections describe the assumptions and analyses made to determine peak runoff discharge from the existing GGNS site.

2.4.2.3.3.2.1 Time of Concentration

The time of concentration (Tc) is defined as the time required for the precipitation falling at the most remote point of the basin to reach the discharge point. The time of concentration includes overland flow time and channel flow time.

*The overland flow time of concentration, (Tco), is computed based upon the method proposed by E. E. Seelye (*Reference 15*) and by Chow (*Reference 16*). The formula proposed by Chow to calculate overland flow time is:*

$$Tco = (2/3)\ [(L*n)/SQR(S)]^{0.467}$$

in which:

Tco	=	*Time of flow for overland flow in minutes*
L	=	*Longest overflow length in feet*
S	=	*Average slope of surface*
n	=	*Retarding coefficient representing the surface roughness. The recommended value of n varies from 0.02 for smooth pavements to 0.80 for dense grass cover (*Reference 16*).*

The average surface slope is determined from the difference in high and low surface elevations divided by the average length of the area.

The channel flow time (Tcd) is calculated based on the average velocity of flow in the channel and length of channel up to the discharge point; then

$$Tc = Tco + Tcd$$

The calculated time of concentration for different subareas ranges from about 24 to 48 minutes. However, during the PMP, the detention of the water due to ponding in each subarea will result *in a longer time of concentration. Therefore, an average concentration time of 30 minutes was used for analyzing the site drainage system capacity during the PMP.*

2.4.2.3.3.2.2 Rainfall Intensity

The PMP rainfall intensity corresponding to a time of concentration of 30 minutes, as used in the analysis, is 16.4 inches/hour. This value is based on the probable maximum half-hour precipitation of 8.2 inches as determined from HMR-33 (Reference 9) *and EM-1110-2-1411* (Reference 10). The PMP rate was calculated in accordance with the criteria of Regulatory Guide 1.59. As stated above, a more recent report, HMR No. 53 (Reference 11), showed only a very small (about 2 percent) increase in probable maximum rainfall rate. Therefore, these values are considered acceptable for a new facility located on the ESP Site.

2.4.2.3.3.2.3 Peak Discharges

Peak discharges from the various subareas were calculated using the rational formula with a rainfall intensity of 16.4 inches/hour and a runoff coefficient of 1.0. Therefore, peak discharge for each subarea is estimated as 16.4 times its area in acres. Peak discharges for Basins A and B were calculated using flood hydrographs developed from the unit hydrographs. For Culvert No. 2, the peak discharge was calculated as the difference between the peak discharges at Culvert No. 1 and the plant subareas. The boundaries and areas in acres for the plant drainage subareas during a PMP are shown in Figure 2.4-13.

The proposed construction areas for a new facility are downstream of these culverts, with exception of proposed construction areas east of the access road (Figure 2.4-18).

2.4.2.3.3.2.4 Ice and Snow

Snowfall in the GGNS site area occurs about once a year with an average depth of 2 inches (Reference 17, Appendix C). *The site is not subject to heavy snow accumulations.*

The maximum depth of precipitation during the winter PMP is smaller than that of the all-season PMP considered in subsection 2.4.2.3.1. Thus, the flood elevation at the site during this condition will be lower than those occurring during the all-season PMP (subsection 2.4.2.3.3).

Therefore, with regards to maximum flooding considerations, the localized intense precipitation due to winter PMP at the plant site would not affect the design of any new safety-related facilities at the GGNS ESP Site.

2.4.3 Probable Maximum Flood (PMF) on Streams and Rivers

The PMF for the Mississippi River has been calculated based on the design-project flood (DPF) for the Lower Mississippi Basin, calculated by the U. S. Army Corps of Engineers (Reference 17). The application of the Corps of Engineers DPF methods for establishing the Mississippi River PMF meets the guidance of Regulatory Guide 1.59. This is consistent with the GGNS UFSAR Project Position on Regulatory Guide 1.59, as described in UFSAR Appendix 3A (Reference 9).

It is important to note that, based on the analysis in Section 2.4.3.5.1, the total Mississippi River and floodplain discharge capacity for water level elevation slightly above 103 feet msl (i.e., above the west bank levee of the Mississippi River) is about 11 million cfs, which is far greater than the estimated PMF discharge of 6.6 million cfs, which was calculated by doubling the DPF discharge rates (see last paragraph in Section 2.4.3.4.1). Thus, the maximum water surface elevation due to a PMF flood in the Mississippi River is about 29 feet below the GGNS Unit 1 plant grade elevation of 132.5 feet msl. Since the proposed site for a new facility is in a location adjacent to the existing GGNS facility, and is located on the bluffs on the east side of the property (Figure 2.4-1), the maximum PMF water surface elevation from a Mississippi River flood would not affect any safety-related structures, systems, or components of the new facility.

2.4.3.1 Probable Maximum Precipitation (PMP)

2.4.3.1.1 Mississippi River Basin

A hypothetical combination of precipitation storms, grouped into sequences, was used to estimate the DPF for the Lower Mississippi River Basin. A number of hypothetical combinations and practical storm transpositions, with regard to time and locations, were developed to establish flood magnitudes that have a reasonable chance of occurring. Details of the hydrometeorological conditions related to the storm combinations are given in Reference 18.

2.4.3.1.2 Local Streams

Distribution of local PMP is discussed in Section 2.4.2.3.1 and the adopted PMP distribution is given in Table 2.4-7. The maximum PMP rainfall intensity is discussed in Subsection 2.4.2.3.3.2.2.

2.4.3.2 Precipitation Losses

2.4.3.2.1 Mississippi River Basin

For the purposes of flood estimation, the Mississippi Basin was divided into drainage areas and subareas. Infiltration indices were determined for each of the subareas by making infiltration studies of storms and floods of record for which adequate hydrologic data were available (Reference 18).

2.4.3.2.2 Local Streams

Information provided by the U. S. Soil Conservation service (Reference 19) *indicates that the predominant soils in this region are of types A and B, which have infiltration rates* (Reference 16) *of 0.30 to 0.45 in/hr and 0.15 and 0.30 in/hr, respectively. In the determination of the PMF for local streams, it was conservatively assumed that no infiltration or retention losses occurred.*

2.4.3.3 Runoff and Stream Course Models

2.4.3.3.1 Mississippi River

Analyses of observed flood discharges at key tributary gaging stations were made for the purpose of determining infiltration indices, recession curves, base flows, and unit hydrographs. Unit hydrographs were developed for 37 separate drainage areas varying in size from 1060 to 80,000 sq mi. These were used to compute flood hydrographs of surface runoff from transposed storms and storms of record for locations where discharge records were not available. Unit hydrographs for 30 areas were determined from floods of record, and synthetic unit hydrographs were computed for seven areas where the recorded hydrologic data were insufficient. Details of the various unit hydrographs are given in an U. S. Army Corps of Engineers report (Reference 18*).*

2.4.3.3.2 Local Streams

Runoff models for streams A and B, and for the plant drainage subareas are discussed in subsection 2.4.2.3.2. A description of the stream course model is contained in subsection 2.4.2.3.3.2.

In assessing the effect of local PMP on the plant area, the following conservative assumptions have been made:

a. *The storm drains are assumed to be blocked and do not carry any runoff.*

b. *No runoff occurs through the abandoned gravel railroad beds, thereby causing all of the runoff to flow over the bed and the abandoned rails if present.*

c. *The runoff coefficient for peak discharges from subareas around the plant is C = 1.0, and no loss due to infiltration or retention occurs.*

d. *The time for peak discharge in the peripheral ditch coincides with the peak discharges coming from the subareas. Actually, peak discharges will not occur at the same time.*

2.4.3.4 Probable Maximum Flood Flow

2.4.3.4.1 Mississippi River

There are innumerable combinations of storms of record that could produce major floods. However, on the basis of meteorological conditions accompanying flood-producing storms, about 35 different storm combinations were studied. Of these, the 13 most logical combinations in which tributary flows occurred without reservoir effects were computed and studied for each storm period and for the total period of each storm combination. The tributary storms and floods forming the various hypothetical floods were analyzed in meteorologically feasible sequences that would cause their peak flow to coincide, as nearly as practicable, at key discharge stations on the Mississippi River. The unregulated flows as a result of 13 hypothetical floods, computed for the tributaries, were routed down the Mississippi River. The preliminary results of the routing of these 13 hypothetical floods were used for comparative purposes in selecting some of the major flood combinations for detailed study. In the detailed study, the storm combinations and arrangements for four hypothetical floods were modified to maximize the flood flows at key locations. Detailed descriptions of the modified storm combinations are given in Reference 18.

The unregulated flows determined for the key gaging stations of the tributary areas were used as a basis for determining the modified hydrographs for the four hypothetical floods due to the operation of reservoirs.

Modified hydrographs were determined for three groups of reservoirs: group E (existing), group EN (existing and due for completion in near future), and group END (existing, near future, and those proposed in the distant future).

The unregulated and modified flows were routed down the Mississippi River to determine the daily flows at St. Louis, Missouri; Cairo, Illinois; Memphis, Tennessee; Helena and Arkansas City, Arkansas; and Vicksburg and Natchez, Mississippi.

The design-project flood discharge obtained (Reference 17) *at certain key locations along the Mississippi River is shown in* Figure 2.4-14*. The Grand Gulf site is located at approximately river mile 406. The DPF hydrograph for the Mississippi River at the site was developed from the Corps of Engineers-derived DPF hydrograph for Arkansas City, which is located at river* mile *547 (*Reference 18*). For this purpose, the discharge for the DPF at Arkansas City was lagged by an appropriate interval of time and augmented to account for the inflow from the Yazoo and Big Black River Basins and other tributaries. Assuming an average flood velocity of 100 mi/day (about 6 fps), a lag of 36 hrs was used. Since the maximum estimated inflow from the Yazoo and Black River Basin is approximately 100,000 cfs* (Figure 2.4-14*) i.e., only three percent of* *the peak DPF discharge, its addition does not cause a significant change in the DPF hydrograph. The regulated and unregulated hydrographs are shown in* Figure 2.4-15.

In order to assign an approximate frequency to the DPF to estimate its severity, a frequency analysis of the Mississippi River floods at Vicksburg was performed. Table 2.4-10 *lists the historical flood peaks for the period 1932 – 1979 at Vicksburg Gaging Station (Station No. 072890).* Data from 1932 through 1988 (Reference 20) has been added to Table 2.4-10 for information and comparison. *In* Figure 2.4-16*, the flood frequency curve for the Mississippi River at Vicksburg obtained from USGS Statistical Computer output based on the Log-Pearson Type III method is plotted. The flood discharges and stages at the site for different frequencies (10, 25, 50 and 100 years) are given in* Table 2.4-11.

Probable maximum flood (PMF) in the Mississippi River at the site is determined from the design project flood (DPF). The DPF is equivalent approximately to the standard project flood (SPF) but is probably somewhat higher. Studies completed to date indicate that the SPF is generally 40 to 60 percent of the PMF (Reference 16)*. Hence, it would be conservative to assume that the DPF is approximately 50 percent of the PMF. At Grand Gulf, the DPF, unregulated by reservoirs, is estimated to be about 3.3 million cfs (*Figure 2.4-15*). Thus, the PMF (unregulated) may be about 6.6 million cfs. The PMF hydrographs at the site are shown in* Figure 2.4-17.

2.4.3.4.2 Local Streams

*The maximum discharges during probable maximum flood for basins A and B are 13,900 and 4,630 cfs respectively (*Figure 2.4-12*), at discharge points A and B (*Figure 2.4-10*) in the floodplain. For drainage basin A, peak flow of 13,900 cfs is equal to a PMF discharge of 4,965 cfs/sq mi and for basin B a PMF discharge of 4,630 cfs corresponds to a discharge of 7,720cfs/sq mi. Examination of the data in* Table 2.4-6 *for observed Mississippi Basin floods indicates that PMF flood discharges of 4,965 and 7,720) cfs/sq mi for basins A and B, respectively, are several times higher than those observed in basins of these sizes on the east bank of the Mississippi River.*

*The natural drainage area up to culvert 1 (basin B) is about 0.5 sq mi. Due to site grading, about 0.35 sq mi of the drainage area of basin B drains up to culvert 1 (*Figure 2.4-18*) and a balance of the drainage from 0.15 sq mi area flows towards basin A. The corresponding prorated PMF discharge in the rerouted outlet channel for basin B at the 15 ft diameter (*Figure 2.4-18*) corrugated-metal culvert 1 (drainage area of 0.35 sq mi) is 2,700 cfs. This value corresponds to the discharge that will be flowing through the channel during the PMF, including the runoff from the plant yard.*

2.4.3.5 Water Level Determinations

2.4.3.5.1 Mississippi River

Figure 2.4-19 *shows the rating curve for the Mississippi River at the site. This rating curve is based on the rating curve at Vicksburg. It is obtained by correlating the stages at Vicksburg and at the site during the period 1972 - 1974 and using the data from water surface profiles (*Figure 2.4-6*), assuming that the discharges at the two locations are equal, since there are no major tributary streams between these locations, except the Big Black River which has a runoff of less than 1 percent of the Mississippi River flow at Vicksburg.*

A flood which produces a peak discharge of about 6.6 million cfs will overtop the levee with maximum elevation of 103 ft. (which can contain about 3 million cfs) and inundate the wide *alluvial floodplain west of the levee. The discharge capacity of the floodplain west of the levee at water level elevation of slightly above 103 feet is conservatively estimated using Manning's roughness coefficient of 0.1, slope of floodplain of 0.2-ft./mile and floodplain width of 60 miles. Based on this analysis, the total river and floodplain discharge capacity for water level elevation slightly above 103 feet is about 11 million cfs, which is far greater than the estimated PMF discharge of 6.6 million cfs. Thus, the maximum water surface elevation due to a PMF flood, in the Mississippi River, is about 29 feet below the plant yard elevation of 132.5 ft*.

Since the proposed site for a new facility is in a location adjacent to the existing GGNS plant, and is located on the bluffs area on the east side of the property (Figure 2.4-1), the maximum PMF water surface elevation from a Mississippi River flood would not affect any safety-related structures, systems or components of a new facility at this location.

2.4.3.5.2 Local Streams

<u>STREAM A</u>

*A 12 foot-diameter corrugated metal culvert (Culvert 9) is provided where the stream draining the area designated Basin A crosses the access road (*Figures 2.4-1 and 2.4-18*). The drainage area at Culvert 9 is about 2.7 square miles and has a peak discharge of 13,490 cfs prorated from the Basin A flood hydrograph (*Figure 2.4-12*). The top of the access road has a minimum elevation of 125 feet. The locally depressed road at this location acts as a broad crested weir during high flows (see profile and section of* Figure 2.4-20*). Water level resulting from the discharge over the access road is calculated using a weir discharge coefficient of 2.9* (Reference 21*) and an average weir length of 580 feet (*Figure 2.4-20*). It is conservatively assumed that Culvert 9 is completely blocked causing the entire PMF flow to overtop the access road. The resulting water surface elevation at the road is 128.9 feet.*

A backwater analysis of stream A using the HEC-2 program for water surface profiles (Reference 22) *was performed to determine the water level at the outlet of the drainage ditch northeast of the power block. Coefficients of expansion and contraction used in the analysis were 0.3 and 0.1, respectively* (Reference 22)*. The cross sections used in the analysis are shown in* Figure 2.4-21*. The PMF peak discharge was taken as 13,490 cfs, and a conservative Manning's coefficient of 0.1 was used. Based on this analysis the maximum water level at the ditch outlet into Stream A is 128.93 feet.*

<u>STREAM B</u>

The stream draining the area designated Basin B is rerouted around the Unit 1 cooling tower. The rerouted channel is concrete lined to a depth of 5 feet, with a 6.67-foot bottom width and side slopes of 3:1. Riprap is provided above the concrete to the plant yard grade. The riprap gradation curve is shown in Figure 2.4-22*. Based on this curve, the median riprap size is about 9 inches. The channel slope of 0.4 percent in the downstream reaches and 1 percent upstream of Culvert 15 makes a hydraulically steep channel* (Reference 23)*. A 15-foot-diameter culvert (Culvert 1) is placed at the downstream end of the channel and under the access road to pass the flow to the floodplain. The channel and culvert are designed to safely pass the PMF from Basin B without endangering safety-related facilities.*

The headwater level for Culvert 1 is calculated using the basic data in Table 2.4-12*. The entrance coefficient of 0.3 is based on the smooth tapered inlet as shown in* Figure 2.4-23 (Reference 24).

*The water surface profile due to the PMP for the Basin B stream channel (*Figure 2.4-24*) is calculated using a standard step backwater method* (Reference 23)*. The analysis uses a peak discharge at Culvert 1 of 2,775 cfs for a drainage area of about 0.35 square mile, prorated from the Basin B hydrograph (*Figure 2.4-12*). It conservatively assumes concurrent peak discharges at all the culverts draining into the channel, obtained from the rational formula as discussed in subsection 2.4.2.3.3.2.1.3* [Section 2.4.2.3.3.2.3]*. The channel backwater analysis assumes a composite Manning's n value as given in* Table 2.4-13 *and expansion and contraction coefficients of 0.3 and 0.1, respectively. Peak discharges for each culvert are subtracted to yield corresponding discharges along the channel.*

Because of the headwater level required at the culvert, the water depth in the channel is greater than the normal depth. Thus, a hydraulic jump, as shown in Figure 2.4-24*, occurs about 1,200 feet upstream of the entrance to Culvert 1. Upstream of this hydraulic jump there is uniform flow in the channel. Based on the criteria of Chow* (Reference 23)*, the ratio of upstream to down-stream depths for this jump yields a Froude number of 1.1. This Froude number classifies the jump as undular or low energy* (Reference 23)*. The corresponding energy dissipation of this type of jump is very low, less than 1 percent.*

The possibility of a substantial amount of blockage of Culvert 1 is highly unlikely because the channel is lined up to the l00-year flood level and riprap is placed above the concrete. The watershed drained by the channel (upstream of Culvert 2 and the plant yard) contains no source for debris that may cause blockage. However, in the unlikely event that some debris could cause blockage of about 45 percent of the culvert entrance area, part of the PMF discharge can be passed through the culvert and the remaining volume can be impounded in the channel and the yard area around the Unit 1 cooling tower below elevation 132.8 feet.

2.4.3.6 Coincident Wind Wave Activity

The maximum water surface elevation in the Mississippi River at the plant site, due to wind-wave activity coincident with the PMF, was computed for the following conditions:

- *a. Static PMF flood elevation of 103 ft (levee top elevation)*
- *b. An overland wind velocity of 40 mph; the wind velocity over water was assumed to be 1.3 times higher than over land*
- *c. Near the plant site, the east bank bluff consists of natural loessial slope approximately 2 (horiz.) to 1 (vert.) and covered with vegetation*

A rise in water level in the Mississippi River to an elevation of 103 feet will create a lake between the bluffs and the levees; the boundaries of the lake near the site are shown in Figure 2.4-25*. The actual fetch (shown by line A in* Figure 2.4-25*) is approximately 4.3 mi which is assumed to be the effective fetch.*

A ground surface profile along the fetch is shown in Figure 2.4-26*. This profile is typical of the floodplain near the site. The average depth of water in the lake (except for the channel of the Mississippi River) is approximately 35 ft.*

On the basis of the preceding data and with 40 mph over land wind speed, the wind setup, significant wave height H_s, the maximum wave height, and the wave runup were determined by using the procedures described by Shore Protection Manual (Reference 25).

The significant wave height for this case is 4.4 ft and the wave period is 4.1 seconds. The results of these computations are summarized in Table 2.4-14*. The maximum water surface* *elevation, including runup will be 108.8 ft. Therefore, the plant, at an elevation of 132.5 ft, will not be affected.*

The integrity of the east bank bluffs in the vicinity of the plant due to water and wind-wave action during a prolonged severe Mississippi River flood was evaluated for GGNS Unit 1 (Reference 8, Section 2.4.3.6). The proposed location for a new facility power block (approximate center of the designated area) is about 1200 ft. west and 1000 ft. north of the GGNS Unit 1 reactor containment center (Figure 2.1-2) and, thus, is closer to the east bank bluffs. Potential impact to a new facility relative to bank stability would be evaluated as required in the final design, taking into consideration the final siting of safety related structures and the impact of construction on nearby banks. Section 2.5.5 provides additional discussion related to slope stability.

2.4.4 Potential Dam Failures, Seismically Induced

The effect of dam failures on the water surface elevation of the Mississippi River has been analyzed considering that the Mississippi River is carrying a flood of DPF magnitude with water surface elevation of 96.2 ft. Although there are no dams on the Mississippi River upstream of the site, in a hypothetical dam failure analysis the peak discharge from failure of the nearest largest upstream dam on a tributary to the Mississippi River was added to the DPF discharge of the Mississippi River near the site. The details for the analysis are discussed in the following sections.

Currently the DPF for the Mississippi River at the GGNS site is 102.1 ft (References 7 and 33). However, based on the analysis for GGNS Unit 1, which follows, and considering this increased DPF, there is no potential for impact to a new facility, located as shown in Figure 2.4-1, from a potential dam failure coincident with the DPF.

2.4.4.1 Description of Reservoirs

*To study the nature of storage in the reservoirs on the different river basins, the Mississippi River Basin was divided into six major drainage areas (*Figure 2.4-27*):*

a. Upper Mississippi

b. Missouri

c. Tennessee-Ohio

d. Red-Ouachita

e. Arkansas-White

f. Lower Mississippi

Numerous regulatory structures, including levees, revetments, navigation locks, and major dams, have been built on these rivers. The total number of dams in the basin exceeds 300, of which 61 dams have capacities greater than one million acre-ft.

Figure 2.4.28 *shows the seismic risk map of United States* (Reference 26). *The United States is divided into three zones of seismic risk. Zone 0 represents minimum risk while Zone 3 represents maximum risk.*

The information on dams listed in Table 2.4-15 *is taken from the report of the International Commission on Large Dams (*Reference 27*) and is arranged on the basis of the major drainage areas in which the dams are located.* Table 2.4-15 *lists dams with reservoir capacities greater than one million acre-ft.*

a. *Upper Mississippi Basin*

The Upper Mississippi Basin has a total estimated storage of 10.0 million acre-ft. Only three dams have capacities greater than one million acre-ft. All dams in this sub-basin are in Seismic Zone 1.

b. *Missouri Basin*

The total storage in the dams of this basin is estimated to be 140 million acre-ft. This includes 21 dams with a capacity of one million acre-ft or more. The dams of this basin are in Zones 1 and 2.

c. *Tennessee-Ohio Basin*

The Tennessee-Ohio Basin contains numerous regulatory structures. The total estimated storage is approximately 45 million acre-ft. There are 14 dams with reservoir capacities greater than one million acre-ft. Nine are in Seismic Zone 2 and the other five are in Zone 3.

d. *Red-Ouachita Basin*

The Red River Basin joins the Mississippi downstream from the site. Hence, consideration of the dams and storage in this basin is not required.

e. *Arkansas-White Basin*

The total estimated storage in this basin is 45 million acre-ft, with 20 dams having capacities greater than one million acre-ft. The Beaver Reservoir on the White River in Arkansas and Oologah Dam on the Verdigris River in Oklahoma are in Zone 3. There are four dams in Zone 2 and the rest of the dams are in Zone 1.

f. *Lower Mississippi Basin*

The Lower Mississippi Basin has an extensive river-control system consisting of levees, revetments, cutoffs, and floodways extending from Cairo, Illinois, to the Gulf of Mexico. There are two dams in Zone 2.

*Between St. Louis and New Orleans, the Mississippi River flows through the lower plains. The floodplain of the Mississippi River covers a relatively flat valley 30 to 60 mi. wide. The width of the floodplain becomes indeterminate near the Gulf of Mexico. The actual channel flow is, however, regulated to a much narrower width of about two to four mi by a system of levees. On the west bank, the levee line begins just south of Cape Girardeau, Missouri, and, except for gaps for admitting tributaries such as the St. Francis, Arkansas-White, and the Red Rivers, extends to the Gulf of Mexico. The area on the eastern side is protected by levees alternating with high bluffs. Levees run in short lengths between Hickman, Kentucky, and Vicksburg, Mississippi. The east bank is hilly from Vicksburg to Baton Rouge, Louisiana. The levees begin again here and run continuously to a point near the river mouth (*Figures 2.4-3 and 2.4-3a*).*

Between Cairo, Illinois, where the Ohio joins the Mississippi, and Grand Gulf, the floodplain is relatively narrow on the eastern side, but is 30 to 60 miles wide on the western side. The levee crests, as designed by the Corps of Engineers, allow in general a freeboard of about three ft above the DPF for the Mississippi River. At Grand Gulf, the ground elevation on the west bank becomes equal to the levee top elevation at a distance of about 60 miles behind the levees. Figure 2.4-29 shows the DPF elevations between Cairo, Illinois, and the Head of Passes.

The summary of the dams closest to the site in each sub-basin, storage volume, and the approximate distances from the site are as follows:

Sub-Basin	*River*	*Total Storage (million acre-ft)*[*]	*Dam Closest to the Site*	*Approximate Distance to the Site (river mi)*
Missouri	*Missouri*	*6.10 [6.300]*	*Fort Randall Reservoir and Dam*	*1300*
Ohio	*Tennessee*	*6.00 [6.129]*	*Kentucky*	*450*
	Cumberland	*2.25 [2.082]*	*Barkley*	*450*
White	*White*	*1.98 [1.983]*	*Norfork Reservoir and Dam*	*350*
Arkansas	*Arkansas*	*1.88 [1.348]*	*Keystone Reservoir and Dam*	*475*
Lower Mississippi	*Mississippi*	*1.34 [2.722]*	*Grenada Reservoir and Dam*	*200*

*Values in [brackets] are updated numbers taken from Reference 28

Of these, the Kentucky reservoir, because it is the largest in the system and closest to the site, was considered in hypothetical dam failure analysis.

Updated dam listings (Reference 28) were reviewed, and the Kentucky reservoir is still the largest in the system and closest to the site. The maximum storage capacity for the Kentucky reservoir is revised to 6,129,000 acre-feet based on the new data.

2.4.4.2 Dam Breaching Effect on the Site

In order to analyze the effect of potential dam failures on the water levels at the site, the following assumptions were made:

a. *The Mississippi River is assumed to be carrying a flood of the DPF magnitude.*
b. *The Kentucky Reservoir in the Tennessee River Basin is assumed to be at the design-flood level, and peak discharge released from the dam failure is superimposed on the Mississippi River DPF discharge near the site.*

Breaching of dams would release water and augment the flow in the Mississippi River. The levee system of the Mississippi River offers, in general, a freeboard of three to five ft above the DPF [of 96.2 ft.] *flowline. High stages due to dam-breaching floods will result in the overtopping of levees and diversion of water into the 30 to 60 mi wide floodplain beyond the levees (*Figure 2.4-30*). Considering the hypothetical complete failure of Kentucky Dam, the initial discharge in this case will be on the order of about 3.0 million cfs* (Reference 29)*, and the flood stage and velocity would attenuate severely as it travels toward the site about 450 mi downstream. Even considering that this dam-breach discharge is released near the site, the total discharge at the* *site, including that of the DPF, will be about 5.7 million cfs, which is below the probable maximum flood discharge of 6.6 million cfs.*

The above analysis is based on conservative assumptions. In fact, the flood peaks and velocity would be attenuated further due to basin storage, friction, and time required emptying the reservoirs. Therefore, the plant at an elevation of 132.5 ft. is safe from the effect of catastrophic dam failures even when combined with the DPF.

As stated above, breaching of dams would augment the flow in the Mississippi River. High stages due to dam-breaching floods would result in the overtopping of levees and diversion of water into the 30 to 60 mile wide floodplain beyond the levees (Figure 2.4-30). This could be expected to occur sooner given the higher DPF for the site area. However, the immensely large floodplain will effectively maintain a maximum water level of about 103 feet resulting from any major dam break upstream, coincident with the DPF. The maximum water surface elevation due to a DPF flood in the Mississippi River is about 29 feet below the Unit 1 plant yard elevation of 132.5 feet msl. Since the proposed site for a new facility is in a location adjacent to the existing GGNS plant and located on the bluffs area on the east side of the property (Figure 2.4-1), the maximum water surface elevation from a Mississippi River flood would not affect any safety-related structures, systems or components of a new facility. Therefore, a new facility at the proposed location on the bluffs at the GGNS ESP Site is safe from the effects of catastrophic dam failures even when combined with the DPF.

The maximum storage capacity for the Kentucky reservoir is revised to 6,129,000 acre-feet based on the new data (Reference 28). However, this 2% increase would have no adverse impact on the analysis results or conclusions.

2.4.5 Probable Maximum Surge and Seiche Flooding

The site is not in a coastal region or on a lake. *Hence, consideration of surge and seiche flooding is not warranted.*

2.4.6 Probable Maximum Tsunami Flooding

The site is located about river mile 406 above the Head of Passes, and is not in a coastal region. *No effects on water level in the Mississippi River due to geoseismic activity are expected to occur at this location.*

2.4.7 Ice Effects

Water temperatures at the USGS gaging station on the Mississippi River at Vicksburg for the period 1973 - 1999 are summarized in Table 2.4-16, and the lowest temperature recorded at the USGS station is 34.7 °F. As reported in Reference 8 water temperatures recorded by the Corps of Engineers of the Mississippi River at Vicksburg for the period 1962-1979 are summarized in Table 2.4-16a. The lowest water temperature reported by the Corps of Engineers in Table 2.4-16a was a range of 30 to 40 °F in January 1970. It is evident from this UFSAR and more recent data that water temperatures are above the freezing point most of the time.

The Corps of Engineers historical database of ice jams on the Mississippi River was searched, and no ice jams have been reported on the Mississippi River in Mississippi or Louisiana. One ice jam was reported for the Mississippi River in Arkansas on February 1, 1940 (Reference 30). Hence, the possibility of a flood due to an ice jam occurring downstream of the site appears to be remote, especially in view of the continued development of river control works for navigation, irrigation, and flood control on the Mississippi River and its principal tributaries.

Even if such a jam were to occur, a rise in water level above 103 ft at the site would result in overtopping of the levees and diversion of water into the alluvial valley to the west. The proposed site for a new facility, located on the upland area of the property is significantly above 103 ft., and would not be affected.

In Section 2.4.8 of the NRC Safety Evaluation Report (NUREG-0831) for GGNS Unit 1, the NRC reported the occurrence of an ice jam at Vicksburg, MS on February 3, 1940. However, the NRC concluded that the occurrence of a major ice jam on the Mississippi River is very unlikely. The NRC concurred that ice flooding was not a design basis consideration for the GGNS site.

2.4.8 Cooling Water Canals and Reservoirs

There are no current or proposed cooling water canals or reservoirs at the Grand Gulf Nuclear Station site.

2.4.9 Channel Diversions

Stabilization and protection of riverbanks of the Mississippi River in the Lower Mississippi Region has been underway by the U. S. Army Corps of Engineers. Means used by the Corps of Engineers for protecting the banks to prevent caving and erosion include revetment composed of an articulated concrete mattress under water, and stone (riprap) paving above the water. Both are placed on a graded bank.

The revetment mattress is composed of 20 individual concrete blocks or slabs, each 4 ft. long, 14 in. wide, and 3 in. thick. The individual blocks are assembled into unit squares 4 ft wide and 25 ft long using corrosion-resistant reinforcing fabric, and the unit squares are fastened together with twisted wires and cable clips to form a 140 ft wide mattress along the riverbank. Each succeeding mattress overlaps the previous mattress like shingles on a roof. Normally, an entire bend is revetted from the upstream point of river current attack to the point where the channel crosses to the opposite bank.

The Mississippi River is known to have undergone and is presently undergoing lateral shifting near the Grand Gulf site. This is evidenced by the presence of oxbow lakes, low-lying swamps, and sand bars. The river divides itself around Middle Ground Island rejoining at approximately river mile 408 (Figure 2.4-5). In order to stabilize the river alignment, the Corps of Engineers has carried out extensive river control work in this area. This includes the construction of submerged dikes across the western channel to divert flow to the eastern channel and construction of the Grand Gulf revetments on the east bank from approximately river mile 400.5 to 407.9 and 408.2 to 410.0 (Reference 31).

The Grand Gulf revetments in the two sections from approximately river mile 400.5 to 405.0 and 408.5 to 409.6 were completed in the 1960s and 1970s. The intervening section, which includes the river stretch near the GGNS site, was left unprotected to undergo erosion until it attained an acceptable alignment. The section on the east bank along the GGNS site boundary was completed in stages from the mid-1970s to the early 1980s, with a small gap at the existing GGNS barge slip (Reference 31). The upper banks are paved with riprap.

It is expected that these measures will stabilize the Mississippi River shoreline near the site. The Corps of Engineers has no plans for additional construction in the immediate vicinity of the site except for occasional maintenance of the existing structures (Reference 7). The Corps of Engineers continues to evaluate the need for additional shoreline work, and would be expected to make improvements as considered appropriate. However, those actions would not be expected to impact site suitability.

2.4.10 Flooding Protection Requirements

A specific plant design for a new facility has not been selected; therefore, the final plant grade has not been determined. Safety-related SSCs for a new facility would be located above maximum flood elevation, or flood protection would be provided such that the requirements of GDC-2 and 10 CFR 100 would be met.

2.4.11 Low Water Considerations

2.4.11.1 Low Flow in Streams

*The Lower Mississippi derives its water from six major sub-basins (*Section 2.4.2, Figure 2.4-4*). Therefore, low-flow conditions in the Mississippi are a function of the nature of flow in the individual sub-basins. The percentage distribution of mean flow is shown in* Table 2.4-1*. The hydrometeorological conditions in the basin vary greatly. Although it is difficult to predict low-flow values in the Lower Mississippi, analysis may be made on the basis of statistical considerations (*Section 2.4.11.3*). There are no dams on the Mississippi River downstream of the site that could affect the low flow condition.*

2.4.11.2 Historical Low Water

Low-water conditions at the site were studied on the basis of stream-flow records at Vicksburg Gaging Station. The minimum daily flows observed at Vicksburg, Mississippi during the period 1932 - 1979 are presented in Table 2.4-17*. In addition, data on minimum river stages expressed in ft MSL are included. The minimum flow observed during the period of record was 99,400 cfs on November 1, 1940. The corresponding historical low-flow elevation at the site is about 28 ft. During the same year, the mean 30-day low flow was 108,000 cfs.*

The minimum daily flows from Reference 20 observed at Vicksburg, Mississippi during the period 1932 - 1988 are also presented in Table 2.4-17. The minimum flow observed during the period 1932 to 1988 for the USGS station was 100,000 cfs on November 1, 1939. The minimum flow observed during the period from 1930 to 2000 was 93,800 cfs on August 31, 1936, according to Corps of Engineers data[1] (Reference 32). This data is consistent with the data used in the analysis for GGNS Unit 1 licensing.

A minimum stage of 39.20 ft msl was observed on February 3, 1940, when the discharge was reduced by ice jams upstream. Flow records for the Lower Mississippi River for the period 1932-1979 were reviewed for incidences of instantaneous low flow. The records indicate that the Mississippi River flow does not undergo sharp and instantaneous reductions of flow. The magnitude and nature of the variations of instantaneous flows in the site region were studied using the records furnished by the continuous recording gauge by the U. S. Army Corps of Engineers at Vicksburg, Mississippi, for the year 1967. A typical trace of the low-flow period during the year 1967 is shown in Figure 2.4-31*. This figure indicates that the rate of fall in the river stage is very gradual, which in turn indicates that the variation in flow is also small.* Table 2.4-18 *gives the dates on which lowest flows occurred, the mean stage and discharge associated with these flows, and the lowest instantaneous stage during the low-flow period for the period 1962 - 1971. Discharges corresponding to lowest instantaneous flows were*

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[1] Data for the year 2000 is still described as preliminary by the Corps of Engineers.

computed by using stage discharge relations furnished by the U. S. Army Corps of Engineers. Values of instantaneous low flows are given in Table 2.4-18*. It is seen from the data given in* Table 2.4-18 *that the difference between instantaneous low-flow values and mean one-day low-flow values is less than two percent. Therefore, the low-flow analysis which has been developed for the site, based on mean one-day low flow, is considered justifiable.*

The Corps of Engineers historical database of ice jams on the Mississippi River was reviewed for this report. See Section 2.4.7 for additional discussion. Ice jams are not a design basis consideration for the GGNS ESP Site.

Table 2.4-19 *gives the 1, 7, and 30 day low flows for different recurrence intervals. This is based on the historic flow data for the period of flow 1933 - 1979 at Vicksburg Gaging Station obtained from the U. S. Geological Survey.* Figure 2.4-32 *shows the plot of frequency duration for low flows of the Mississippi River at Vicksburg.*

According to information provided by the U.S. Army Corps of Engineers, the Low Water Reference Plane for river mile 406 is 37.5 feet msl (Reference 1). The Low Water Reference Plane is based on the average stage from 1982-1991 representing the discharge equaled or exceeded 97 percent of the time (Reference 33).

Makeup and service water for a new facility would be supplied by an intake located on the east bank of the Mississippi River on the north side of the existing barge slip. A new facility would require a maximum makeup flow rate of approximately 85,000 gpm of water (equivalent to about 190 cfs). Using the most conservative minimum flow value at Vicksburg of 93,800 cfs (Reference 32), the maximum expected withdrawal for a new facility would be approximately 0.2% of the minimum historical flow. Design details of the intake would consider the minimum river level for location of inlet screens.

In the event of an emergency shutdown of the reactor, and assuming that the makeup water system is not in service, emergency service water (the ultimate heat sink) for a new facility provided from closed-loop systems utilizing basins, which would not rely on the river intake for cooling capability, would be unaffected by the low river stage.

2.4.11.3 Future Controls on the Mississippi River

Continued development of upstream reservoirs for flood control, navigation, irrigation, low-flow augmentation, and hydroelectric power will alter the flow characteristics of the Lower Mississippi. In a study prepared by the Mississippi River Commission (Reference 17), *the river flows were projected, with anticipated development in the basin, to the year 2020. This study indicated that the future development in the Mississippi River will tend to increase the low flows and decrease the periods of high flow.*

The proposed surface water intake for a new facility could be impacted by future controls on the Mississippi River; however, the Corps of Engineers has no plans for additional construction in the immediate vicinity of the site except for occasional maintenance of the existing structures (Reference 7). It is anticipated that the Corps of Engineers will continue control measures to maintain the river alignment and to allow adequate flow for navigation purposes.

The Corps of Engineers and the State of Mississippi do not currently restrict the quantity of water that can be withdrawn from the Mississippi River. The Mississippi Department of Environmental Quality (MDEQ) issues permits for surface water withdrawals that are effective for 10 years. The permit may then be renewed for an additional 10 years (Reference 3).

The owner of a new facility would be required to coordinate with the Corps of Engineers, and obtain permits from the Corps and/or appropriate regulatory agencies for construction of the embayment and intake structure when the final design of the embayment and intake structure and its exact location are defined. The design and placement of the embayment and intake structure would be in accordance with the Corps of Engineers guidance, MDEQ and EPA requirements, and good engineering practice.

2.4.11.4 Plant Requirements

Makeup to the normal heat sink cooling towers, balance of plant cooling systems (e.g., plant service water), and other raw water makeup needs of a new facility would be supplied from an intake located on the east bank of the Mississippi River near the location of the existing barge slip. The intake structure would include necessary intake screens, pumps, etc., to convey the river water to a system of clarifiers or other type cleanup equipment before its use in the facility. Normal makeup flowrate to the plant would be approximately 50,320 gpm, and maximum expected makeup flow is approximately 85,000 gpm. Refer to Table 1.3-1 for specific users of this makeup water, and amounts required. Using the most conservative minimum flow value at Vicksburg of 93,800 cfs (Section 2.4.11.3), the facility withdrawal would be about 0.2% of the minimum river flow. Intake and embayment final design would include consideration of sedimentation and littoral drift influence on the ability to provide the necessary facility makeup water.

The normal heat sink circulating water system for the new facility, if required, would be a closed-cycle type system coupled with either hyperbolic natural draft wet cooling towers or mechanical draft wet cooling towers. Circulating water system flow through the cooling towers, on a per unit basis, is estimated at 865,000 gpm (Table 1.3-1).

Effluent from a new facility would be combined with that from the existing GGNS Unit 1 facility, and would be discharged into the river downstream of the new facility intake such that recirculation to the embayment area and intake screens of the new facility would be precluded.

Emergency cooling water for a new facility would be provided from separate closed-loop cooling system(s) which utilize storage basins with mechanical draft cooling towers, and which would not be reliant on the source of water from the river intake, except for normal (non-emergency operation) makeup. Therefore, low river water conditions would not impact the ability of emergency cooling water systems and the ultimate heat sink to provide the required cooling for normal operations, anticipated operational occurrences and emergency conditions.

The final location for the embayment and intake structure would be chosen such that there would be inconsequential interference, if any, with the pumping ability of the surrounding existing GGNS Unit 1 radial collector wells. The existing GGNS Unit 1 radial well no. 5 is located about 250 ft. to the south of the existing barge slip, and has one lateral line which extends directly beneath the barge slip inlet area. This lateral line is located at a depth of about (-) 40 ft. msl, which is well below the depth of excavation that would be required for a river intake (estimated bottom of the embayment at about 10 ft. msl). The locations of the radial well fields are shown on Figure 2.4-33 (only the south well field is used), and the Unit 1 radial wells are shown on Figures 2.4-1 and 2.4-40. A proposed Well #6 would be located about 1000 ft. north of the existing barge slip area, out of the area proposed for the embayment and intake structure.

2.4.11.5 Heat Sink Dependability Requirements

Makeup and non-emergency cooling water (e.g., plant service water) for a new facility would be provided via an intake on the east bank of the river.

Emergency cooling (the ultimate heat sink) for a new facility would be provided from closed-loop cooling system(s) which utilize basins and mechanical draft cooling towers, and which would not be reliant on the source of water from the river intake for cooling. Since the emergency cooling water system will be a separate closed-loop system, no warning of impending low flow from the river water makeup system would be required.

2.4.12 Ground Water

2.4.12.1 Description and Onsite Use

2.4.12.1.1 Regional Aquifers, Formations, Sources, and Sinks

*The region of ground water investigations discussed herein encompasses the area east of the Mississippi River within approximately a 25-mile radius of the plant site (*Figure 2.4-2*). The region includes most of Claiborne County and bordering areas of Warren, Hinds, Copiah, and Jefferson Counties, Mississippi.*

The area west of the Mississippi River is excluded from this study because the river forms an effective hydrologic boundary.

Geologic formations dip south across the region at an average of 26 ft per mile and strike approximately east-west. The regional water table slopes southward and generally conforms to the attitude of geologic structure and land surface. The water table is 50 to 100 ft below land surface in the upland areas and is at or near the surface in the lowland areas (Reference 55). *The stratigraphic position of the regional geologic formations, along with a brief description of their physical and waterbearing characteristics, is presented in* Table 2.4-20.

The principal sources of ground water occur in the Holocene Mississippi River alluvium, Pleistocene terrace deposits, and the Miocene series, primarily the Catahoula Formation. Other less prominent aquifers occur in the Citronelle Formation (Pliocene-Pleistocene), Forest Hill Formation (Oligocene), and the Cockfield Formation (Eocene) (References 55, 57).

<u>Holocene Mississippi River Alluvium</u>

The Mississippi River alluvium is the most prolific waterbearing unit in the region. The alluvium, up to 200 ft in thickness, generally consists of a basal, coarse-sand and gravel zone grading upward into silt and clay. Recharge is derived from precipitation in areas where surficial deposits are permeable and from adjacent formations. The Mississippi River and its tributary streams, and lakes also contribute recharge during high water levels (Reference 17).

<u>Pleistocene Terrace Deposits</u>

Terrace deposits underlie the Holocene alluvium locally and blanket the upland areas bordering the Mississippi River and its larger tributaries. In the uplands, the terrace deposits are commonly overlain by Pleistocene loess. Terrace deposits are similar in lithology to Holocene alluvium and vary regionally from 0 to 120 ft in thickness. Rural domestic wells are completed at shallow depths in these deposits along the Mississippi River and its main tributaries and yield several gallons per minute (Reference 55*). Recharge to the terrace deposits is from underflow and downward seepage through overlying loess.*

<u>Miocene Series</u>

Aquifers of the Miocene series underlie the entire region. The Miocene series consists of three stratigraphic units: Pascagoula, Hattiesburg, and Catahoula Formations. The Pascagoula and Hattiesburg Formations are important as aquifers only in the extreme southeastern portion of *the region. Permeable zones within the Catahoula Formation are the source of water for the majority of public and private wells in Claiborne, Copiah, and Jefferson Counties, and they supply several small wells in southern Hinds and Warren Counties. The depth to Miocene aquifers varies greatly over the region from near surface in the north to about 1100 ft in southern areas. The Catahoula Formation consists of lenticular deposits of sand, clayey silt, and sandy-silty clay, locally cemented. Sand layers are predominantly fine-grained and range in thickness from a few inches to more than 100 ft* (Reference 55*). The recharge area for the Catahoula lies to the north in Warren and Hinds Counties beneath the alluvial plain and loess bluffs.*

2.4.12.1.2 Local Aquifers, Formations, Sources, and Sinks

*The Mississippi River alluvium is the principal aquifer at the site. With the potential for induced recharge from the river, the alluvial aquifer is capable of meeting plant service water requirements. The uplands terrace deposits contain localized permeable zones which yield several hundred gallons of ground water per minute. The Catahoula Formation underlies the alluvial and terrace deposits and generally contains ground water under semiconfined conditions. The loess deposits, Vicksburg group, and formations below the Forest Hill Formation are not considered to have water supply potential at the site (*Table 2.4-20*).*

<u>Holocene Mississippi River Alluvium</u>

The Mississippi River alluvium occupies the floodplain portion of the site (Figure 2.4-33)*. It consists of a surficial layer of clay and silt overlying lenses of sand, gravel, silt, and clay. In the area between Hamilton and Gin Lakes and the Mississippi River, the alluvium is predominantly a fine-to-medium grained sand with varying amounts of gravel, silt, and clay. Alluvium thickness, as determined by borings, generally ranges from 95 to 182 ft. The greatest thickness of gravel generally occurs at the base of the alluvial deposits just above the Catahoula formation. East of the lakes and west of the bluffs, clay and silt are the principal constituents of the alluvium, with lesser amounts of sand and gravel present. Hydrogeologic cross sections of the floodplain area are shown on* Figures 2.4-36 and 2.4-37.

Recharge to the alluvium is derived from infiltration of precipitation, westward flow of ground water across the terrace-alluvium contact at the bluffs, and the Mississippi River during high river stages. It is unlikely that any appreciable recharge is derived from Hamilton and Gin Lakes due to a thick clay/silt layer beneath the lakes.

<u>Pleistocene Loess and Terrace Deposits</u>

Boring log data indicate that the eastern uplands area of the site is blanketed by 22 to 82 ft of Pleistocene loess. The loess deposits generally lie above the regional water table (Figure 2.4-37*). However, saturated zones in the loess were encountered at a few locations just above the contact between the loess and the underlying terrace deposits. These are localized occurrences in areas where impermeable terrace clays form shallow basins in which infiltrating water accumulates.*

The loess is underlain by 0 to 151 ft of Pleistocene terrace deposits. Terrace materials are similar in lithology to the Mississippi River alluvium and consist of lenticular deposits of sand, gravel, silt, and clay. Perched water tables were encountered at various depths in the immediate vicinity of the Power Block Structures, where the underlying Catahoula Formation forms a ridge-like feature that rises about 20 ft above the regional water table (Figure 2.4-37). *Ground water migrates downward through the terrace deposits and accumulates on the terrace clay lenses* *above the Catahoula or at the terrace/Catahoula contact above the regional water table. Perched water tables also were encountered in the terrace deposits at observation wells OW 201 and OW 208 outside the plant area* (Figure 2.4-33).

Hydrogeologic properties of the terrace deposits at the site vary greatly due to the lenticular nature of the deposits. Thick deposits of relatively clean sand and gravel located in the vicinity of TW-1 (Figure 2.4-33) *represent the most productive zone within the terrace deposits at the site. Terrace sand and gravel deposits outside of this area are thinner and are finer grained.*

Regionally, the primary source of recharge to the terrace deposits is via percolation through the overlying loess. The Mississippi River recharges the terrace deposits locally during high water.

Miocene Series

The Catahoula Formation is continuous across the entire site and lies beneath the floodplain alluvium and terrace deposits and at a few locations directly beneath the loess. It consists of lenticular beds of locally indurated fine sand, silty clay, and clayey silt with occasional silt and fine sand seams.

Recharge to shallow water-bearing zones within the Catahoula Formation is from percolation through the overlying terrace deposits and alluvium. Deeper water-bearing zones within the Catahoula receive recharge laterally at the contact with floodplain alluvium and terrace deposits to the north.

A hydrogeologic cross-section, which indicates the approximate east and west boundaries of the proposed construction area for the power block of a new facility, is shown in Figure 2.4-37.

The Pascagoula, Hattiesburg, and Catahoula formations are part of the Southern Hills Regional Aquifer System (Reference 41), which was designated as a sole source aquifer in 1988 (Reference 40).

2.4.12.1.3 Onsite Use

2.4.12.1.3.1 Plant Operating Requirements

GGNS Unit 1 Facility Requirements

Plant service water is supplied from radial collector wells located in the floodplain that parallels the Mississippi River (Figure 2.4-33). *The collector wells are designed to derive water from the Mississippi River via induced infiltration.*

*The Mississippi River will provide a reliable source of water for the collector well system even during low-flow periods. The lowest recorded water level in the Mississippi River near the site is El. 28-0 (*Section 2.4.11.3*) which is sufficient head to induce flow to the collector wells* ((Appendix 2.4A) [Appendix 2.4A of Reference 8 not included herewith]*.). At this stage the river discharge is about 100,000 cfs and maximum plant demand under the most adverse conditions will be less than 103 cfs.*

GGNS Unit 1 currently submits an Annual Water Use Survey to the Mississippi Department of Environmental Quality (MDEQ). According to the most recent data available for the 2001 calendar year (Reference 43) the facility has 18 water wells with a total of 1.13E+10 gallons pumped in 2001. This total includes the four radial collector wells at 21,332 gpm; three wells used for general site purposes rated at 513, 535, and 577 gpm; and dewatering wells.

Three wells completed within the Catahoula formation are currently used to supply water for general site purposes including potable, sanitary, air conditioning and landscape maintenance.

Two of the wells are in routine use and have electric pumps, and the third well is a backup well with a diesel pump. The backup well (north construction well) was installed in 1976 to supply water for construction purposes, and the remaining two wells (north drinking water well and south drinking water well) were installed in 1995 and 1996. During GGNS Unit 1 refueling outages, the two wells operate at near full capacity. Therefore, these existing wells would not have adequate production to supply the water needs for a new facility.

New Facility Requirements

Makeup (cooling tower makeup and other raw water needs) and normal service water for a new facility would be supplied from the Mississippi River via an intake located on the east bank of the river on the north side of the existing barge slip (see Section 2.4.11 and Figure 2.1-1). Ground water would likely be utilized for general plant water uses including potable, sanitary, fire protection, demineralized water, and landscape maintenance. The expected average consumption of ground water for these uses is approximately 1,310 gpm (Table 1.3-1). The expected maximum consumption of ground water for these uses is approximately 3,570 gpm (Table 1.3-1). Since the existing GGNS Unit 1 facility ground water wells would not have adequate capacity for a new facility, the installation of additional wells (likely in the Catahoula formation) for these purposes would be necessary, if ground water is the desired source.

2.4.12.1.3.2 Construction Requirements

Construction activities required approximately 500,000 gpd (gallons per day) or 350 gpm of water for concrete batch plant operation, dust suppression, and sanitary needs.

It is expected that construction of a new facility would require a similar quantity of water. The recommended planning number for tapwater consumption for workers in hot climates is 3 gpd for each worker (Reference 44). Based on the maximum construction worker population of 3,150 people indicated in the PPE (Table 1.3-1), water consumption is estimated at 9,450 gpd. The installation of an additional well(s) would be required for construction purposes.

2.4.12.1.3.3 Chemical Quality of Water

Ground water and surface water samples were collected for chemical analyses to evaluate the chemical character of local water resources. Ground water samples were obtained from test and observation wells on site and from selected private wells within the limits of the well survey. Surface water samples were taken from the Mississippi River and Bayou Pierre. Results of chemical analyses of samples are presented in Table 2.4-23*.*

Samples of ground water from the Mississippi River alluvium indicate a range in dissolved solids and hardness of 358 to 604 ppm and 285 to 443 ppm, respectively. Chemical constituents of notable concentrations are sodium, calcium, magnesium, and iron. Water samples of ground water from terrace deposits range in total dissolved solids concentrations from 277 to 442 ppm. The ground water sample obtained from the Catahoula Formation contains 460 ppm total dissolved solids.

The surface water samples generally contain less total dissolved solids than the ground water samples. A water sample from the Mississippi River indicates a total dissolved solid concentration of 316 ppm.

The water pumped by the collector well system is a mixture of natural ground water from the alluvial aquifer and river water induced through the riverbed. The initial quality of well water is closer in character to the natural ground water than to the river water. With continued pumping of the system, induced infiltration of the river water will be achieved, and the well water quality *will eventually approach that of the river water. The magnitude to which well water quality approaches river water quality depends on … infiltration rate through river bottom, river stage, water temperatures, permeability of the aquifer, and proximity of the collector wells to the river.*

Water quality sampling was conducted for the Mississippi River and for radial wells completed in the alluvial aquifer in 1988, as summarized in Table 2.4-26 (Reference 46).

Additional surface water quality data for the Mississippi River was obtained from the USGS sampling point at Vicksburg dating from 1961 to 1999. This surface water sampling data is provided in Tables 2.4-16.

GGNS is required to conduct storm water sampling in accordance with storm water permit number MSR000883 (Reference 45). Recent surface water sampling data is included in Table 2.4-24.

Three ground water wells completed in the Catahoula Formation are currently used to supply water for general site purposes (Section 2.4.12.1.3.2). These wells are located on the western boundary of the bluffs area near the Energy Services Center (ESC) building. Pre-treatment sampling of the well water is conducted on a routine basis; water quality sample data for the wells is included in Table 2.4-25.

2.4.12.2 Sources

2.4.12.2.1 Present Ground Water Use

There are few population concentrations and little industry located in the region, and most water wells are used for domestic purposes. Use of alluvial aquifers is limited to several industrial wells in Warren County and shallow domestic wells along the Mississippi River and its larger tributaries. Pleistocene terrace deposits provide water for domestic wells in the upland areas of the region and one small public supply in Warren County. The Citronelle Formation supplies several shallow municipal, industrial, and domestic wells in the vicinity of Crystal Springs in Copiah County; however, use is very limited outside of this area. Aquifers of the Miocene series provide pumpage for more than 95 percent of the public, domestic, and industrial wells in Claiborne and Jefferson Counties and about 50 percent of the wells in Copiah County. Use of Miocene aquifers in Warren and Hinds Counties is limited to a few rural domestic wells. Ground water from the Forest Hill Formation is used primarily for domestic purposes, but this source also supplies several small public and industrial wells in Hinds and Warren Counties.

The Kosciusko and Cockfield Formations supply wells of all types in Hinds County and, to a lesser extent, in Warren County. Use of these aquifers is restricted in areas to the south because of increasing depth and salinity (References 58 and 59*).*

Public water supply and industrial wells in Copiah County utilize the Catahoula, Citronelle, Miocene series, and Forest Hill Sand. Public water supply and industrial wells in Hinds County utilize the Cockfield Formation, Sparta Sand, Meridian-Upper Wilcox, Forest Hill Sand, and Catahoula formation. Public water supply and industrial wells in Jefferson County utilize the Catahoula and Miocene series formations. Public water supply and industrial wells in Warren County utilize the Mississippi River alluvial aquifer, Cockfield formation, Forest Hill Sand, and Catahoula formation. Data pertaining to public and industrial supply wells in Claiborne, Copiah, Hinds, Jefferson, and Warren Counties are presented in Table 2.4-27.

Public water supply wells in Claiborne County (excluding GGNS) are supplied by the Catahoula formation with well depths ranging from 166 to 960 feet (Reference 47). Nine active public water supply systems were located in Claiborne County as of May 2002, not including GGNS

(Reference 48). The closest area of concentrated ground water withdrawal is the Port Gibson municipal water system about five miles southeast of the site. Pumpage for Port Gibson is provided by five wells completed in the Catahoula Formation and withdrawals average 0.85 mgd (Reference 49). The Port Gibson municipal system is the largest in the county, serving a population of 4,845; details of the Port Gibson wells are provided in Table 2.4-28.

According to information on water use for 1995 (Tables 2.4-3a through 2.4.3i), total ground water withdrawals in Claiborne County were 33.9 million gallons per day (mgd), broken down as follows:

Quantity (mgd)	Usage
1.25	Public Supply
0.23	Domestic (Self-Supplied)
0.12	Irrigation
0.08	Livestock
32.05	Thermoelectric Power (GGNS Unit 1)
0.17	Commercial

Detailed data pertaining to ground water use in Claiborne County and in surrounding counties from 1995 are presented in Tables 2.4-3a through 2.4.3i.

Table 2.4-29 provides a listing of water wells within a four-mile radius of GGNS (Reference 50) and Figure 2.4-38). According to U. S. Census data for 2000, as discussed in Section 2.1.3, the population within a two-mile radius of the plant is quite small, i.e. 51 people (excluding GGNS plant personnel) in 2002. Based on published USGS sources (Reference 51), users of self-supplied water systems typically use 45 gpd. If the entire population utilized ground water as a source, the estimated ground water withdrawal within a two-mile radius of the plant is 2,295 gpd.

2.4.12.2.2 Projected Future Ground Water Use

Aside from GGNS Unit 1, the primary use of ground water in Claiborne County is for public supply purposes with a small percentage used for domestic water, irrigation, and livestock. Within a two-mile radius of the plant site, essentially all ground water is used for domestic purposes. Therefore, aside from plant use, future ground water demands in the vicinity of the site may be estimated on the basis of projected population growth.

According to the population projections provided in Section 2.1.3, the population within the two-mile radius of the plant projected the year 2070, is predicted to be essentially unchanged, i.e., 58 people (excluding GGNS plant personnel). Applying the same methods described above regarding water usage for the projected population, the estimated ground water withdrawal within a two-mile radius of the plant by the year 2070 will be 2,610 gpd.

2.4.12.2.3 Ground Water Levels and Movement

There are three levels of ground water in the site area: a) the regional water table in the Mississippi River alluvium and adjacent terrace deposits, b) perched water tables in the terrace deposits, and c) the potentiometric level of the confined aquifer within the Catahoula Formation

(Figure 2.4-37). *Ground water levels measured in selected piezometers and observation wells* (Tables 2.4-30 and 2.4-31 *are presented by hydrographs in* Figure 2.4-39 *(5 sheets) for the period 1972 through mid 1979. Observation well and piezometer locations are shown on* Figure 2.4-33*. Hydrographs of the water levels of Hamilton and Gin Lakes and the Mississippi River for the corresponding period are shown in* Figure 2.4-41.

In the site area the regional ground water table slopes gently westward, with local gradients dipping toward the major tributary valleys. The gradient steepens toward Hamilton and Gin Lakes. West of the lakes, the ground water table slopes toward the river at a gradient that varies with the prevailing river stage (Figure 2.4-33). *The regional ground water table within the site property ranges from about El. 60-0 to 80-0 during normal river elevations. The normal ground water gradient in the floodplain and the bluffs is temporarily reversed during flood stages of the Mississippi River.* Figure 2.4-42 *shows the configuration of the ground water table at the site during the spring flood of 1973. The ground water contours represent the highest ground water levels recorded at the site during the period January 1972 to May 1976.*

Perched water zones occur in the area indicated on Figure 2.4-33 *which corresponds to the area underlain by a ridge-like feature formed by the Catahoula Formation. The perched water levels range from El. 90-0 to 130-0 in the site area. The highest perched water level (130 ft) was recorded at observation well OW-201, located near the eastern site property line. Observation wells OW-6, OW-6A, OW-6B, OW-6C, OW-115A, OW-115B, OW-116, and OW-118 were constructed in the perched water zone in the vicinity of the power block area. The highest perched water level recorded in these wells was El. 112-0 at OW-6A* (Figure 2.4-39, sheets 4 and 5). *All observation wells and piezometers in the power block area were destroyed during excavation. Additional observation wells were later installed to monitor the perched water levels during plant construction* (Figure 2.4-43). *Hydrographs of these wells* (#1 through #8, Figure 2.4-43), *for the period 1974-1975, are shown in* Figure 2.4-44 *(5 sheets). The highest perched water level recorded during this period was El. 113-0 at the ultimate heat sink location. These were wells also destroyed as excavation and installation of the tie back wall … progressed. These wells were replaced with six new monitor wells* (MW-1 through MW-6), *which were installed in the sand backfill inside the tie back wall* (Figure 2.4-43) *in 1976. Hydrographs for the replacement observation wells are shown on* Figure 2.4-45 *for the period September 1976 through January 1979 and construction details are shown on …* Table 2.4-32*. Hydrographs are not shown for observation wells MW-1 and MW-2, because these wells are located inside the portion of the Unit 2 excavation that was not backfilled during the period of record. Water levels during the period were below El. 93.2 feet and El. 90.5 feet, respectively. Hydrographs of water levels in MW-1 through MW-7 for the period 1979 to 1991 were developed for a ground water study completed in 1992* (Reference 60 …). *….*

In 1986, five wells (MW-8 through MW-12) were installed to monitor water levels in the circulating water pipe trench (CWPT) backfill and in the terrace deposits east of the power block. The wells were installed to determine the cause of elevated ground water levels in DW-8. In addition, a supplemental dewatering well (DW-8a) was installed in the terrace deposits in the vicinity of DW-8. The locations of these wells are shown on Figure 2.4-43 ....

Fifteen additional monitoring wells (MW-I3 through MW-26; however, in 2001, four monitoring wells, MW-16, MW-17, MW-19 and MW-20 were subsequently removed for the installation of the Auxiliary Cooling Tower) were installed in the backfill and terrace deposits in the Unit 1 cooling tower area and in the northern portion of the site in 1990. The wells were installed in conjunction with studies to better define sources of ground water recharge and ground water flow patterns across the site. The locations of these wells are shown on Figure 2.4-43*. ….*

*Hydrographs of water levels in these wells were developed for a ground water study completed in 1992 (*Reference 60 …*).*

An assessment of the hydrographs shows that ground water levels within the power block and cooling tower areas at GGNS are at elevations greater than the surrounding regional levels. Ground water levels are generally between El. 100 and 105 feet in the northern portion of the area and between El. 105 feet and 110 feet in the southern portion of the power block. The elevated ground water levels roughly coincide with locations where the top of the Catahoula is above 70 ft. in elevation and follow the northwest trend of the Catahoula "ridge". The top of the Catahoula Formation exceeds 70 feet in elevation throughout most of the power block area and exceeds 100 feet between the power block and the cooling tower. This rise in elevation obstructs the regional ground water flow causing the ground water flow to diverge north and south of the site area.

The water levels shown on the hydrographs have also been influenced by operation of the dewatering wells during much of the period from their installation in 1979 and 1980 through 1991. The pumping masked the determination of the source and effects of recharge. Before March 1990, the pumping rates of these wells are not recorded, and, therefore, the degree to which they affected water levels could not be determined. However, for selected periods when the pumps were not in operation, and for the period after March 1990 when pumping rates for the dewatering wells were known, the hydrographs provided data that could be used to assess and predict long term ground water level patterns.

*The water levels in observation wells and piezometers constructed within the Catahoula Formation range from about El. 55-0 to 80-0 during normal river elevations. The highest water level recorded in observation wells or piezometers in the Catahoula during the period 1972 through 1979 was El. 113-0 at P-117A; however, the hydrograph of P-117A (*Figure 2.4-39, Sheet 5*) indicates that the piezometer was not functioning properly. Therefore, the El. 113-0 water level does not represent actual ground water conditions. Water levels higher than the overall regional water level and considerable water level variation during the period 1984 through 1991 have been experienced within the Catahoula Formation at OW-10, one of three regional monitoring wells open to the Catahoula Formation (*Table 2.4-32*). Water levels as high as El. 154.5 ft have been measured in this well. The cause of the fluctuation in water levels is generally attributable to damaged casing, damage to the surface seal, or ponding of water outside the casing* (Reference 61). *Water levels have gradually returned to typical regional water levels within a period of several months after repairs to the well casing or improvements in surface drainage were made. Similar fluctuations have not occurred in the other two monitoring wells used to measure water levels in the Catahoula Formation.*

The top of the Catahoula formation is at a lower elevation in the proposed location for the power block of a new facility, and ranges between 50 feet elevation above msl on the eastern side of the footprint of a new facility to 20 feet elevation below msl on the western side of the area proposed for a new facility power block. Therefore, the ground water levels are expected to be generally lower in the area of the new facility in comparison to those measured in the area of GGNS Unit power block and cooling tower. A hydrogeologic cross section which indicates the approximate east and west boundaries of the proposed construction area for the power block of the new facility is shown on Figure 2.4-37.

Table 2.4-33 provides a summary of water levels in DW-7, DW-8, MW-12, and MW-13 based on monthly measurements from 1996 to 2001 (Reference 52). These wells are located in the Terrace deposits around the existing GGNS Unit 1 power block (Figure 2.4-43).

Ground water level measurements from 1965 to 1994 for a well completed in the alluvial aquifer in Vicksburg are presented in Table 2.4-21, and a hydrograph is presented in Figure 2.4-34.

Ground water level measurements from 1910 to 1996 for a well completed in the lower Catahoula formation in Port Gibson are presented in Table 2.4-22, and a hydrograph is presented in Figure 2.4-35.

2.4.12.2.4 Hydrogeologic Properties of Subsurface Materials

Hydrogeologic properties of the Mississippi River alluvium, terrace deposits, and Catahoula Formation were determined by field and laboratory methods. Calculated permeability values are contained in Table 2.4-34.

<u>Mississippi River Alluvium</u>

Hydrogeologic investigations were conducted in the area along the Mississippi River bankline to determine the feasibility of an induced infiltration water supply using radial collector wells developed in alluvial deposits (Appendix 2.4A) [Appendix 2.4A of Reference 8 not included herewith]. ….

The two most productive zones within the alluvial deposits, as determined from these tests, are in two segments designated as the "South Field" and "North Field" (Figure 2.4-33). *In the South Field the aquifer consists of fine-to-medium sand with coarse sand and gravel zones of variable thickness at the base of the deposits. Total thickness of the alluvium in the South Field ranges from 95 to 128 ft, with the thickness generally increasing in the direction of the river. Clay and silt deposits overlie the aquifer in portions of the South Field. Subsurface conditions in the North Field are more complex than those in the South Field due to the highly variable depth of the top of the Catahoula Formation which ranges from El. -47-0 to -115-0. At test sites PW-2 and PW-3, two productive zones are separated by a clay/silt aquitard (Appendix 2.4A)* [Appendix 2.4A of Reference 8 not included herewith]. *Aquifer tests conducted separately on these two productive zones indicate that hydraulic connection between the lower zone and the river is impeded by the aquitard. The lower zone at sites PW-2 and PW-3 was not present at site PW-4. At test site PW-9, a 70-ft thick clay/silt layer overlies predominantly clean sand containing numerous gravel zones.*

Published values for the Mississippi River Alluvial Aquifer include a hydraulic conductivity range from 200 to 400 feet per day (Reference 53).

<u>Terrace Deposits</u>

The aquifer potential of the terrace deposits was investigated to determine an adequate source for a construction water supply. An 8-in. diameter steel cased, gravel-packed well, TW-1 (Figure 2.4-33), *was constructed in a 60-ft section of terrace sand and gravel deposits. An aquifer test was conducted at a constant rate of 500 gpm for approximately 25 hrs (Appendix 2.4B)* [Appendix 2.4B of Reference 8 not included herewith].

During the test, water levels were measured in the pumping well and six observation wells with an electric sounder. Water levels in the wells were monitored for approximately 20 hrs following the aquifer test. Test data were analyzed to obtain hydrologic coefficients (Appendix 2.4B) [Appendix 2.4B of Reference 8 not included herewith].

A hydrogeologic investigation was conducted in the plant power block area for the purpose of estimating excavation dewatering requirements. Two aquifer test wells, TW-2 and TW-3, were constructed at locations within the excavation area. Each test pattern contained one 6-in.

diameter pumping well and two 3-in. diameter observation wells. All wells were developed in a basal terrace sand zone which contained perched water. Several attempts were made to conduct constant-rate aquifer tests at TW-2 and TW-3, but continuous pumping could not be maintained in either well due to excessive drawdown (Appendix 2.4B) [Appendix 2.4B of Reference 8 not included herewith]. *In test well TW-2, the volume of water pumped during each brief test was approximately equal to the volume of water standing inside the well casing before pumping. Residual drawdown measurements made in the pumping well after loss of pump suction were analyzed by the residual drawdown method for a bailed wall* (Reference 62). *After several unsuccessful attempts at pumping well TW-3, pumping equipment was removed and falling-head permeability tests were performed and analyzed in accordance with NAVFAC DM-7* (Reference 63).

Field falling-head permeability tests also were performed in piezometers P34B and P34C (Figure 2.4-33), *which were constructed in terrace sands*. *Additional permeability data were obtained for terrace silts and clays from laboratory consolidation tests. Permeability coefficients for the terrace deposits obtained by all methods are compiled in* Tables 2.4-34 and 2.4-35.

In association with construction and post-construction ground water monitoring, a series of tests to determine the hydraulic conductivity of the terrace and backfill materials were performed in 1990 and 1991. The hydraulic conductivity of the terrace deposits in the main site area is highly variable with values ranging from 0.15 ft/day east of the cooling tower to 300 ft/day west of the cooling tower (Table 2.4-35). *The geometric mean of the 22 tests performed during this period is 5 ft/day. The higher conductivity materials are generally south and west of the cooling tower with the lower conductivity materials north and east of the power block.*

Catahoula Formation

Most permeability data for the Catahoula Formation were obtained from laboratory consolidation tests on samples. One field falling head permeability test was conducted at piezometer P4 (Figure 2.4-33), *which was constructed in a fine silty sand stratum at approximately El. -198-0. Permeability coefficients of the Catahoula Formation are given in* Table 2.4-34.

Published values for five test locations in the Catahoula Formation in Claiborne County indicate a hydraulic conductivity ranging from 13 to 120 feet per day, and a well yield from 20 to 240 gpm (Reference 53).

2.4.12.2.5 Potential Reversibility of Ground Water Flow

Operation of the radial collector wells for plant water supply does not cause reversal of present water table gradients in the site vicinity. The creation of a depression cone at the collector wells results in induced infiltration from the river to the wells. The area in which the ground water is influenced by collector well field pumpage is limited to the floodplain alluvium due to the following: laterals extend toward the Mississippi River and obtain the major portion of the well yield from induced infiltration; the clay lens beneath Hamilton and Gin Lakes forms a partially effective hydrologic barrier to the east of the "South Well Field"; and the permeability of the alluvium east of the lakes and adjacent to the terrace deposits is generally lower than that of the alluvial aquifer.

A long-term pumping test was performed with two radial collector wells from August 7, 1979, to December 19, 1979 (134 days). Wells #3 and #5 were pumped at the average rates of 8000 gpm and 7600 gpm, respectively.

Water level measurements were made periodically during the test in Wells #3 and #5, 27 observation wells, and at staff gages in Hamilton Lake, Gin Lake, and the Mississippi River (locations shown in Figure 2.4-40*). Periodic measurements of the pumping rates and the discharge water temperature from Wells #3 and #5, and the temperature of the Mississippi River were also taken. A compilation of all measurements made during the long-term pumping test is contained in (Appendix 2.4C)* [Appendix 2.4C of Reference 8 not included herewith].

A ground water level contour map showing pre-pumping static conditions is shown in Figure 2.4-40*. Ground water level contour maps are also shown for the lowest (November 6, 1979) and the highest (December 10, 1979) river levels during the pumping test* (Figures 2.4-46 and 2.4-47, *respectively)*. *The contours in these figures indicate the impact of radial collector well pumpage on the ground water levels in the site area.*

A hydrograph of water levels in Wells #3 and #5 and the Mississippi River level during the pumping test is shown in Figure 2.4-48.

The results of the pumping test were used to assess the ground water levels resulting from operation of the planned radial collector well field. It is assumed that the six collector wells in the field will each pump 8000 gpm continuously. The depression cone created by pumping at Well #3 (8000 gpm) during the long-term pumping test was used to calculate the drawdown caused by pumping at each of the six radial collector wells.

The interference effects of all six wells were computed and the total composite drawdown was subtracted from the ground water level contours for November 17, 1978 (Figure 2.4-49) *when the level of the Mississippi River was at elevation 39'-0". The results of this analysis are shown in* Figure 2.4-50 *as the projected ground water level contours for six wells pumping (8000 gpm/well) during low river conditions. Although lower river levels have occurred, November 17, 1978 is the lowest river level for which ground water levels are available. A similar analysis was made using the ground water level contours for August 7, 1979* (Figure 2.4-40), *as the normal river level conditions (El. 61'-7"). The projected ground water level contours for six wells pumping (8000 gpm/ well) during normal conditions are shown in* Figure 2.4-55.

The ground water level contours for six wells shown in Figure 2.4-55 *were made considering withdrawals for 2 unit operation. Only four of the wells were constructed for single unit operation. Therefore, while not representative of actual conditions, the impact on the alluvial aquifer is less than predicted.*

The ground water levels recorded during the long-term pumping test in observation wells F-4 and F-6 and the water level in Hamilton Lake are shown on the hydrograph in Figure 2.4-51. *Hamilton Lake is located between observation wells F-4 and F-6* (Figure 2.4-40). *The hydrograph indicates that the drawdown cone created during the test lowered ground water levels beneath Hamilton Lake. This phenomenon indicates that Hamilton Lake is not in direct hydraulic communication with the ground water, and that the lowering of ground water levels from radial collector well pumpage will not affect the water level of Hamilton Lake.*

The potential for ground water flow reversals due to offsite overdraft is low as the estimated increase in pumpage by the year 2020 is about 2500 gpd [current projection for year 2070 is about 2,610 gpd] (Section 2.4.12.2.2). *The ground water gradient may be temporarily reversed locally during prolonged flood stages of the Mississippi River* (Figure 2.4-42).

The ground water levels in the site area are slightly modified as a result of the effects of radial collector well field pumpage, construction dewatering (temporary), topographic modifications, relocation of surface drainage systems, and structure installation. A ground water contour map *of the site area indicating expected average ground water conditions during the operating life of the plant is provided in* Figure 2.4-52.

The map is based on ground water levels that have occurred since the achievement of final site configuration, the absence of cooling tower leakage, and the lack of pumping from dewatering wells.

As stated in Section 2.4.1.1, makeup (cooling tower makeup and other raw water needs) for a new facility would be supplied directly from the Mississippi River, rather than from wells as for GGNS Unit 1 as described above. Therefore, activities associated with construction or operation of a new facility at the GGNS ESP Site are expected to have a similarly small effect on ground water levels in the immediate area of the facility, and are not expected to produce any ground water flow reversal scenarios.

2.4.12.2.6 Potential Recharge Areas Within Influence of Plant

There are no significant ground water recharge areas located within the influence of the plant.

The site area is graded to allow runoff to drain to either Stream "A" or Stream "B" and the runoff is then retained in either Sedimentation Basin "A" or Sedimentation Basin "B" for gradual release to the Mississippi River (Figure 2.4-18). *Minor amounts of recharge to the terrace deposits and Mississippi River alluvium occur from infiltration of water retained in these basins.*

Ground water levels in the terrace deposits and backfill that are higher than the regional water table are the result of infiltration from precipitation and/or leakage from onsite sources. The only source of recharge from leakage associated with the plant facilities was from the cooling tower that provided recharge to the backfill and terrace deposits in the site area until repaired in 1992. Although the surface area of the site has been reduced by structures and paving, sufficient open area remains for the infiltration of precipitation. Ground water levels at GGNS appear to be influenced by periods of high or low precipitation occurring over several consecutive months. Water levels generally rise when the precipitation is high and fall when the precipitation is low. The 6-month cumulative precipitation is the total precipitation occurring in that month and the preceding 5 months. Approximately parallel behavior between ground water levels and the 6-month cumulative precipitation for the period 1987 through 1991 is shown on the hydrographs on Figure 2.4-53*, thus demonstrating the influence of precipitation on water levels.*

Hamilton and Gin Lakes do not comprise ground water recharge areas as they are underlain by low permeability clay/silt sediments.

Figure 2.4-54 shows ground water level and rainfall hydrographs for 2001.

2.4.12.3 Monitoring or Safeguard Requirements

GGNS Unit 1 currently has an ongoing Radiological Environmental Monitoring Program and submits an Annual Radiological Event Environmental Operating Report to the NRC. Samples are collected as shown in Table 2.4-36 (Reference 54). A program to monitor and track radiological parameters and ground water levels for a new facility with specific well locations and well design details would be provided when the type of plant to be constructed and construction details are known.

2.4.12.4 Design Basis for Subsurface Hydrostatic Loadings

Ground water level data have been obtained at the site since early 1972. The highest perched ground water level in the power block area measured prior to and during construction of the GGNS Unit 1 plant is El. 113-0 (Section 2.4.12.2.3). The highest perched ground water level in the GGNS Unit 1 power block area measured since construction was completed is El. 114.00 in April 1999. Due to the fact that the top of the Catahoula formation is at a lower elevation in the proposed location for the power block of a new facility, the ground water levels are expected to be generally lower in the area of the new facility in comparison to those measured in the area of GGNS Unit 1 power block and cooling tower.

2.4.13 Accidental Releases of Liquid Effluents in Ground and Surface Waters

In the event of an accidental release of liquid radioactive material at the site, the contaminants would encounter the regional water table beneath the site and would move laterally toward the Mississippi River to the west. There are no ground water users between the plant and the river; therefore, potential contamination of existing ground water users is nil. During normal plant operation, the contaminants would be captured by the radial collector well field pumpage and would not enter the Mississippi River. However, it is assumed that the wells would be inoperable by the time the contaminants reached the well field; therefore, the contaminants could ultimately enter the Mississippi River.

Should a spill occur, the contaminants would initially encounter the ground water within the Catahoula Formation which forms a local ridge beneath the site (Figure 2.4-37). *The Catahoula consists of low-permeable silt and clay material; however, it is conservatively assumed that the contaminants would move along fracture paths within these deposits at the same flow rate as in the adjacent terrace deposits. Based on aquifer test data from test well TW-1* (Figure 2.4-33), *the hydraulic conductivity of the sand and gravel lenses in the lower terrace deposits is about* 3.0×10^5 *ft/yr. The alluvium adjacent to the terrace deposits consists principally of silt and clay deposits underlain by basal sand deposits*. *The hydraulic conductivity of the alluvium between the terrace deposits and Hamilton Lake* (Figure 2.4-37*) is conservatively assumed to be about* 5.0×10^3 *ft/yr. The hydraulic conductivity of the alluvial aquifer between Hamilton Lake and the Mississippi River, as determined from aquifer tests, is about* 1.3×10^5 *ft/yr. The Catahoula Formation underlies the terrace deposits and alluvium, and is assumed to comprise a confining layer to downward ground water movement. The travel time analysis is based on the ground water flow rates through each of the three zones of hydraulic conductivity: terrace deposits, clay-silt alluvium, and alluvial aquifer. The effective porosity in each zone is conservatively assumed to be 25 percent.*

The hydraulic head difference across two of the three zones was determined from well hydrographs. The maximum difference between water levels in wells OW-29A and OW-43, and OW-43 and the Mississippi River is conservatively assumed to be the hydraulic head difference used to compute the hydraulic gradient across the terrace deposits, clay-silt alluvium, and alluvial aquifer, respectively. Hydraulic gradients and flow lengths for each of the three flow zones are contained in Table 2-4-37.

The hydraulic head difference across the terrace deposits was determined by using the difference in average water level between DW-8 (Reference 60) *located near the radwaste building and OW-29A* (Reference 61, and Figure 2.4-33).

The stage of the Mississippi River generally controls the regional ground water table at the site. Figures 2.4-33 and 2.4-42 *show the ground water contours during normal and flood conditions, respectively. During flood conditions, the ground water flow direction is temporarily reversed at the site. An accidental release during flood conditions would result in a temporary movement of contaminants away from the Mississippi River. However, the ground water flow direction would return to normal after flood conditions wane, and the contaminants would move toward the river. Existing ground water users east of the site … would not be affected by an accidental release of* *contaminants during flood conditions. Contaminants released during flood conditions would require a longer travel time to reach the river than during low conditions. The travel time analysis conservatively assumes a maximum hydraulic gradient under low river-stage conditions.*

The travel times of the ground water movement through the terrace deposits, clay-silt alluvium, and alluvial aquifer were computed ….

…. The computed travel time for contaminants from an accidental spill to move in the ground water from the site to the Mississippi River is about 12.5 yrs. This travel time represents a highly conservative value. The actual travel time would be longer due to the low-permeable silts and clays within the Catahoula ridge beneath the site and alluvium adjacent to the terrace deposits.

The concentration of contaminants would be reduced during migration by the processes of ion exchange, dispersion, and radioactive decay. The total effect of these processes on the contaminant concentrations at the point where the contaminants would enter the Mississippi River was determined ….

The radionuclides considered in this analysis are strontium (Sr-90) and cesium (Cs-137), as they comprise the greatest potential health hazard in the event of an accidental spill. The maximum concentrations of Sr-90 and Cs-137 are 3.36E+01 and 3.56E+01 μcuries/cc, respectively. These maximum concentrations are contained in two RWCU phase separator tanks. It is assumed that … [an accidental] *spill … would be released instantaneously into the ground water beneath the site.*

A conservative estimate of the longitudinal dispersion D_L, was determined for the terrace deposits, clay-silt alluvium, and alluvial aquifer as the product of the mean grain size (d_{50}) of each material and the average interstitial ground water velocity in each material. Mean grain-size values were determined from data contained in Appendix 2.4B [Appendix 2.4B of Reference 8 not included herewith]*. Calculated dispersion coefficients are contained in* Table 2.4-37.

…Conservative limits of the data were used to compute the average interstitial velocities of the radionuclides. Parameter values and velocities are contained in Table 2.4-37.

… [T]*he concentrations of Sr-90 and Cs-137 are reduced below Maximum Permissible Concentration (Sr-90 - 3.0 x 10^{-7} μC/cc; Cs-137 - 2.0 x 10^{-5} μC/cc) at a distance of about 57 ft from the* [existing GGNS Unit 1] *plant, at a time corresponding to the ground water travel time through the terrace deposits. The concentration of the contaminants at the Mississippi River after the estimated ground water travel time of 12.5 years to the river would be essentially zero (<10^{-20} μC/cc).*

Site hydrogeological characteristics relevant to this analysis have not changed in any significant way since the performance of the GGNS Unit 1 UFSAR analysis described and referenced above. Key assumptions have been reviewed and found to be valid for a new facility at the proposed location. The evaluation for GGNS Unit 1 indicated that the strontium and cesium isotopic concentrations would be below the maximum permissible concentration at a distance of 57 feet from the plant. Since the proposed location of a new facility, about 1200 ft west and 1000 ft north of the GGNS Unit 1 plant, is still approximately 3,200 feet from the Mississippi River, the isotopic concentrations from a similar spill into the ground water from a new facility would be expected to be well below the maximum permissible concentration before they reach the Mississippi River.

The nearest downstream user of Mississippi River water is Southeast Wood Fiber located at the Claiborne County Port facility, approximately 0.8 mile downstream of the Grand Gulf site property and about 2 miles from the barge slip location. The maximum intake requirement for this facility is estimated to be less than 0.9 million gallons/day (mgd) for industrial purposes; however, none of this intake is used as potable water (Reference 3). There are only three public water supply systems in the state of Mississippi that use surface water as a source, and none of these are located within 50 miles of the GGNS site (Reference 4). There are no downstream or upstream intakes within 100 miles of the GGNS site that use the Mississippi River as a potable water supply (References 3 and 5). Tables 2.4-2a and 2.4-2b identify the nearby surface water users of the Mississippi River and the maximum rate of withdrawal from the Mississippi River. Since users on the Louisiana side of the river are outside the region of interest for the GGNS ESP Site evaluation (i.e., greater than 50 miles), withdrawal rates for these users are not provided in Table 2.4-2b.

Based on information on water use for 1995 (Reference 6), total surface water withdrawals in Claiborne County were 0.47 million gallons per day (mgd), broken down as follows:

Quantity (mgd)	Usage
0.35	Irrigation
0.12	Livestock

Detailed data pertaining to surface water use in Claiborne County and in adjacent Mississippi counties are presented in Table 2.4-3 (Reference 6). A discussion of ground water users is provided in Section 2.4.12.2.

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2.5 Geology, Seismology, and Geotechnical Engineering

This section of the SAR presents information on the geological, seismological, and geophysical characteristics of the Site Region (200-mile radius), Site Vicinity (25-mile radius), Site Area (5-mile radius), and Site Location (0.6-mile radius) (Figure 2.5-1). This information was used to evaluate geologic and seismic hazards at the location of the proposed new unit at the Grand Gulf Nuclear Station and to develop the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE) ground motions. These analyses were performed in accordance with the applicable federal regulations and regulatory guidelines described in Section 1.3 of this report, and which are summarized below.

- Federal regulation 10CFR52 - "Early Site Permits, Standard Design Certifications, and Combined Licenses for Nuclear Power Plants" requires that the ESP application contain a description and safety assessment of the site on which the facility is to be located, including seismic, hydrologic, and geologic characteristics (Reference 1).
- 10CFR52 references Appendix S of 10CFR50 - "Earthquake Engineering Criteria for Nuclear Power Plants", which provides requirements for development of the Safe Shutdown Earthquake ground motions (Reference 2).
- 10CFR100 "Reactor Site Criteria", Part 23 - "Geologic and Seismic Siting Factors", sets forth the principal geologic and seismic considerations required to demonstrate the suitability of a proposed site and adequacy of the design basis in consideration of the geologic and seismic characteristics of the proposed site for the new facility (Reference 3).

The ground motion analysis was performed in compliance with Regulatory Guide (RG) 1.165 – "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion" (Reference 4). This guide provides detailed methodology and guidance to satisfy the requirements of 10CFR52, Appendix S of 10CFR50, and 10CFR100 Part 23 for the assessment of ground motions at the site.

Detailed site investigations and laboratory analyses completed to evaluate site conditions in accordance with RG-1.165 were performed following the methodology provided in:

- Draft Regulatory Guide, DG-1101 (the proposed revision to RG-1.132), Site Investigations for Foundations of Nuclear Power Plants (Reference 5); and,
- Draft Regulatory Guide, DG-1109 (the proposed revision to RG-1.138), Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants (Reference 6).

These investigations and analyses were performed to support evaluation of ground motion site response and to provide a preliminary assessment of geotechnical parameters (i.e. modulus reduction) at the site. A detailed geotechnical evaluation of the site as required for full compliance of DG-1101 (RG-1.132) will be performed following selection of the final site design and footprint of the facility.

Ground motion site response was evaluated following the methodology provided in NUREG/CR-6728 (Reference 7).

Regulatory Guide 1.165 recommends that a probabilistic seismic hazard assessment (PSHA) be performed to define the median rock ground motion at the site that has an annual probability of exceedance of not greater than 10^{-5}, and for soil sites, that a site response analysis be performed to develop the SSE ground motion. RG-1.165 further recommends that the applicant may use either the Lawrence Livermore National Laboratory (LLNL) or Electric Power Research Institute (EPRI) PSHA methodology to develop the median 10^{-5} rock ground motion at the site. Either of these methodologies may be used provided that a thorough review of geological, seismological, and geophysical data and information published since the LLNL, 1993 (Reference 10) or EPRI 1986 (Reference 9) studies does not show significant change in either the seismic source model or ground motion model. If changes have occurred then an updated LLNL or EPRI model should be used to perform the PSHA.

For this ESP application, the EPRI methodology (Reference 11) was adopted for developing the 10^{-5} median rock ground motion at the site. Because most of the seismic source characterization for the EPRI study occurred in 1985, data and information published since 1985 was compiled and reviewed to evaluate the current status of scientific knowledge regarding seismic sources in the Grand Gulf Site Region (including the New Madrid Seismic Zone). This review is documented in Engineering Report ER-01 “Seismic Source Characterization for updated EPRI PSHA” (Reference 12), and is presented below in Section 2.5.1.

Review of data published since 1985 show that the EPRI seismic source model should be updated to include an improved understanding of the New Madrid source zone and a recently identified potential seismic source, the Saline River source zone, within the Site Region. These sources are described in Section 2.5.1 and the updated EPRI PSHA is summarized in Section 2.5.2.

In parallel with this review of the seismic source model, EPRI (Reference 13) performed a review of the 1986 EPRI SOG ground motion attenuation model. This review showed a significant change in the ground motion model for the central and eastern United States, including the Gulf Coast region. This updated model was used for the PSHA for the Grand Gulf site (Reference 14). Based on the PSHA, a site response analysis was performed to develop the SSE ground motion at the site as desired in section 2.5.2.

As recommended by RG-1.165, a site geotechnical investigation was performed to develop information on soil properties to support the ground motion Site Response analysis. These geotechnical investigations were performed following the methodologies provided in RG-1.132 and 1.138, although a full geotechnical evaluation of the site in compliance with these guides will be deferred until selection of the final plant design and footprint of the facility during the Construction and Operating License (COL) phase of the project. Results of the site geotechnical investigations are provided in Engineering Report ER-02 “Geologic, Geotechnical, and Geophysical Field Exploration and Laboratory Testing, Grand Gulf ESP” (Reference 15), and are presented in Sections 2.5.1.2.5, 2.5.4, and 2.5.5.

Other geological hazards, including surface faulting, stability of subsurface materials, liquefaction, stability of slopes, and safety of embankments and dams are described in Sections 2.5.3 through 2.5.6, respectively. References of literature and data sources used in this assessment are presented in Section 2.5.7.

2.5.1 Basic Data

This section provides basic data and information on the geology, seismology, geophysics and tectonic setting of the Site Region. A detailed description of the existing site and Site Region is provided in the updated Final Safety Evaluation Report (UFSAR) for the Grand Gulf Nuclear Station (Reference 16). This information has been reviewed and approved by the NRC staff, and forms the basis for understanding the site geology.

Information contained in the UFSAR has been updated based on review of data and information published since the 1986 EPRI study (Reference 9) and discussions with current researchers familiar with the regional geology. References reviewed are listed in Section 2.7. In addition, new geologic maps showing the distribution of surficial deposits in the Site Vicinity, Site Area, and Site Location have been prepared, and new geologic cross-sections and subsurface contour maps have been prepared incorporating data from the geotechnical exploration program (Reference 15).

The proposed location of the new facility at the Grand Gulf Nuclear Station (Grand Gulf Site) is in west-central Mississippi adjacent to the Mississippi River floodplain (Figure 2.5-1). The Site Region is divided into both physiographic and geologic provinces and subprovinces, which are shown on Figures 2.5-2 and 2.5-3 respectively, and are summarized in Table 2.5-1.

2.5.1.1 Regional Geology

The Gulf Coastal Plain consists of two primary geological provinces, the Gulf Coast Basin and Mississippi Embayment (Figure 2.5-3). These geologic provinces encompass a variety of geologic features including localized uplifts, zones of salt migration, growth faults, pre-Quaternary tectonic faults, and basins. These provinces and geologic features are described in Section 2.5.1.1.2 and 2.5.1.1.5.

The Gulf Coastal Plain has been dominated by marine and fluvial processes along the Gulf of Mexico continental margin for several hundred million years (Reference 17). Thick sedimentary sequences deposited by the Mississippi River within the Gulf Coastal Plain played an important role in the geologic processes of the region since post-Miocene time. The distribution of major geologic features and sedimentary units in the Gulf Coastal Plain and Site Region is shown on Figures 2.5-3 and 2.5-4.

The Gulf Coast Basin contains marine sediments deposited during episodic sea-level transgressions and regressions, and terrestrial sediments deposited on river floodplains and deltas along the continental margin. The sediments are composed of sand, silt, gravel, clay, marl, limestone, salt, and chalk that range in age from Jurassic to Holocene, and form a seaward thickening wedge greater than 50,000-feet-thick near the present Gulf of Mexico coastline. Development of the thick sedimentary wedge resulted in depression of the crust within the Gulf Coast Basin to depths of up to 7 miles (Reference 18).

Global climatic changes and tectonic events played important roles in the geologic history of the Gulf Coastal Plain. Tectonic and climatic events from the eastern coast of North America to as far west as the Rocky Mountains influenced the formation of sedimentary rocks, emplacement of igneous bodies, and deformation of the crust and overlying sedimentary section in the Site Region. The principal tectonic events include: the Taconic, Acadian, and Allegheny orogenies that formed the Appalachian Mountains and the Ouachita Orogenic Belt; continental rifting that formed the Gulf of Mexico; and changes in regional stress that deformed the crust along the Reelfoot Rift and formed the Mississippi Embayment. Secondary processes such as igneous intrusion, basin settlement, and salt diapirism also played important roles in the geological development of the Site Region.

The Site Region is characterized by extremely low rates of earthquake activity (Figure 2.5-5). Previous seismic hazard investigations, such as the original licensing studies for the Grand Gulf Nuclear Station (Reference 16), the 1986 EPRI study (Reference 9), and the 2002 USGS National Seismic Hazard maps (Reference 19) all indicate that the rate of earthquake activity in the Gulf Coastal Plain is among the lowest in the United States. The geologic setting and modern tectonic framework suggest that the earthquake hazard for the Site Region will remain low for the foreseeable future. A detailed discussion of the seismological setting is presented in Section 2.5.1.1.6.

2.5.1.1.1 Regional Physiography

The Grand Gulf Site is located within the Gulf Coastal Plain physiographic province (Figure 2.5-2). The Site Region also includes the Ouachita Mountains province and a buried continuation of the Southern Appalachian province (Figure 2.5.2). The Gulf Coastal Plain province is divided into subprovinces including the Mississippi Alluvial Valley, Chenier/Delta Plain, Loess Hills, Prairie Coastwise Terrace, Southern Hills, Eastern Hills, and Western Hills.

2.5.1.1.1.1 Loess Hills Subprovince

The Grand Gulf Site straddles the margin of the Loess Hills subprovince and the Mississippi Alluvial Valley subprovince (described below; Figure 2.5-2). The Loess Hills subprovince extends along the eastern bank of the Mississippi River from Kentucky to southwestern Mississippi (Figure 2.5-2). The Loess Hills consists of an eastward thinning loess (silt) deposit that is zero to 100-feet-thick and extends 10- to 30-miles east of the Mississippi River (References 17,21).

The topography of the Loess Hills is characterized by flat-topped ridgelines and fluvial terraces separated by deeply incised dendritic drainage systems. In the Site Vicinity, the Loess Hills vary in elevation from 100- to 300-feet above mean sea level (amsl). Erosion along the eastern edge of the Mississippi River flood plain has formed a steep escarpment along the western edge of the Loess Hills. At the Grand Gulf Nuclear Station the bluff is approximately 65- to 80-feet high.

The Loess Hills were formed through deposition of successive sheets of silt during late Quaternary time. Up to five distinct periods of loess deposition are documented. Each of these deposits are separated by leached buried soils that represent significant periods of landscape stability (Reference 20; 21). Loess deposits up to 82-feet-thick are present in the Site Vicinity. These deposits are described in Section 2.5.1.2, below.

2.5.1.1.1.2 Mississippi Alluvial Valley Subprovince

The Mississippi Alluvial Valley subprovince extends up to 80 miles west and 200 miles north and south of the proposed new facility at the Grand Gulf Nuclear Station (Figure 2.5-2). In the Site Region, the Mississippi Alluvial Valley subprovince also includes a number of interdistributary lowlands, basins and ridges. Elevations generally range from 50 to 250 feet. Higher elevations occur in tributary valleys with highs of 300 feet in the Ouachita River valley and 500 feet in the upper Red River valley near the Ouachita Mountains. The topographic highs along the Mississippi River are remnants of older alluvial deposits that mostly were eroded and removed from the valley. The valley topography is relatively flat with a gentle southward gradient and is characterized by fluvial geomorphic features typical of a braided stream and meandering river system (e.g. valley train, oxbow lakes, meander belts, and floodplains). Deposits in the Mississippi Alluvial Valley consist primarily of Pleistocene to Holocene sediments derived from the Mississippi River and its tributaries.

2.5.1.1.1.3 Eastern Hills Subprovince

The Eastern Hills subprovince lies north of the Southern Hills and east of the Loess Hills (Figure 2.5-2). The subprovince covers the area from central Mississippi and central Alabama to western Tennessee, and extends to the eastern margin of the Gulf Coastal Plain. The topography is characterized by gently rolling hills that range in elevation from 100 to 600 feet (amsl) and which gradually decrease in elevation southward. The Eastern Hills are underlain by Miocene to Paleocene sedimentary rocks and drained by tributaries of the Mississippi River.

2.5.1.1.1.4 Western Hills Subprovince

The Western Hills subprovince lies north of the Southern Hills and west of the Mississippi Alluvial Valley (Figure 2.5-2). The subprovince covers the area from central Louisiana to central Arkansas, and extends westward into eastern Texas. The topography is characterized by gently rolling hills that range in elevation from 200 to 700 feet (amsl) and gradually decrease in elevation southward. The Western Hills are underlain by Miocene to Paleocene sedimentary rocks and drained by the Arkansas River and Red River, two major tributaries of the Mississippi River.

2.5.1.1.1.5 Southern Hills Subprovince

The Southern Hills subprovince occupies the area between the Prairie Coastwise Terrace (described below) and the Eastern and Western Hills subprovinces (Figure 2.5-2). The Southern Hills cover portions of southern Mississippi, southern Louisiana, and southeastern Texas. The topography of this subprovince is characterized by gently rolling hills and flat-topped ridges that range in elevation from 50 to 500 feet, and generally decrease toward the Gulf Coast. The Southern Hills are underlain by the Miocene Catahoula Formation, and the Pliocene and Pleistocene Upland Complex.

2.5.1.1.1.6 Prairie Coastwise Terrace Subprovince

The Prairie Coastwise Terrace subprovince occupies the area south of the Southern Hills, and north of the Chenier and Delta Plain subprovinces (described below) along the Gulf Coast (Figure 2.5-2). The subprovince extends across southern Mississippi, southern Louisiana and southeastern Texas. The topography of the Prairie Coastwise Terrace is characterized by gently rolling hills and remnants of dissected terrace surfaces that range in elevation from 25 to 150 feet and gradually decrease in elevation coastward. This subprovince is underlain by terrace deposits of the late Pleistocene Prairie Complex.

2.5.1.1.1.7 Chenier Plain Subprovince

The Chenier Plain subprovince occupies the area between the Prairie Coastwise Terrace and the Gulf of Mexico (Figure 2.5-2). The subprovince extends along the Louisiana and eastern Texas coastline. “Cheniers” are abandoned beaches of the Gulf of Mexico, with large expanses of Holocene marshes that developed on prograding mudflats (Reference 17). A typical chenier ridge is less than 10-feet high, but may extend for miles or tens of miles. The topography of the Chenier Plain is characterized by low lying coastal ridges and marshes. The most prominent features are abandoned beach ridges at elevations of between sea level and 25-feet amsl. Subtle variations in elevations, on the order of inches, have a pronounced effect on vegetation and habitat in the Chenier Plain (Reference 17). The only preserved pre-Holocene features are remnants of the Prairie Coastwise Terrace and emergent landforms developed above salt dome piercement structures (Reference 17).

2.5.1.1.1.8 Delta Plain Subprovince

The Delta Plain subprovince occurs in southeastern Louisiana where the Mississippi River meets the Gulf of Mexico (Figure 2.5-2). The topography of the Delta Plain is characterized by abandoned distributary channels, distributary levee ridges, and coalescing delta complexes near the mouth of the Mississippi River. The distributary levee ridges form the most prominent topographic features, but do not exceed 10 feet elevation. Distributary channels radiate in a fan shape and form apices of delta complexes (Reference 17). The morphologic expression of the channel and distributary features become markedly less pronounced with increasing age, and eventually become buried due to coastal subsidence

2.5.1.1.2 Regional Geological Provinces

The Gulf Coastal Plain province is divided into two primary geological provinces, the Gulf Coast Basin and the Mississippi Embayment (Figure 2.5-3). Both the Gulf Coast Basin and Mississippi Embayment have distinct geological histories.

2.5.1.1.2.1 Mississippi Embayment

The Mississippi Embayment extends from the buried Ouachita Orogenic belt to the northern margin of the Gulf Coastal Plain and lies between the Appalachian Mountains in west-central Alabama and the Ouachita Mountains in southern Arkansas (Figure 2.5-3). The Mississippi Embayment formed in response to crustal downwarping associated with extension of the Reelfoot Rift (described in Section 2.5.1.1.5.4) within the North American craton during the Late Cretaceous. The Mississippi Embayment is underlain by Paleozoic strata, and igneous and metamorphic basement rocks. The structure of the embayment is characterized by a south-southwest plunging syncline that continues southward across the Gulf Coast Basin (Figure 2.5-3). The top of the Paleozoic section in the Mississippi Embayment defines a slightly asymmetric syncline: the western limb dips 0.59 degrees and the eastern limb dips 0.34 degrees. The southern portion of the Mississippi Embayment and the seismically active Reelfoot Rift lie within the northern part of the Site Region.

2.5.1.1.2.2 Gulf Coast Basin

The Gulf Coast Basin extends from the Gulf of Mexico to the buried Ouachita Orogenic Belt (Figure 2.5-3; described in Section 2.5.1.1.4.2). The Gulf Coast Basin formed during initial rifting of the Gulf of Mexico in the Triassic. As a result of continental rifting and formation of new oceanic crust, the properties of basement materials within the Gulf Coast Basin are transitional between continental and oceanic materials. In the northern part of the basin, the basement is defined as thick transitional crust reflecting continental affinity. In areas closer to the Gulf of Mexico oceanic plate the crust is defined as thin transitional crust reflecting oceanic affinity (Reference 18). The basin has been affected by a long series of tectonic, volcanic, depositional, isostatic and climatic processes, which are described in greater detail below.

The southward plunging syncline that characterizes the Mississippi Embayment projects across the Gulf Coast Basin and forms a structural downwarp that affects the depth to basement and thickness of the overlying sedimentary column. The limbs of the syncline in the Gulf Coast Basin typically dip less than 1-degree towards the synclinal axis (Figure 2.5-6).

2.5.1.1.3 Regional Geologic History

Crystalline basement of the North American craton in the central United States is wholly Precambrian in age, with the possible exception of basement rocks underlying the Gulf Coast Basin (Reference 18, 22, 23). The central United States basement complex is divided into eight major cratonic elements (Figure 2.5-7). These are the products of major Precambrian orogenic events, ranging in age from Archean (3.8 billion years) to middle Proterozoic (750 million years [Ma]; Reference 22). The North American craton is inferred to have progressively enlarged to the south and east due to lateral accretion during successively younger Precambrian orogenies (Reference 23).

Primary tectonic elements within the south-central part of the North American craton include the Reelfoot Rift complex, Paleozoic Ouachita Orogenic belt, and Appalachian Mountains (Figure 2.5-3). The Reelfoot Rift, and possibly other rift systems within the North American craton, were reactivated and experienced additional extension and intrusion during early Mesozoic time (Reference 24; 25). The similarity in ages of rift systems within the craton suggests that they initially formed as failed arms of triple junctions during an episode of late Precambrian continental fragmentation that predated the Paleozoic Ouachita and Appalachian orogenies (Reference 26). The sequence of major geological events is summarized on Figure 2.5-8.

Cratonic rocks of south-central North America extend to the southern margin of the Ouachita Orogenic Belt (Figure 2.5-7). The exact nature of the basement materials beneath the Paleozoic sediments south of the Ouachita Orogenic Belt is equivocal. However, the basement materials likely are related to formation of oceanic crust during rifting and evolution of the Gulf of Mexico (Reference 27). The Gulf of Mexico began forming in Triassic time by tensional rifting of the supercontinent Pangea and the divergent motion of the North American and Afro-South American plates (Reference 28).

As separation of Pangea continued through mid-Jurassic time, the Gulf Coastal Plain began to develop north of the Gulf of Mexico by the slow deposition of sediment on top of the Paleozoic sedimentary rocks. During the Triassic, sediments accumulated in grabens formed during rifting and block faulting, and by the mid-Jurassic, the region became a restricted seaway with evaporitic condition that accumulated more than 9,900 feet of salt deposits (Reference 28). By the late Jurassic, conditions changed to an open marine environment and resulted in the first major marine transgression into the Gulf Coast Basin and Mississippi Embayment (Reference 29). During the Cretaceous, a series of transgressive and regressive episodes, and coincident crustal subsidence caused widespread deposition of carbonates over the Jurassic sediments and salt deposits throughout the Gulf Coast basin (Reference 30).

In the Mississippi Embayment, crustal subsidence continued into the Early Cretaceous allowing marine deposition to extend further north and west towards the Ouachita Mountains (Reference 17; 32). During the mid-Cretaceous, the area was uplifted and partially eroded, although minor deposition locally occurred. During the Late Cretaceous, marine sediments lapped onto Early Cretaceous and older coastal plain sediments in response to the advance of the Gulfian Sea (Reference 17). The weight of these sediments accelerated subsidence of the Mississippi Embayment in the early part of the Upper Cretaceous. Minor transgressions and regressions of the Cretaceous Gulfian Sea caused deposition of alternating shallow and moderately deep water lithologies that are separated by unconformities. Near the end of the Cretaceous, volcanic activity and igneous intrusion formed the Sabine and Monroe Uplifts, and the Jackson Dome (Figures 2.5-3 and 2.5-4; Reference 34). These features continued to uplift into the Oligocene (Reference 34). Formation of these volcanogenic structural highs, oriented across the axis of the Mississippi Embayment, isolated the northern part of the embayment from the Gulf Coast Basin to the south (Reference 17).

During the latest Cretaceous and early Tertiary, the Laramide orogeny in western North America supplied voluminous quantities of terrigenous siliciclastic sediment to the Mississippi Embayment and Gulf Coastal Basin (Reference 35). Paleocene marine sediments of the Midway group were deposited unconformably on top of the Cretaceous sediments in the northernmost Mississippi Embayment (Reference 36). Subsidence of the Mississippi Embayment ceased in the Eocene due to a tectonic change from crustal extension to crustal shortening with development of folds and faults along the Reelfoot Rift. In Oligocene time, the locus of deposition shifted southward in response to progradation of sediments within the

Mississippi Embayment. In the southern part of the basin, where the Cretaceous deposits are thickest, the weight of overlying sediments initiated the intermittent upward diapiric movement of salt plugs and folds, which eventually formed salt domes during the Tertiary (References 30; 37). Localized tensional faults are associated with the salt domes. Growth of salt domes in the Mississippi and Northern Louisiana salt basins ceased in the Oligocene (Reference 30). South of the Mississippi Embayment, in the Gulf Coast Basin, minor sea level fluctuations resulted in partial erosion of sediments.

During the Cenozoic, the rate of deposition into the Gulf Coast Basin exceeded the rate of regional subsidence, resulting in gulfward progradation of the Gulf Coastal Plain by as much as 250 miles. The rates of sedimentation, basin subsidence, and eustatic changes were not synchronous, so that transgressive and regressive cyclic deposits characterize the late Tertiary stratigraphic section. The basin depocenter, located along successive shelf edges, migrated across the Gulf Coast Basin throughout Tertiary time reflecting changing sediment sources and volumes (Reference 17; 29; 38).

Sea level retreat in the late Tertiary (Reference 39) allowed deposition of the littoral and non-marine Catahoula Formation (Miocene) and the alluvial Citronelle Formation (Pliocene) on the exposed Gulf Coastal Plain (Reference 17). The Catahoula Formation, which underlies the Site Vicinity, was deeply eroded in the Late Miocene and Pliocene (Reference 16).

During the Pleistocene, massive volumes of sediment were transported to the Gulf Coast Basin by the Mississippi River, partly in response to advances and retreats of continental glaciers (References 17; 31; 32; 40). The thickest accumulations of Pleistocene deposits occur along the present Louisiana shelf edge (Reference 41). The entire sedimentary wedge in the vicinity of the Louisiana shelf edge is on the order of 50,000-feet thick (Reference 17). Late Wisconsin sea level rise submerged the late Pleistocene continental shelf and reached its present position approximately 3,000 to 4,000 years ago, defining the current configuration of the Gulf Coast margin (Reference 17). Throughout the Quaternary, alluvial material was deposited in the Mississippi Alluvial Valley and extensive blankets of loess mantled the former ground surface (Reference 32; 21).

The prograding clastic wedge of the Mississippi delta has been affected by gravity-failure structures, such as the syndepositional growth faults observed in southern Louisiana and eastern Texas (Figures 2.5-3 and 2.5-5). The growth faults typically are oriented parallel or subparallel to the depositional strike (east-west orientation), and are characterized by (1) down-to-the-south displacement; (2) notable thickening of displaced strata on the downthrown side; (3) an increase in stratigraphic throw with depth; and (4) lack of significant seismic activity. Post-depositional gravity failures, or growth faults, also are common intra-basin structures. No surficial growth faults have been mapped at the surface closer than about 90 miles from the Grand Gulf site.

The Site Region is characterized by very low rates of historical seismicity (Figure 2.5-5). Only one earthquake of m_b 3.3 to 3.9 has been recorded within 90 miles of the site since 1777 and only 39 earthquakes $>m_b$ 3.3 have been recorded in the entire 200 mile radius area around the site since 1777. Most earthquakes in the Site Region occur in areas underlain by crystalline basement rock of the North American Craton.

2.5.1.1.4 Regional Stratigraphy

Regional stratigraphic units within the Gulf Coastal Basin are described from youngest to oldest in the following sections. Geologic maps of the Site Region (200 miles), Site Vicinity (25 miles), and Site Area (5 miles) are shown on Figures 2.5-4, 2.5-9 and 2.5-10, respectively. Cross-sections through the Site Region and Site Vicinity are shown on Figures 2.5-6, 2.5-11, and 2.5-12. The major stratigraphic units are summarized on Figure 2.5-13. A detailed description of the Site Location stratigraphy is presented in Section 2.5.1.2.

2.5.1.1.4.1 Cenozoic Era

2.5.1.1.4.2 Quaternary System

Quaternary deposits within the Site Region occur along the Mississippi Alluvial Valley and its tributaries, the Southern Hills subprovince of the Gulf Coastal Plain, and the Loess Hills subprovince (Figure 2.5-4). Quaternary deposits predominantly include alluvial sediments related to the Mississippi River, lacustrine sediments, and eolian silt derived from sediment sources in the Mississippi Alluvial Valley (Reference 17; 32). The composition, texture and morphology of Quaternary sediments in the Site Region are strongly influenced by climatic changes and glacial cycles. The response of regional marine, alluvial, and terrestrial systems to these changes is summarized in Table 2.5-2.

In the Pleistocene, episodes of continental glaciation produced massive volumes of sediment that were transported through the Mississippi Alluvial Valley to the Gulf of Mexico (References 17; 31; 32). These sediments were deposited at various elevations due to climatic changes, local depositional environments (e.g. lakes formed behind glacial outwash deposits) and the isostatic effects of continental glaciations, sea level fluctuations, and regional epirogenic uplift. The major Holocene and Pleistocene units are described below.

2.5.1.1.4.2.1 Holocene Series

Within the Site Region, Holocene deposits include alluvium and loess that occur within the Mississippi River valley and its tributary valleys, and deltaic and beach facies within the Chenier Plain and Delta Plain (Reference 17). Holocene sediments within the Site Vicinity and Site Area include alluvium (Hal), backswamp (Hb), and a series of Mississippi meander belt (Hmm_1 to Hmm_3) deposits (Figures 2.5-9 and 2.5-10).

Holocene alluvial and deltaic deposits thicken from a few tens of feet in the northern portion of the Site Region to greater than 600 feet in the southern portion of the Site Region (Reference 16). In the Site Vicinity, the thickness of Holocene deposits in the Mississippi Alluvial Valley is on the order of 0 to 400 feet thick (Reference 17). Holocene sediments in the two main tributary valleys within the Site Vicinity, Bayou Pierre and Big Black River (Figure 2.5-9), range in thickness from 70 to 100 feet (Reference 16).

The composition of Holocene alluvial deposits varies depending on the specific type of depositional environment. The meander belt deposits commonly form an upward fining sequence that grades from a basal gravel and coarse sand into a sand facies capped by silt and clay facies (Reference 17). Backswamp deposits consist of overbank sediments (silt and fine sand) along with a large component of organic material. Lacustrine deposits are also fine grained with significant organic materials. The Chenier Plain consists of Mississippi deltaic sediments that were deposited episodically in beach environments by longshore transport (Reference 17). The thickness and areal distribution of Holocene alluvial deposits are variable and occur as interfingering lenses of sand, silt, and clay.

2.5.1.1.4.2.2 Pleistocene Series

2.5.1.1.4.2.2.1 Loess Deposits

Regionally extensive sheets of Pleistocene loess occur along the eastern edge of the Mississippi Alluvial Valley and the surrounding areas (Figure 2.5-2). The deposits also occur within the Site Vicinity and Site Area (Figures 2.5-9 and 2.5-10). Erosion along the eastern side of the Mississippi flood plain forms a prominent erosional escarpment in the loess.

Loess deposits mantle the former landscape and consist predominantly of silt with minor sand and clay fractions (Reference 44). The loess has internal stratigraphy with distinct silty layers separated by buried soils. In the Site Region, loess deposits occur in a belt up to 30 miles wide on the east side of the Mississippi River (Figure 2.5-2). These deposits unconformably overlie Pleistocene to Pliocene alluvial deposits, and Tertiary deposits in the Site Vicinity and Site Area (Figures 2.5-8 and 2.5-9).

During near-maximum to early-waning stages of glaciation, strong seasonally prevailing, north-to-northwest winds carried large quantities of silt from unvegetated areas of glacial outwash in the central United States for tens to hundreds of miles throughout the Site Region (Table 2.5-2; Reference 17). In the Vicksburg area, depositional rates for the Peoria loess (late Wisconsin age) exceeded 2 mm/yr between about 15,500 and 17,000 years ago (Reference 42). Individual loess sheets are well-sorted, massive to subtly banded, unconsolidated, tan to brown silt. The maximum thickness (75 feet) and most prominent outcrops of the loess occur east of the Mississippi Alluvial Valley in a 10 to 30 -mile-wide zone across the Site Region (Reference 17). Loess deposits thin considerably eastward and form only localized deposits outside of the Loess Hills subprovince. Four discrete loess deposits are identified in the region, including from youngest to oldest, the Peoria, Ferndale, Roxana, and Loveland loess sheets (Reference 21, 32; 43). In the Site Vicinity, only the Peoria, Roxanne and Loveland loess sheets are present.

2.5.1.1.4.2.2.2 Terrace Deposits

Pleistocene terrace deposits occur along most of the Mississippi Alluvial Valley and extend across the Site Region (Reference 17). The terraces are assigned different names in different parts of the Site Region (Figure 2.5-13). Terrace deposits that occur in eastern Texas and southwestern Louisiana include the Beaumont and Lissie terraces. Terrace deposits in southern Louisiana include the Prairie, Montgomery, Bentley, and Williana terraces. Terrace deposits in southern Arkansas, Northern Louisiana, and west-central Mississippi include valley trains, Deweyville Complex, Prairie Complex, and Intermediate Complex. In the Site Vicinity, these include undifferentiated terraces in Bayou Pierre (probable Prairie Complex) and the Pliocene to Pleistocene Upland Complex.

Investigations of the Quaternary geology of the Mississippi Alluvial Valley (Reference 17; 32; 44) resulted in major updates and refinements of the seminal work of Fisk (Reference 31). Figure 2.5-14 and Table 2.5-3 present comparisons of the proposed terrace relationships (References 31; 32). The model of Fisk (Reference 31) was revised because the sequence of continental glaciations leading to terrace formation along the Mississippi River is far more complex than thought in 1944, and the processes leading to terrace formation are better understood. Fisk's postulated model (Reference 31) involves progressive narrowing and downcutting of the Mississippi Alluvial Valley (Figure 2.5-14). However, during the Pleistocene the Mississippi Alluvial Valley progressively widened during downcutting, rather than narrowing (Reference 32). This observation indicates that the Pleistocene terraces of Fisk are now interpreted to be Pliocene to early Pleistocene age (i.e. Upland Complex). Saucier also observed that Quaternary erosional surfaces, or “strath” terraces are present in the Site Region and likely formed in response to base-level changes (Reference 17).

Early to Late Wisconsin valley train terraces occur in the northern portion of the Site Region, but not within the Site Vicinity. Five distinct levels of Early Wisconsin terraces and two distinct levels of Late Wisconsin terraces are mapped (Reference 44). The deposits consist of thin, 5- to 10-feet thick, very silty and sandy clays, silts, and silty sands that overlie much thicker coarse grained sediments (Reference 17). The fine-grained surface and near surface deposits are slightly organic, horizontally bedded, slack-water accumulations of clays, silts, sands, loess, and local lacustrine deposits. These sediments directly overlie massive, clean sands that may be 75 to 100 feet in thickness and are indicative of high energy fluvial channel deposition. The clean sands locally overlie coarse sand and gravel, forming an upward-fining sequence.

Terrace deposits of the Deweyville Complex occur in the northwestern portion of the Site Region (Figure 2.5-4) along the Ouachita and Saline Rivers, but are not present in the Site Vicinity. The Deweyville Complex is similar in age to the Wisconsin valley train deposits, and is characterized by unique meander scars that are considerably larger than observed along the present river courses (Reference 45). There is little direct information regarding this complex (Reference 17). Based on analogy with other terrace complexes, the Deweyville Complex most likely includes multiple fluvial environments, such as point bar, backswamp, and abandoned channel. The deposits consist of a fining upward sequence approximately 100-feet thick. The coarser grained deposits of the Deweyville Complex, relative to other terrace complexes, may reflect higher stream discharges and energy levels than along the current fluvial system (Reference 32).

Terrace deposits of the Prairie Complex occur within the Site Region along the Gulf Coast from Texas to Alabama (included in unit Qp on Figure 2.5-4). The Prairie Complex includes a wide range of sediments including fluvial terrace deposits, colluvium, estuarine, deltaic and marine deposits. The Prairie Complex deposits range in age from pre-Wisconsin to late-Wisconsin. Undifferentiated terrace deposits in the Site Vicinity occur along tributary stream valleys (shown as Ptu on Figures 2.5-9 and Pt1 to Pt3 on 2.5-10), including Big Black River and Bayou Pierre, and may be related to the Prairie Complex (Reference 44). In the Site Area, terrace deposits equivalent to the Prairie Complex occur between elevations of 140 +/- 10 feet and 180 +/- 20 feet.

Terrace deposits of the Intermediate Complex occur in the western and southern portions of the Site Region, but are not mapped in the Site Vicinity. The deposits occur in tributary valleys west of the Mississippi River and in a 10- to 20-mile-wide, coast-parallel belt that extends from Texas to Alabama. Very little information is available regarding the Intermediate Complex, but the available data suggest that much of the complex consists of sediments deposited as a broad alluvial apron by small streams draining the adjacent higher terraces and uplands (Reference 17). The Intermediate Complex represents a transitional unit between the younger Prairie Complex and the Pliocene-Pleistocene Upland Complex described below.

Deposits of the Upland Complex occur extensively along the Mississippi Alluvial Valley and Gulf Coast margin in the Site Region, Site Vicinity, Site Area, and Site Location (Figures 2.5-9, 2.5-10, and 2.5-27). The deposits range in age from Pliocene to Pleistocene (approximately 1 to 4 million years) reflecting uncertainty in the time of deposition; we describe the Upland Complex in greater detail in the Pliocene-Pleistocene discussion, below. In general, the Upland Complex includes the Lafayette and Citronelle gravels and consists of sandy gravels, clayey sandy gravels, silty sands, and clayey gravelly sands (Reference 46). The deposits may be more than

100 feet thick and individual beds typically are lenticular and laterally discontinuous. Beds of clay and silt are rare.

Pleistocene terraces extend continuously along the length of the Mississippi Valley (Reference 44). The continuity and absence of vertical deformation of the terraces serves to demonstrate the tectonic stability of the Gulf Coastal Plain through the Pliocene and Pleistocene.

2.5.1.1.4.2.3 Tertiary System

Tertiary deposits are more than 6,000-feet thick in the Site Vicinity (Figure 2.5-9). These deposits thicken from north to south across the region with a maximum thickness greater than 50,000 feet in the Gulf of Mexico. The Tertiary deposits consist of terrigenous sediment eroded from the interior of North America and marine sediment deposited during marine transgressions and regressions. These deposits are divided into a number of formations in the Site Region and Site Vicinity and are described below (Figure 2.5-13).

2.5.1.1.4.2.3.1 Pliocene-Pleistocene Series

Pliocene deposits occur in the southern part of the Site Region, but are not present in the Site Vicinity (Figure 2.5-4). South of the Site Vicinity, the Pliocene section consists of interbedded marginal marine sediments that reach a maximum thickness of about 6,000 feet offshore. These deposits are overlain unconformably by the Upland Complex deposits (Figure 2.5-13).

The Pliocene-Pleistocene Upland Complex, also referred to as the Citronelle and Lafayette formations, is one of the most regionally extensive deposits in the Gulf Coastal Plain (Reference 32). Remnants of Upland Complex are identified in a 10- to 50-mile wide band east of the Mississippi River and extend from the head of the Mississippi Embayment to the Gulf of Mexico (Reference 17). This formation covers the majority of southern Mississippi, south of Jackson, and also crops out west of the Mississippi Alluvial Valley in south-central and southwestern Louisiana (Reference 17). The Upland Complex represents a widespread sand and gravel sheet deposited prior to regional stream entrenchment (Reference 44). Other Pliocene units in the Site Region include the Willis formation in southeastern Texas, and Graham Ferry in southeastern Mississippi, eastern Alabama, and offshore (Figure 2.5-13)

Deposits of the Upland Complex generally consist of a basal gravel and coarse sand facies, overlain by a finer sand facies that grades into an upper silt-and-clay facies. Gravels are predominantly chert and quartz and are reddish in color, while the silt-and-clay facies vary in color from reddish to light gray and tan (Reference 47). Silicified wood is common near the base of higher terraces. Individual terraces range in thickness from tens to hundreds of feet and commonly are buried by loess. The basal contact of the terrace deposits, as identified in test wells, ranges from 85 feet to over 300 feet below ground surface (Reference 47).

The Upland Complex is considered to be a combination of glacial outwash and non-glacial fluvial deposits of both central United States and Appalachian Mountains provenance (References 17; 48). However, the age and origin of the deposits are controversial. Fluvial gravels were inferred to have been deposited in the Mississippi Valley during the Pliocene to Early Pleistocene (Reference 49). The source of the Upland Complex terrace material was attributed to glacial outwash along the Mississippi River (Reference 31), and to erosion of the eastern Appalachian Mountains (References 46; 48). The deposits most likely formed from a combination of both sources (Reference 17).

A prolonged period of low sea level in the early Pleistocene led to entrenchment of upland areas, and erosion and partial redistribution of Pliocene glacial outwash and alluvial fan deposits

(Reference 17). Inset terraces formed due to reworking of Upland Complex deposits and grading of streams to sequentially lower base levels during the Early Pleistocene. These reworked terrace deposits occur at progressively lower elevations and are generally finer grained than the source materials. These Early Pleistocene terraces commonly are described as being a part of the Upland Complex. At some localities, the deposits clearly originated from glacial outwash processes (Reference 17). Thus, the younger terrace deposits may represent a combination of alluvial fan and glacial outwash deposits that merged or interfingered at the mouth of tributary valleys.

Deposits of the Upland Complex are present in the Site Location, and are described in greater detail in Section 2.5.1.2, Site Geology

2.5.1.1.4.2.3.2 Miocene Series

Miocene Series deposits (Tm) occur in the Site Region and Site Vicinity (Figures 2.5-4 and 2.5-9. Miocene Series formations include the Catahoula, Pascagoula, Hattiesburg, Amphist shale, and Flemming formations (Figure 2.5-12). The locus of deposition for the Catahoula formation shifted through time as a result of eustatic sea level fluctuations. In the eastern and southern part of the Site Region, the Catahoula Formation was deposited in the upper Oligocene and lower Miocene. In the Site Vicinity, the Catahoula formations is of Miocene age.

Miocene deposits occur beneath the Grand Gulf Nuclear Station at depths of between approximately 140 and 260 feet (Figure 2.5-11). The Miocene deposits reflect a regressional sequence of nonmarine clays, sandy clays, and sands that grade upward to deltaic and occasional lignitic non-marine sand and clay (Reference 16). The Miocene deposits consist of hard, gray, green or blue, freshwater to brackish-water clay and sandy clay interbedded with irregular fine sand, cemented sandstone, and lenses of black chert gravel (Reference 17). The thickness of Miocene deposits ranges from 750 feet to more than 44,000 feet from north to south across the Gulf Coastal Plain and offshore northern Gulf of Mexico (References 17; 16; 50; 51).

In the Site Vicinity, the Miocene Series has an unconformable lower contact with Oligocene and Upper Eocene marine deposits and an unconformable upper contact with the Pliocene-Pleistocene Upland Complex (Reference 16). The unconformable lower contact projects to the surface in the northern portion of the Site Vicinity near Vicksburg, and the unconformable upper contact with the Upland Complex occurs in the southeastern portion of the Site Vicinity (Figure 2.5-9). In the Site Vicinity, the Miocene deposits are covered by loess, Upland Complex deposits, alluvium, and colluvium (Figure 2.5-9).

The Miocene Series deposits dip gently southward across the Site Region. There are no surficial faults or structures that deform these deposits in the Site Vicinity (References 52; 53).

The Miocene Catahoula Formation is one of the most prominent and widespread deposits in the Site Vicinity (Figure 2.5-9). The formation underlies the Site Area and is identified as the load-bearing stratum for the existing Grand Gulf Nuclear Station. These deposits are described in greater detail in Section 2.5.1.2, Site Geology.

2.5.1.1.4.2.3.3 Oligocene Series

The Oligocene Series is exposed in the Site Vicinity and consists of the Vicksburg Group, including the Bucatunna, Byram, Mint Springs, Forest Hill, Red Bluff formations, and the Glendon, Bump Nose, and Marianna limestone formations (Figures 2.5-9 and 2.5-13). Other Oligocene formations in the Site Region include the Paynes Hammock, Chickasawhay, Hackberry, Frio, Anahuac, and Catahoula formations (Figure 2.5-13). As shown on Figure 2.5-4, Oligocene Series deposits are exposed in the banks of the Mississippi River bluffs for approximately 20 miles in the vicinity of Vicksburg (Reference 17). Additionally, Oligocene deposits crop out in the uplands northwest of Sicily Island and the uplands of southwestern Mississippi (Reference 17). Oligocene Series deposits increase in thickness southward and dip into the subsurface south of Vicksburg.

Deposits of the Vicksburg Group consist of estuarine to marine, limestone and marl with lesser amounts of bentonite, clay, and sand (Reference 52). These deposits unconformably overlie freshwater, interbedded, clayey, lignitic silts and fine cross-bedded sands of the Forest Hill Formation. The Forest Hill Formation is in unconformable contact with the underlying Eocene Jackson Group (described below). Oligocene deposits range in thickness from about 300 feet in the Site Vicinity (Figure 2.5-10) to a maximum thickness of approximately 12,000 feet in the southern portion of the Site Region (Reference 17; 54). The Oligocene Series deposits occur at a depth of about 350 feet beneath the Grand Gulf Site (Figure 2.5-11), and are described in greater detail in Section 2.5.1.2, Site Geology.

A structure contour map of the top of the Glendon Limestone Formation of the Vicksburg Group shows no evidence for faults or structures that deform these deposits in the Site Vicinity (Figure 2.5-15). The structure contours project smoothly through the Site Area documenting the absence of faulting or other forms of tectonic or non-tectonic (i.e. salt piercement structures) deformation in the Site Area. As shown by the structure contour map, salt diapirs have formed domes in the Oligocene deposits approximately 8-miles to the northeast and southwest, respectively. However, the salt diapirs have not pierced the Oligocene horizon at these locations.

2.5.1.1.4.2.3.4 Eocene Series

The Eocene Series is exposed in the Site Region (Figure 2.5-4) and includes the Jackson (Te3), Claiborne (Te2), and the Wilcox (Te1) Groups (Figure 2.5-13). As shown on Figure 2.5-6, these stratigraphic groups occur beneath the Site Area at depths of between approximately 1,000 to 7,000 feet. Deposits of the Eocene Series in the Site Region range in thickness from 2,900 to 6,900 feet (Reference 17; 33). The Eocene Series deposits are composed of carbonaceous and calcareous shales, sandy clays, marls, sands, silts, and beds of lignite (Reference 52).The Eocene Series is interpreted to have an unconformable upper contact with the Oligocene deposits and a transitional or conformable contact with underlying Paleocene deposits (Reference 50). The lower contact with the Paleocene was later reinterpreted to be locally unconformable (Reference 52).

Deposits of the upper Eocene Jackson Group are exposed in a continuous 50- to 75-mile-wide band that extends from the uplands of southeastern Arkansas northeastward into the uplands of western Tennessee and southwestern Kentucky (Reference 17; Figure 2.5-4). The deposits also are exposed in the bluffs west of the Ouachita River in central Louisiana and in the bluffs east of the Yazoo Basin in western Mississippi. The maximum thickness of the Jackson Group is 540 feet (Reference 17). In the Site Region, the Jackson Group includes the Whitsett, Manning, Wellborn, Cadell, Yazoo Clay and Moodys Branch Formations (Figure 2.5-13). In the Site Vicinity, the Yazoo Clay Formation consists of dark gray to brown, massive fossiliferous clay with irregular zones of fine sand and silty clay. The Yazoo Clay overlies the Moodys Branch Formation, which consists of fossiliferous, sandy and clayey marls with occasional limestone nodules.

Deposits of the Claiborne Group are exposed in the Site Region (Figure 2.5-4). Subdivisions are shown on Figure 2.5-13 and vary by region. The Claiborne Group has a total thickness of up to 1,450 feet (Reference 56). In the Site Vicinity, the formations include thinly interbedded gray to gray-brown clays, silt and silty sands, thick brown clays, massive fine to medium grained sands, and fossiliferous, calcareous, clays, marls, and sands. Faults deform Claiborne Group deposits in the eastern portion of the Site Region, approximately 135 miles east of the site (Figure 2.5-4)

Deposits of the lower Eocene-upper Paleocene Wilcox Group occur beneath the site at depths between approximately 3,500 feet and 7,000 feet (Figure 2.5-6), but are not exposed at the surface within the Site Region (Figure 2.5-4). Subdivisions of the Wilcox Group are shown on Figure 2.5-13. In the Site Region, the Wilcox Group ranges in thickness from 100 to 3,500 feet and consists of fine- to medium-grained sands and sandy clays interbedded with massive coarse grained and gravelly sands (References 17, 56). The Wilcox Group has unconformable contacts with both the overlying Claiborne Group and the underlying Paleocene Midway Group.

2.5.1.1.4.2.3.5 Paleocene Series

The Paleocene Series (Tx, Figure 2.5-4) includes the Porters Creek Clay, Clayton, Wills Point, Kincaid, and Naheola formations of the Midway Group (Figure 2.5-13). These deposits are exposed in the eastern and northern portions of the Site Region (Figure 2.5-4), but are not exposed within the Site Vicinity (References 17; 44). The Porters Creek Clay Formation consists of massive, dark gray to black fissile shales, clay shales, and clays with sandy clay beds. The underlying Clayton Formation consists of gray, calcareous, glauconitic, fossiliferous, shales with lenses of white limestone. Deposits of the Midway Group occur beneath the Grand Gulf site at depths of 5,000 to 6,000 feet (Reference 16), and unconformably overlie Upper Cretaceous rocks (Figure 2.5-12). The maximum thickness of Paleocene deposits in the Site Region ranges from 730 to 1,200 feet (References 17, 33, 56).

2.5.1.1.4.3 Mesozoic Era

Mesozoic deposits in the Site Region consist of buried Triassic and Jurassic rocks, and locally exposed Cretaceous marine and terrestrial sediments that accumulated in response to active rifting and marine transgressions and regressions (Figures 2.5-4, 2.5-8). Non-marine, Triassic and Jurassic deposits in the Site Region were originally termed the Eagle Mills Formation or “Red Beds” (References 57, 58). Later, the “Red Bed” sequence was further subdivided into the Late Triassic Eagle Mills Formation and the Middle Jurassic Werner, Luann, and Norphlet Formations (Figure 2.5-13). Accumulation of sediment accelerated crustal subsidence and formation of the Mississippi Embayment in the northern Gulf Coast Plain. Each of the major stratigraphic systems of the Mesozoic Era is described below.

2.5.1.1.4.3.1 Cretaceous System

Deposits of the Cretaceous System are exposed in the eastern and northern portions of the Site Region (Figure 2.5-4). The subdivisions of the Cretaceous System are shown on Figure 2.5-13. In the Site Vicinity, deposits of the Cretaceous System occur at depths of between 3,000 and 10,000 feet (Figure 2.5-12). The Cretaceous System is also referred to as the Gulfian Series, which is subdivided into the Arkadelphia Marl and Nacatoch Sand formations (Figure 2.5-13; Reference 17). Previous mapping of Cretaceous System deposits includes a greater number of subdivisions including the Tuscaloosa Formation, Eutaw Formation, and Selma Group (Reference 52). Current stratigraphic nomenclature is summarized on Figure 2.5-13 (Reference 56).

Deposits of the Cretaceous Selma Group (Arkadelphia Marl Formation of Reference 17), include chalk and calcareous clay, glauconitic sand and sandy limestone and marl (Reference 52). Deposits of the underlying Eutaw Formation consist of massive, cross bedded, glaucanitic, fine sand, and deposits of the Tuscaloosa Formation consist of irregularly bedded sand, clay and gravel (Reference 52). Each of the above formations is separated by erosional unconformities. The Cretaceous System deposits have a maximum combined thickness of more than 5,000 feet beneath the site (Reference 16).

2.5.1.1.4.3.2 Jurassic System

Deposits of the Jurassic System in the Site Region include the Cotton Valley Group (Upper Jurassic), the Louark Group (Upper Jurassic), Louann Salt Group (Middle Jurassic), and unnamed Lower Jurassic deposits of anhydrite, sandstone, and conglomerate (Figure 2.5-13; Reference 56). These deposits are not exposed, but occur in the subsurface in the Site Region and Site Vicinity. The Cotton Valley Group includes the Knowles Limestone, Schuler, and Bossier formations and consist of marine and terrestrial sandstone, shale, and limestone. The Louark Group includes the Haynesville, Buckner, Smackover, and Norphlet formations and consist of basal red clay overlain by oolitic limestone, shale, and sandstone. The Louann Salt consists of thick evaporite deposits. Plastic flow of the Louann Salt related to sediment loading effects caused widespread diapirism and associated folding and faulting in the Interior Salt Basin and Coastal Salt Basin (Figure 2.5-3). The Louann Salt overlies the Werner Formation, which is also part of the evaporite sequence. Cumulatively, the Jurassic deposits in the southern portion of the Site Region have a thickness of nearly 10,000 feet (References 33, 59).

2.5.1.1.4.3.3 Triassic Deposits

The Eagle Mills Formation is the only Late Triassic deposit identified in the Site Region. This depositional sequence is not exposed at the surface, but has been penetrated by wells in southern Arkansas, eastern Texas, west-central Mississippi, northern Louisiana, south-eastern Mississippi, and southern Alabama at depths ranging from 984 feet to 9,840 feet (Reference 60). Deposits of the Eagle Mills Formation consist of non-marine, clastic, varicolored (red, purplish, greenish-gray, or mottled) shales, mudstones, and siltstones with less abundant fine- to very fine-grained sandstone (Reference 60). Basal units of the Eagle Mills Formation contain pebbles and cobbles of Paleozoic limestone. The Eagle Mills Formation represents the deposits that filled grabens, half grabens, and rift basins in prograding alluvial fan, fluvial, deltaic plain, and freshwater lake environments. The lower contact of the Eagle Mills formation is unconformable with Paleozoic rocks and the upper contact is unconformable with the Jurassic Werner Formation. The Eagle Mills Formation changes thickness over short distances from less than 10 feet to over 7,200 feet due to contemporaneous deposition in an active rift system (Reference 60).

2.5.1.1.4.4 Paleozoic Era

Paleozoic rocks are exposed in the northwestern portion of the Site Region, but do not occur in the Site Vicinity Figure 2.5-4. In the subsurface, deposits of the Paleozoic Era consist of seven major stratigraphic series and 19 individual formations (References 17, 56). The maximum combined thickness of Paleozoic deposits in the northwestern portion of the Site Region is in excess of 5,600 feet (Reference 17) and the maximum thickness south of the site is unknown. South of the Ouachita and Appalachian Mountains, Paleozoic and older deposits are not exposed. The depth to these deposits in the subsurface beneath the Site Vicinity is greater than 13,000 feet (Figure 2.5-6). Deposits of the Mississippian and Pennsylvanian Systems consist of interbedded shale, fine-grained sandstone, and minor limestone. Deposits of the Ordovician

System consist of dolomite interbedded with thin beds of limestone, shale, and sandstone. Paleozoic rocks have an unconformable contact with the overlying Mesozoic rocks. The nature of the lower contact is unknown, but most likely is a nonconformity separating the Paleozoic deposits from crystalline basement rocks.

2.5.1.1.4.5 Precambrian

Precambrian basement rocks are not exposed in the Site Region (Figures 2.5-4 and 2.5-16a). The depth to basement in the Site Vicinity is estimated to be between 6 and 8 miles (Figure 2.5-16b; Reference 18).

Samples obtained from deep oil and gas exploration wells in the Site Region indicate the presence of Precambrian age North American continental crust beneath the Paleozoic stratigraphic section along the buried Ouachita Orogenic Belt (Reference 61). The basement rocks consist of sialic hornblende syenite dated approximately 785 +/- 34 Ma. The location of this subcrop, association with other samples collected from deep exploration borings, and similarity in age and composition to samples from the Blue Ridge Terrane of the southern Appalachian Mountains (described below) suggests that the Precambrian rocks encountered in the Site Region are related to the North American craton.

South of the buried Ouachita Orogenic Belt, Precambrian crystalline basement consists of highly attenuated continental crust or transitional crust related to formation of the Gulf of Mexico (Figure 2.5-5; Reference 18). Due to the depth of the crust in the Gulf Coast Basin actual rock samples have not been obtained. However, based on seismic velocity surveys the crust is thought to be transitional between continental and oceanic materials (Reference 18).

2.5.1.1.5 Regional Tectonic Setting

In 1986, EPRI developed a seismic source model for the Central and Eastern United States (CEUS) including the Site Region (Reference 9). The seismic source model included the independent interpretations of six earth science teams and reflected the general state of knowledge of the geoscience community as of 1986. The seismic source models developed by each of the six teams for the EPRI model were based on the tectonic setting and the occurrence, rates, and distribution of historical seismicity.

Since 1986, additional geological, seismological, and geophysical research has been completed in the Site Region. This more recent research has identified a potentially active seismic source, the Saline River source zone within the Site Region that includes the trends of the Arkansas, Saline, and Ouachita river lineaments in southeastern Arkansas (Figure 2.5-5). Recent research also has improved the characterization of seismic source parameters associated with the New Madrid seismic zone, the source of the 1811-1812 earthquake sequence.

In the following sections, we describe each of the major tectonic features in the Site Region, and the tectonic basis for their identification. The original seismic sources identified by EPRI (Reference 9) are thoroughly described in the EPRI report. The discussion below provides a summary of each tectonic feature modeled by EPRI in the Site Region and focuses on new information acquired since 1986 that is relevant to the assessment of seismic parameters for each source zone. A description of the Saline River source zone and new information on the New Madrid seismic zone is provided.

The EPRI Earth Science teams independently defined the geometry and source parameters of seismic sources in the CEUS. This independent assessment led to a range of interpretations that captured the variability and uncertainty in each seismic source. Each team modeled the major tectonic elements of the CEUS to develop their seismic source models. Figure 2.5-5 illustrates the distribution of tectonic features and historical seismicity in the Site Region from which the six EPRI team source models are based. The tectonic features shown on Figure 2.5-5 reflect the cumulative deformation of tectonic events throughout the Paleozoic, Mesozoic, and Cenozoic Eras. A chronology of events that influenced the development and distribution of tectonic features in the Site Region is described below and presented in Figure 2.5-8.

The south central United States is a passive continental margin with no relative differential motion between the Gulf of Mexico oceanic plate and the North American continental plate (Reference 63). The region is one of low earthquake activity and low stress, and is cited as an example of a stable continental region (References 62; 64, 65, 66, 67). The orientation of the maximum horizontal stress is northeast to east-northeast within the craton. The orientation of maximum extension is south-southeast near the Gulf Coast (Figure 2.5-5; Reference 68; 69). The southward oriented extension along the Gulf Coast reflects crustal loading and deformation within the Mississippi River deltaic complex in the Gulf of Mexico and may be distinct from the regional east-northeastward directed regional compressive stress in the underlying basement.

The primary tectonic elements of the region are fossil rift systems such as the Reelfoot Rift, or former collision zones such as the Paleozoic Ouachita Orogenic Belt and Appalachian Mountains (Figures 2.5-5). Each of these structures are regional in scale, and geologically and geophysically recognizable. Quaternary active structures, if present, appear to be entirely related to reactivation of these older bedrock rift or collisional structures. Nearly all earthquakes with well-located hypocenters occur within the Precambrian basement complex, and a majority of events >M4.5 appear related to regional scale structures such as the Reelfoot Rift, or Ouachita Orogenic Belt (Figure 2.5-5; Reference 70).

2.5.1.1.5.1 Tectonic Stress in the Mid-Continent Region

Expert teams that participated in the 1986 EPRI evaluation of intra-plate stress found that tectonic stress in the CEUS primarily is characterized by NE-SW-directed horizontal compression. In general, the expert teams concluded that the most likely source of tectonic stress in the mid-continent region was ridge-push force associated with the Mid-Atlantic ridge, transmitted to the interior of the North American plate by the elastic strength of the lithosphere. Other potential forces acting on the North American plate were judged to be less significant in contributing to the magnitude and orientation of the maximum compressive principal stress ($\sigma 1$). Some of the expert teams noted that deviations from the regional NE-SW trend of $\sigma 1$ may be present along the east coast and in the New Madrid region. They assessed the quality of stress indicator data, and discussed various hypotheses to account for what were interpreted as variations in the regional stress trajectories.

Since 1986, an international effort to collate and evaluate stress indicator data resulted in publication of a new World Stress Map (References 68; 71). Data for the map were ranked in terms of quality, and plate-scale trends in the orientations of principal stresses were assessed qualitatively (Reference 72). Subsequent statistical analyses of stress indicators confirmed that the trajectory of the maximum compressive principal stress ($\sigma 1$) is uniform across broad continental regions at a high level of statistical confidence (Reference 73). In particular, the NE-SW orientation of $\sigma 1$in the central and eastern United States inferred by the EPRI experts is statistically robust, and is consistent with the theoretical trend of compressive forces acting on the North American plate from the mid-Atlantic ridge (Reference 73).

The more recent assessments of lithospheric stress have not confirmed inferences of some EPRI expert teams that the orientation of $\sigma 1$ may be locally perturbed in the New England area, along the east coast of the United States, or in the New Madrid region. Zoback and Zoback summarized a variety of data, including well-bore breakouts, results of hydraulic fracturing studies, and newly calculated focal mechanisms, which indicate that the New England and eastern seaboard regions of the U.S. are characterized by horizontal NE-SW to E-W compression (Reference 68). Similar trends are present in the expanded set of stress indicators for the New Madrid region. All of these regions, were grouped with a large area of eastern Canada, and the central and eastern U.S. in an expanded "Mid-Plate" stress province (Reference 68).

In addition to better documenting the orientation of stress, research conducted since 1986 has addressed quantitatively the relative contributions of various forces that may be acting on the North American plate to the total stress within the plate. Richardson and Reding (Reference 74) performed numerical modeling of stress in the continental U.S. interior, and considered the contribution to total tectonic stress from three classes of forces:

1) Horizontal stresses arising from gravitational body forces acting on lateral variations in lithospheric density. These forces are commonly called "buoyancy forces". Richardson and Reding emphasize that what is commonly called "ridge-push force" is an example of this class of force (Reference 74). Rather than a "line-force" that acts outwardly from the axis of a spreading ridge, "ridge push" arises from the pressure exerted by positively buoyant, young oceanic lithosphere near the ridge against older, cooler, denser and less buoyant lithosphere in the deeper ocean basins (Reference 75). The force is an integrated effect over oceanic lithosphere ranging in age from about 0 to 100 million years (Reference 76). The "ridge push" force is transmitted as stress to the interior of continents by the elastic strength of the lithosphere.
2) Shear and compressive stresses transmitted across major plate boundaries (i.e., strike-slip faults and subduction zones).
3) Shear tractions acting on the base of the lithosphere from relative flow of the underlying asthenospheric mantle.

The observed NE-SW trend of σ_1 in the central and eastern United States dominantly reflects "ridge-push" body forces (Reference 74). They estimated the magnitude of these forces to be about 2 to 3 x 10^{12} N/m (i.e., the total vertically integrated force acting on a column of lithosphere 1 meter wide), which corresponds to average equivalent stresses of about 40 to 60 MPa distributed across a 50-km-thick elastic plate. The fit of the model stress trajectories to data is improved by addition of modest compressive stress (about 5 to 10 MPa) acting on the San Andreas fault and Caribbean plate boundary structures (Reference 74). The fit of the model stresses to data further indicated that shear stresses acting on these plate boundary structures must also be in the range of 5 to 10 MPa.

The general NE-SW orientation of σ_1 in the central and eastern United States also can be reproduced by numerical models that assume a shear stress, or "drag", is acting on base on the North American plate (Reference 74). This model is not favored (Reference 74; 68) as a significant contributor to total stress in the mid-continent region, however, because it predicts or requires that the horizontal compressive stress in the lithosphere increase by an order of magnitude moving from east to west across the central United States. The state of stress in the southern Great Plains is characterized by north-south extension, which is contrary to this prediction (Reference 68). They further observed that seismic activity generally increases from west to east across the central and eastern U.S., which is not consistent with the prediction of the basal drag model that compressive stresses (and presumably rates of seismic activity) should be higher in the west central U.S. than in the eastern U.S.

2.5.1.1.5.2 Appalachian Mountains

The Appalachian Mountains extend from Newfoundland, Canada to central Alabama. The Appalachian Mountains consists of a southwest-trending complex of folded, thrusted, and metamorphosed terranes that evolved over a period of approximately 800 million year.

The Appalachian Mountains are up to 400 miles wide and 2,000 miles long and include the Valley and Ridge, Piedmont, and Blue Ridge terranes. Each terrane is bounded by a zone of major thrust faults. These terranes include Proterozoic and younger age rocks of both oceanic and continental affinity that were accreted to the North American craton during three episodes (or orogenies) of plate collision and northwest-directed crustal shortening. The episodes of plate collision include the Allegheny orogeny (270 to 350 Ma), Acadian orogeny (350 to 400 Ma), and Taconic orogeny (400 to 500 Ma; Reference 77). The Taconic orogeny produced the Blue Ridge terrane which consists of highly metamorphosed, folded and thrust faulted Proterozoic and Cambrian crystalline rocks. The Acadian orogeny produced the Piedmont terrane and deformed the eastern Blue Ridge. The Piedmont terrane consists of metamorphosed Precambrian and Paleozoic sediments and volcanic rocks that were intruded by granitic plutons. The Allegheny orogeny produced the Valley and Ridge terrane and deformed the Blue Ridge and Piedmont terranes. The Valley and Ridge terrane consists of a thick sequence of folded and thrust faulted Paleozoic sediments (Reference 77). Each subsequent orogeny deformed the pre-existing rocks from earlier orogenies resulting in a complex sequence of poly-deformed and metamorphosed rocks.

The surface expression of the Appalachian Mountains terminates outside of the 200-mile Study Region. However, the northeast-trending geological structures associated with the Appalachian Mountains extend in the subsurface into the northeastern portion of the Site Region where they merge with the northwest-trending Ouachita Mountains in southeastern Mississippi and southwestern Alabama (Figure 2.5-4). The southern end of the Appalachian Mountains structures approximately coincides with the Pickens-Gilberttown fault zone (Figure 2.5-5). The Appalachian and Ouachita Mountains define the eastern and southeastern edges, respectively, of the current North American craton (Reference 78).

Many Paleozoic thrust faults of regional extent are mapped within the Appalachian Mountains. However, in the Site Region none of these faults have geological or seismological evidence of Quaternary activity and only the southernmost portion of the Appalachian Mountains extends in the subsurface into the Site Region. There are no distinct faults identified as individual seismic sources within the Appalachian Mountains in the Site Region. Historical seismicity generally aligns along the northeastern trend of the Appalachian Mountains, but within the Site Region, only nine earthquakes m_b 3.3 to 3.9 (lower bound threshold used by Reference 9) were recorded between 1777 and 1986. Since the EPRI 1986 study, only one earthquake (m_b<3.9) occurred within the subsurface extent of the Appalachian Mountains in the Site Region during the period 1986 and 2002 (Reference 11; Figure 2.5-5). The seismicity that occurs at the southern end of the buried Appalachian Mountains also coincides with the location of the Pickens-Gilberttown fault zone. These earthquakes are spatially related to an area of high petroleum withdrawal and may be triggered events caused by fluid recovery.

The April 2003 M_w 4.9 Alabama earthquake occurred within the Appalachian Mountains province, outside of the Site Region (Figure 2.5-17). This event is within the normal range of earthquake magnitudes expected for this region. The event occurred at a depth of about 3 miles (5 km) and had a strike-slip focal mechanism. The event was not felt at the Grand Gulf Nuclear Station and did not trigger any monitoring instruments at the site.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the Appalachian Mountains province that range from m_b 5.4 to 7.2 (M_w 5.1 to 7.6). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of M_w 7.5 for the Appalachian Mountains in the Site Region. No new information was identified during our data review that provides estimates of the maximum earthquake magnitudes for the Appalachian Mountains that are outside of the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.3 Ouachita Orogenic Belt

The Ouachita Orogenic Belt is the eroded core of a mountain belt that formed during continental collision and formation of the supercontinent Pangea, in the Paleozoic (Figure 2.5-8; Reference 79). The Ouachita Orogenic Belt extends from western Alabama through northern Mississippi, central Arkansas, southeastern Oklahoma, and eastern Texas (Figure 2.5-5). The Ouachita Orogenic Belt consists of an arcuate salient of complexly folded, thrust-faulted, and metamorphosed rocks that, like the Appalachian Mountains, includes accreted oceanic crust of Proterozoic age (Reference 79).

The Ouachita Orogenic Belt is up to 50 miles wide and 1,260 miles long, although about 80 percent of its length is buried beneath Mesozoic and Tertiary sediments of the Gulf Coast Basin. The Ouachita Orogenic Belt defines the northern edge of the Gulf Coastal Basin, the southern margin of the Mississippi Embayment, and the southern edge of the North American craton (Figures 2.5-3 and 2.5-7). The belt includes three regional subdivisions including the Southeastern Ouachitas, the Ouachita Mountains, and the Subsurface Ouachitas of Texas.

The topography of the Ouachita Orogenic Belt is expressed by a low relief erosional surface that was buried by Jurassic sediments in the Gulf Coastal Plain. Across the Gulf Coastal Plain from Alabama to southern Texas this erosional unconformity dips toward the Gulf of Mexico at an angle of less than 1 degree (References 79; 80).

Repeated episodes of deformation formed asymmetrical folds, and low- and high-angle thrust faults that involve Middle to Upper Paleozoic rocks along the edge of the North American craton (Reference 81). Middle to Upper Paleozoic rocks are unconformably overlain by late Paleozoic rocks that were not involved in the Ouachita orogeny. Thus, deformation along the Ouachita Orogenic Belt ceased in late Paleozoic time.

Throughout the entire length of the Ouachita Orogenic Belt, the base of the orogen is defined by a major decollement, along which allochthonous marine sedimentary rocks are thrust northward over North American cratonic rocks. The northern side the Ouachita Orogenic Belt overlies 21- to 24-miles of North American continental crust (Reference 82). On the southern, or Gulf Coast side, the Ouachita Orogenic Belt overlies transitional continental crust (Reference 18; 82).

Two major stratigraphic units collectively known as the Ouachita facies compose the majority of rocks in the Ouachita Orogenic Belt. The lower stratigraphic unit, referred to as the pre-orogenic off-shelf facies, ranges from Late Cambrian to Early Mississippian in age, and is approximately 9,500 to 11,000 feet thick. This lower stratigraphic unit consists of shale, sandstone and micrite that grade upward to chert, siliceous shale, and novaculite.

The upper stratigraphic unit is referred to as the synorogenic facies. This unit ranges from Late Mississippian (Meramecian) to Early Permian (Wolfcampian) in age, and represents over 50,000 feet of shelf-delta clastic deposits that originated in foreland basins, and outboard deep water clastic wedge deposits. The shelf-delta deposits of the foreland basin were deformed by folding and faulting during the Ouachita orogeny (Reference 79).

The Southeastern Ouachitas, in the Site Region, lie entirely in the subsurface of northern Mississippi and southwestern Alabama (Reference 81), within the Gulf Coastal Plain (Figure 2.5-2). On the northern side of the Ouachita Orogenic Belt, Carboniferous age shelf-delta deposits (upper stratigraphic unit) occur in the subsurface foreland basin and extend southward into the frontal thrusts in Mississippi. Southwest of the Orogenic Belt undifferentiated pre-orogenic and synorogenic rocks are present.

In Mississippi, the decollement beneath the Southeastern Ouachitas ramps downward into the shelf strata of the Appalachian Mountains and interleaves with the decollement beneath the southern part of the Appalachian Mountains (Reference 79). The intersection of the Ouachita Orogenic Belt and the thrust faults of the Appalachian Mountains leads to a cross-cutting fault pattern (Figure 2.5-5).

Although many large Paleozoic thrust faults of regional extent are mapped through the Ouachita Orogenic Belt, none display geological evidence of Quaternary activity. As shown on Figure 2.5-5, historical seismicity occurs along the trend of the Ouachita Orogenic Belt, but within the Site Region, only 18 earthquakes of m_b 3.3 to 3.9 (lower threshold used by EPRI (Reference 9) were recorded between 1777 and 1986. Since the EPRI study, only three earthquake of m_b<3.9 occurred during the period 1986 and 2002, within the Ouachita Orogenic Belt in the Site Region (Figure 2.5-5; Reference 83).

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Ouachita Orogenic Belt that range from m_b 5.5 to 7.2 (M_w 5.1 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of M_w 7.5 for the Ouachita Orogenic Belt in the Site Region (Reference 84). This new information is within the range of estimates of maximum earthquake magnitude for the Ouachita Orogenic Belt provided by the EPRI teams (Reference 9). The USGS estimate of M_w 7.5 is defined for an areal source zone that includes the entire area of the Gulf and East Coasts that extends from the edge of the North American cratonic rocks to the coastline (Reference 84).

Several potential Quaternary active fault zones within the Ouachita Orogenic Belt have been identified primarily by geomorphic evidence of basin asymmetry, and localized evidence of faulting in road-cuts and trenches, weak clustering of earthquake epicenters, and liquefaction features (Reference 85). The potential faults are identified along the Arkansas River, Saline River, and Ouachita rivers in northern Louisiana and Arkansas. Detailed descriptions of these features are provided in Section 2.5.1.1.5.7.

2.5.1.1.5.4 Arkoma Basin and Black Warrior Basins

The Arkoma and Black Warrior basins are located directly north of the Ouachita Orogenic Belt (Figure 2.5-3). Both basins straddle the margin of the Site Region. The Arkoma and Black Warrior basins are foreland basins containing synorogenic sedimentary deposits associated with the Ouachita Orogenic Belt. The sedimentary deposits overlie North American cratonic rocks. The major period of deposition and basin deformation ceased in Late Paleozoic to early

Mesozoic time (Figure 2.5-8). There are no active tectonic features identified within the Arkoma Basin and Black Warrior basins (Reference 86, 90).

Paleozoic thrust faults in the Arkoma and Black Warrior basins show no evidence of Quaternary activity. Historical seismicity within the parts of the Arkoma and Black Warrior basins that are within the Site Region is sparse Figure 2.5-5. Only two earthquakes of m_b 3.3 to 3.9 (lower threshold used by Reference 9) were recorded between 1777 and 1986. Since the EPRI study, no additional earthquakes greater than m_b 3.3 have been recorded (Figure 2.5-5) in the Site Region. A swarm of small magnitude earthquakes m_b<4.5 occurred in central Arkansas, within the Arkoma Basin, outside of the Site Region. This event, referred to as the Enola earthquake swarm, occurred within a small volume of crust (approximately 25 km^3; Reference 159). The earthquake swarm is interpreted to be associated with a short, 2.6-km long, west-northwest-trending fault segment, that is related to a basement listric fault within a Paleozoic graben (Reference 160). This fault may have a favorable orientation with respect to the east-northeast maximum compressive stress (Reference 69) to produce left-lateral strike slip deformation (Reference 159). Based on the cross-cutting fault patterns within this area (Reference 160) larger earthquakes are not expected to occur in the Enola, Arkansas area.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Arkoma and Black Warrior basins that range from m_b 5.4 to 7.2 (M_w 5.1 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of Mw 7.5 for the area encompassing the Arkoma and Black Warrior Basins. The estimate of maximum earthquake magnitude for the area encompassing the Arkoma and Black Warrior basins is within the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.5 Reelfoot Rift

The Reelfoot Rift represents a northeast-trending fault system that originated in Precambrian or Early Cambrian time during extension of the North American continent (Figure 2.5-8; References 81; 87). The Reelfoot Rift extends from southern Illinois at the northern end of the Mississippi Embayment, to east-central Arkansas and northern Mississippi beneath the Ouachita Orogenic Belt (Reference 27). As shown on Figures 2.5-3 and 2.5-5, the closest approach of faults within the Reelfoot Rift to the site is approximately 175-miles. The Reelfoot Rift now accommodates crustal shortening due to northeast-southwest directed regional compressive stress (References 68, 69).

The Reelfoot Rift is approximately 45 miles wide and 180 miles long with as much as 25,000 feet of structural relief (Reference 88). An alignment of magnetic intrusive rocks defines the rift boundaries (References 24, 87; 91). Within the Reelfoot Rift, Upper Paleozoic through Middle Cretaceous strata are absent and a major unconformity exists between Late Cretaceous and Early Paleozoic strata (Reference 92). The Reelfoot Rift comprises a number of distinct structural features, including the Commerce Geophysical Lineament, Western Margin of Reelfoot Rift, Crowleys Ridge, Sikeston Ridge, New Madrid Seismic Zone, and Eastern Margin of Reelfoot Rift (Reference 93). The New Madrid Seismic Zone is the primary seismically active tectonic feature within the Reelfoot Rift, and is described in Section 2.5.1.1.5.6, below.

The geologic history of the Reelfoot Rift includes numerous episodes of uplift, subsidence, intrusion, and sedimentation (Figure 2.5-8). During Precambrian to Cambrian time, the Reelfoot Rift formed as a result of continental rifting and crustal extension of the North American continent (Reference 27). In Late Cambrian time, rifting ceased and the Reelfoot Rift was filled with Paleozoic marine clastic and carbonate rocks (Reference 92). During Middle Cretaceous time, the Reelfoot Rift was reactivated forming an arch that resulted in erosion and removal of Late Paleozoic to Middle Cretaceous rocks of the Late Cambrian Reelfoot Rift (Reference 27; 85).

Reactivation of the Reelfoot Rift in Middle Cretaceous time was accompanied by emplacement of igneous rocks along the rift margins (Reference 85; 94). The emplacement of plutons and crustal arching in the Middle Cretaceous may have been related to the North American continent passing over the Bermuda Hot Spot (Reference 85). Cox and Van Arsdale (Reference 85) also suggest that reactivation of the Reelfoot Rift occurred in Middle Cretaceous time rather than Jurassic time, and therefore could not have been related to opening of the Gulf of Mexico (Reference 92). Reactivation of rift structures in the Late Cretaceous to Eocene caused crustal subsidence and formation of the Mississippi Embayment subprovince of the Gulf Coastal Plain, and initial deposition of alluvial sediment from the Mississippi River over Jurassic age carbonates in the northern Gulf of Mexico.

Regional stress again changed from extension to compression in Late Eocene time causing minor folding and faulting (e.g. Crittenden County fault) within the Reelfoot Rift (References 92; 95). Oligocene and Miocene strata are absent in the Mississippi Embayment and deposits in the Gulf Coast Basin indicate that the embayment was subaerially exposed and subjected to erosional processes during this time. Pliocene to Pleistocene glacial outwash deposits of the Upland Complex unconformably overlie Eocene deposits in the Mississippi Embayment (as well as Miocene deposits in the Site Vicinity). The Mississippi Embayment was entrenched during the Pleistocene and Holocene resulting in progressive flights of terraces incised into Upland Complex deposits along the Mississippi River and its tributaries (Reference 17).

Potentially active faults within the Mississippi Embayment may be associated with the Precambrian, Middle Cretaceous, Late Cretaceous, or Early Tertiary faults of the Reelfoot Rift (Reference 87). The potentially active faults may have been reactivated in Late Eocene time when the regional stress field changed from extension to NE-SW compression. Extensive geophysical investigations of the Reelfoot Rift have been completed for a variety of purposes including deep crustal dynamics, oil exploration, active tectonics, and geotechnical projects (Reference 92). These geophysical investigations indicate that many faults in the Reelfoot Rift do not offset post-Cretaceous deposits (Reference 88). However, Tertiary and Quaternary age faults are identified beneath the margins of Crowley's Ridge (References 97; 98), Sikeston Ridge (References 99, 100), Blytheville Arch (References 89, 101, 102, 104), Benton Hills (Reference 103), Reelfoot fault (Reference 105, 106, 108, 109), Bootheel Lineament (Reference 100, 107), Crittenden County fault (Reference 95; 96), Commerce Geophysical Lineament (Reference 110) and one of the west-bounding faults of the Reelfoot Rift (Reference 98).

With the exception of seismicity associated with the New Madrid seismic zone (described below), seismicity within the Reelfoot Rift is diffuse (Figure 2.5-5). A visual assessment of seismicity patterns indicates that pre-1985 and post-1985 earthquake occurrence has been relatively constant.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Reelfoot Rift (exclusive of the New Madrid Seismic Zone) that range from m_b 5.4 to 7.2 (Mw 5.0 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of Mw 7.5 for the Reelfoot Rift (Reference 84). The USGS estimate of maximum earthquake magnitude for the area encompassing the Reelfoot Rift is within the range of values developed by the six EPRI teams (Reference 9). The USGS estimate of Mw 7.5 is defined for an areal source zone that includes the entire area along the southern and eastern edge of the North American craton to the Gulf and Atlantic coasts.

2.5.1.1.5.6 New Madrid Seismic Zone

The New Madrid Seismic Zone (NMSZ) lies within the Reelfoot Rift and is defined by post-Eocene to Quaternary faulting, and historical seismicity. The NMSZ extends from southeastern Missouri to northeastern Arkansas and northwestern Tennessee (Figure 2.5-18). The NMSZ lies outside of the Site Region, but remains a significant contributor to the seismic hazard at the site of the proposed new facility at GGNS.

EPRI (Reference 9) defined the NMSZ as an aerial source zone that is approximately 124-miles long and 25-miles wide. Additional information published since 1986 shows that a distinct fault system is embedded within this source zone. The fault system consists of three distinct segments (Figure 2.5-18). These three segments include a southern northeast-trending dextral slip fault referred to as the Cottonwood Grove fault and Blytheville Arch, a middle northwest-trending reverse fault referred to as the Reelfoot fault, and a northern northeast-trending dextral strike-slip fault referred to as the East Prairie fault (References 92; 102; 111; 112; 113). In the current east-northeast to west-southwest directed regional stress field, Precambrian and Late Cretaceous age extensional structures of the Reelfoot Rift have been reactivated as right-lateral strike-slip and reverse faults (Reference 114).

The NMSZ produced three large magnitude earthquakes (estimates range from M_w 7.1 to 8.4) between December, 1811 and February, 1812 (Reference 115; 116; 117; 114; 118; 119; 120). The actual size of these pre-instrumental events is not known with certainty and is based primarily on various estimates of damage intensity and amount and pattern of liquefaction. Magnitude estimates using these approaches range from Mw 7.1 to 8.4.

The December 16, 1811 earthquake is inferred to be associated with strike-slip displacement along the southern portion of the NMSZ, either on the Blytheville Arch-Cottonwood Grove fault, or Blytheville Arch-Bootheel Lineament (Figure 2.5-18; References 118; 114). The southern portion of the NMSZ extends for approximately 70 miles from northeastern Arkansas through the eastern corner of the Missouri “Bootheel” (References 92; 113). This southwestern part of the NMSZ follows the pre-middle Ordovician subsurface Blytheville Arch and coincides with the axis of the Reelfoot Rift. Johnston estimated the December event to have a magnitude of M_w 8.1 ± 0.31 (Reference 118). Hough, later re-evaluated the intensity data for the region and concluded that the event had a magnitude of M_w 7.2 to 7.3 (Reference 117). Bakun and Hopper also re-evaluated the intensity data and derive a magnitude of M_w 7.2 for the December,1811 event (Reference 115).

The February 7, 1812 New Madrid earthquake is associated with reverse displacement along the middle part of the NMSZ (Figure 2.5-18; Reference 108; 109; 114; 115; 118). This earthquake most likely occurred along the northwest-trending Reelfoot fault that extends approximately 43 miles from northwestern Tennessee to southeastern Missouri (Reference 121; 122). The Reelfoot fault is a northwest-trending southwest-vergent reverse fault (Reference 109; 123). The Reelfoot fault forms a topographic scarp developed as a result of fault-propagation (References 109; 122; 124). Kelson et al. (Reference 109) investigated near-surface deformation along the trace of the scarp and found evidence for three events within the past 2,400 years. The most recent event was associated with the 1811-1812 earthquake sequence. The penultimate event is estimated to have occurred between A.D. 1260 and 1650. The pre-penultimate event occurred prior to about A.D. 780-1000 (Reference 108). A range of recurrence intervals for the Reelfoot fault are estimated between 150 to 900 years, with a preferred range of about 400 to 500 years (Reference 109). The geometry and reverse sense of motion of the Reelfoot fault implies that the fault serves as a step-over segment between the southern and northern portions of the fault (Reference 92; 113). Johnston estimated a magnitude of M_w 8.0 $\pm$ 0.33 for the February, 1812 event (Reference 118). Hough (Reference 117) later re-evaluated the intensity data for the region and concluded that the February event had a magnitude of M_w 7.4 to 7.5. Bakun and Hopper (Reference 115) also re-evaluated the intensity data from 1811-1812 sequence and derive a magnitude of Mw 7.2 to 7.6 for the event.

The January 23, 1812 earthquake is inferred to be associated with strike-slip displacement on the East Prairie fault along the northern portion of the NMSZ (Figure 2.5-30; Reference 114). The northern portion of the NMSZ extends 45 miles in a northeast direction through southeastern Missouri, and approximately coincides with the northwestern boundary of the Reelfoot Rift (Reference 114). The interpretation that the January, 1812 earthquake occurred along the East Prairie fault of the NMSZ is based on fault mechanics and limited historical data, and is more poorly constrained than interpretations of the December 16, 1811 and February 7, 1812 earthquakes. Baldwin et al. conducted paleoseismic investigations along this segment of the fault (Reference 99). Although they have identified liquefaction evidence for the 1811/1812 earthquake sequence, their data do not support the presence of a major throughgoing fault with repeated late Holocene events.

Johnston estimated a magnitude of Mw 7.8$\pm$0.33 for the January, 1812 event (Reference 118). Hough et al. later re-evaluated the intensity data for the region and concluded that the January event had a magnitude of Mw 7.1 (Reference 117). Bakun and Hopper also re-evaluated the intensity data from 1811-1812 sequence and derive a magnitude of M_w 7.1 for the January 23, 1812 event (Reference 115).

2.5.1.1.5.6.1 Earthquake Recurrence

Because there is very little surface expression of faults within the NMSZ, earthquake recurrence estimates are based largely on dates of paleo-liquefaction and offset geological features (References 12, 125; 126;109). These data suggest that strong earthquakes occurred around A.D. 900 +/- 100, A.D. 1450 +/- 150, and A.D. 1810 +/- 130 (References 125; 127; 128; 129). Kelson dated the penultimate event that deformed the scarp of the Reelfoot fault between A.D. 1260 and 1650, and an older event between A.D. 780 and 1000 (References 12, 109).

Conclusions from paleoseismic investigations suggest that the recurrence interval for surface deforming earthquakes in the NMSZ is about 200 to 800 years (Reference 125; 130; 131; 132; 133; 109; 127; 129). The 200 to 800 year recurrence estimate, with a preferred estimate of 500 years is significantly shorter than the 5,000 year earthquake recurrence interval used in the 1986 EPRI study based on extrapolation of historical seismicity (Reference 9).

2.5.1.1.5.6.2 Slip Rate

A wide range of slip rates are reported for the NMSZ. Slip rate estimates include data from geodetic measurements that range from 5 to 7 mm/yr (Reference 134) to no detectable deformation (Reference 135), and geologic rates that range from 1.8 to 6.2 mm/yr for the Holocene, and 0.0003 to 0.002 mm/yr for the late Cretaceous to late Eocene (References 122; 136). Mueller and Pujol (Reference 123) report a slip rate along the northern and southern portions of the NMSZ of 1.8-2.0 mm/yr based on the geometric relationships (fault strike and slip vectors) with the Reelfoot fault.

2.5.1.1.5.6.3 Maximum Earthquake Magnitude

The six EPRI teams developed estimates of maximum earthquake magnitudes for the NMSZ that range from m_b 7.1 to 7.9 (Mw 7.3 to 8.7). Since the EPRI study, several independent estimates of maximum earthquake magnitudes for the NMSZ have been developed (Reference 84; 118; 117; 115). The estimates of maximum earthquake magnitude of Frankel et al. (Reference 84) and Johnston (Reference 118) are within the range of values developed by the six EPRI teams (Reference 9). The estimates presented by Hough et al. (Reference 117), Bakun and Hopper (Reference 115), and Mueller and Pujol (Reference 123) are lower than the EPRI range of maximum magnitudes for the NMSZ.

2.5.1.1.5.7 Gulf Coast Basin

The Grand Gulf Nuclear Station is located in the Gulf Coast Basin (Figure 2.5-3), a broad, low relief geomorphic province extending from eastern Texas to western Alabama and Florida, and from southern Arkansas to the Gulf Coast. The Gulf Coast Basin is a north-south trending syncline approximately 280 miles long and 400 miles wide. The basin is structurally bounded by the buried Ouachita Orogenic Belt on the north, and southern Appalachian Mountains on the east. These structures define the boundaries of a deep crustal depression that contains more than 50,000 feet of Mesozoic and Cenozoic sediment (Reference 17). Sediments within the Gulf Coast Basin accumulated since post-Jurassic continental rifting and formation of the Gulf of Mexico (Reference 27). The amount of sediment transported to the Gulf Coast Basin exceeded the volume that could be accommodated through basin subsidence and infilling, and as a result, fluvial depocenters have migrated through time, and the sedimentary complex has prograded gulfward over 250 miles. Each shift in the depocenter was marked by development of a series of growth faults (e.g. Pickens-Gilberttown, Southern Arkansas, Gulf Margin Normal faults) that defined the margins of unstable shelves. The growth faults are interpreted as aseismic gravitational collapse features that slip basinward under sedimentary load. Currently active growth faults are located along the Cretaceous shelf edge in the vicinity of the modern Gulf Coast, 90 miles south of the site (Figure 2.5-5; Reference 29).

2.5.1.1.5.8 Pickens-Gilberttown and Southern Arkansas Fault Zones

The Pickens-Gilberttown and Southern Arkansas fault zones are a system of faults that extend from southwestern Alabama through west-central Mississippi (Figure 2.5-5, Reference 137) to southern Arkansas and eastern Texas. The Pickens-Gilberttown and Southern Arkansas fault zones consist of a series of grabens developed in Paleozoic to Middle Tertiary deposits, on the gulfward side of the Ouachita Orogenic Belt (Reference 16).

The Pickens-Gilberttown and Southern Arkansas fault zones together are more than 500 miles long in a zone typically less than 25-miles wide (Figures 2.5-3 and 2.5-5). The Pickens-Gilberttown and Southern Arkansas fault zones offset Mesozoic and Cenozoic deposits. Mesozoic and Cenozoic deposits thicken gulfward across the fault zones indicating syndepositional down-to-the-south movement. Movement along the Pickens-Gilberttown and Southern Arkansas fault zones displaces Miocene age sediments as much as 200 feet, but Pliocene and Pleistocene age deposits are not offset. Pre-Miocene deposits are offset up to 1,000 feet at depth, and similar age deposits on opposite sides of the fault zones are as much as 10-fold thicker on the down-dropped, gulfward side of the structure (Reference 16). The Pickens-Gilberttown and Southern Arkansas fault zones formed by gravitational collapse related to large sedimentary loads in the Tertiary age Gulf Coastal Plain, or continental shelf. The Pickens-Gilberttown and Southern Arkansas fault zones are Tertiary age analogues to the currently active Gulf Margin Normal faults.

Unfaulted Pliocene and Pleistocene Upland Complex terrace deposits overlie the Pickens-Gilberttown fault zone in the vicinity of the Alabama River (Reference 138). The continuity of Pliocene and Pleistocene deposits across the fault zone indicates that the Pickens-Gilberttown fault zone is not active. Seismic data and continuity of stratigraphy documented from deep exploration wells also indicate that the Southern Arkansas fault zone has not been active since Miocene time (Reference 139).

Very little historical seismicity has occurred along the Pickens-Gilberttown and Southern Arkansas fault zones (Figure 2.5-5). Six earthquakes of m_b 3.3 to 3.9 occurred along the southeastern portion of the Pickens-Gilberttown fault zone near the Mississippi-Alabama border within the Site Region, and three additional earthquakes (m_b<4.4) occurred along the trend of the fault zone in southern Alabama, outside of the Site Region. These earthquakes occurred at the 1.8- to 3.6-mile depth of fluid recovery in active well fields, suggesting that they are most likely triggered earthquakes related to hydrocarbon recovery (Reference 140). No earthquakes > m_b 3.3, the lower threshold used by EPRI (Reference 9), have been recorded along the Southern Arkansas fault zone in the Site Region.

EPRI defined a- and b-values to characterize earthquake occurrence for major tectonic features within the Site Region (Reference 9). However, because the geologic data indicate that these fault zones have been inactive since post-Miocene time, none of the six EPRI Teams specifically characterized the Pickens-Gilberttown or Southern Arkansas fault zones in their seismic source models. The Pickens-Gilberttown and Southern Arkansas fault zones were incorporated within background seismic source zones across the Gulf Coastal Plain gulfward of the Ouachita Orogenic Belt. Therefore, no specific seismicity parameters were developed for the Pickens-Gilberttown or Southern Arkansas fault zones for the EPRI study. Since the EPRI study, only one new earthquake of m_b 3.3 to 3.9 has occurred along the entire 500 mile long Pickens-Gilberttown Southern Arkansas fault zone. The addition of this one earthquake does not significantly modify the earthquake rate parameters within the Site Region used by the six EPRI Teams in their seismic source model for the southern portion of the Gulf Coastal Plain.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Pickens-Gilberttown and Southern Arkansas fault zones (Gulf Coastal Plain south of Ouachita Orogenic Belt) that range from m_b 4.6 to 7.2 (Mw 4.2 to 7.5). Since the EPRI study, maximum earthquake magnitudes for this area have been estimated to be Mw 7.5 (Reference 19) and m_b 5.0 (Reference 70). These estimates of maximum earthquake magnitude are within the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.9 Saline River Source Zone

The Saline River source zone lies within the Ouachita Orogenic Belt and structurally overlies the southwestward subsurface extension of the Proterozoic Reelfoot Rift. The Saline River source zone is located primarily in southeastern Arkansas and northwestern Mississippi, with a minor extension into northern Louisiana (Figure 2.5-19). The source zone was not identified by any EPRI earth science team, and is defined based on more recent geomorphic, geologic and seismologic data that is suggestive of Holocene and late Pleistocene deformation and paleoseismicity (Reference 150; 151; 152; 153). Although suggestive of late-Pleistocene deformation, the evidence is not conclusive and may alternatively be explained by activity along the Reelfoot Rift and/or through non-tectonic processes such as isostatic adjustments from glacial loading to the north, or sediment loading within the Mississippi Embayment and/or Mississippi delta fan complex.

2.5.1.1.5.9.1 Geomorphic Evidence

Basin analysis techniques were used to assess possible tectonic influences on the location and orientation of the Ouachita, Saline, and Arkansas Rivers (Reference 150). Based on the distribution and ages of river terraces, the progressive southwestward migration of each river channel producing drainage basins with distinct asymmetries was documented. The southwestward river migration and drainage basin asymmetry was interpreted to reflect southwestward tilting of a series of northwest-trending structural blocks (Reference 154). These northwest-trending, tilted structural blocks are bordered by assumed northwest-trending normal or oblique slip faults and are interpreted to control the patterns, position, and orientation of these major drainages.

Quaternary geological mapping (References 44; 154) identified a sequence of Quaternary fluvial terraces within the Mississippi River and tributary valleys. In the vicinity of the Arkansas, Saline, and Ouachita rivers these terraces include from oldest to youngest the Intermediate Complex, Prairie Complex and Deweyville Complex (Figures 2.5-20, 2.5-21 and 2.5-22). Each of these individual terrace complexes contains several discrete terrace treads.

The amount of stream incision into terraces of known age can be used as a proxy to estimate the total amount and rate of block uplift and thus, the amount and rate of vertical separation on the assumed bordering faults (Reference 161). This approach was used to evaluate the possible rate of deformation within the Saline River source zone. Cross-sections used to estimate slip rates on the Saline River source zone are shown on Figure 2.5-23. The incision rates provide an order of magnitude estimate of long-term incision and slip rate. Figure 2.5-23 provides estimates of incision rates, used as a proxy for vertical slip-rates, for various terrace surfaces. The rates range from 0.05 to 1.7 mm/yr.

The location and vertical position of terraces within the Arkansas, Saline, and Ouachita rivers indicate basin asymmetry. The oldest and highest terraces (e.g. Intermediate Complex) typically are preserved on the northeast side of the basin. The lowest and youngest terraces (Deweyville Complex), as well as the active stream channels, are located on the southwest sides of the basins (Figures 2.5-29, 10 and 11). Although there is a general pattern of basin asymmetry, the positions of Holocene to recent stream patterns do not always follow this pattern as streams have migrated locally due to channel avulsion (Reference 17). Furthermore, geomorphic mapping (References 17; 154;150) is preliminary and regional in nature, and therefore the mapped locations and correlations of some terraces are uncertain.

2.5.1.1.5.9.2 Geological Evidence – Surface faulting

Geological field investigations in the vicinity of Saline River were conducted to evaluate faults initially identified in road-cuts (Reference 151). Trenches were excavated at several of the road-cuts to evaluate the recency of fault activity. The locations of the field investigation areas are shown on Figure 2.5-20. Investigations have not yet been conducted along the Arkansas or Ouachita Rivers. Observations made in the trench and road-cut exposures indicate post-Eocene faulting and are suggestive of Quaternary faulting, but are not conclusive.

Surface expression of the Saline River source zone includes topographic lineaments and linear drainage patterns. Six small-displacement fault splays have been identified in trenches and road-cuts near Monticello, Arkansas (References 85; 151). Two of these faults trend in a northwest direction parallel to the Saline River. Four subsidiary faults strike east-northeast. The chronology of deformation for each of the sites is summarized in Table 2.5-4.

Five trench and road-cut locations expose faults with Eocene or younger deformation (Reference 151). All faults deform Eocene Jackson Group deposits (Figure 2.5-24). Three trenches exposed faults that deform Pliocene to Pleistocene Upland Complex (Lafayette Gravel). One fault may displace the late Pleistocene Peoria Loess. Holocene silt deposits may be deformed in two trenches, although these relationships are equivocal and could be explained by erosional processes (Reference 151). Relationships observed in the fault exposures indicate strike-slip, normal and reverse senses of displacement. One fault splay underlies a gentle anticline that deforms alluvium with an age of 640 cal. yr B.P. (Figure 2.5-25; note: all ages are reported as 2-sigma calibrated radiocarbon years before A.D. 1950 (present)). This fold is interpreted to be a fault-propagation fold related to Holocene activity along the Saline River fault zone (Figure 2.5-25; Reference 155).

2.5.1.1.5.9.3 Geological Evidence – Liquefaction

Liquefaction-related features have been identified locally within the Saline River source zone in Ashley County and Desha County, Arkansas (Reference 152). The liquefaction features are recognized on the surface as sand blows (Figure 2.5-26). These surficial sand blows were trenched (Reference 152) at three locations to document their stratigraphic relationships and provide estimates of event ages. The three liquefaction sites include Portland and Montrose in Ashley County, and Kelso in Desha County. The liquefaction data from the three sites are summarized in Tables 2.5-5, and 2.5-6.

One or two liquefaction events are stratigraphically discernable at the Portland site in Ashley County ((Reference 152; Table 2.5-5). The oldest event at this site is identified as a series of sand dikes that feed a sand layer. Sand dikes are cross-cut by a krotavina dated 150 to 500 cal. yr B.P. and therefore are older than the age of the krotavina. Charcoal from within the sand blow yielded ages of 0 to 430 cal. yr B.P. Charcoal from the substrate alluvium yielded an age of 910 to 990 cal. yr B.P., which provides a maximum possible age for this liquefaction event. The youngest event is constrained by stratigraphic relationships where a sand vent cross-cuts the older sand blow and is therefore younger than 150 to 500 cal. yr B.P. This younger event could be a separate liquefaction event, or could be related to the initial liquefaction event.

Three liquefaction events are stratigraphically discernable at the Montrose site in Ashley County including an upper sand blow crater and sand dikes (Event III), a middle vented sand layer and sand-dikes (Event II), and a lower vented sand layer and sand dikes (Event I; Table 2.5-5). The youngest liquefaction event is preserved as a sand blow crater filled with organic material dated between 320 and 740 cal. yr B.P., which represents a minimum limiting age for Event III. The middle sand layer (Event II at Montrose) overlies and cross-cuts the lower sand (Event I); no soil development is observed between the two sand units representing Events I and II. The maximum limiting age for Event III and minimum limiting age of Events II and I is constrained by a radiocarbon date on the organic soil that is developed within the middle sand layer (1,300 to 1,550 cal. yr B.P.). The maximum limiting age of Events I and II is constrained by the radiocarbon age of the underlying substrate (5,055 to 5,320 cal. yr B.P.). Event I could have occurred anytime after deposition of the alluvial substrate. We infer that the minimum age of liquefaction events I and II must be a minimum of several hundred years older than the age of the soil dated (1300 to 1550 cal. yr B.P.), as development of the soil horizon on the sand blow would require a period of time. Thus, we infer a minimum age for Events I and II of about 1700 ybp. The exact ages of these events are equivocal. Because there is an absence of soil development between these two events, it is possible that the two sand layers may represent the same event.

Three possible liquefaction events are recognized at the Kelso site in Desha County (Reference 152). The youngest event (Event III) is based on an anecdotal report that describes ground cracking and bank failures, possibly associated with liquefaction during the 1812 New Madrid earthquakes at this location (Reference 152). The older events (Events I and II) are recognized based on stratigraphic relationships observed in the trench where sand vents feed a sand horizon. Charcoal from organic fill in these sand vents yield ages of 740 to 1,000, 960 to 1,310, 1,030 to 1,040, 2,010 to 2,190, and 2,230 to 2,310 cal. yr B.P. Cox (Reference 152) interprets these dates to represent two events. Event II is inferred to have occurred prior to 740 and 1,310 cal. yr B.P., and Event I is inferred to have occurred prior to 2,010 and 2,310 cal. yr B.P. An alluvial horizon at the base of the trench was dated using infrared spectral luminescence (IRSL) at 5740+/-560 ybp and represents the maximum limiting age for Events I and II.

The available data support the interpretation of three to five liquefaction events. The three event interpretation involves:

- Event III – Liquefaction at Portland (prior to 150 to 990 cal. yr B.P.), Kelso (prior to 740 to 1310 cal. yr B.P.), and Montrose (prior to 320 to 1550 cal. yr B.P.);
- Event II – Liquefaction at Kelso (prior to 2010 to 2310) and Montrose (prior to 1700 ybp inferred based on repose time necessary to produce an organic soil (dated 1300 to 1550 cal. yr B.P.) on vented sand layer);
- Event I – Older event at Montrose some time between 1700 ybp (inferred as above), and 5320 cal. yr B.P.

The four event interpretation involves:

- Event IV – Liquefaction at Portland (prior to 150 to 990 cal. yr B.P.) and Montrose (prior to 320 to 1550 cal. yr B.P.);
- Event III – Liquefaction at Kelso (prior to 740 to 1310 cal. yr B.P.);
- Event II - Liquefaction at Kelso (prior to 2010 to 2310) and Montrose (prior to 1700 ybp inferred based on repose time necessary to produce an organic soil (dated 1300 to 1550 cal. yr B.P.) on vented sand layer);
- Event I – Older event at Montrose some time between 1700 ybp (inferred as above), and 5320 cal. yr B.P.

The five event interpretation involves:

- Event V - Liquefaction at Portland post 150 to 560 cal. yr B.P.
- Event IV – Liquefaction at Portland (prior to 150 to 990 cal. yr B.P.) and Montrose (prior to 320 to 1550 cal. yr B.P.);
- Event III – Liquefaction at Kelso (prior to 740 to 1310 cal. yr B.P.);
- Event II - Liquefaction at Kelso (prior to 2010 to 2310) and Montrose (prior to 1700 ybp inferred based on repose time necessary to produce an organic soil (dated 1300 to 1550 cal. yr B.P.) on vented sand layer);
- Event I – Older event at Montrose some time between 1700 ybp (inferred as above), and 5320 cal. yr B.P.

The observed liquefaction features can be interpreted in three ways. First, the liquefaction events record local moderate magnitude earthquakes that produced small liquefaction fields. These events may have been associated with earthquake activity within the Saline River source zone. Second, the observed liquefaction features record far-field ground shaking related to events along the New Madrid Seismic Zone. This is supported by the historical observation of ground cracking and bank failures near the Kelso site during the 1811-1812 New Madrid earthquake sequence (Reference 156), although this also may be a local 1812 triggered aftershock within the Saline River source zone. Third, the observed liquefaction fields record a combination of these processes.

2.5.1.1.5.9.4 Seismological Evidence

Very little historical seismicity has occurred within the Saline River seismic zone (Figures 2.5-5 and 2.5-20). Nine earthquakes of m_b 3.3 (lower bound used by EPRI, 1985) to 4.9 occurred within the source zone during the period 1777 to 1985. These events were not temporally or spatially sufficient for the EPRI earth science teams to identify a unique source zone in the Saline River area. Three additional earthquakes of m_b 3.3 to 3.9 occurred in the source zone during the period 1985 to 2002. Based on the locations of events smaller than m_b 3.3, Cox et al. (Reference 151) suggest that these earthquakes form a weak alignment in a northwest-southeast direction along the trends of the Ouachita, Saline and Arkansas rivers (Figure 2.5-20).

2.5.1.1.5.9.4.1 Earthquake Recurrence Interval

To evaluate earthquake recurrence using these paleoliquefaction features, we calculate average recurrence intervals assuming that three to five events occurred between 5320 and 150 ybp (assumes events post-A.D. 1800 would have been reported). The recurrence times are shown on Table 2.5-6. The calculated average recurrence times are 2,585, 1,725, and 1,295 years. We also calculate the average recurrence assuming that three to five events occurred between 1700 (inferred based on repose time necessary to produce an organic soil (dated 1300 to 1550 cal. yr B.P.) on vented sand layer) and 150 ybp (A.D. 1800), the minimum allowable time period. These calculated recurrence intervals are 775, 517, 388 years. Geological data from the Montrose site, where three events are recognized, support a maximum inter-event recurrence interval of approximately 3,500 to 4,000 years. Based on these estimates, we have selected the following recurrence times to represent the uncertainty in earthquake recurrence within the Saline River source zone: a low value of 390 years (minimum recurrence for minimum time period); and a middle value of 1,725 years (middle recurrence for maximum time period); and a high value of 3,500 years (lower estimate of maximum recurrence interval from the geological record at the Montrose site).

2.5.1.1.5.9.4.2 Slip Rate

The amount of stream incision into terraces of known age can be used as a proxy to estimate the total amount and rate of block uplift and thus, the amount and rate of vertical separation on the assumed bordering faults (Reference 157). This approach was used to evaluate the possible rate of deformation within the Saline River source zone. Cross-sections used to estimate slip rates on the Saline River source zone are shown on Figure 2.5-23. Although not as precise as displacement data from paleoseismic trenches, the incision rates provide an order of magnitude estimate of long-term incision and slip rate. Figure 2.5-23 provides estimates of incision rates, used as a proxy for vertical slip-rates, for various terrace surfaces. The rates range from 0.05 to 1.7 mm/yr.

We use the geologic relationships in trenches near Monticello (Sites 3 and 4 of Reference 151) to estimate fault slip-rate. As shown on the enlargement on Figure 2.5-20, a subsidiary northeast-trending fault is offset approximately 30 meters by a northwest-trending fault that possibly deforms Upland Complex deposits. The base of the Upland Complex is offset by the northwest trending fault; this fault terminates within the Upland Complex. Based on the 30-meter offset of the secondary fault and a 1 to 4 million year age range of the Upland Complex, the fault slip rate is estimated to be 0.008 to 0.03 mm/yr. Because this fault is likely a subsidiary fault within a larger fault zone, we infer that this slip-rate is a minimum bounding estimate for the rate of deformation within the Saline River source zone.

2.5.1.1.5.9.4.3 Maximum Earthquake Magnitude

Potential magnitudes of M 5.5 to 6.0 for the events that produced the liquefaction fields in Ashley and Desha counties have been estimated (Reference 152). If the events reflect localized seismicity, this magnitude range is a reasonable lower bound estimate for the maximum magnitude within the Saline River source zone. However, if each of the liquefaction fields corresponds to a prior New Madrid seismic zone event, the observed liquefaction features would not support the presence of a distinct seismic source along the Saline River in southeastern Arkansas.

2.5.1.1.5.10 Non-Tectonic Structural Features

In addition to the tectonic features described above, non-tectonic (non-seismogenic; Reference 141) processes also produced structural and topographic features in the Site Region. These features locally deformed Gulf Coastal Basin sediments and include volcanic domes, salt diapirs, and growth faults. The timing and processes controlling these features are described in the following sections.

2.5.1.1.5.10.1 Volcanic Domes

The Jackson Dome is a circular, 16-mile-diameter volcanic plug located at the southern margin of the Mississippi Embayment near the city of Jackson in west-central Mississippi (Figure 2.5-3). The dome was formed by the arching of strata above a deep-seated igneous intrusion. The dome became active in the Early Cretaceous, continued to rise through post Oligocene time, and has a total structural relief of about 10,000 feet. Outcrops of the Oligocene Vicksburg Group, including the Glendon Limestone are preserved on the dome’s northwestern flank (Reference 142). Although the dome appears to be dormant, radiometric dates in the State #2 Fee well show a 26-million-year gap in activity between 101- and 75-million year old igneous rocks suggesting long intervals between periods of activity (Reference 142). Interpreted seismic lines along the flanks of the Jackson Dome have identified several faults in the Jackson area, including an east-west-trending fault south of Florence, Mississippi, and six additional northwest-southeast trending faults that extend from the dome’s eastern flank (Reference 34). The youngest strata offset by these faults is the Upper Cretaceous Eutaw Formation. Bograd speculated that a 1927 earthquake that shook houses as far away as Meridian, Mississippi occurred on a fault in the Jackson area (Reference 143). However, there is no clear association of earthquake activity with faults associated with the Jackson Dome.

The Monroe Uplift is a volcanic dome that straddles southern Arkansas, northern Louisiana, and west central Mississippi (Figure 2.5-3). The northern margin of the Gulf Coast Basin and southwestern extent of the Mississippi Embayment coincides with the Monroe Uplift. The circular area of the dome is approximately 93 miles in diameter and is characterized by the arching of strata above a deep-seated igneous intrusion. The Monroe Uplift initially became active in the Jurassic and experienced continued movement into post-Miocene time. There is no topographic expression of the Monroe Uplift at the surface. However, Burnett and Schumm (Reference 144) evaluated fluvial geomorphic features distributed across the uplift and concluded that the rivers were adjusting to modern deformation. Upstream of the uplift the river had less bank erosion, a reduced sinuosity, lower channel and valley gradient, and lower channel depth than downstream (Reference 144). Additionally, they found that the river terraces showed a convex pattern across the Monroe Uplift and inferred active uplift in the Pleistocene and Holocene.

The Sabine Uplift is a volcanic dome located in east Texas and western Louisiana (Figure 2.5-3). The dome has a roughly oval shape, approximately 124-miles long in the north-south direction and 93-miles wide in the east-west direction. The uplift is a flat-topped structural high that was active in post-Middle Eocene time. No active faulting or seismicity has been associated with the Sabine Uplift.

2.5.1.1.5.10.2 Salt Diapirs

Salt migration structures or salt domes occur in two subprovinces within the Gulf Coastal Plain, the Interior Salt Basin and the Coastal Salt Basin (Figure 2.5-3). Salt migration produced anticlinal structures, ridge-like diapiric folds, and piercement domes in these subprovinces. Salt originated from the Middle Jurassic Louann Salt and salt migration structures are concentrated in an approximately 100-mile-wide zone extending from southwestern Alabama to eastern Texas (Figure 2.5-3). The source depth for the Louann Salt is around 15,000 feet and becomes progressively deeper to the south (Reference 30). Salt Domes in the Interior Salt Basin were active from Late Cretaceous to Oligocene and have not been active since (Reference 30).

Salt Domes in the Coastal Salt Basin began to form in the Miocene and have been active through the Quaternary. The source depth for the Louann Salt in the Coastal Salt Basin is around 35,000 feet and approaches 65,000 feet in the vicinity of the southernmost offshore salt domes.

Salt migration in the Coastal Salt Basin deforms the ground surface. The Five Islands structural uplift is a northwest-southeast trending line of salt domes in south central Louisiana. These domes are expressed at the surface and deform a subsurface Quaternary gravel suggesting Pleistocene activity (Reference 17).

2.5.1.1.5.10.3 Growth Faults

East-west-trending growth faults along the southern margin of the Gulf Coastal Basin are referred to as the Gulf Margin Normal faults. These faults include the Tepetate-Baton Rouge, Denham Springs-Scotlandville, Lake Hatch, Golden Meadow, Lake Sand, Grand Chenier, Lake Arthur and Mamou faults, as well as many other un-named faults. Seismicity within the zone is sparse, with only nine felt earthquakes in historic time (Reference 145).

The opening of the Gulf of Mexico formed a south–facing, rifted margin during the Triassic. Along this margin, a thick package of Jurassic and younger sediment was deposited including the Louann Salt, and overlying carbonate and clastic marine sediments. This sedimentary sequence is in excess of seven miles thick in the vicinity of the Gulf Margin Normal faults. The Louann Salt is inferred to form a sliding layer on which the overlying sedimentary section has mobilized forming a series of Tertiary and Quaternary growth faults. Because the faults are located in poorly lithified rocks and sediments, they may not be able to support the stresses required for the propagation of significant seismic ruptures that could cause damaging ground motions (Reference 113).

Faults generally dip between 50 and 70 degrees at the surface and shallow to less than 50 degrees at depth (Reference 29). Additionally, strata increase in thickness on the downthrown side of faults and displacements increase with depth. Periods of movement on the faults range in age from late Eocene to Holocene depending on the location of the Mississippi River depo-center. The current Gulf Margin Normal faults are localized along the subsurface Cretaceous shelf edge and experience high rates of aseismic slip.

Slip rate estimates for the Baton Rouge fault vary from a Pleistocene rate of 0.05-0.08 mm/yr (References 113; 146) to a Holocene rate of 9 mm/yr determined by leveling surveys conducted by the Louisiana Water Research Institute (Reference 16). Rates as high as 4 cm/yr have been measured from Global Positioning System (GPS) data (Reference 147). The largest earthquakes recorded in Louisiana were two M 4.4 events that occurred on the same day in April, 1964, however, the majority of the recorded earthquakes in Louisiana range in magnitude from 2.5 to 3.5 (Reference 148). The most recent and best located event occurred on October 16, 1983. The depth determination for this event shows that it occurred at approximately 8.5 miles (Reference 148; 149), possibly in basement materials beneath the sedimentary prism.

2.5.1.1.6 Regional Seismicity

Much of the central and eastern U.S. seismicity appears to occur due to reactivation of older Rift bounding faults and sutures between exotic terranes (References 164, 165). Historical seismicity in the region is most strongly concentrated in the Reelfoot Rift and New Madrid Seismic Zone north of the Gulf Coastal Plain. Small magnitude earthquakes also occur along the general trend of the Ouachita Orogenic Belt and Appalachian Mountains. In the areas south of the Ouachita Orogenic Belt and Appalachian Mountains there is a very low rate and a random spatial distribution of epicenters.

Due to the regions tectonic stability, there have been relatively few recorded earthquakes. Reference 78 compared the seismicity of the central U.S. to that of the southern California. The activity rate of magnitude 4 earthquakes in the 3,000,000 km^2 area of the central U.S. is more than a factor of 10 lower than that of a 200,000 km^2 area of southern California. The rate of magnitude 6 earthquakes is about a factor of 30 lower. This low rate of activity has characterized the seismicity of the Gulf Coastal Plain for over 150 years, and most likely throughout the Quaternary.

Because the south central United States is a passive continental margin, there are *no plate boundary fault systems* that accommodate relative plate motion, focus earthquake activity, and produce repeated large magnitude events. Earthquake activity appears to be concentrated along reactivated older tectonic elements such as the Reelfoot Rift. Furthermore, no faults have been mapped within approximately 90 miles of the proposed location of the new facility at the Grand Gulf Nuclear Station.

2.5.1.1.6.1 Location and Distribution

The location of seismicity is shown on Figure 2.5-5. The seismicity shown on this figure is for the period 1777 to 1984, which covers the period used in the 1986 EPRI analysis, and 1985 to 2002, which covers the period since the EPRI study. The updated EPRI Seismicity catalog is described in section 2.5.2.1.4. As can be seen on Figure 2.5-5, the current seismicity trends are very similar to the location and distribution of seismicity for the period considered in the EPRI study (Reference 9). The events are concentrated along the Reelfoot Rift, Ouachita Orogenic Belt, and Appalachian Mountains, primarily in regions underlain by continental crust. Few earthquakes have occurred within the Gulf Coast Basin, and no earthquakes have been recorded within the Site Vicinity or Site Location.

2.5.1.1.6.2 Historical Events in Site Region

The Site Region is characterized by very low rates of seismic activity. Only one earthquake of $3.3<m_b<3.9$ has been recorded within 90 miles of the site since 1777 and only 39 earthquakes of $m_b>3.3$ have been recorded in the entire 200 mile radius area around the site since 1777. Most earthquakes in the site region occur in areas underlain by crystalline basement rock of the North American craton, and within the buried Ouachita Orogenic Belt, or Appalachian Mountains.

Since the 1986 EPRI study, only four earthquakes of $m_b>3.3$, the lower limit used in the EPRI study, have been recorded in the Site Region.

2.5.1.1.6.3 Historical Events in Site Vicinity

Historical seismicity records for the Site Region extend back to A.D. 1777. Based on our review and analysis of these historical seismicity records there have been no earthquakes recorded within the Site Vicinity. The nearest earthquake to the site occurred approximately 90 miles to the west in central Louisiana.

2.5.1.2 Site Geology

This section presents information on the physical setting, geological history and subsurface conditions within the Site Area (5-mile radius) and Site Location (0.6-mile or 1-km radius) of the proposed new facility at the Grand Gulf Nuclear Station. Engineering Report ER-02 (Reference 15) provides the results of detailed field and laboratory investigations performed at the proposed location of the new facility during this study.

2.5.1.2.1 Site Physiography and Geomorphology

The Site Area and Site Location straddle the western boundary of the Loess Hills physiographic subprovince (Figure 2.5-2). The proposed location of the new facility is approximately 1.1 miles east of the Mississippi River and adjacent to the Mississippi River flood plain (Figures 2.5-9 and 2.5-27). The boundary between the Mississippi Alluvial Valley and Loess Hills physiographic subprovinces crosses the Site Location and is defined by the approximately 65- to 80-foot-high north-trending erosional escarpment at the edge of the Mississippi River flood plain.

As shown on Figure 2.5-27, the topography of the Loess Hills in the Site Area is characterized by steep-walled stream valleys, flat-topped ridgelines, and dendritic drainage systems. Large river terraces occur along river floodplains and valley bottoms. Older terraces are present between elevations of about 140 and 200 feet along the tributary valleys of Bayou Pierre and Big Black River, and along the eastern margin of the Mississippi Valley (Figures 2.5-9 and 2.5-27). The topography of the Mississippi Alluvial Valley in the Site Area is relatively flat and characterized by flood plain, cut-banks, point bars, and oxbow lakes. The 0.6-mile radius of the Site Location does not extend to the active channel of the Mississippi River.

The proposed location of the new facility encompasses approximately 30 acres (Figure 2.5-27). The location does not represent the footprint of the proposed power block, but a larger area for overall construction purposes that envelops all potential facility footprints being considered. The proposed location straddles two previously graded surfaces at elevations of 132 feet and 155 feet, separated by a 23-foot high engineered cut-slope (Figure 2.5-28). The graded surfaces were former parking lots and lay-down areas used during construction of the existing Grand Gulf Nuclear Station.

The proposed facility location is bounded on the east by existing internal plant roads and parking lots (Figure 2.5-28). The location is bounded on the west by the erosional escarpment at the edge of the Mississippi River flood plain and on the north and south by two ravines that drain the Site Location.

2.5.1.2.2 Site Geologic History

The geological formations underlying the Site Area and Site Location record a long history of tectonic stability and deposition. The formations include both marine and terrestrial sediments that reflect distinct changes in depositional environments, climatic conditions, and glacial-eustatic cycles over the past 36 Ma. Deposits of at least Oligocene and younger age dip very gently southward and are laterally continuous across the Site Region (Figures 2.5-6, 2.5-11 and 2.5-12). These deposits are not deformed and thus document long term tectonic stability. The geological history of the Site Area and Site Location from the Oligocene period to the present is discussed below; regional geological history and descriptions of events that are older than Oligocene are presented in Section 2.5.1.1.

The Oligocene depositional environment in the Site Area was dominated by shallow marine seas, in which the Glendon Limestone and Byram Marl formations of the Vicksburg Group were deposited (Reference 16). These deposits primarily consist of limestone and marl with interbedded calcareous sands and clays. The Byram Marl was overlain by the late Oligocene Bucatunna Clay Formation, possibly representing a transition to a deep water or estuarine environment. The Glendon Limestone occurs at a depth of approximately 300 feet beneath the Site Area (Figure 2.5-15; Reference 16). These deposits are overlain unconformably by the Miocene Catahoula Formation.

In the Miocene, the depositional environment at the site changed from a marine to a marginal shoreline environment, in which the Catahoula Formation was deposited (Reference 16). These deposits consist of silty to sandy clays, clayey silts, and sands (Reference 15). The surface of the Catahoula Formation was deeply eroded at the site prior to deposition of the Pliocene to Pleistocene age Upland Complex based on the structural contour map shown on Figure 2.5-29.

In the Pliocene and Pleistocene, the depositional environment again changed from a marginal shoreline to an alluvial environment, in which alluvial deposits correlative with the Upland Complex were deposited. These deposits consist of coarse sand and gravel derived from both glacial and non-glacial sources (Reference 17). Pliocene-Pleistocene Upland Complex deposits unconformably overlie the eroded surface of the Catahoula Formation (Figures 2.5-30, and 2.5-31).

Late Pleistocene terraces were deposited in response to Wisconsin-age glacial cycles that supplied large volumes of sediment to the Mississippi Alluvial Valley (References 17; 31; 32). Subsequent stream incision eroded the terraces along north-northeast trending valleys that cross the Site Location (Figure 2.5-32).

At various periods in the late Pleistocene, strong seasonally prevailing winds transported silt from unvegetated glacial outwash in the central United States (Reference 17). As a result, the Peoria, Ferndale, Roxanna, and Lovelend loess sheets were deposited in the Site Vicinity and Site Area, between Vicksburg and Natchez (Figure 2.5-8). The youngest loess sheet, the Peoria Loess, is late Wisconsin in age (Reference 21). The average thickness of loess in the Site Location is about 65 feet; however, individual loess sheets have not been differentiated in the

Site Location. Throughout the Holocene, loess deposits were deeply eroded by tributary streams to the Mississippi River. During this time alluvial sediment also was deposited on the Mississippi River flood plain in the western part of the Site Area and Site Location, and in tributary stream valleys along the northern and southern portions of the Site Area and Site Location (Figures 2.5-9 and 2.5-27). Deposition of alluvial deposits during peak glacial outwash may have changed local base-levels, blocking stream outlets and leading to the ponding or deposition of silt and alluvium in tributary valleys. The subsequent drop in river-level in the current interglacial period is inferred to have caused incision and formation of the terraces remnants along Bayou Pierre and Big Black River.

The Oligocene and younger deposits demonstrate a long period of tectonic stability and the absence of tectonic deformation in the Site Area and Site Location. As shown on Figures 2.5-9, there are no faults or folds in the Site Area. A structure contour map on the surface of the Oligocene Glendon Limestone (Figure 2.5-15) also documents the absence of post-Miocene age deformation. Figure 2.5-12, a cross-section through the Site Area, documents the lateral continuity of strata, and therefore the absence of faulting within the Site Area.

2.5.1.2.3 Site Geologic Conditions

The characteristics of the individual deposits that occur in the Site Area and Site Location are described below in Section 2.5.1.2.4.1. Geologic maps of the Site Area and Site Location are shown on Figures 2.5-9 and 2.5-27, respectively. Geologic cross-sections are shown on Figures 2.5-11 for the Site Vicinity, and Figures 2.5-30 and 2.5-31 for the Site Location.

2.5.1.2.3.1 Site Stratigraphy

Extensive geological and geotechnical data for the Site Area and Site Location are available as a result of the investigations completed for the existing Grand Gulf Nuclear Station (Reference 16). During this investigation, 275 borings were drilled within the Site Area to a maximum depth of 447 feet. The borings were completed to document geological and geotechnical conditions of the Site Area. In addition, 22 seismic refraction surveys were completed. The seismic refraction surveys were completed to document the lateral continuity and seismic velocity characteristics of the subsurface stratigraphy.

In addition to the existing database for the Grand Gulf Nuclear Station, three new soil borings, four Cone Penetrometer Tests (CPT), two down-hole geophysical surveys, and geological field observations were completed during this study to evaluate subsurface conditions at the proposed location of the new facility and to provide input parameters to assess dynamic response of subsurface materials (Sections 2.5.2 and 2.5.4; Reference 15). The new soil borings were advanced to depths ranging from 141 to 238 feet and penetrated strata ranging in age from the Holocene to the Miocene. The CPTs were advanced to depths of 60 to 80 feet terminating in sands and gravels of the terrace deposits of probable Pleistocene age.

2.5.1.2.3.1.1 Quaternary Deposits

Holocene and Pleistocene age gravels, sands, silts, and clays occur within the Site Area and Site Location (Figures 2.5-9 and 2.5-27). These deposits are related to fluvial processes along the Mississippi River and its tributaries, and eolian processes that formed the Loess Hills along the eastern margin of the Mississippi Alluvial Valley. The Quaternary deposits described in this section typically have an unconformable depositional relationship with the underlying Pliocene to Pleistocene Upland Complex, or Tertiary Catahoula deposits, described below.

2.5.1.2.3.1.1.1 Holocene Series

Holocene sediments consist of fluvial deposits on the flood plain of the Mississippi River, alluvium and terrace deposits in tributary valleys, and colluvium along hill slopes in the Loess Hills. Holocene fluvial deposits of the Mississippi River flood plain occur between the Mississippi River and the Loess Hills bluff, and represent the filling of at least two abandoned river channels (Reference 16). Hamilton and Gin lakes, which lie within or adjacent to the Site Location, are oxbow lakes that represent abandoned Mississippi River meander scars. The area between Hamilton Lake and the Loess Hills bluff is underlain by backswamp deposits (Hb) shown on Figure 2.5-9.

Holocene alluvium and terrace deposits in the Site Area occur along Bayou Pierre and small tributary streams (Figure 2.5-9). Terrace deposits along Bayou Pierre lie at elevations of approximately 120 feet and form well-defined planar surfaces above the modern flood plain. Remnants of Holocene terraces also occur along the Loess Hills bluff and along the tributary valley that crosses the Site Location (Figure 2.5-27). Holocene alluvial deposits in the Site Area range in thickness from 22 to 182 feet and unconformably overlie the Miocene Catahoula Formation (Reference 16).

Holocene colluvial deposits in the Loess Hills drape the base of the bluffs and valley walls along the flood plain and tributary valleys of the Mississippi River. The colluvial deposits consist of brown silt, clayey silt, or silty clay derived from erosion of the loess materials and are up to 47 feet thick (Reference 16).

2.5.1.2.3.1.1.2 Pleistocene Series

The distribution of Pleistocene sediments within the Site Area and Site Location is shown on Figures 2.5-9 and 2.5-27, respectively.

<u>Terrace Deposits</u>

Pleistocene terrace deposits occur in the Site Area along the Loess Hills bluff, Bayou Pierre, and small tributary streams (Figures 2.5-9, 2.5-33). Although not within the Site Area, Pleistocene terraces also occur along the Big Black River. The Pleistocene terraces in the Site Area were mapped in a generalized manner (undifferentiated), as shown on Figure 2.5-8 (Reference 44). Figures 2.5-9 and 2.5-27 present more detailed mapping of the Pleistocene terraces. The terraces shown on Figures 2.5-9 and 2.5-27 were identified based on aerial photograph interpretation, topographic analysis, and field observations.

Terraces are recognized as broad very low relief surfaces up to 0.75-miles across that are dissected by dendritic surface drainage systems (Figure 2.5-33). The back-edges of the terraces are defined by topographic breaks in hillslopes. In the Site Area, terraces occur at elevations of approximately 140, 160, and 180 feet. The elevations of the terrace treads vary by plus or minus 10 feet. Additional discontinuous remnants of terraces may occur at elevations in excess of 200 feet, though distinguishing these from older pediment surfaces is difficult.

The location of the proposed new facility lies on an inferred latest Pleistocene terrace surface at an elevation of approximately 150 feet. Based on subsurface data from borings completed at the site (Figures 2.5-34 through 2.5-37), the Pleistocene terrace surface is underlain by up to 75 feet of loess. The loess is underlain by coarse-grained alluvial sand and gravel deposits of the Upland Complex (described below).

The Pleistocene terraces appear to be formed on the loess deposits or have incorporated reworked loess within the alluvial systems. Therefore, these surfaces are inferred to be of late Pleistocene (late-Wisconsin) age, the age of the loess sheets in the Site Area (Reference 21).

The Pleistocene terraces are inferred to have formed through a combination of processes. During the late-Wisconsin the Mississippi River was a much higher energy river and as such would have a higher base level to tributary drainages (Reference 17). The model involves either erosion of loess deposits within the tributary valleys, or ponding of loess within tributary valleys, as a result of the higher base level in the Mississippi River. Transport of course-grained valley train deposits during the late-Wisconsin also could have dammed or bridged the mouths of tributary streams causing formation of fill terraces or lakes. The late-Wisconsin Lake Monroe is an example of a lake formed by natural damming of an alluvial valley by the valley train deposits (Reference 17).

Incision of alluvial systems within tributary valleys where fluvial terraces are preserved is related to a lowering of base level along the Mississippi River. This change in base-level may be partly related to the fall in river base-level following de-glaciation. Elevation differences between Pleistocene valley train deposits and the Holocene meander belts indicates a minimum base-level change of 16 to 32 feet. Flexural bending of the crust due to large sediment loads in the Mississippi River delta also may have caused uplift and subsequent stream incision. Land leveling data indicate that uplift is occurring with rates of 0.039 in/yr (1 mm/yr) to 0.078 in/yr (2 mm/yr) extending as far north as Jackson, Mississippi (Reference 158), which encompasses the Site Area. A rate of 0.039 in/yr (1 mm/yr) extrapolated over the past 18 thousand years would result in approximately 60-feet (18-meters) of uplift. The combination of base-level change following deglaciation and uplift due to flexural bending provides a sufficient change in relative base-levels (i.e. 76 to 92 feet) to have caused incision and preservation of the fluvial terraces observed in Bayou Pierre and the smaller tributary valleys in the Site Area. The formation and preservation of Pleistocene terraces in the Site Area is interpreted to have occurred due to the combination of these non-tectonic processes.

<u>Loess</u>

Three distinct Pleistocene age loess sheets occur between Vicksburg and Natchez in the Site Vicinity. These include the Peoria, Roxanne, and Loveland loess sheets (Reference 21). Within the Site Area, the loess deposits are undifferentiated. Loess deposits are up to 100 feet thick and consist of well sorted, yellowish brown, damp, medium stiff sandy to clayey silt with weak blocky structure (Reference 15). Below depths of about 12 to 15 feet, the loess has a slightly darker color, becomes more calcareous and massive with depth, and contains zones of gastropods and shell fragments. Zones with shell fragments are interpreted to represent either reworked surficial deposits or small ponds and depressions in the loess surface that supported gastropods. The loess unconformably overlies Upland Complex deposits.

2.5.1.2.3.1.2 Tertiary Deposits

2.5.1.2.3.1.2.1 Pliocene – Pleistocene Series

Upland Complex deposits occur beneath the loess deposits in the Site Area (Figure 2.5-9; Reference 17, 32, 33). This complex consists of interbedded alluvial gravel, sand, and clay (Reference 17). Individual depositional units and unit ages within the Upland Complex are not differentiated.

Borings advanced in the Site Location encountered two alluvial units (Figures 2.5-30 and 2.5-31; Reference 15); these alluvial deposits are mapped as part of the Upland Complex

(Reference 44). At the proposed location of the new facility, the upper alluvial deposit is first encountered between 68 to 71 feet elevation and ranges from 46 to 85 feet thick. The upper alluvial deposit consists of light gray to brownish yellow sand to silty sand. The silty sand consists of fine- to medium-grained well-sorted quartz grains with silt, and is massive, dense, and friable to very friable (Reference 15).

The lower alluvial deposit is first encountered between elevations of 24 to –14 feet and ranges from 11 feet to 89 feet thick across the proposed facility location. The variation in the thickness of the lower alluvial deposit is due to the amount of relief on the underlying and eroded Catahoula Formation surface (Figure 2.5-29). The lower alluvial deposit consists of stratified thinly bedded sands, silty clays, and gravels. The silty clay beds range in thickness from a few inches to feet, and are yellowish brown to brown. Sand beds are similar to the upper alluvial deposit described above, but generally are better sorted, finer grained, and have a greater degree of oxidation. Gravel layers range in thickness from one foot to tens of feet, and are composed of fine- to medium-grained, sub-rounded gravel with localized cobbles (Reference 15).

2.5.1.2.3.1.2.2 Miocene Series

Miocene deposits are not mapped at the surface in the Site Area or Site Location, but underlie terrace and loess deposits at shallow depth (Figures 2.5-29, 2.5-30, and 2.5-31). In the subsurface, Miocene deposits include the shallow marine sediments of the Catahoula Formation. These deposits consist of hard to very hard, gray to gray-green, silty to sandy clay, and clayey silt and sand, with some locally indurated or cemented clay, sand, and silt seams (Reference 22; Reference 15). The Catahoula Formation occurs about 125- to 175-feet below the Site Location (-20 to -30 feet elevation) and has a maximum thickness of 320 feet in the Site Area (Reference 16). The Catahoula Formation unconformably underlies the Upland Complex and loess, and overlies the Oligocene Vicksburg Group. The Catahoula Formation is identified as the load-bearing stratum for the existing major plant structures at the Grand Gulf Nuclear Station (Reference 16).

2.5.1.2.3.1.2.3 Oligocene Series

Oligocene deposits do not occur at the ground surface in either the Site Area or Site Location. The Oligocene deposits in the subsurface include sediments of the Vicksburg Group and the Forest Hill Formation (Figures 2.5-5 and 2.5-11). The Vicksburg Group consists of four formations, which from youngest to oldest include the Bucatunna, Byram Marl, Glendon Limestone, and Mint Spring formations. These deposits were encountered in two previous borings in the Site Location (B-4 and B-84; Reference 16) and two previous borings in the Site Area (G-3 and G-4; Reference 16). Lithologic descriptions of the Vicksburg Group formations are presented below.

The Bucatunna Formation consists of stiff to hard greenish-black to black clay with thin, gray, fine sand seams. This formation occurs at an elevation of -250 feet and unconformably overlies the Byram Marl. The Byram Marl Formation consists of hard to very hard, green to gray, fine sandy, calcareous clay, is discontinuous, and conformably overlies the Glendon Limestone. The Glendon Limestone consists of interbedded, light gray, fossiliferous limestones, and hard to partly indurated, grayish-green, fine sandy, calcareous clays. This formation occurs between elevations of –260 and –340 feet, and unconformably overlies the Mint Springs Marl. The Glendon Limestone Formation is laterally continuous beneath the Site Area and provides an excellent marker horizon to construct a structure contour map from which to evaluate the presence or absence of tectonic deformation (Figure 2.5-15). The Mint Springs Marl consists of hard, grayish green fossiliferous, glauconitic sand and clay and is at least 45 feet thick beneath the Site Location. The Mint Springs Formation unconformably overlies the Forest Hill Formation.

2.5.1.2.4 Site Structure

2.5.1.2.4.1 Faults and Folds

Laterally continuous deposits of Oligocene and younger age extend in the subsurface across the Site Area (Reference 16). These deposits have a gentle southward depositional gradient and are undeformed (Figures 2.5-10, 2.5-30 and 2.5-31). No faults are mapped within the 5-mile radius of the Site Area (Figure 2.5-9; References 52; 53).

The continuity of subsurface deposits demonstrates the tectonic stability of the Site Area and Site Vicinity from at least Oligocene time, approximately 30 Ma, to present. For example, the top of the Glendon Limestone surface shows no morphology indicative of tectonic deformation (Reference 16). The top of the Glendon Limestone Formation within the Vicksburg Group slopes to the southeast from elevations of approximately -140-feet in the northwestern part of the Site Area to -440-feet in the southeastern part of the Site Area (Figure 2.5-15). The surface appears to have been eroded, forming a buried drainage basin morphology. The lateral continuity of the formation and the absence of faults or folds documents the absence of post-Oligocene deformation in the Site Area and Site Location. No new information has been developed since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

The Oligocene Vicksburg Group was eroded and unconformably overlain by deposits of the Miocene Catahoula Formation. The top of the Catahoula Formation in the Site Location forms a gentle southwestward sloping surface (Figure 2.5-29). The Catahoula surface morphology preserves a Pliocene to Pleistocene erosion surface of the ancestral Mississippi Alluvial Valley, as well as a former tributary valley that extended across the Site Location; variations in elevations across the surface of the Catahoula Formation reflects former stream erosion. The top of the Catahoula Formation shows no morphology indicative of tectonic deformation, and no new information is available since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

Upland Complex deposits in the Site Location are eroded and two west-trending drainages cross the Site Location (Figure 2.5-32). These drainages are the current active channels in the Site Location. As discussed above, the Upland Complex is unconformably overlain by loess. The surface of the Upland Complex shows no morphology indicative of tectonic deformation, and no new information is available since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

2.5.1.2.4.2 Unconformities

With the exception of the conformable contact between the Oligocene Glendon Limestone and Byram Marl formations of the Vicksburg Group, all of the subsurface deposits in the Site Area and Site Location are separated by erosional unconformities. The unconformities indicate that erosion rather than tectonic deformation is responsible for elevation differences across the surfaces of the Upland Complex alluvial deposits, Catahoula Formation, and the Glendon Limestone Formation (Figures 2.5-15, 2.5-29, and 2.5-32).

2.5.1.2.4.3 Other Structures

2.5.1.2.4.3.1 Salt Domes

The proposed location of the new facility at the Grand Gulf Nuclear Station is located along the northern margin of the Mississippi Salt Basin (Figure 2.5-3). However, no salt domes occur in the Site Area or Site Location. The nearest salt domes are the Bruinsburg Dome located 6.5 miles southwest of the site, and the Galloway Dome located 8 miles northeast of the site (Figure 2.5-8). The depth to salt of the Bruinsburg Dome is 2020 feet, and the depth to salt of the Galloway Dome is 4196 feet (Reference 16). The Bruinsburg and Galloway domes have upwarped the Glendon Limestone strata in the Site Vicinity (Figure 2.5-15), but do not affect the Miocene Catahoula Formation.

2.5.1.2.5 Geotechnical Properties of Subsurface Materials

On the basis of review of existing UFSAR and site investigation data (Reference 15), the proposed ESP location appears to be suitable for support and good performance of the new facility. Plant foundations should be supported on dense alluvium, old alluvium, or Catahoula Formation below the surficial loess soils. Because the Catahoula Formation claystone was encountered at a significant depth below the ESP Site (greater than 170 feet deep), unreasonably deep excavations extending well below the water table would be required to place foundations in this material. It is more likely that dense layers within the alluvium or old alluvium will be considered for foundation support of the new plant. The alluvium primarily consists of medium dense to dense sands that should be suitable for foundation support provided that future quantitative analyses confirm that liquefaction or cyclic pore pressure increases will not adversely affect foundations. The old alluvium consists of sandy and clayey strata that appear to be in a dense to very dense (very stiff to hard) condition, and are similar to the materials described as supporting the existing GGNS foundations. According to the UFSAR, the operating GGNS has performed well without adverse foundation movements (Reference 16).

As discussed previously, a plant design has not been selected, and the footprint and embedment depth of the plant have not been determined. It is anticipated that any new facility will maintain the existing plant grade of approximately Elevation 132, but that the plant will be founded in alluvium, at or below the bottom of the loess deposits, at approximately Elevation 80, or lower, where the average shear wave velocity exceeds 1,000 feet per second. If the bottom of the plant is located above this elevation, then the natural soils should be excavated to below the loess and replaced with engineered fill that has a minimum shear wave velocity of 1,000 feet per second. Any excavation outside the structural walls of the plant would also be backfilled with engineered fill. All engineered fill would be compacted to a density that would preclude settlement or, should it be below the water table, liquefaction under dynamic loading conditions. The ESP site envelopes all potential plant layouts and embedment depths. Additional site exploration, laboratory testing, and geotechnical analyses will be performed specifically to characterize site conditions for geotechnical analyses and foundation design for the Construction and Operating License (COL) phase of the project after a plant design has been selected. These additional studies should include the following:

- Additional conventional SPT and mud rotary borings on a pattern throughout the plant footprint area;
- Additional CPT and geophysical surveys;
- Additional laboratory index, strength and consolidation testing;

- Quantitative liquefaction, bearing, and settlement analyses;
- Dynamic soil-structure interaction;
- Stability analyses for planned cuts and foundation excavations;
- Groundwater and potential excavation seepage studies;
- Confirmatory site-response analysis.

2.5.1.2.5.1 Static Properties

Static soil properties are described in Section 2.5.4.1, and are summarized on Table 2.5-7. These properties include: moisture content, dry density, Atterberg Indices, mechanical sieve and hydrometer grain size analyses, and consolidated undrained (CU) triaxial shear testing.

No swelling or consolidation tests were conducted for the ESP study, but the UFSAR for the existing plant (Reference 16) states that: *"Tests were performed to evaluate the swell potential of the Catahoula Formation. Swell tests and X-ray diffraction indicate the Catahoula Formation is nonexpansive and the swell deformation potential is negligible. The natural moisture content is near the plastic limit, which indicates preconsolidation. The Catahoula Formation is a granular-cohesive material which is insensitive, the compressibility is low, and the overconsolidation ratio is in excess of 2."*

An overconsolidation ratio of 2 referenced in the UFSAR (Reference 16) appears to actually be a lower bound value based on both the geologic history of the site and the material properties. As described in Section 2.5.1.2.5.2, generally good agreement was obtained between the field and laboratory shear wave velocity measurements of the Upland Complex upper and lower alluvial deposits. Laboratory measurements were made when specimens were reconsolidated assuming a Ko value of 1.0, consistent with an overconsolidation ratio of 4 to 8 (Reference 162). Additionally, as described in Section 2.5.4.1.5, the CPT results suggests that the alluvium and loess are overconsolidated. Quantitative determination of the overconsolidation ratio for materials underlying the proposed site location should be performed during the COL phase on the basis of additional field and laboratory testing.

In summary, from a geotechnical and foundation engineering point of view, the loess is a clayey silt which exhibits moderately high strengths and stands vertically in cuts because of weak cementation when dry. However, the loess is potentially susceptible to gully erosion and collapse when saturated, and is not suitable for support of heavy or safety-related structures. The Upland Complex alluvium is a fairly clean coarse to fine sand, and the old alluvium is a clayey sand and silt with claystone clasts derived from the underlying Catahoula Formation. Both are relatively old and stiff and could serve as the foundation support layer for the facility designs being considered.

2.5.1.2.5.2 Dynamic Properties

Dynamic properties for "equivalent linear" site response analysis are: (1) shear wave velocity or low strain shear modulus; and (2) relationships that define the "equivalent linear" or secant shear modulus and the damping ratio as a function of cyclic shear strain. For convenience, the secant shear modulus is usually normalized to the low strain shear modulus. The required relationships are usually referred to as shear modulus reduction and damping curves. These curves are needed for each material type and, since these properties may vary with confining pressure, for as many depth ranges as is necessary. Shear wave velocity profiles for the ESP site are shown in Figures 2.5-34 through 2.5-37. Shear modulus reduction and damping curves are presented and discussed in Section 2.5.4.1.4.

2.5.2 Vibratory Ground Motion

This section describes the data and methodology used to develop the Safe Shut-down Earthquake (SSE) ground motion for the proposed new unit at the existing Grand Gulf Nuclear Station (GGNS) in Grand Gulf, Mississippi (hereafter referred to as the "Site"). Regulatory Guide 1.165 (Reference 4) "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion" states that the SSE ground motion can be developed using either the Electric Power Research Institute (EPRI) Seismicity Owners Group (SOG) project or Lawrence Livermore National Laboratory (LLNL) Probabilistic Seismic Hazard Analyses (PSHA) methodologies (References 8 and 9), updated through a comprehensive review of the geology, seismology and geophysics of the Site Region (200-mile radius around the site). If review of existing data shows a significant change to either the seismic source model or ground motion model (i.e., attenuation relationships), then Regulatory Guide 1.165 recommends that an updated PSHA be performed to develop the SSE ground motion.

Regulatory Guide 1.165 (Reference 4), therefore, provides the following four-step process to develop the SSE ground motion:

1. Review and update the EPRI or LLNL seismic source model with new information, as appropriate.
2. Review and update the EPRI or LLNL ground motion model with new information, as appropriate.
3. Perform an updated PSHA utilizing the updated seismic source model and/or ground motion model, if appropriate.
4. Develop the SSE ground motion using the original or updated EPRI or LLNL PSHA results corrected for site-specific soil properties, as required.

This process has been completed and documented for the GGNS ESP site. Section 2.5.2.1 describes the seismic source model used in the analysis. Section 2.5.2.2 describes the ground motion model and development of the vibratory rock ground motion from the PSHA. Sections 2.5.2.3 and 2.5.2.4 describe the site-response analysis and development of the SSE ground motion for the GGNS ESP site.

For the GGNS ESP application, the EPRI SOG methodology was adopted to develop the SSE ground motion, including use of the 1986 EPRI SOG seismic source model developed by six Earth Science Teams (EST's), an updated EPRI ground motion model (Reference 13), and the EPRI EQHAZARD software (Reference 14). Following review of the data and information developed since publication of the EPRI SOG results in 1986, significant new information regarding seismic sources and earthquake ground motion attenuation in the Site Region was identified. To address new information and approaches for ground motion attenuation modeling, EPRI (Reference 13) developed a new ground motion attenuation model for the central and eastern United States, including the Gulf Coast region. These new relationships were used in the PSHA and are described in Section 2.5.2.2

The seismic source model used to develop the SSE ground motions for the Site was developed following a comprehensive review of geological, seismological and geophysical data related to active tectonic features in the Site Region (Section 2.5.1). In particular, data were reviewed to identify any significant changes in: (1) source geometry – primarily in terms of changes of source to site distance; (2) maximum earthquake magnitude; and (3) earthquake recurrence. Based on the review of literature and syntheses of regional data (e.g. Reference 86), there are no newly identified features of tectonic origin with convincing evidence of Quaternary activity in the Site Region. Wheeler and Crone (Reference 86) identify four features, the Wiggins Arch, Gulf Margin Normal faults, Monroe Uplift, and Saline River source zone that display evidence of Quaternary activity, but which appear to have originated from non-tectonic processes or lack convincing evidence to conclude that they are seismogenic.

With two exceptions, our review and analysis of existing data shows that all tectonic features in the GGNS Site Region, and northern extension including the Reelfoot Rift Complex, are adequately characterized by the EPRI SOG seismic source model. The two exceptions identified in our review of existing data are (1) identification of the Saline River source zone within the Site Region, and (2) revision of source parameters for the New Madrid Seismic Zone (NMSZ), which lies within the Reelfoot Rift Complex north of the Site Region. Revisions to the NMSZ source parameters include changes in source geometry, maximum magnitude, and earthquake recurrence since publication of the 1986 EPRI SOG source model.

Based on the new information on seismic sources and new ground motion attenuation modeling that have been published since the 1986 EPRI SOG study, the EPRI PSHA has been updated for use in this ESP application. The EPRI PSHA was updated by revising the seismic source model, adding the ground motion attenuation model developed by EPRI (Reference 13), and updating the EPRI EQHAZARD software that was published in 1986 (Reference 14).

The seismic source model developed for input to the PSHA for the Site adopts the 1986 EPRI SOG source model, updated through addition of the Saline River source zone and a characteristic earthquake model for the NMSZ. The new information for the Saline River source zone and NMSZ do not replace any of the existing EPRI SOG source zones, but are added, or “layered”, onto the EPRI SOG seismic source model. The details of this model are described in Section 2.5.2.1.

Regulatory Guide 1.165 recommends that a PSHA be performed to define the median rock ground motion at the site that has an annual probability of exceedance of 10^{-5}, and for soil sites, that a site-response analysis be performed to develop the SSE ground motion. The PSHA used to develop the 10^{-5} median rock ground motions is described in Section 2.5.2.2. Because the Site is underlain by soils rather than rock, a site-specific site-response analysis was conducted following the methodology described in NUREG/CR-6728 (Reference 7). The site-specific site-response analysis is described in Sections 2.5.2.3 and 2.5.2.4. The site investigations and laboratory analyses that were completed to provide the soil parameters for the site-response analysis are described in Section 2.5.4. The seismic source characterization, site investigation and laboratory analyses, and site-response analysis also are described in Engineering Reports ER-01, ER-02, and CP-01, respectively.

2.5.2.1 Seismic Source Characterization

As described in Section 2.5.1, a comprehensive review of available geological, seismological, and geophysical data was performed for the GGNS ESP site and region. This review generally shows that the existing EPRI 1986 seismic source model adequately captures the source information and uncertainty associated with new data and knowledge developed since the mid-1980’s. No new information was found that would suggest significant modification to the EPRI 1986 seismic source model, with two exceptions:

1. The average recurrence interval for large magnitude earthquakes in the New Madrid source zone is approximately 300 to 800 years based on new paleoseismic and paleoliquefaction information, as opposed to several thousand years in the EPRI seismic source model, and the geometry of the source zone has been modified to include three distinct fault segments imbedded within the source zone. New maximum magnitude information also has been developed for the source zone and a characteristic earthquake model is used to estimate recurrence for the fault segments.
2. The Saline River source zone represents a new postulated seismic source in southern Arkansas. The closest approach of this new source zone is approximately 90 miles to the GGNS ESP site.

These two revisions to the EPRI source model are described in Sections 2.5.2.1.2 and 2.5.2.1.3, respectively.

Conducting a PSHA requires information on the location of seismic source zones, maximum earthquake magnitudes, and earthquake recurrence intervals for each seismic source zone included in the model area. The estimated value for each of these parameters is presented in a seismic source model. Seismic source zones are characterized using a logic tree approach to explicitly document the range of estimated parameter values considered and to assign weights to each parameter estimate to indicate the degree of certainty that a given estimate is the correct alternative (Reference 166 and 167). The seismic source parameters for the EPRI SOG model are presented in Table 2.5-8, and are described in detail in EPRI (Reference 9). In addition to the EPRI seismic source model, we provide new logic tree characterizations for the Saline River source zone and the revised NMSZ.

Logic trees are composed of a series of nodes and branches. Each node represents an assessment of an input parameter value necessary to perform the analysis. Each branch leading from the node represents one possible alternative for the state of nature or parameter value being assessed. In practice, a sufficient number of branches are placed at a given node to adequately express the range of uncertainty in the parameter characterization. Each branch of the logic tree, therefore, represents a credible model of the behavior of a seismic source that has a certain probability that it is the correct representation of that seismic source.

Weights are assigned to each branch of the logic tree and represent a probability that the branch is the correct estimate of the input parameter. Because the available data are typically too limited to allow for objective statistical analyses, weights are assigned subjectively on the basis of scientific judgment. The logic tree approach simplifies the subjective assessments because the uncertainty of a single parameter is considered individually assuming that all other parameters leading up to that parameter assessment are known with certainty. Thus, the nodes of the logic tree are sequenced to provide for the conditional dependencies among the parameters and to provide a logical progression from general to specific in defining the input parameters for an evaluation.

In order to compute the SSE ground motion for the Site, we have developed a seismic source model that describes the seismic source zones and related parameters for the Site Region, and includes the NMSZ that extends approximately 300-miles farther northward (Figure 2.5-38). As described in greater detail below, we have not modified the original EPRI SOG seismic source model, but have added the Saline River source zone and the NMSZ characteristic earthquake model as new sources to the 1986 EPRI SOG source model. This is a conservative approach that preserves the integrity of the seismic source model developed by the six EPRI EST’s, while incorporating the new geological, seismological, and geophysical data of the Site Region.

The remainder of this section provides descriptions of the seismic source model used to compute ground motions at the proposed location of the new facility at the Grand Gulf site and includes a general description of the EPRI SOG seismic source model, and detailed descriptions of the Saline River source zone, and revised NMSZ.

2.5.2.1.1 Summary of EPRI Seismic Source Model

This section summarizes the seismic sources and parameters used in the 1986 EPRI SOG project (Reference 9) and subsequent PSHA completed by EPRI in 1989 (Reference 10). The descriptions of seismic sources is limited to those within 200 miles of the ESP Site (the "Site Region") and those at distances greater than 200 miles that may significantly contribute to the ground motion hazard at the Grand Gulf ESP Site.

For the EPRI SOG project, six ESTs evaluated geologic, geophysical, and seismological data to develop seismic source zones in the Central and Eastern United States (CEUS). These source zones were used to model the occurrence of future earthquakes and evaluate earthquake hazards at nuclear power plant sites across the CEUS. The six ESTs involved in the EPRI project were the Bechtel Group, Dames & Moore, Law Engineering, Rondout Associates, Weston Geophysical Corporation, and Woodward-Clyde Consultants. Each team produced a report (Volumes 5 through 10 of Reference 9) providing detailed descriptions of how they identified and defined the seismic source zones in the CEUS. For the computation of hazard in the 1989 study, a few of the seismic source parameters were modified or simplified from the original parameters developed by the six ESTs during the 1986 EPRI SOG study. The parameters used in 1989 PSHA calculations are the primary source for the seismicity parameters used in this study.

The seismic source models developed for each of the six EPRI teams are shown on Figures 2.5-39 through 2.5-44. The spatial relationship between seismicity and regional tectonic features is illustrated on Figure 2.5.5. The earthquake epicenters shown on this figure includes events from the EPRI SOG earthquake catalog for the period between 1777 and 1984, updated with seismicity for the period between 1985 and 2001, as described in Section 2.5.1.1.6. The plot shows events greater than body-wave magnitude (m_b) > 3.3, the lower magnitude cut-off used in the EPRI SOG (Reference 9) study used to estimate a- and b-values.

The maximum magnitude, closest distance, and probability of activity of each ESTs seismic sources are summarized in Tables 2.5-8a through 2.5-8f. These tables list the parameters assigned to each source and specify whether or not the source was included in the site hazard in the original EPRI 1989 seismic hazard analyses. The tables also indicate whether new information has been identified that would lead to a revision of the source's geometry, maximum earthquake magnitude, or recurrence parameters. The seismicity recurrence parameters (a- and b-values) used in the EPRI seismic hazard study were computed for each 1-degree latitude and longitude cell that intersects any portion of a seismic source.

The EPRI SOG seismic hazard study expressed maximum magnitude (Mmax) values in terms of m_b, whereas most modern seismic hazard analyses describe Mmax in terms of moment magnitude (M_w). To provide a consistent comparison between magnitude scales, the average of three individual magnitude conversion relations is used (References 168, 169, and 170) to convert m_b to M_w and vice-versa. Throughout this section, the largest assigned values of Mmax distributions assigned by the ESTs to seismic sources are presented for both magnitude scales, to give perspective on the maximum earthquakes that were considered possible in each source. As shown on Tables 2.5-8a through 8f, the estimate of Mmax established by the ESTs for sources in the Site Region often are less than m_b 5.0 or in the range from m_b 5.1 to 5.3. in the conversion from m_b to M_w, these values would convert to M_w of less than 5.0. In the conversion from m_b to M_w, therefore, for the purpose of hazard calculations, we do not allow M_w to be less than 5.0.

The following sections describe the most significant EPRI sources for each of the six ESTs, with respect to the ESP Site. The nomenclature used by each EST to describe the various seismic sources in the CEUS varies from team to team. Therefore, a number of different names may be used by the EPRI EST to describe similar tectonic features, or one team may describe seismic sources that another team does not. For example, the Dames & Moore team describes the source of the 1811-1812 New Madrid earthquake sequence as the New Madrid Compression Zone while the Rondout team describes this source as the New Madrid Seismic Zone, and the Bechtel team describes this source as the New Madrid fault zone. The reader is referred to the original 1986 EPRI report for the data and rational used by each EST to define each seismic source zone.

2.5.2.1.1.1 Bechtel Team

The Bechtel team identified five seismic source zones within the Site Region (Table 2.5-8a and Figure 2.5-39). Although outside of the 200-mile Site Region, they also identified the New Madrid fault zone, which contributes to the hazard at the Site.

The site is located within Bechtel's Gulf Coast Region background source zone “BZ1”. This source zone was defined based on geopotential and seismic data, and magnetic and gravity anomaly data. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source.

The Northern Plains Region, background source zone “BZ3” is located 30 miles northeast of the Grand Gulf Site. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source.

The Ouachita source zone is located 70 northwest of the Grand Gulf Site. This source was defined based on geopotential data outlining the crystalline core of the fold belt, historical seismicity above the background level, and the surface exposure of the Ouachita Mountains in Arkansas and Oklahoma. The western boundary of the source zone was defined as the intersection of the Ouachita Mountains with the rocks of the Wichita-Arbuckle system. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) for this source zone and determined that known faults of the Ouachita feature were not favorably oriented in the contemporary stress field for reactivation.

The New Madrid region background source zone “BZ0” is located 140 miles north of the Grand Gulf Site. This source zone was defined based on the possibility of moderate-to-large earthquakes occurring outside of recognized source zones contained within the background zone. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.7-6.6 (M_w 5.3-6.5) to this source.

The Reelfoot Rift source zone is located 190 miles north of the Grand Gulf Site. This source was defined based on geophysical and geopotential data (magnetic and gravity anomalies), which identified ancient structures that parallel local seismicity trends. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.7-6.6 (M_w 5.3-6.5) to this source zone. Association of the Reelfoot Rift with moderate-to-large earthquakes was based on spatial association and a favorable orientation for reactivation in an east-west compressive stress field.

The New Madrid fault zone is located 235 miles north of the Grand Gulf Site. This source was defined based on distinct microseismicity patterns, seismic reflection profiles, and the occurrence of the 1811 and 1812 earthquake sequence. The Bechtel team assigned a maximum earthquake magnitude of m_b 7.4-7.5 (M_w 7.9-8.0) to this source.

New information on seismic sources in the Site Region, published since the 1986 EPRI SOG study, was compiled and reviewed to evaluate whether the source geometry, Mmax, or source recurrence parameters should be updated. The reviewed information identifies a potential seismic source in southeastern Arkansas, the Saline River source zone. The characteristics of this potential seismic source are discussed in Section 2.5.2.1.3. New information also is available regarding the magnitude estimates and earthquake recurrence intervals for 1811-1812 “type” earthquakes on the NMSZ, discussed in Section 2.5.2.1.2. This new information has been accounted for by adding new seismic source zones over the existing EPRI SOG seismic source model. The EPRI SOG source zones for each of the six ESTs that are overlain by the new source zones are indicated by a “yes” in the right-hand columns of Table 2.5-8a through 2.5-8f.

2.5.2.1.1.2 Dames & Moore Team

The Dames & Moore team identified six seismic source zones within the Site Region (Table 2.5-8b and Figure 2.5-40). Although outside of the 200-mile Site Region, they also identified the New Madrid Compression Zone, which makes a significant contribution to the hazard at the Site.

The site is located within Dames & Moore's Southern Coastal Margin source zone. This source zone was defined based on its fairly low, diffuse seismicity and represents the down warping miogeosynclinal wedge of sediment that accumulated within the Gulf Coast Basin since the Cretaceous. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.3-7.2 (M_w 4.9-7.5) to this source zone. The team did not provide a tectonic basis to explain the occurrence of seismicity in this source zone. The Saline River source zone partially overlies the northern part of the Southern Coastal Margin zone.

The Ouachita fold belt source zone is located about 60 miles northwest of the Grand Gulf Site. This source zone was defined based on historical and instrumental patterns of recent microseismicity. The Dames and Moore team considered the historical and instrumental seismicity rates to be indicative of future activity. Kinks or bends in the source zone geometry were defined based on the margin of failed arms of former continental rifts. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.5-7.2 (M_w 5.1-7.5) to this source zone. The Saline River source zone partially overlies the southeastern part of the Ouachita fold belt.

The Indiana-Illinois Block source zone is located about 165 miles north of the Grand Gulf Site. This source zone was defined based on geophysical anomalies, basement structural boundaries, and diffuse seismicity. However, the team lacked confidence in identifying a tectonic basis to explain the diffuse seismicity. The block is bound on the north and east by basement warps including the Kankakee Arch, Cincinnati Arch, and Nashville Dome, on the northwest by the Illinois Basin/Lasalle Anticlinal Belt, and on the west by the trend of the Mississippi Embayment/Reelfoot Rift-Southern Indiana Arm Eocambrian rifts. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.7-7.2 (M_w 5.3-7.5) to this source zone.

The Reelfoot Rift source zone is located about 165 miles north of the Grand Gulf Site. This source zone was defined based on the pattern of linear, segmented seismicity, and earthquake structure within the zone. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 6.9-7.2 (M_w 7.0 to 7.5) to this source zone.

The Appalachian fold belt source zone is located about 170 miles northeast of the Grand Gulf Site. This source zone was defined based on historical and instrumental seismicity. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 6.0-7.2 (M_w 5.7-7.5) to this source zone.

The Eastern Marginal Basin source zone is located about 175 miles northeast of the Grand Gulf Site. This source zone was defined based on the occurrence of several moderate-sized earthquakes and diffuse background seismicity. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.6-7.2 (M_w 5.2-7.5) to this source zone.

The New Madrid compression zone is located about 250 miles from the Grand Gulf Site. This source was defined as an independent source within the Reelfoot Rift source zone based on the long, linear zone of microseismicity between Marked Tree, Arkansas and the area north of New Madrid, Missouri. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 7.2-7.5 (M_w 7.5-8.0) to the New Madrid compression zone. The Dames & Moore team also considered the New Madrid compression zone combined with the Reelfoot Rift as an optional source geometry. A new source characterization for the NMSZ has been overlain on the New Madrid compression zone source of Dames & Moore.

2.5.2.1.1.3 Law Engineering Team

The Law Engineering team identified four seismic source zones within the Site Region (Table 2.5-8c and Figure 2.5-41). Although outside of the 200-mile Site Region, they also identified the Postulated Faults in Reelfoot Rift source zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf Site is located within Law Engineering's Southern Coastal Block source zone. The southern boundary of this source zone was defined based on broad wavelength magnetic anomalies that extend from the southeast Texas-Mexico border to the continental shelf offshore Florida. The northern boundary of this source zone was defined by the Paleozoic edge of the North American craton (Reference 171). The Law Engineering team assigned a maximum earthquake magnitude of m_b 4.6-4.9 (M_w 4.2-4.5) to this source zone. The Saline River source zone partially overlies Law Engineering's Southern Coastal Block.

The Mississippi Embayment source zone is located about 80 miles northeast of the Grand Gulf Site. This source was defined based an anomalously broad gravity high that extends into the central United States up the Mississippi Valley (Reference 171). The Law Engineering team assigned a maximum earthquake magnitude of m_b 5.2-5.7 (M_w 4.8-5.3) to this source zone.

The Eastern Basement source zone is located about 140 miles east of the Grand Gulf Site. This source was defined based on an area of buried Precambrian-Cambrian normal faults developed in the North American craton and includes the Giles County-Eastern Tennessee seismic zone, the Pennsylvania Aulacogen, and the Scranton Gravity High. The Law Engineering team assigned a maximum earthquake magnitude of m_b 5.7-6.8 (M_w 5.3-6.8) to this zone.

The Reelfoot Rift source zone is located about 170 miles north of the Grand Gulf Site. This source zone was defined based on gravity and magnetic anomalies. The Law Engineering team assigned a maximum earthquake magnitude of m_b 6.2-6.8 (M_w 5.9-6.8) to this zone.

The Postulated Faults in Reelfoot Rift source zone is located about 230 miles north of the Grand Gulf Site. This source zone was defined based on the occurrence of the 1811-1812 earthquakes. The Law Engineering team assigned a maximum earthquake magnitude of m_b 7.4 (M_w 7.9) to this source zone. A new source characterization for the NMSZ has been overlain on the Postulated Faults in Reelfoot Rift source zone of Law Engineering.

2.5.2.1.1.4 Rondout Team

The Rondout team identified six seismic source zones within the Site Region (Table 2.5-8d and Figure 2.5-42). Although outside of the 200-mile Site Region, they also identified the New Madrid seismic zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf Site is located within Rondout's Gulf Coast/Bahamas source zone. This source zone was defined based on the unique, rapid accumulation of sediments in the Gulf Coastal basin and differences in the orientation of the stress regime between the Paleozoic crust within the zone and the Appalachian crust of roughly the same age to the east and northeast. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this source zone. The new Saline River source zone partially overlies Rondout's Gulf Coast/Bahamas source zone.

The Southern Oklahoma Aulacogen-Ouachita source zone is located about 100 miles northwest of the Grand Gulf Site. This source was defined based on an association with complex disturbed crust related to the Eocambrian Southern Oklahoma Aulacogen (Reference 172; Reference 173), Ouachita and Arbuckle Mountains, and Arkoma and Anadarko Basins. The zone also was defined based on seismicity; however, the Rondout team did not present a correlation between specific tectonic features and observed seismicity. The Rondout team assigned a maximum earthquake magnitude of m_b 5.8-6.8 (M_w 5.4-6.8) to this zone. The new Saline River source zone partially overlies Rondout's Southern Oklahoma Aulacogen-Ouachita source zone.

The Pre-Grenville PreCambrian Craton source zone is located about 110 miles northeast of the Grand Gulf Site. This source was defined as all “older-than-Grenville crust” that was not previously included in a seismic source zone. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this background source zone.

The Grenville Crust source zone is located about 125 miles east of the Grand Gulf Site. This source zone was defined based on a level of background seismicity higher than other Grenville Crust areas and all areas of Grenville crust not previously captured in other source zones. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this source zone.

The New Madrid Rift Complex (Reelfoot Rift) source zone is located about 170 miles north of the Grand Gulf Site. This source was defined based on geological, geophysical, and seismicity data (Reference 174) that divide the Reelfoot Rift into three arms. These arms include the Rough Creek Graben, Southern Indiana Arm, and Saint Louis Arm. An earthquake density contour map (Reference 175) was used to define the margins of the Southern Indiana and Saint Louis Arms. The Rough Creek Graben was excluded from the source zone because it is not favorably oriented for reactivation by the prevailing east-west horizontal stress field. The Rondout team assigned a maximum earthquake magnitude of m_b 6.6-7.0 (M_w 6.5-7.2) to this source zone.

The Southern New York-Alabama Lineament source zone is located about 180 miles northeast of the Grand Gulf Site. This source was defined based on a major discontinuity in the basement rocks underlying the western part of the Appalachians fold belt (Reference 176). The discontinuity corresponds to a change in strike of the magnetic anomaly pattern and intensity of seismicity. The Rondout team assigned a maximum earthquake magnitude of m_b 5.2-6.5 (M_w 4.8-6.3) to this source zone.

The is located about 255 miles north of the Grand Gulf Site. This source was defined based on the location of the 1811-1812 earthquake sequence, and the boundary of intense seismicity presented in Stauder (Reference 177). The zone was divided into three elements roughly coincident with the 1811-1812 earthquakes. The Rondout team assigned a maximum earthquake magnitude of m_b 7.1-7.4 (M_w 7.3-7.9) to this source zone. A new source characterization for the NMSZ has been overlain on the New Madrid seismic zone of Law Engineering.

2.5.2.1.1.5 Weston Geophysical Corporation Team

The Weston Geophysical Corp. team identified five seismic source zones within the Site Region (Table 2.5-8e and Figure 2.5-43). Although outside of the 200-mile Site Region, they also identified the New Madrid fault zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf site is located within their Gulf Coast background source zone. This source zone was defined as an independent background source that does not contain any other seismic source regions. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.0 (M_w 5.0-5.7) to this background source zone. The new Saline River source zone partially overlies Weston's Gulf Coast background source zone.

The South Central background source zone is located about 60 miles northeast of the Grand Gulf Site. This source was defined based on boundaries with other source zones including the Reelfoot Rift on the west, Southern Appalachian background to the east, Pickens-Gilberttown fault zone to the south, and Rough Creek Graben-Kentucky River fault zone to the north. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this background source zone. The new Saline River source zone partially overlies the South Central background source zone.

The Ancestral Rockies source zone is located 100 miles northwest of the Grand Gulf Site. This source was defined based on a region of seismicity coincident with the Wichita-Ouachita Uplifts and the Anadarko-Arkoma Basins. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source zone. The new Saline River source zone partially overlies the Ancestral Rockies source zone.

The Southern Appalachian background source zone is located about 160 miles northeast of the Grand Gulf Site. This source zone was defined based on physiographic province boundaries that include the western terminus of the Valley and Ridge thrust belt and the eastern margin of the Towaliga, Lowdenville, and Kings Mountain fault trends. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source zone.

The Reelfoot Rift source zone is located about 185 miles north of the Grand Gulf Site. This source was defined based on interpretation of geophysical and seismicity data. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude (M_{max}) of m_b 7.2 (M_w 7.5).

The New Madrid fault zone is located about 235 miles north of the Grand Gulf Site. This source was defined based on a dense pattern of microseismicity. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude (M_{max}) of m_b 7.2 (M_w 7.5) to this source zone. The team also considered the New Madrid fault combined with the Reelfoot Rift as an optional source geometry. A new source characterization for the NMSZ has been overlain on the New Madrid fault zone of Weston Geophysical Corporation.

2.5.2.1.1.6 Woodward Clyde Consultants Team

The Woodward Clyde Consultants team identified three seismic source zones within the Site Region (Table 2.5-8f and Figure 2.5-44). Although outside of the 200-mile Site Region, they also identified the Saint Louis Arm and "None of the Above" (NOTA), Southern Indiana Arm and NOTA, and Disturbed Zone of Reelfoot Rift, which make a significant contribution to the ground motion hazard at the Site. The NOTA incorporates the alternative "*that none of the identified seismic sources were associated in a genetic manner"* with observed earthquakes.

The Grand Gulf Site is located within Woodward Clyde Consultants' River Bend regional background source zone. This source zone was defined as an independent background source that does not contain any other seismic source regions. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.0 (M_w 4.6) to this source zone. The new Saline River source zone partially overlies the River Bend regional background source zone.

The Reelfoot Rift -New Madrid Rift Complex source zone is located about 130 miles north of the Grand Gulf Site. This source zone was defined as the portion of the New Madrid rift system that extends to the southwest from the Cottage Grove-Rough Creek fault zone, and was based on aligned gravity and magnetic anomalies along its edges (Braile et al., 1982). The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.4-7.2 (M_w 5.0-7.5) to this source zone. The team also considered the Reelfoot Rift-New Madrid Rift Complex combined with the Disturbed Zone of Reelfoot Rift (described below) as an optional source geometry.

The New Madrid Rift Loading Volume source zone is located about 135 miles north of the Grand Gulf Site. This source zone was defined based on scattered seismicity outside of the concentrated seismicity associated with the Disturbed zone of Reelfoot Rift. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.6-6.9 (M_w 5.2-7.0) to this source zone.

The Disturbed Zone of Reelfoot Rift source zone is located about 225 miles north of the Grand Gulf Site. This source zone was defined based on the occurrence of the 1811-1812 earthquake sequence, strong localization of microseismicity, seismic reflection data (Reference 178), and distribution of abundant liquefaction sand blows. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 7.2-7.9 (M_w 7.5-8.7) to this source zone. A new source characterization for the NMSZ has been overlain on the New Madrid fault zone of Woodward Clyde Consultants.

The Southern Indiana Arm and NOTA source zone is located about 310 miles north of the Grand Gulf Site. This source zone was defined as the northeast-trending arm of the New Madrid rift system that extends from New Madrid into south-central Indiana, and was based on gravity and magnetic anomalies and scattered seismicity. The Wabash Valley fault zone defines the northwestern border of the southwestern half of the Southern Indiana Arm. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.8-7.4 (M_w 5.4-7.9) to this source zone.

The Saint Louis Arm and NOTA source zone is located about 325 miles north of the Grand Gulf Site. This source zone was defined as the rift arm that extends northwesterly from New Madrid to Saint Louis, and was based on magnetic and gravity anomalies and scattered seismicity centered on the rift arm. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 6.2-7.2 (M_w 6.1-7.6) to this source zone.

2.5.2.1.2 Characterization of the New Madrid Seismic Zone

A characteristic earthquake model for the NMSZ has been added to the existing EPRI SOG seismic source model. The characteristic earthquake model is added to incorporate new data on source geometry, estimated maximum earthquake magnitude, and earthquake recurrence interval. The NMSZ characteristic earthquake model identifies specific fault segments within the NMSZ, maximum earthquake magnitudes, and earthquake recurrence intervals rather than treating the NMSZ as a single areal source zone with an exponential earthquake recurrence model. The logic tree for the NMSZ (Figure 2.5-45) describes the range of values considered for the following parameters: (1) Source geometry; (2) Maximum magnitude; and (3) Recurrence (note: numbers refer to nodes shown on the logic tree).

2.5.2.1.2.1 Source Geometry

Node 1 considers the source geometry used in the hazard calculation. The source geometry for the NMSZ is defined by the closest approach (modeled as a point source) of the three fault segments that approximate the locations of the 1811-1812 earthquake events (Reference 123; Reference 179; Reference 180). From closest to furthest from the Site, the three fault segments include: (1) the Blytheville Arch fault (BAF); (2) the Reelfoot fault (RF); and (3) the East Prairie fault (EPF) (Figure 2.5-18). Because the maximum magnitude earthquakes for each of the three fault sources are conservatively modeled as occurring at the closest approach to the Site, additional alternative fault geometries are not considered. The points of closest approach were identified using the fault geometries of Johnston (Reference 179), Crone (Reference 102), Van Arsdale et al. (Reference 121), and Champion et al. (Reference 181) and are summarized in Table 2.5-9 and Figure 2.5-18. The three fault segments are modeled as point sources at the southernmost end of each fault due to the large source to site distances and the subparallel northward trend of the NMSZ with respect to the directional bearing to the Site.

2.5.2.1.2.2 Characteristic Earthquake Magnitude

As summarized in Table 2.5-10, significant differences exist in the estimated magnitudes of the largest historical events in the NMSZ. Hough et al. (2000, Reference 180) and Bakun and Hopper (Reference 115) discuss factors that may contribute to the uncertainty in magnitude estimates. These factors include: (1) the lack of instrumental data on large magnitude events from the NMSZ; (2) the paucity of intensity data, especially west of the Mississippi River, and the sparse, and sometimes inconsistent intensity data east of the Mississippi River; (3) the subjective nature of interpretation of felt reports and contouring of damage intensity data, especially with sparse and or old reports; (4) the lack of large recent earthquakes in the eastern United States to calibrate the intensity attenuation relation; and (5) the potential bias introduced by site response in the intensity assignments. In addition, magnitude estimates based on liquefaction features have considerable uncertainty due to the variability of local soil conditions, site-response effects, and the broad uncertainties associated with empirical relations based on world-wide databases (e.g. Reference 126; Reference 182; Reference 183).

For this study, maximum magnitudes assigned to each of the major faults within the NMSZ are considered on Node 2 of the logic tree (Figure 2.5-45). The southern segment is alternatively considered in the literature as either the Blytheville Arch/Bootheel Lineament or Blytheville Arch/Cotton Grove fault. For our purposes, the southern termination of both alternatives is the same (Figure 2.5-45). The characteristic maximum earthquake magnitudes for the southern segment are assigned the following values: M_w 7.3 (0.4), M_w 7.7 (0.5), and M_w 8.1 (0.1). The highest value of M_w 8.1 represents the preferred value of Johnston (Reference 118 and 114) for the December 1811 event based on isoseismal areas and a common attenuation relationship developed for a worldwide database of all stable continental regions. The lowest value of M_w 7.3 reflects the magnitude estimate of Hough et al. (Reference 180) after adjusting intensities for site amplification. The M_w 7.3 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Wells and Coppersmith (Reference 184) as cited in Cramer (Reference 130), assuming a 117-km rupture length and 15-km rupture width. This value also agrees with the preferred magnitude estimated by Bakun and Hopper (Reference 115) for this event. The intermediate value of M_w 7.7 reflects the current magnitude estimate for the largest events of the 1811-1812 sequence used by the U.S. Geological Survey in their recent PSHA for the United States (Reference 19). The M_w 7.7 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Sommerville and Sakia (Reference 185) as cited in Cramer (Reference 130), assuming a 117-km rupture length and 19-km rupture width. Frankel et al. (Reference19) also note the general similarity in the isoseismals with distance between the 2001 Bhuj India earthquake (M_w 7.6-7.7) and those of the December 1811 New Madrid event, although they caution that there may be differing rates of attenuation of intensities for the eastern U.S. and India.

The characteristic maximum magnitudes assigned to the Reelfoot fault encompass the range of published estimates for the February 1812 event. In addition, consideration is given to estimates based on the constraints for the geometry and extent of the Reelfoot fault (e.g., Reference 123; Reference 130). The following magnitude distribution is assigned to this fault: M_w 7.2 (0.2), M_w 7.4(0.4), M_w 7.6 (0.3) and M_w 8.0 (0.1). The lowest value is based on the estimated moment and magnitude presented by Mueller and Pujol (Reference 123) that uses fault geometry, slip rate, and displacement data from seismicity, geomorphic, and trench data. The M_w 7.4 and M_w 8.0 values reflect the estimated magnitudes from isoseismal contours of this event as given by Hough et al. (Reference 180) and Johnston (Reference 118), respectively. The M_w 7.4 value also represents the preferred value of Bakun and Hopper (Reference 115). The M_w 7.6 value captures the weighted average value assigned to the February 1812 Reelfoot fault event by experts in the general research community for the US Geological Survey model (Reference 19).

The characteristic maximum magnitudes assigned to the East Prairie fault encompass the range of published estimates for the January 1812 event. The following magnitude distribution is assigned to this source: M_w 7.0 (0.4), M_w 7.4 (0.5), and M_w 7.8 (0.1). The high and low values reflect estimates of Johnston (Reference 118) and Hough et al. (Reference 180), respectively. The intermediate value captures the upper range of values estimated by Bakun and Hopper (Reference 115). The M_w 7.4 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Somerville and Sakia (Reference 185) as cited in Cramer (Reference 130), assuming a 59-km rupture length and 19-km rupture width. The lower and middle magnitude values are judged to be more consistent with the preferred fault length and downdip width (~15 km based on microseismicity) and, therefore, are given higher weight than the highest value estimated from intensity data.

In addition to the intensity based magnitude estimates described above, we have also considered in our assignment of magnitude weights the physical process of strain accumulation and release, and the relationship between earthquake magnitude and recurrence interval. Given the relatively short 200-800 year earthquake recurrence interval for 1811-1812 earthquake sequences, we consider it more likely that the correct estimate of earthquake magnitude is represented by the lower or middle values in the distribution (Figure 2.5-45). This interpretation is supported by geologic slip rate and coseismic displacement data. These data do not support the occurrence of earthquakes of magnitude greater than M_w 7.7 with recurrence intervals of 200 to 800 years. A discussion of the dependency of earthquake recurrence on magnitude is presented in Section 2.5.2.1.2.4.

As discussed in the next section, the present interpretation of the paleo-earthquake data is that the penultimate and pre-penultimate events prior to the 1811-1812 sequence also consisted of multiple large-magnitude earthquakes within the NMSZ. Therefore, for this assessment, the "characteristic" event is considered to be a clustered rupture of all three faults in the NMSZ within a short period of time. Therefore, a set of five alternative magnitude sets, or clusters of characteristic ruptures were developed from the distributions for each fault. These magnitude clusters are shown in the logic tree on Figure 2.5-45.

2.5.2.1.2.3 Recurrence

For this study, characteristic earthquakes for the NMSZ are considered on Node 3 of the logic tree (Figure 2.5-45). The best constraints on recurrence of characteristic NMSZ events are direct paleoseismic data from studies of the Reelfoot fault (Reference 109) and the New Madrid North (East Prairie) fault (Reference 99), and are supported by paleoliquefaction studies throughout the entire New Madrid region (Reference 125). Paleoseismic data are considered the most reliable data source because paleoseismic investigations document and date discrete displacements of geologic features. The paleoseismic data from the Reelfoot fault indicate that there have been three events within the past 2,400 years. The most recent event was associated with the 1811-1812 earthquake sequence. The penultimate event is estimated to have occurred between A.D. 1260 and 1650. The pre-penultimate event is estimated to have occurred prior to about A.D. 780-1000 (Reference 108). Kelson et al. (Reference 109) estimated a preferred recurrence interval of about 400 to 500 years for the Reelfoot fault.

Baldwin et al. (Reference 99) conducted paleoseismic investigations to identify possible evidence of surface deformation related to the January 1812 earthquake. The available information is currently insufficient to determine whether the observed features represent the primary trace of the New Madrid North fault, secondary deformation, or solely liquefaction-related features. However, the available data do not support the presence of a major fault with repeated M>7.8 earthquakes occurring with an average recurrence interval of 500 years.

Investigations in the NMSZ also have identified paleoliquefaction features associated with the 1811-1812 earthquake sequence, as well as two prior events at approximately A.D. 1450 and A.D. 900 (Reference 125; Reference 126). Based on the liquefaction data, Tuttle et al. (Reference 125) estimate recurrence intervals for 1811-1812 type events to be 200 to 800 years with a best estimate of 500 years. In addition, the composite characteristics of sand blow features are interpreted by Tuttle et al. (Reference 125) to indicate that the previous earthquake cycles involved multiple earthquake events similar to the 1811-1812 earthquake sequence. Similarity in the size of the liquefaction fields (Reference 125) and amount of displacements observed from paleoseismic trench investigations (Reference 109) indicate that the previous events were of similar size to the 1811-1812 earthquake sequence.

The composite characteristics of the sand blows suggests that rupture of the NMSZ occurs as an event sequence, and therefore all three fault segments are modeled as rupturing within a short period of time in a cluster of events. Based on the paleoseismic and paleoliquefaction data we have assigned recurrence times and probabilities for these event clusters of 200 years (0.1), 500 years (0.6), and 800 years (0.3). The minimum and maximum values are assigned based on the paleoliquefaction data, and the middle value is assigned based on consideration of both the paleoseismic and paleoliquefaction data.

2.5.2.1.2.4 Dependency of Magnitude on Earthquake Recurrence

Maximum earthquake magnitudes for each of the 1811-1812 fault ruptures were selected from published intensity-based magnitude estimates (Reference 114; Reference 115; and Reference 117), paleo-liquefaction-based magnitude estimates (Reference 123; Reference 126; and Reference 185), estimates of seismic moment from the Reelfoot fault (Reference 123; Reference 181), and empirical relationships between magnitude and rupture area (Reference 130). Published magnitude estimates for the 1811-1812 earthquake sequence are summarized in Table 2.5-10.

The range of magnitudes are M_w 6.7 to 7.8 for the East Prairie fault, M_w 7.0 to 8.0 for the Reelfoot fault, and M_w 6.8 to 8.1 for the Blytheville Arch fault. As discussed in Section 2.5.2.1.2, magnitude estimates were weighted after considering the most recent published analyses, physical constraints on potential rupture areas and displacements, and dependency on earthquake recurrence intervals.

The dependency of maximum earthquake magnitude on earthquake recurrence interval was considered in assigning weights to the magnitude estimates because the relationship

Seismic Moment Rate = Area * Displacement * Shear Modulus/Slip Rate

requires that, assuming constant slip rate, larger magnitude earthquakes have longer earthquake recurrence intervals (Reference 186; Reference 187). Therefore, the weights assigned for each magnitude estimate in the hazard calculation for the NMSZ reflect a preference for lower published magnitude values given the 200 to 800 year range of earthquake recurrence intervals from paleoseismic and paleoliquefaction studies, and fault displacement data.

Data from the Reelfoot fault are used to estimate seismic moment and moment magnitude for the February 1812 earthquake (Table 2.5-11). This earthquake is inferred to be the largest event by Bakun and Hopper (Reference 115) and Hough et al. (Reference 180) and, therefore, provides an estimate of seismic moment and earthquake recurrence for the largest event in the New Madrid earthquake sequence. Seismic moment (M_o) is the product of fault rupture area, average coseismic displacement, and an assumed shear modulus of 3.5×10^{11} dyne cm^2.

The moment magnitude (M_w) is computed from seismic moment using the relationship:

$$M_w = 2/3 * \log M_o – 10.7 \text{(Reference 187).}$$

Earthquake magnitudes estimated from geological data shown in Table 2.5-11 are within the range of intensity-based values estimated for the February 1812 earthquake on the Reelfoot fault by Hough et al. (Reference 180) and Bakun and Hopper (Reference 115). However, the magnitude estimates are inconsistent with the M_w 8.1 +/- 0.3 magnitude estimates of Johnston

(Reference 118) for the February 1812 earthquake on the Reelfoot fault. The physical parameters required to produce an M_w 8.1 earthquake on the Reelfoot fault (i.e. area and displacement) are inconsistent with the geological observations. To illustrate this point we have included two hypothetical earthquakes in the calculations shown in Table 2.5-11. The required rupture area to produce an M_w 8.1 earthquake is more than a factor of 3.3 larger than the documented fault area for the Reelfoot fault (Reference 123), and the required displacement is more than a factor of 2.6 larger than the observed fault displacements (Reference 109). Consequently, we give lower weight in the logic tree for a M_w 8.1 earthquake on the Reelfoot fault (or other segments of the NMSZ).

Seismic moment rate and earthquake recurrence intervals are computed for the range of potential earthquake magnitudes on the Reelfoot fault using the seismic moment (Table 2.5-12) and estimated fault slip rates for the Reelfoot fault (Reference 122; Reference 181).

Three estimates of fault slip rate are used in the recurrence calculation (Table 2.5-12). The low slip rate estimate (2 mm/yr) is based on seismic reflection data that show 16 m of displacement across the Reelfoot fault in the past 9000 years (Reference 122). The mid slip rate estimate (4 mm/yr) is based on a 29.5-foot (9-meter) displacement of 2290 +/-60 year old sediment across the Reelfoot fault at Tiptonville Dome (Reference 181), and the high slip rate estimate (6 mm/yr) is based on offset deposits observed in trenches across the Reelfoot scarp (Reference 109; Reference 122). For each slip rate, recurrence intervals are calculated for the range of magnitudes estimated by Mueller and Pujol (Reference 123).

The calculation of earthquake recurrence shown in Table 2.5-12, illustrates that for the mid- to high-slip rate estimates, the recurrence intervals for M_w 7.2 to 7.5 earthquakes is consistent with the 200 to 800 year estimate of recurrence that is based on the paleoliquefaction data of Tuttle et al. (Reference 125), and the paleoseismic data of Kelson et al. (Reference 109). The recurrence interval for a M_w 7.2 earthquake using the low slip rate estimate is also within the 200 to 800 year range based on the paleoliquefaction data of Tuttle et al. (Reference 125). Recurrence intervals for M_w 7.3 to 7.5 earthquakes using the low slip rate estimate are longer than and outside the 200 to 800 year range. Recurrence intervals for events greater than M_w 7.5 are outside the 200 to 800 year range for all slip rate estimates.

The recurrence calculations in Table 2.5-12 provide constraints on the likely size of earthquakes given the 2 mm/yr, 4 mm/yr, and 6 mm/yr slip rate estimates for the Reelfoot fault (Reference 109; Reference 122; and Reference 181), and the geological evidence of 200 to 800 year recurrence for characteristic earthquakes within the NMSZ (Reference 125). Based on these magnitude and moment rate recurrence calculations, greater weight is given to smaller intensity-based magnitude estimates of M_w 7.3 to 7.5 (Reference 180) and M_w 7.4 (Reference 115), over the larger intensity-based magnitude estimate of M_w 7.9 to 8.1 (Reference 179).

2.5.2.1.3 Saline River Source Zone Characterization

The logic tree for the Saline River source zone (Figure 2.5-46) describes the range of values considered for the following parameters: (1) Probability of Existence (also called Probability of Activity in the EPRI SOG methodology); (2) Source Geometry; (3) Maximum Magnitude; (4) Recurrence Model; (5) Geological Approach for Estimating Recurrence; and (6) Recurrence (note: numbers refer to nodes shown on the logic tree).

2.5.2.1.3.1 Probability of Existence

Node 1 considers the probability that the Saline River source zone is an independent seismic source or whether the features observed in the Saline River area can be explained by the seismic source models by the ESTs either as part of activity in background source zones, by earthquake activity in the NMSZ, or by other non-tectonic processes. We assign a 50% probability to this branch to express the large uncertainty in the existence of the source. The coincidence of liquefaction, sparse seismicity, late Tertiary and possibly Pleistocene fault rupture, and geomorphic asymmetry of drainage basins suggests that a local seismic source may be present (Section 2.5.1). However, it is equally likely that the liquefaction features observed in southeastern Arkansas were produced from: (1) infrequent moderate magnitude events in the background source zone; or (2) distant ground shaking related to events along the NMSZ.

Alternatively, the geomorphic drainage basin asymmetry may be caused by regional tectonic arching, glacio-eustatic rebound, or non-tectonic processes related to sediment loading in the Mississippi River delta. Geologic evidence of faulting is not sufficient to define with certainty that a distinct capable fault is present within the Saline River source zone. Only one fault shows conclusive evidence for repeated late Quaternary activity (Site 4; Table 2.5-13 and Figure 2.5-20). Deformation along other faults is inferred to be Pliocene to early Pleistocene age (Upland Complex time). Based on the information presented in Cox et al. (Reference 151), neither the type of fault or sense of displacement is well known. Furthermore, each of the observed faults appears to be short, with minimal displacement, and variable orientation. Based on the available data it is not possible to confirm the existence, with certainty, of a distinct throughgoing fault.

2.5.2.1.3.2 Source Geometry

Node 2 describes the geometry of the Saline River source zone (Figures 2.5-19 and 2.5-46). We define an areal source zone for the Saline River source zone that encompasses all of the geomorphic, liquefaction, seismicity, and geologic data that suggest the existence of a localized seismic source. The source zone is defined by the intersection of the southwestward extension of the Proterozoic Reelfoot Rift and the Paleozoic Ouachita Orogenic Belt. The source zone geometry is defined based on the interpretation that northeast-trending faults within the Reelfoot Rift in the continental basement may structurally interact with northwest-trending faults in the overlying Ouachita Orogenic Belt. As with the NMSZ, faults within this zone of intersection may be reactivated due to east-northeast directed regional compressive stress (Section 2.5.1.2.2.1).

The northwestern boundary of the zone is defined based on the Northern Boundary fault of the Reelfoot Rift (Reference 188). The southeastern boundary is defined based on the southward projection of recently identified Reelfoot Rift-related marginal faults (Reference 189). The southwestern boundary of the seismic zone is defined based on the southern rifted margin of the North American craton. The Reelfoot Rift is a Proterozoic structure within the continental basement of the North American craton and was truncated by southward-directed rifting of the Gulf of Mexico in Triassic time. Therefore, the southern continuation of the Reelfoot Rift system is constrained by the limit of the North American continental crust. The northeastern boundary of the seismic zone is defined by the northernmost occurrence of basin asymmetry along the Arkansas River.

2.5.2.1.3.3 Characteristic Earthquake Magnitude

Node 3 describes the characteristic maximum earthquake magnitude for the Saline River source zone (Figure 2.5-46). The characteristic earthquake magnitude is estimated taking into consideration the observations of faulting from trenches along the Saline River fault (Reference 151), and the extent of liquefaction features observed in Ashley and Desha counties (Reference 152).

The range of characteristic magnitudes and weightings are M_w 6.0 (0.3), M_w 6.5 (0.6), and M_w 7.0 (0.1). The M_w 6.0 and 6.5 estimates are based on the empirical relationship between size of a liquefaction field and earthquake magnitude (Reference 182) and encompass the upper bound estimate provided by Cox et al. (Reference 151). The liquefaction field observed in Ashley County is approximately 9-miles (15 kilometers) across. The Ambrayses (Reference 182) relationship predicts a M_w 5.5 for a liquefaction field of this size; to be conservative we assign a magnitude of M_w 6.0 for the lower bound maximum magnitude. If the liquefaction features observed at the Kelso (Desha County) and Montrose (Ashley County) sites occurred during a single event the liquefaction field would be approximately 30-miles (50-kilometers) across corresponding to a magnitude estimate of M_w 6.5 (Reference 182). The occurrence of M_w 6.5 earthquakes along the Saline River source zone also is consistent with the observation of minor surface fault rupture. The limited occurrence of liquefaction features and evidence for minor discontinuous surface fault ruptures are consistent with earthquake magnitudes in the M_w 6.0 to 6.5 range.

A M_w 7.0 characteristic earthquake also is considered in the magnitude assessment. Although the occurrence of a larger magnitude event is a possibility, the geological data do not support the occurrence of an earthquake of this size. The repeated occurrence of M_w 7.0 earthquakes in this region would have produced more pronounced geomorphic expression of tectonic deformation, and also would have produced much more pronounced and extensive surface manifestation of liquefaction in susceptible deposits along the Arkansas, Saline, Ouachita, and Mississippi Rivers. As a sensitivity analysis, we calculated the size of the 0.1g isoseismal contour for a M_w 7.0 event. This area represents the likely size of the area that would exhibit surface manifestation of liquefaction in susceptible deposits. The radius of the 0.1g isoseismal using the 2-sigma ground motion attenuation relations (Reference 13) is about 70 miles (120 kilometers). Therefore, if there had been repeated Holocene M_w 7.0 events, the distribution of liquefaction features would be far more extensive than the limited extent of features observed in Ashley and Desha counties. The lack of these extensive liquefaction features, and minor expression of evidence of surface faulting supports the higher weighting on the M_w 6.0 to 6.5 characteristic earthquake magnitude than the M_w 7.0 magnitude.

2.5.2.1.3.4 Earthquake Recurrence

Node 4 describes the models used to compute earthquake recurrence. We consider both the exponential earthquake recurrence model (Reference 186) and the characteristic earthquake recurrence model (Reference 190) and weight these 0.1 and 0.9, respectively.

The characteristic earthquake recurrence model is given a predominant weighting of 0.9 because there is a record of several earthquake cycles, and a sequence of geomorphic terraces that provide a geological basis to estimate rates of tectonic deformation. The exponential recurrence model is given a lower weighting of 0.1 because of the sparse seismicity in the area and incomplete historical record.

2.5.2.1.3.5 Characteristic Earthquake Recurrence Model

Node 5 describes the geological approach for estimating the characteristic earthquake recurrence. The characteristic earthquake recurrence is estimated using both paleoliquefaction data and fault slip-rate data. The recurrence of the characteristic earthquake using paleoliquefaction data is assigned a weight of 0.6. The recurrence of the characteristic earthquake using fault slip-rate data is assigned a weight of 0.4. We assign a higher weight of 0.6 to the recurrence model using paleoliquefaction data because these data are better constrained through paleoseismic investigations, and several earthquake cycles are recorded.

2.5.2.1.3.5.1 Paleoliquefaction

In Node 6, the recurrence times for characteristic earthquakes based on the paleoliquefaction data are estimated at 390, 1,725, and 3,500 years. We assign weights of 0.2, 0.4, and 0.4 respectively, to these recurrence estimates. The shortest recurrence time of 390 years represents the average recurrence time for five events during the period 150 ybp (A.D. 1800) to 1,700 ybp, the shortest allowable time period. The 1,725 year recurrence time represents the average recurrence time for five events occurring between 150 and 5,320 ybp (Table 2.5-14). The 3,500 year recurrence time represents the maximum recurrence based on the dated maximum interval between liquefaction events at the Montrose site in Ashley County.

2.5.2.1.3.5.2 Slip-Rate

The recurrence times for characteristic earthquakes based on slip-rate data are estimated for each characteristic earthquake magnitude (M_w 6.0, 6.5 and 7.0), also shown in Node 6. The recurrence time is estimated by dividing the characteristic displacement by the slip rate. The recurrence calculations are summarized in Table 2.5-15. Characteristic displacement is derived from the empirical relationship between earthquake magnitude and average displacement from Wells and Coppersmith (Reference 184). Slip-rates are estimated from the amount of stream incision recorded along the Saline River as described in Engineering Report ER-01 (Figure 2.5-23). The assigned weights for each recurrence calculation reflect a preference for slip-rate values of 0.01, 0.05 and 0.1 mm/yr.

The recurrence times vary for each of the M_w 6.0, 6.5 and 7.0 characteristic earthquake magnitudes because the amount of displacement required to produce these earthquakes varies; larger earthquakes require greater displacement than smaller earthquakes. For M_w 6.0 characteristic earthquakes the recurrence times and assigned weights are 1,000 years (0.3), 2,000 years (0.6), and 10,000 years (0.1), respectively. For M_w 6.5 characteristic earthquakes the recurrence times and assigned weights are 3,000 years (0.3), 6,000 years (0.6), and 30,000 years (0.1), respectively. For M_w 7.0 characteristic earthquakes the recurrence times and assigned weights are 12,500 years (0.3), 25,000 years (0.6), and 125,000 years (0.1), respectively.

2.5.2.1.4 Effect of Updating the Earthquake Catalog on the EPRI SOG Seismicity Parameters

The EPRI earthquake catalog, updated to include seismicity from 1985 to 2002, was examined to evaluate possible correlation of seismicity to geologic structures, possible changes to the EPRI source geometry or seismicity parameters (a and b values), and any possible new or previously unrecognized seismic source. The original EPRI catalog covers earthquakes in the CEUS for the time period up to 1984. This catalog was updated for the period 1985 to 2002 for the region within 200 miles of the site (within the latitude interval from 28.5 to 35.5 degrees North and longitude interval from 87.5 to 94.5 degrees West).

Table 2.5-14 identifies 23 earthquakes for magnitude 3.0 and greater (m_b) that have occurred since 1984 within 200 miles of the site. These events were added to the EPRI earthquake catalog. All of the events were assumed to be main events. Figure 2.5-38 shows the distribution of earthquake epicenters from both the EPRI (pre-1984) and updated (post-1984) earthquake catalogs in comparison to major tectonic features and geologic structures in the Site Region. Evaluation of the updated earthquake catalog yields the following conclusions:

1. No new earthquakes of magnitude greater than m_b 3.0 have occurred within approximately 110 miles of the ESP Site since 1985;

2. The updated catalog does not show any earthquakes within the site region that can be correlated with a known geologic structure. The majority of seismicity appears to be occurring in areas underlain by continental crust that coincide with either the Appalachian Mountains, Ouachita Orogenic Belt, or Reelfoot Rift/NMSZ;
3. The updated catalog does not show a unique cluster of seismicity that would suggest a new seismic source outside of the EPRI source model;
4. The updated catalog does not show a pattern of seismicity that would require significant revision to the EPRI seismic source geometry;
5. The updated catalog does not show any increase in M_{max} for any of the EPRI sources;
6. The updated catalog does not show any increase in the estimated rate of earthquake occurrences.

Seismicity parameters (a- and b-values) for the seismic sources defined by the Earth Science Teams were based on an analysis of the earthquake catalog developed as part of the EPRI SOG project. To evaluate the sensitivity of the updated EPRI earthquake catalog to estimated earthquake recurrence rates, the EPRI program EQPARAM was used. EQPARAM is part of the EPRI EQHAZARD software package. Calculations were performed for the Woodward Clyde background source around the GGNS site. The GGNS site is located at the center of this source which is defined as a square polygon, 6 degrees on a side. An evaluation of the change in seismicity parameters for this seismic source provides a measure of the effect of the updated earthquake catalog. The EQPARAM evaluation was performed using the same seismicity options specified by the Woodward Clyde team (Reference 10).

Figure 2.5-47 shows a comparison of the estimated frequency of earthquake occurrences for the Woodward Clyde background seismic source based on the original EPRI earthquake catalog and the catalog updated to 2002. The results indicate that the earthquake frequencies based on the updated catalog are slightly lower than the frequencies based on the original EPRI SOG seismic parameters. For this reason, it was concluded it was not necessary to update the EPRI SOG source seismicity parameters. Therefore, the original EPRI seismicity parameters (a- & b- values) were used to calculate seismic hazard at the ESP site with the EPRI seismic sources.

Possible changes in the seismicity parameters for the New Madrid seismic source zones were not evaluated. Because the New Madrid source zone for all EST's were updated to include a characteristic event and current estimates of the frequency of these events, an update of the seismicity parameters for events smaller than the characteristic earthquake (associated with the exponential part of the earthquake recurrence model) is not necessary.

2.5.2.2 GGNS Probabilistic Seismic Hazard Analysis

A probabilistic seismic hazard analysis (PSHA) was performed for the GGNS following the procedure provided in RG 1.165 (Reference 4). The results were deaggregated in terms of earthquake magnitude (M_w) and distance to determine the controlling earthquakes for the site. The PSHA calculations were performed for rock site conditions. The PSHA results were input to a site response analysis to determine the free-field surface ground motion and Safe Shutdown Earthquake (SSE).

2.5.2.2.1 Seismic Source Characterization

The GGNS PSHA was performed using the EPRI SOG seismic sources listed in Tables 2.5-8a through 2.5-8f, the New Saline River seismic source described in Section 2.5.2.1.3 and the revised New Madrid seismic source described in Section 2.5.2.1.2. As described in Section 2.5.2.1, the Saline River seismic source and revised New Madrid seismic source are added to the EPRI SOG seismic sources without revision to these sources. The potential double-counting of hazard using this approach is conservative. The parameters for these sources are presented in Figures 2.5-45 and 46.

2.5.2.2.2 Magnitude Conversion

In the EPRI SOG study earthquake occurrences were defined in terms of body-wave magnitude, m_b (Reference 9). Modern seismic hazard studies define seismicity with respect to moment magnitude (M_w). Similarly, the new EPRI recommended ground motion models (Section 2.5.2.2.3) are based on moment magnitude. For the new Saline River seismic source developed in this analysis and for the updated seismicity parameters for the New Madrid characteristic events, seismicity also is defined in terms of moment magnitude. To perform the PSHA calculations, the seismicity parameters specified for seismic sources in the EPRI SOG study were input as originally defined and converted to moment magnitude as part of the calculation. To account for the uncertainty in this conversion, three alternative m_b– M_w models were used: Atkinson and Boore (1995), EPRI (1993), and Johnston et al. (1996). These models were assigned equal weight in the analysis.

2.5.2.2.3 Ground Motion Attenuation Models

The ground motion attenuation models developed as part of an EPRI-sponsored project were used in the PSHA (Reference 13). The EPRI 2003 ground motion models estimate ground motions for rock sites and include, for a given ground motion frequency (e.g., spectral acceleration (S_a) 1 Hz), alternative estimates of the median and aleatory uncertainty in ground motion. The alternative models of the median and aleatory uncertainty and their probability weights represent the epistemic uncertainty in ground motions.

The EPRI 2003 ground motion model provides median ground motion models for the Mid-continent and the Gulf region of the central and eastern U.S. (Reference 13). In addition, the model is defined for different seismic source types, including General Area sources, and Fault sources or sources capable of generating large magnitude ($M_w > 7$) events. In addition, specific ground motion models were defined for fault sources in rifted and non-rifted regions (Reference 191).

For the New Madrid seismic source, the Mid-continent, rifted ground motion attenuation models were used. For this case there are 12 estimates of the median ground motion, and 4 estimates of the aleatory uncertainty. This produces 48 ground motion model estimates. For seismic sources located in proximity to the GGNS, the General Area ground motion models for the Gulf region were used. For this case there are 9 estimates of the median ground motion, which combine with 4 aleatory variability models to produce 36 ground motion model estimates.

As described in the EPRI (2003) ground motion report, when General Area sources and Fault sources (also sources capable of generating large magnitude events at large distances) are included in a seismic source combination (i.e., both seismic source types are simultaneously active), these models are correlated (Reference 13).

2.5.2.2.4 Lower-Bound Magnitude

The PSHA calculations were performed using a lower-bound magnitude of 5.0 M_w. This value is consistent with the findings in EPRI (Reference 11) which recommended a lower-bound magnitude for PSHA calculations performed for well-engineered facilities such as nuclear power plants. The study recommended a lower-bound magnitude of 5.0 M_w**.** At the time, a lower-bound magnitude of 5.0 M_w was estimated to correspond to a lower-bound magnitude of 5.3 in terms of m_b. Thus, the lower-bound of m_b 5.0 used in the EPRI SOG study was slightly conservative..

The deaggregation of the seismic hazard at the GGNS ESP site was performed for seven magnitude and seven distance bins. The magnitude-distance bins are:

Magnitude (M_w): 5.0-5.5, 5.5-6.0, 6.0-6.5, 6.5-7.0, 7.0-7.5, 7.5-8.0, 8.0, and greater,

Distance (km): 0.0-15, 15-25, 25-50, 50-100, 100-200, 200-300, 300, and greater.

The distance bins are defined in terms of epicentral distance.

2.5.2.2.5 PSHA Calculations

The seismic hazard calculations for the GGNS PSHA were performed using the EPRI EQHAZARD software which has been upgraded to include the characteristic earthquake model, the EPRI 2003 ground motion model, expanded logic tree modeling capabilities, and the calculations described in RG 1.165.

2.5.2.2.5.1 Results

The seismic hazard results for rock site conditions are shown in Figures 2.5-48 to 2.5-54 for each ground motion frequency (1Hz, 2.5Hz, 5Hz, 10H_z, 25 Hz and PGA). The results are provided in terms of the 0.15, 0.50 and 0.85 fractiles and the mean. Table 2.5-15 shows the 10^{-5} median uniform hazard response spectra (UHS) for the GGNS for rock site conditions.

Following the procedure in RG 1.165 the median hazard results were deaggregated for low (1 and 2.5 Hz) and high frequencies (5 and 10 Hz). Figure 2.5-57 shows the low-frequency magnitude-distance deaggregation. The results show that the majority of the hazard contribution is produced by characteristic earthquake events associated with the New Madrid seismic source zone. The high-frequency deaggregation results are shown in Figure 2.5-58. The results show that the majority of the hazard contribution is produced by events of magnitude less than 5.5 and distances less than 100 km. However, there is also a contribution from the characteristic earthquakes on faults within the New Madrid seismic source zone.

To manage the execution time of these calculations one simplification was introduced. For seismic sources defined in the original EPRI SOG study for which multiple seismicity options (e.g., alternative models for the a- and b-values of the exponential recurrence relationship), the mean hazard for these options was calculated and used in the final hazard calculation. This simplification reduced the number of branches in the logic tree and significantly reduced the computation time. This simplification is reasonable due to the low sensitivity of the median hazard to alternative seismicity options defined by the ESTs (Reference 10). The sensitivity of the Grand Gulf median seismic hazard estimates was evaluated and determined to be small as shown in Figures 2.5-55 and 2.5-56 for spectral accelerations of 1 and 10 Hz, respectively

2.5.2.2.5.2 Controlling Earthquakes

Following the procedure recommended in RG 1.165, the controlling earthquakes for low and high-frequency ground motions was determined. The calculated events are listed in Table 2.5-16. For the GGNS, the contribution of large distant events (distances greater than 100 km) to low frequency ground motions was greater than 5 percent. Therefore as recommended in RG 1.165 an additional distant controlling event was calculated. This event is also listed in Table 2.5-16.

For each controlling earthquake, a median response spectrum shape was determined using the EPRI (Reference 13) ground motion models. These median response spectra are shown in Figure 2.5-59 with the median 10^{-5} UHS. As shown, the response spectra from the S_a(1-2.5Hz) (including all distances) and the S_a(5-10Hz) controlling earthquakes approximate well the shape and amplitude of the UHS for frequencies greater than 1 Hz. At frequencies greater than approximately 15 Hz, the high frequency spectrum slightly under predicts the UHS amplitudes. This underprediction is less than 10 percent.

The rock response spectra for the S_a(1-2.5Hz) (including all distances) and the S_a(5-10Hz) controlling earthquakes are used in the site response analysis to determine the site transfer function and the resulting soil ground motions. This analysis is described in Sections 2.5.2.3 and 2.5.2.4.

2.5.2.3 Seismic Wave Transmission Characteristics of The Site

The rock outcrop UHS as well as the associated 1 to 2.5 Hz and 5 to 10 Hz scaled spectra presented in Section 2.5.2.2 (Figure 2.5-59) are based on updated CEUS attenuation relations for hard rock site conditions (Reference 13). The hard rock site conditions reflect a mid-continent crustal structure (Reference 170, 191) with a defined shear-wave velocity of 2.83 km/sec. This high velocity is generally associated with very competent crystalline or metamorphic basement material, which occurs at the GGNS ESP site at depths exceeding 10,000 ft, where Paleozoic basement material is encountered (Section 2.5.1).

To develop the SSE at the surface, site response analyses must accommodate the effects of the local shallow soils as well as deeper soils and soft rock to a depth where the shear-wave velocity reaches about 2.8 km/sec. Since the UHS and consequently the SSE are defined to 0.5 Hz (2 seconds) as the lowest frequency, accommodation of the deeper materials is required to depths which results is capturing the amplification to the lowest frequency of interest (Reference 170, 192, 193, 194). For typical deep firm profiles, maximum amplification at 0.5 Hz is reached at depths of about 1,000 ft (305m), at low levels of loading (Reference 193). To conservatively accommodate potential low frequency amplification, the local soil profile is extended to a depth of 3,300 ft (1 km) and Approach 2A of McGuire et al. (Reference 194) is used to accommodate the effects of both the local soils and deeper materials as well as their variabilities on the design ground motions.

The shear-wave velocity profile at the site was based on three suspension log surveys, with the deepest extending to a depth of about 225 ft (Section 2.5.2.4). The base case profile as well as the suspension log profiles are shown in Figure 2.5-60. These shallow materials consist of about 75 ft of loess, 85 ft of young alluvium, with old alluvium to a depth of about 200 ft where claystones of the Catahoula formation were encountered. Both the old and young alluvium comprise the terrace deposits of the Uplands Complex. To extend the profile to a depth of about 3,000 ft, a generic Mississippi embayment shear-wave velocity profile was used. This generic profile was developed for ground shaking studies in the embayment by Professor Glenn Rix of the MAE Center (Reference 195). The profile is based on a large number of shallow and several deep velocity surveys and extends to a depth of 3,600 ft (1,100m). For the site base case profile, the shallow velocities to a depth of about 225 ft (Figure 2.5-60) replaced those of the generic Mississippi embayment upland profile, which had similar velocities (about 2,000 ft/sec) at these depths. The complete base case profile is shown in Figure 2.5-61 to a depth of 1 km, where shear-wave velocity is set to 2.8 km/sec, appropriate for hard rock conditions.

Nonlinear dynamic material properties, G/Gmax and hysteretic damping curves, are based on laboratory testing of undisturbed samples taken during the site exploration program (Section 2.5.4). Generally, the laboratory dynamic test results showed similarity with the EPRI (Reference 170) G/Gmax and hysteretic damping curves for cohesionless soils. Specifically, samples within the loess (approximately top 75 ft) were similar to the EPRI (Reference 170) curves for depths of 120 to 250 ft while the test results for the alluvium and old alluvium were similar to EPRI (Reference 170) curves for depths of 250 to 500 ft and 500 to 1,000 ft, respectively (Section 2.5.4). Due to the similarity between the laboratory dynamic testing results and those developed by EPRI (Reference 170), the EPRI (Reference 170) curves were adopted for use and are shown in Figure 2.5-62. The deeper EPRI (Reference 170) curves (500-to-1,000 ft) were used to a depth of 500 ft, below which linearity was assumed (Reference 194). To constrain the damping below 500 ft, the kappa value at the surface was assumed to be 0.04 sec, a conservative estimate for this region of the Mississippi embayment (Reference 196).

2.5.2.4 Site Response Analysis

The site response analyses followed Approach 2A recommended in McGuire et al., 2001 (Reference 194) in which the 1 to 2 Hz and 5 to 10 Hz controlling earthquake spectra (R.G. 1.165) scaled to the UHS are used as control motions (Figure 2.5-63). Transfer functions, soil surface-to-hard rock outcropping, are developed for each controlling earthquake, enveloped, and the envelop applied to the rock UHS. This process is intended to conservatively maintain the hazard level of the rock outcrop UHS while incorporating variability in site-specific dynamic material properties (Reference 194).

Variability in the base case shear-wave velocity profile is accommodated through development of 60 randomized profiles for each control motion. The profile randomization scheme is based on an analysis of variance of over 500 measured profiles (Reference 194; Reference 197), and randomly varies both shear-wave velocity as well as layer thickness. To provide for uncertainty in depth to hard rock, depth is randomized using a uniform distribution from 850m to 1,150m.

To accommodate variability in modulus reduction and hysteretic damping curves, the curves are independently randomized about the base case values. A log normal distribution is assumed with a σ_{ln} of 0.30 at a cyclic shear strain of 3 x 10^{-2}%. These values are based on an analysis of variance on a suite of laboratory test results. An upper and lower bound truncation of 2σ is used to prevent modulus reduction or damping models that are not physically possible. The random curves are generated by sampling the transformed normal distribution with a σ_{ln} of 0.30, computing the change in normalized modulus reduction or percent damping at 3 x 10^{-2}% shear strain, and applying this factor at all strains. The random perturbation factor is reduced or tapered near the ends of the strain range to preserve the general shape of the median curves (Reference 198).

The ensemble average, or mean transfer function, for each of two control motions (1 to 2 Hz and 5 to 10 Hz), then reflects the best estimate effect of the soil/soft rock column, accommodating site specific variability in dynamic material properties as well as depth to basement material. For the top of loess, the two mean transfer functions (5% damped response spectra), corresponding to the 1 to 2 Hz and 5 to 10 Hz control motions (Figure 2.5-63), are shown in Figure 2.5-64 along with their envelop. To accommodate the possibility of removing the surficial loess to a depth of about 50 ft for structure embedment, transfer functions were also estimated considering the top of 1,000 ft/sec material as surficial outcrop (Figure 2.5-60). The corresponding estimate of the mean transfer function is shown in Figure 2.5-65 and shows little impact of the top 50 ft (Figure 2.5-64).

2.5.2.5 Safe Shutdown Earthquake

Applying the envelop mean transfer function for the top of loess and top of 1,000 ft/sec material (Figure 2.5-64 and 2.5-65 respectively) to the rock UHS results in horizontal soil motions that are consistent with the median 10^{-5} APE hard rock UHS. These expected soil motions are shown in Figure 2.5-66 along with the hard rock UHS. Design horizontal ground motions are taken as the envelope of the two expected soil motions and are shown in Figure 2.5-67 (solid line). For comparison, the R.G. 1.60 spectrum scaled to 0.3g is shown also in the Figure.

As a preliminary estimate of vertical motions, the V/H ratio of R.G. 1.60 was applied to the horizontal design motions. This ratio is 2/3 at low frequency (0.1 Hz to 0.3 Hz) increasing with frequency to unity near 8 Hz. With the deaggregation suggesting little contribution for sources within about a 50 km distance (Section 2.5.2.2) use of the R.G. 1.60 V/H ratio is considered to conservatively reflect expected vertical soil motions (Reference 197) and is shown in Figure 2.5-68.

2.5.2.6 Operating Basis Earthquake

The Operating Basis Earthquake (OBE) ground motion spectrum is assumed to be one third of the SSE ground motion spectrum in accordance with Appendix S to locFR50.

2.5.3 Surface Faulting

There is no potential for surface fault rupture at the Grand Gulf Site Location, and there are no capable tectonic sources within a 5-mile radius of the site (Site Area). A capable tectonic source is a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the Earth's surface in the present seismotectonic regime (U.S. NRC, 1997). The following sections provide the data, observations and reference citations to support this conclusion. The information contained in these sections was developed in accordance with Appendix D of Regulatory Guide 1.165 “Geological, Seismological, and Geophysical Investigations to Characterize Seismic Sources” (U.S. NRC, 1997) and is intended to satisfy 10CFR100.23 “Geologic and Seismic Siting Criteria” (U.S. NRC, 2002).

2.5.3.1 Geological, Seismological, and Geophysical Investigations

Investigations performed to assess the potential for surface fault rupture at the Grand Gulf Site and Site Area included: (1) compilation and review of existing data; (2) interpretation of aerial photography; (3) discussions with researchers familiar with the geology of the Site Area; (4) review of seismicity; and (5) field reconnaissance. In particular, an extensive body of existing information is available for the Grand Gulf Site and Site Area. This information derives from three principal sources: (1) work performed as part of the existing Grand Gulf Nuclear Station (GGNS) and reviewed and accepted previously by NRC staff; (2) published and unpublished geologic mapping performed primarily by the U.S. Geologic Survey, States of Mississippi and Louisiana, and researchers from the University of Memphis; and (3) seismicity data compiled from published journal articles and evaluated as part of this study.

This existing information was supplemented by field reconnaissance and air photo interpretation of the Site Area and Site Location. In particular, an updated map of surficial deposits and geomorphology was prepared for the Site Location (Figure 2.5-27). The new geologic map was used in combination with existing maps showing the surface of buried stratigraphic horizons to provide direct evidence documenting the absence of surface or subsurface faulting or other forms of tectonic and non-tectonic deformation at the site.

2.5.3.2 Previous Site Investigations

Previous site investigations performed for the existing Grand Gulf Nuclear Station are presented in the Updated Final Safety Analysis Report (UFSAR) (Reference 16). These previous studies provide extensive subsurface data illustrating the distribution of buried stratigraphic horizons across the site. In particular, structure contour maps of the top of the Oligocene age Glendon Limestone (Figure 2.5-15), Miocene Catahoula Formation (Figure 2.5-29), and Pliocene to Pleistocene Upland Complex (Figure 2.5-32) show that these stratigraphic horizons, although eroded, are not deformed by faulting, folding, or tilting across the Site Location and Site Area. In addition, these subsurface data document the absence of salt diapirs beneath the Site Location, collapse structures, volcanic intrusions, or other forms of non-tectonic deformation.

New information developed since the original Grand Gulf site investigation confirms that no active faults exist within the Site Area (5-mile radius). Significant revisions to our knowledge of active faulting and tectonic process have been made since the early investigations of the Mississippi Alluvial Valley (Reference 31; Reference 163). Models of faulting proposed by Fisk and Krinitzsky were initially addressed during the original Grand Gulf site investigations (Reference 16), and new additional data have been developed that further support the conclusions of the Grand Gulf investigations (Reference 17; Eversull, 1984).

Fisk was the first to address Quaternary faulting in the Mississippi Alluvial Valley (Reference 31). He postulated that the Mississippi Alluvial Valley was crossed by a dense rectilinear pattern of northeast-southwest- and northwest-southeast-trending fractures. This interpretation was heavily influenced by the prevailing belief by geologists of Fisk's era that the earth's crust contained a world-wide grid pattern of faults caused by planetary-scale influences (Krinitzsky, 1950). Fisk interpreted the association of photographic lineaments with geomorphic criteria including sharp river bends, linear lake margins, topographic breaks, and oriented drainages to infer the presence of faults in the region.

Krinitzsky (Reference 163) mapped the distribution of several hundred inferred faults in the Mississippi Alluvial Valley and Delta Plain regions. His mapping was primarily based on physiographic evidence. However, at three localities, he used closely spaced borings to verify the presence of faults in uppermost Tertiary deposits. The three localities include sites at Big Creek and Old Town Lake west of Friars Point, Mississippi, and a site west of Reelfoot Lake, south of New Madrid, Missouri.

The development of plate tectonic theory over the last several decades dramatically updated the tectonic models prevalent in Fisk's era. Since 1950, detailed Quaternary mapping and numerous site-specific engineering geologic investigations have disproved the presence of the majority of the faults and fault zones indicated by Fisk and Krinitzsky (Reference 204), although high-resolution seismic surveys identified some faults in Tertiary and Cretaceous formations. In the Site Region, these older faults lack surface expression in Quaternary deposits, providing evidence that they have not been active during Quaternary time (Reference 17).

Fisk (Reference 205) suggested that two possible fault zones may intersect about 3 miles north of the site, near the mouth of the Big Black River. These potential fault zones were evaluated during the original Grand Gulf site investigation using borings, geologic mapping, literature review, and LANDSAT imagery (Reference 16). A cross section was constructed using Boring G-3 from the original site investigation and borings AH-5 and E-161 previously drilled by the Mississippi State Geological Survey. Differences in formation contact elevations across the inferred faults were attributed to the regional dip of stratigraphic units rather than fault offset along the Big Black River (Reference 16). The second lineament identified by Fisk in the Site Vicinity coincided with the alignment of Bayou Pierre; however, continuous stratigraphy documented from borings drilled north and south of Bayou Pierre demonstrates the continuity of subsurface deposits and the absence of faulting (Reference 16). These investigations disproved the existence of Fisk's previously inferred fault zones and verify that no faults exist within 5 miles of the site (Reference 16).

2.5.3.3 Geological Evidence, or Absence of Evidence, for Surface Deformation

As previously discussed, there is no evidence of Quaternary fault offset in the Site Location or the Site Area. Furthermore, there is no evidence of non-tectonic deformation at the site or in the Site Area. The closest Holocene active fault to the site are growth faults in the Gulf Coast Basin province about 90 miles south-southwest of the site. The closest postulated Quaternary active tectonic fault is the Saline River Lineament approximately 90 miles north-northwest of the site (Figure 2.5-19) (referred to as the Saline River source zone, Section 2.5.1). Two salt diapers, the Bruinsburg salt dome and the Galloway salt dome, are within approximately 8.5 miles to the southwest and northeast of the site, respectively (Figure 2.5-9).

2.5.3.4 Correlation of Earthquakes with Capable Tectonic Sources

There are no reported earthquake epicenters that can be associated with any fault within 5 miles of the site. The closest earthquake of Mw 3.0 or larger is located 90 miles west of the site (Figure 2.5-5).

2.5.3.5 Characterization of Capable Tectonic Sources

There are no capable tectonic sources within 5 miles of the Grand Gulf Site. As described in Section 2.5.1, the Site Area is underlain by approximately 500 feet of Oligocene and younger sediments that were deposited within the Gulf Coastal Plain (Figure 2.5-9). These deposits are gently warped forming a broad synclinal structure, the limbs of which dip less than one degree and extend from western Alabama to western Louisiana (Figures 2.5-4 and 2.5-11). The axis of this syncline approximately follows the current position of the Mississippi Alluvial Valley, and also forms the axis of the Mississippi Embayment to the north. The downwarping of the Mississippi Alluvial Valley is a slow, ongoing process related to deposition of the thick sedimentary sequence. Although the axis of the syncline trends through the Site Area, this is not considered a seismogenic feature, but rather is related to slow isostatic adjustment of the crust due to sediment loading in the Mississippi Alluvial Valley and Gulf Coastal Plain (Reference 17).

Although pre-Quaternary faults are mapped in the Site Region, none are mapped within the Site Vicinity or Site Area. Tertiary faults of the Pickens-Gilbertton and Southern Arkansas fault zones are mapped approximately 80 miles northeast of the Site Area, and approximately 100 miles northwest from the Site (Figure 2.5-5). The Saline River lineament in northern Louisiana and southeastern Arkansas is approximately 90 miles from the Site, and the growth faults in southern Louisiana are also approximately 90 miles from the Site at their closest approach (Figure 2.5-5). The growth faults in southern Louisiana are related to gravitational collapse of the Mississippi delta complex. The faults in the eastern and western portions of the Site Region are exposed in Eocene or older deposits and do not affect Quaternary deposits. The Saline River lineament in northern Louisiana is the only potentially active Quaternary tectonic fault in the Site Region, but is not mapped across the Mississippi Alluvial Valley (References 17; 44). There are no faults mapped closer than 90 miles to the site, or within either the Site Vicinity or Site Area (References 52; 53).

Investigations by the Army Corps of Engineers (Reference 206) were conducted to document subsurface geological conditions along the Mississippi River. Based on a series of geotechnical borings, the Army Corp developed geologic cross sections of Quaternary and Holocene alluvium in the Mississippi River channel. The boring data support previous conclusions that Quaternary deposits in the Site Area are unfaulted. The Army Corp data also support the interpretation that the faults previously mapped by Fisk (Reference 205) along the Big Black River and Bayou Pierre are not present (Reference 206).

Subsurface borings completed for the existing Grand Gulf Nuclear Station document the absence of faulting in the Site Area (Reference 16). Oligocene and younger deposits decrease in elevation from north to south, are laterally continuous, and have a constant gradient across the Site Area. No faults are identified along this section (Figure 2.5-16; Reference 16). Additional subsurface data from deep exploration borings across the Site Vicinity in eastern Louisiana also document lateral continuity of Tertiary and younger deposits (Reference 207).

The continuity of subsurface deposits demonstrates the tectonic stability of the Site Location, Site Area, and Site Vicinity from at least Oligocene time, approximately 30 Ma to the present. the top of the Oligocene Glendon Limestone Formation slopes to the southeast (Figure 2.5-15). The surface appears to have been eroded, forming a buried drainage basin morphology, but does not show morphology indicative of tectonic deformation (Reference 16).

The top of the Miocene Catahoula Formation in the Site Location forms a gentle westward sloping surface (Figures 2.5-29). The surface morphology preserves the Pliocene to Pleistocene age erosion surface of the ancestral Mississippi Alluvial Valley, and a former tributary valley across the Site Location. The morphology of the surface of the Catahoula Formation is related to former stream erosion. The top of the Catahoula surface shows no morphology indicative of tectonic deformation (Reference 16).

As shown on Figure 2.5-32, the surface of the Pliocene to Pleistocene Upland Complex deposits have been eroded during the Pleistocene and Holocene forming two west-trending drainages that cross the property. These drainages are the current active channels in the Site Location. The surface of the terrace deposits shows no morphology indicative of tectonic deformation (Reference 16).

2.5.3.6 Zones of Quaternary Deformation Requiring Detailed Fault Investigation

There are no zones of Quaternary deformation requiring detailed investigation within the Site Area.

2.5.3.7 Potential for Tectonic or Non-Tectonic Deformation at the Site

As discussed above, geologic cross sections and structure contour maps of the Site Vicinity, Site Area, and Site Location demonstrate the continuity of deposits of Oligocene and younger age, and the long-term tectonic stability of the Site Area. Therefore, the potential for surface-fault rupture at the site is considered negligible. In addition, there is no evidence of non-tectonic deformation in the Site Location or Site Area such as collapse structures, salt diapirs, growth faults, volcanic intrusion, etc.

2.5.4 Stability of Subsurface Materials and Foundations

2.5.4.1 Detailed Site Investigation Program

An engineering geologic and geotechnical site investigation (geotechnical investigation) was performed for the proposed location of the new facility to: (1) characterize site conditions to develop site-specific seismic design criteria; and (2) evaluate potential seismically-induced ground failure and hazard. The information also was used for an initial screening assessment of foundation conditions. The locations of the site explorations are shown on Figure 2.5-69 and 2.5-70, and the detailed results from the geotechnical investigation are included in Engineering Report ER-02 “Geologic, Geotechnical, and Geophysical Field Exploration and Laboratory Testing, Grand Gulf Early Site Permit” (Reference 15). At this time, a plant design has not been selected, and the footprint and embedment depth of the plant have not been determined. Additional site exploration, laboratory testing, and geotechnical analyses will be performed to develop final plant design criteria for the Construction and Operating License (COL) phase of the project after a plant design has been selected.

The exploration and testing activities were specifically developed to comply with:

- NRC Regulatory Guide 1.165 “Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion” (Reference 4).

The site investigation also is in partial compliance with:

- Draft Regulatory Guides DG-1011 “Site investigations for foundations of nuclear power plants” (proposed revision to Regulatory Guide 1.132; Reference 5); and,
- DG-1109 “Laboratory investigations of soils and rocks for engineering analysis and design of nuclear power plants” (proposed revision to Regulatory Guide 1.138; Reference 6).

The COL phase investigations and testing will include additional exploratory borings throughout the planned excavation and building footprint area to obtain information for foundation design and site grading in full compliance with Regulatory Guides 1.132 and 1.138 and Draft Regulatory Guides D-1101 and D-1109.

2.5.4.1.1 Borings and Sampling

Four exploratory borings (Borings WLA B-1, B-2, B-2A, and B-3) were drilled at the proposed site location to depths of between 141.5 and 238.0 feet to characterize subsurface geologic conditions, perform in-situ testing and borehole geophysical surveys, and to obtain laboratory geotechnical test samples. Figure 2.5-70 shows the locations of the exploratory borings, and Tables 2.5-19 and 2.5-20 summarize the characteristics of the exploratory borings and general site stratigraphy. Figures 2.5-34 through 2.5--74 are summary logs of encountered conditions. Detailed boring logs are included in Engineering Report ER-25-75 (Reference 15). Geologists classified the rock and soil materials according to standard engineering classification, and also assigned geologic units, inferred ages, and made interpretations of genesis for each stratum.

2.5.4.1.2 Site Geotechnical Profile

Geologic cross sections in Figures 2.5-75 through 2.5-77 show the site stratigraphy and subsurface conditions. Subsurface materials were classified into four different geologic units:

late Pleistocene loess, Pliocene to Pleistocene Upland Complex alluvium (Qa), Upland Complex old alluvium (Qoa), and Miocene Catahoula Formation claystone based on field examination of recovered samples. In addition to these geologic units, localized fill was placed in the former topographic swales that crossed the site (Figure 2.5-69) to develop the current level pads. This fill is variable in thickness, and appears to consist mainly of excavated on-site loess that was removed from cut parts of the pads. Boring WLA B-3 is located in the approximate axis of one of the infilled swales. The materials encountered in the boring consist of massive silt similar to natural loess deposits, and exhibit similar field SPT and CPT response and laboratory index values. Therefore, the fill could not be differentiated from the natural loess, and was grouped together with the loess for site ground motion response and hazard analysis. The fill encountered in Boring WLA B-3, therefore, is not broken out as a separate unit, and is not described separately. Based on topography and site use history the infilled swale near Boring WLA B-3 should contain approximately 30 feet of fill.

The classification of deposits is based on textural composition, degree of sorting, relative density, color, and structures according to standard geologic interpretive procedures described in Compton (Reference 200). Each geologic unit is separated by a laterally continuous, subhorizontal, erosional unconformity that represent a hiatus in the depositional phase of each unit, and/or intervening period of erosion. The unconformable contacts, therefore, represent the former land surface at different times during the late Pliocene, Pleistocene, and Holocene. Structural contour maps showing the elevation of the unconformable contacts between old alluvium and alluvium, and alluvium and loess, are included in Figures 2.5-78 and 2.5-79, respectively.

The stratigraphy encountered generally agrees with the stratigraphy shown on the UFSAR boring logs, with the exception that the UFSAR borings describe the alluvium as “terrace alluvium”, and old alluvium as “Catahoula Formation”. Accounting for the differences in unit nomenclature between this study and UFSAR borings, material descriptions and contacts generally are consistent between the two data sets.

2.5.4.1.3 Material Engineering Properties

Standard Penetration Tests (SPT) were obtained at various intervals in the borings to provide estimates of the in situ density/consistency of site materials, obtain disturbed samples for index testing, and to use as a screening tool to evaluate potential liquefaction susceptibility and foundation properties. As described in Reference 15, all SPT blow counts reported for this study are uncorrected for equipment and confining stress. SPT blow counts are summarized and compared against the blow counts from the GGNS UFSAR data on the geologic cross sections in Figures 2.5-75 through 2.5-77. In general, the blow counts from this investigation are somewhat lower than reported in the UFSAR for GGNS borings. The differences may be related to different equipment and techniques used during this study and earlier studies, such as different hammer efficiencies. Automatic trip hammers were used for this investigation and may have higher impact force efficiency than hammer systems used for the UFSAR investigations.

Ranges and averages of SPT blow counts for different geologic layers underlying the proposed site are summarized in Table 2.5-21.

2.5.4.1.3.1 Loess

Loess was encountered in each of the borings, and forms the surface layer across the site. The loess ranges from about 55- to 85-feet thick, and consists of relatively uniform, yellow-brown, slightly- to moderately-plastic silt to clayey silt (ML) with some silty clay (CL) intervals, weak blocky structure and pervasive small root pores and voids. Small gastropod and clam(?) shells commonly occur in discrete beds or zones. The silt typically exhibited a silky feel, is micaceous, and has low to moderate plasticity. The loess exhibits coarse layering defined by differences in clay content, color, shell content, and consistency. However, the engineering properties of the different loess layers do not differ significantly, and the index engineering properties fall within a narrow range throughout the deposits. Regionally and locally, the loess exhibits a slight carbonate cementation, and soil structure that allows it to stand vertically in cuts and stream banks. In borehole samples, the loess characteristically exhibits a moderate reaction to hydrochloric acid, documenting the weak calcium carbonate cementation. Typically, loess deposits contain calcium carbonate cementation as precipitates in root pores and voids, and may gain additional cohesion from clay films on silt grain surfaces (Reference 203). Testing performed for the UFSAR (Reference 16) showed that the loess has a honeycomb structure. Some weakly-developed paleosol layers marked by slightly clayier zones may separate individual pulses of loess deposition. The CPT soundings show that the loess exhibits individual layers that are between about 6-inches and 40-feet thick. SPT data show that the loess is medium stiff to stiff, with estimated undrained shear strengths on the order of 750 to 1,500 pounds per square foot (fps). The CPT-determined undrained shear strength of loess ranged between 2000 and >8000 psf (maximum instrumental range), increasing with depth. Shear wave velocities in loess ranged between 590 and 1,450 fps.

2.5.4.1.3.2 Alluvium (Upland Complex)

The alluvium consists of light yellow brown and gray, interbedded sand and silty sand (SP, SM) with lesser clayey sand (SC), gravelly sand (SW), and sandy gravel (GW) lenses. Discontinous layers ranged between about 6-inches and 3-feet thick. Individual layers could not be traced between the borings and CPT soundings. Sand grains are subrounded to subangular, fine- to medium-grained, and consisted of quartz with lesser feldspar and mafic lithologies. The alluvium typically is well sorted with low fines content, and low plasticity. The alluvium was readily drilled with mud rotary equipment, but some sandy layers below the water table caused caving problems in Boring WLA B-2A. SPT blows in the alluvium indicate that it is in a medium dense to dense condition. CPT refusal was met in the alluvium in each sounding after penetration of between 5 and 30 feet into the alluvium (10-ton capacity CPT rig). CPT shear strength values ranged between 4,000 to >8,000. Shear wave velocities in the alluvium ranged between 740 and 1,750 fps.

2.5.4.1.3.3 Old Alluvium (Upland Complex)

The old alluvium consists of interbedded, green to dark gray (gleyed) clayey sand, sandy clay, silty sand, and clean to gravelly sand. The old alluvium was poorly to well sorted, typically exhibiting much poorer grading than the overlying alluvium. Layering in the old alluvium ranged between about 3-inches and 3- to 4-feet thick, and some layers contained dark manganese and carbon streaks and pods, with some relict plant remains. Gravel-size clasts included a large percentage of soft clay and claystone rip-up clasts. Finer-grained layers exhibited low to moderately high plasticity. Drilling was moderately easy to moderately hard (slow), and some sandier zones appeared to have locally ravelled into the holes. SPT blow counts in the old alluvium indicate that it is dense to very dense. Shear wave velocity ranged between 530 and 3,360 fps.

2.5.4.1.3.4 Catahoula Formation

The Catahoula Formation was only encountered in Boring WLA B-2A (the deepest boring for this investigation), and consists of gray-green, hard clay to claystone that exhibited a slight degree of induration and somewhat brittle behavior. The claystone has a partial blocky structure, and contains silica-coated fractures. Some of the broken surfaces in the recovered core exhibited randomly-oriented slickensides, and the core slaked in water after several tens of minutes of saturation. The claystone is highly plastic. Drilling was hard (slow, near-refusal), and the sole SPT sample had a blow count of 82. This SPT value correlates with a very hard (very dense) consistency, and is typical for soft rock-like material. Shear wave velocity in the Catahoula Formation ranged between 1,500 and 2,830 fps. The claystone Plasticity Index (PI) and clay content suggest that it may be expansive.

2.5.4.1.4 Borehole Geophysical Velocity Surveys (P-S)

Borehole geophysical surveys were performed in three borings (WLA B-1, B-2A, and B-3) upon completion of drilling between July 29 and August 17, 2002 by GEOVision Geophysical Services (GEOVision) and under observation by the WLA geologists. The surveys were performed with an OYO Model 170 Suspension Logging system that measures both compression wave (P) and horizontal shear wave (V_{SH}) velocity in formation materials comprising the borehole walls. A description of the equipment, procedures, and detailed survey results are provided in Engineering Report ER-02 (Reference 15). The results of the surveys are summarized as velocity-depth plots on Figures 2.5-80. All P-S surveys were performed in uncased holes because this results in better resolution of stratigraphic velocity layers. A thick mud was used to maintain the holes during the P-S logging.

The P-S velocity survey obtains a vertical velocity profile of the stratigraphy along borehole walls using both compressive (Vp) and shear (Vs) waves. Ranges of compression and shear wave velocities for the site geologic materials are shown in Table 2.5-22.

No clear velocity differences were observed between the loess and Upland Complex alluvium, or the Upland Complex alluvium and old alluvium. Rather, velocities typical increased gradationally in the various geologic layers (Figure 2.5-80). A well-defined velocity increase was observed in the lower half of the old alluvium that is not marked by a significant stratigraphic change based on the borehole logging data. It is possible that the higher velocities occur in more-dense and indurated sublayers within the old alluvium that are not marked by a lithologic change. Velocities remained relatively high in the Catahoula Formation.

The P-S datalogger used for this study (Reference 15) represents a marked improvement and advancement of technique over the cross-hole seismic velocity techniques and equipment that were used for the operating GGNS in the 1970’s (Reference 16). Therefore, a direct comparison cannot be made between the two data sets. However, the velocities for the various geologic layers generally fall within similar ranges, if the UFSAR data for the Catahoula Formation are compared against the velocity data for the Upland Complex Old Alluvium. A comparison between the shear wave velocities is made below.

2.5.4.1.5 Cone Penetrometer Test (CPT) Surveys

Four cone penetrometer test (CPT) soundings were performed by Eustis Engineering Company, Inc. (Eustis) in the proposed site location (Figure 2.5-70) to depths of between 79.0 and 95.3 feet. Summary CPT logs are shown on Figure 2.5-81, and the detailed results from the CPT surveys are included in Engineering Report ER-02 (Reference 15). Each sounding was advanced to practical refusal, which occurred in the upper part of the Upland Complex alluvium. Because of refusal within the Upland Complex alluvium, CPT data could only be obtained for the loess, and uppermost part of the alluvium. No CPT data was obtained in the Upland Complex old alluvium or Catahoula Formation. The first CPT sounding (CPT-1) was located adjacent to boring WLA B-1 for calibration purposes. Comparisons of subsurface materials and contacts between boring WLA B-1 and CPT-1 were very good.

Tip resistance values in the loess were relatively uniform and below 100 tons per square foot (tsf). Tip resistance increased markedly at or near the top of the Upland Complex alluvium below the base of the loess, and were greater than 200 to 400 tsf. The loess exhibited typical friction resistance values of between 300 and 1,600 pounds per square foot (psf). The Upland Complex alluvium exhibited typical frictional resistance values from 2,400 psf to greater than CPT rig refusal (10 tons), but some local finer-grained layers had frictional values similar to those for loess.

The published relationships of Robertson (Reference 199) were used by Eustis to classify materials based on the CPT data. The CPT material classification roughly matched field and laboratory classifications, but tended to be somewhat coarser (sandier) than the field classifications and laboratory testing results. The CPT classifications and tip results show that the grain size and consistency of the loess are relatively homogenous, and the loess exhibits a generally coarse layering with individual strata on the order of several feet to up to about 40-feet thick. This is in agreement with the field borehole and laboratory data. Finer layering and increasing variability in tip and friction resistance occurred in the lower parts of the loess near the contact with the underlying Upland Complex alluvium. The finer stratigraphy and variability appear to be the result of possible paleosols at the top of the alluvium, and/or different pulses of sedimentation and reworking of the alluvium during initiation of loess deposition. The Upland Complex alluvium exhibited fine to medium stratigraphic layering, but was predominantly classified as sand with some gravelly layers.

Undrained shear strength estimates from CPT data were made by Eustis according to Lunne et al. (Reference 201), and using a Cone Factor value of 15 which Eustis has found to be regionally applicable for projects in Mississippi and Alabama. The CPT-determined undrained shear strength of loess ranged between 2,000 and >8,000 psf, and increased with depth. CPT undrained shear strength values for Upland Complex alluvium ranged between 4,000 to >8,000 psf. Estimated SPT blow counts from CPT data were made by Eustis according to correlations by Lunde (Reference 201), and are in general agreement with the range of SPT blow counts obtained in the exploratory borings. Equivalent SPT N60 values were calculated from CPT data by Eustis according to Lunne et. al. (Reference 201), and ranged between about 10 and 20 for the loess, and typically were greater than 40 for the alluvium. Evaluation of CPT data according to methodology of Andresen et al. (Reference 202) suggests that the overconsolidation ratios of loess and Upland Complex alluvium are both considerable, possibly in the ranges of greater than 2 for loess, and about 1.5 to 5 for Upland Complex alluvium.

2.5.4.1.6 Static Laboratory Analysis

Sixty samples of loess, Upland Complex alluvium, and Catahoula Formation bedrock from site borings were tested by Eustis for basic geotechnical properties in their Metairie, Louisiana laboratory. Index properties also were measured for the six samples submitted to the University of Texas, Austin (UTEXAS) for dynamic testing. The samples were shipped to Eustis by Federal Express (FedEx), and were transported to UTEXAS in a passenger vehicle. Both sample sets were documented with a chain-of-custody form. Engineering Report ER-02 (Reference 15) contains descriptions of the laboratory test methods, equipment, and data results. The scope of the laboratory index testing program included the following:

- fifty nine moisture content (ASTM D 2166)

- twenty four dry density (ASTM D 2216)
- seventeen Atterberg Indices (ASTM D 4318)
- forty nine mechanical sieves (ASTM D 422)
- fifteen hydrometer (ASTM D 422)
- six consolidated, undrained triaxial test series (1 to 3-point series; ASTM D 4767)

Table 2.5-23 and 2.5-24 summarizes the laboratory test program and testing data. Figures 2.5-82 and 2.5-83 summarize the results from the moisture content and grain size testing, respectively.

2.5.4.1.6.1 Laboratory Results for Loess

Twenty six samples of loess were tested for static geotechnical properties. Water content in the loess samples varied between 15.7% and 29.5%, with an average of 22.8%. Dry densities of loess ranged between 85.8 pcf and 104.7 pcf, with an average of 94.8 pcf. These dry densities show that the loess is relatively stiff, with relative densities ranging on the order of greater than 50% to about 75% (Reference 203). The densities suggest that the loess has a moderately low to low potential for saturation-induced settlement from particle structure collapse and dissolution of cementation (Reference 203). The loess is subject to gully erosion and possible piping, as evidenced by steep-walled erosional gullies in loess.

Plasticity Indices (PIs) for loess samples ranged between 3% and 16%, with an average of 10.5%, with corresponding Liquid Limits (LL) of between zero and 32%. These values indicate that the loess classifies as a low plasticity silt (ML). The fines percentage (silt and clay; minus 200 sieve) of loess samples ranged between 73.2 and 99.8, with an average of 97%. The clay-size fraction determined from hydrometer testing ranged between 8.2% and 11.1%, and show that the loess primarily consists of silt-size grains. The grain size distribution of the loess samples was quite uniform (Figure 2.5-83), and typical for loess deposits.

Two triaxial CU test series performed on loess samples indicate total stress cohesion of zero and internal friction angles of between 32 and 33 degrees. Effective strength internal friction angles were between 33 and 34 degrees. The results of these strength tests are on the high end for published values for loess (e.g., Reference 203), and indicate a high degree of grain interlocking and cementation. Locally, steep and vertical road cuts in loess soils appear to be quite stable, suggesting that some cementation and apparent cohesion exists in the natural, undisturbed loess.

2.5.4.1.6.2 Laboratory Results for Upland Complex Alluvium

Twenty one samples of Upland Complex alluvium were tested for static geotechnical properties. Water content in the alluvium samples varied between 9.9% and 25.5%, with an average of 19.2%. Dry densities ranged between 93.2 and 129.4 pcf, and averaged 106.0 pcf. These densities are typical for medium dense to dense silty and clean sands (Reference 203). PIs for alluvium samples ranged between 0% and 4% and LLs ranged between zero and 21%. This indicates that Upland Complex alluvium is essentially non-plastic.

The Upland Complex alluvium consisted primarily of sand to silty sand (SM-SP). Sand percentages ranged between 2% and 95.3%, with an average of 68.6%. Two samples contained significant gravel content (24.3% and 41.6% gravel); other samples had either zero, or less than 5%, gravel. The fines content of Upland Complex alluvium ranged between 4.7%

and 92.9%, with an average of12%, and the clay-size fraction determined by hydrometer analysis ranged between 2.8% and 10.6%. The hydrometer test results show that the fines in the Upland Complex alluvium consist primarily of silt-size material. The grain size distribution of the alluvium samples was relatively uniform, primarily poorly-graded to silty sands (Figure 2.5-83). The grain size and sorting is typical for moderate-energy alluvial deposition and point bar deposits typical along the modern Mississippi River.

Three triaxial CU test series performed on Upland Complex alluvium samples indicate total stress cohesions of between zero and 1.16 psf, and internal friction angles of between 36 and 40 degrees. Effective strength cohesion was zero, and friction angles varied between 36 and 41 degrees. These results are relatively high for alluvium with silty sand to poorly graded sand consistency (Reference 203), and suggest that the alluvium is quite dense with interlocking packed grains.

2.5.4.1.6.3 Laboratory Results for Upland Complex Old Alluvium

Fifteen samples of Upland Complex old alluvium were tested for static geotechnical properties. Water content in the old alluvium ranged between 5.6% and 36.1%, and averaged 23.4 %. Two dry density determinations were 89.3 (sand layer) and 94.9 pcf (clay layer). These densities are low for sandy alluvium, but in the typical range for clayey alluvium (Reference 203). PIs for the fines component of the old alluvium ranged from zero to 16%, and averaged 9%. The corresponding LLs were between 17 and 42%. These results indicate that the Upland Complex old alluvium is non-plastic to moderately plastic, and that the fines classify as ML-CL soils. The fines in the old alluvium generally exhibit a higher plasticity than the fines in the overlying alluvium, suggesting differing sediment sources and/or weathering histories.

The Upland Complex old alluvium samples classify as a range of soil types, including lean clay and silt (CL and ML), silty and clayey sand (SM and SC), and poorly graded sand (SP). The sand content of the old alluvium samples ranged between zero and 89.2%, with an average of 34.0%. In general, the Upland Complex old alluvium has a lower percentage of sand, and higher clay content, than the overlying alluvium unit. Two samples had significant gravel content: 8.5% gravel; and 22% gravel. Other samples had zero or less than 0.3% gravel. Fines content in old alluvium samples ranged between 3 and 99%, with and average of 54.4%. The clay content of hydrometer samples ranged between 6.2 and 12.2% with an average of 9.4%. The hydrometer analyses show that the fines fraction in the old alluvium is primarily silt-size. The grain size distribution of Upland Complex old alluvium samples is significantly more poorly-sorted than the overlying alluvium, and samples typically contain a wide range of grain sizes commonly associated with sediments that are not transported far from the source deposits.

No triaxial strength tests were performed on old alluvium samples.

2.5.4.1.6.4 Laboratory Results for Catahoula Formation

Only one acceptable sample of Catahoula Formation claystone was obtained from the exploratory borings for laboratory testing. This sample had a moisture content of 21.5%, PI of 35%, LL of 54%, and fines content of 80.6%. No hydrometer or triaxial strength tests were performed on samples of Catahoula Formation. The PI of the Catahoula Formation sample is significantly higher than any of the other tested materials, and plots in the zone of highly plastic clay in the UCSC classification. The PI and grain size of the Catahoula Formation claystone suggest that it is an expansive material, and classifies as a fat clay (CH).

2.5.4.1.6.5 Comparison of ESP and UFSAR Laboratory Test Results

Results from the ESP laboratory testing are in a similar range to the results from the UFSAR laboratory testing for layers with similar composition and texture. Figures 2.5-84 through 2.5-86 are comparison plots of some index properties between the ESP and UFSAR testing programs. Index values for the ESP samples generally fall within the ranges of those determined for the UFSAR samples. Loess, in particular, exhibits quite similar properties (Figure 2.5-84) for moisture content, liquidity index, and dry density. The laboratory data show that the loess is uniform across the proposed site location. The Upland Complex alluvium unit exhibits higher dry densities, and lower moisture contents, than the UFSAR terrace alluvium samples (Figure 2.5-85). This may be due, in part, to local variations in the sand content of the alluvium. The moisture content and liquidity index for the Upland Complex old alluvium and Catahoula Formation samples are generally within the ranges reported for the UFSAR samples, but depart from the UFSAR data for ESP samples in the elevation range of between about zero and 20 feet (Figure 2.5-86). The differences may be because of a thin coarser-grained zone that exhibits locally higher moisture contents.

2.5.4.1.7 Dynamic Soil Testing

Shear modulus reduction and damping curves for the upper part of the site soil column were obtained from torsional shear and resonant column (TSRC) testing of six relatively undisturbed samples at the UTEXAS laboratory under the direction of Professor K.H. Stokoe II. Dynamic testing was performed to obtain dynamic modulus reduction curves and damping data in site soils for site response analysis. Testing was constrained to materials that could be successfully sampled in a relatively undisturbed state with thin walled Shelby tubes, and included 2 tests of eolian silt, 2 tests of Upland Complex alluvium, and 2 tests of Upland Complex older alluvium. The Catahoula Formation claystone could not be successfully sampled for dynamic testing. Table 2.5-25 summarizes the properties of the samples, and Figure 2.5-80 shows the locations of the samples and comparisons between borehole and laboratory-measured shear wave velocities. The dynamic testing results are summarized in Figures 2.5-87 through 2.5-94, and the complete laboratory test results and plots are presented in Engineering Report ER-02 (Reference 15).

All dynamic test samples were relatively undisturbed Shelby tube samples that were transported to the laboratory in a passenger vehicle. A chain-of-custody form was filled out and maintained to document sample transportation, and is retained in the project files.

Each test specimen was subjected to a suite of tests at varying confining pressures and cyclic strain levels. Specimens were driven in the torsion shear mode of the TSRC equipment at increasing cyclic strain levels up to the limit of the equipment and were then excited in the resonant column mode to obtain results at higher strain levels. In order to obtain resonance of these specimens the frequencies of excitation were somewhat higher than those used in the torsional shear mode. General properties of the specimens are shown in Table 2.5-25.

Table 2.5-25 shows the estimated in-situ confining pressure for each test specimen. A K_o value of 0.5 was used for the loess specimens, and a value of 1.0 used for the Upland Complex alluvium and older alluvium. The ratio of the shear wave velocity measured in the laboratory at small strains and the shear wave velocity measured in the field at the same depth are shown in the table. These data include tests conducted the portion of the tests conducted at the estimated in-situ confining pressures and tests conducted at four times the estimated in-situ confining pressure (4 specimens). Ideally this ratio should approach unity. It appears that the estimate of K_o that was used for the loess specimens may have been too low. A better approximation of the field conditions was obtained by testing these samples at four times the estimated in-situ confining pressure.

The results of the TSRC tests are shown in Figures 2.5-87 through 2.5-94 as: (1) a function of the cyclic shear strain as values of the modulus reduction ratio (G/Gmax), that is the shear modulus divided by the low strain shear modulus; and (2) the damping ratio. The ESP data are plotted on the family of depth dependent modulus reduction and damping ratios developed by EPRI (Reference 170). The pattern of the ESP data is generally similar to the shape of the EPRI curves, however the ESP data are generally more linear. This is likely because the EPRI curves were developed for normally consolidated Holocene silty and clayey sands, whereas the soils at the proposed site location are both older (Pliocene to Pleistocene) and overconsolidated. The dynamic test results were evaluated with respect to the geologic origin and index properties of each test specimen to identify logical groupings of results for assigning modulus reduction and damping parameters for site response analyses. As a result of this evaluation, the UTEXAS test results were partitioned onto two different graphs: one set of graphs for loess, and the other set of graphs for Upland Complex alluvium and old alluvium (Figures 2.5-87 to 2.5-90, and 2.5-91 to 2.5-94).

2.5.4.2 Site Groundwater Occurrence

Because water was continuously injected into the hole during drilling operations, elevation of the groundwater table could not be directly evaluated in the borings. However, borehole seismic velocity P-S surveys allowed estimation of the groundwater table location using prominent increases in compression wave velocity that are not matched by shear wave velocity increases. The P-S determined groundwater table ranged between 70 and 100 feet deep, and corresponded to elevations of between 55 and 63 feet. The groundwater table exhibits a southwestward flow towards the Mississippi River floodplain with a gradient on the order of a 1-foot drop over a 100 to 125 foot distance (gradients of between 0.008 and 0.009) (Section 2.4). The groundwater levels and gradient are shown on the cross sections in Figures 2.5-75 through 2.5-77. It is possible that shallow perched water could form in parts of the loess during periods of high rainfall, especially over finer-grained zones. Such perched zones likely would dissipate rapidly after cessation of heavy rainfall.

2.5.4.3 Response of Soil to Dynamic Loading

Based on results from the geotechnical site investigation, the geologic materials underlying the proposed site location are not prone to dynamically-induced failure or excessive strength loss or deformation. The susceptibility of the deposits to liquefaction is low, as specifically addressed in Section 2.5.4.4. The preliminary assessment of bearing capacity and settlement are discussed in Section 2.5.4.5.2. The dynamic shear modulus reduction and damping of site soils are discussed in Section 2.5.4.1.4.

2.5.4.4 Liquefaction Potential and Seismic Site Stability

Geologic deposits underlying the proposed site location range in age from Miocene (Catahoula Formation), late Pliocene to Pleistocene (Upland Complex old alluvium and alluvium), and late Pleistocene (loess). These deposits all appear to be overconsolidated, and have acquired a certain level of liquefaction resistance by aging effects. No unconsolidated Holocene, sandy or silty deposits that are susceptible to liquefaction were identified at the site location, or are expected to occur based on extensive existing subsurface data. Obermeier et al. (Reference 126) report that the vast majority of identified liquefaction occurrences during the New Madrid earthquakes in 1811-1812 were within Holocene floodplain sediments. No Holocene floodplain deposits underlie the proposed site, and no reported paleoliquefaction features have been found at the GGNS or within the Site Vicinity.

Although the grain size and density of loess are within the range of potentially liquefiable deposits (Figure 2.5-83), it is Pleistocene in age, cemented, and above the groundwater table at the proposed site. Additionally, future plant structures would be founded below the loess. The Upland Complex alluvium and old alluvium are saturated and contain silt and sand-size material within the grain size and sorting range of potentially liquefiable deposits (Figure 2.5-83). However, both the alluvium and old alluvium are overconsolidated, and are Pliocene to Pleistocene in age. The age and past loading history of these deposits makes them resistant to liquefaction. SPT blow counts (Table 2.5-21; Figures 2.5-75 through 2.5-77) also show that the alluvium is in a medium dense to dense condition, and the old alluvium is in a dense to very dense condition. The density of the Upland Complex alluvial deposits make them very resistant to liquefaction. The Catahoula Formation claystone is Miocene in age, and partially lithified, and is not susceptible to liquefaction.

The influence of aging reduces liquefaction susceptibility in the Upland Complex alluvium and old alluvium. This process is reflected by the modulus reduction and damping characteristics described in 2.5.4.1.4 that show that these materials are significantly overconsolidated.

2.5.4.5 Static Site Stability

The proposed site location is on a bluff overlooking the Mississippi River that has been stable since at least late Pleistocene time when the loess deposits were laid down over the Upland Complex alluvium. It is not anticipated that the plant construction would significantly affect the site's static stability. Long term monitoring of the bluff for the existing GGNS indicates that there has been no appreciable instability during the monitoring period.

2.5.4.5.1 Bearing Capacity and Settlement

Detailed calculations of bearing capacity and settlement will be made during the COL phase of the project. Based on the known site conditions, the bearing capacity and settlement properties of the Upland Complex alluvium are expected to be suitable for a new nuclear power plant, and are not anticipated to provide any obstacles to construction. As noted in Section 2.5.4.3, it is anticipated that any new facility will maintain the existing plant grade of approximately elevation 132 feet, but that the plant will be founded in the Upland Complex alluvium, at or below the bottom of the loess deposits, at approximately elevation 80 feet, or lower, where the average shear wave velocity exceeds 1000 feet per second, or if the bottom of the plant is located above this elevation, that the natural soils would be excavated to this elevation and replaced with engineered fill that has a minimum shear wave velocity of 1000 feet per second. Consolidation tests will be performed on relatively undisturbed samples, particularly of the more clayey materials, to more precisely define the material overconsolidation ratios for quantitative settlement analyses. Any localized clayey layers present in the upper portion of the Upland Complex alluvium will be excavated and replaced with engineered fill as necessary.

2.5.4.5.2 Foundation Rebound

Excavation though the loess deposits into the Upland Complex alluvium will result in the removal of a minimum of about 7 kips per square foot (ksf) overburden. Up to several inches of predominantly elastic rebound may occur as a result of the excavation. This is insufficient to threaten stability of the excavation. Construction of the plant structure and backfilling of the excavation will cause reversal of much of the rebound. Construction of the existing plant required removal of approximately 11 ksf of overburden to reach the bearing stratum identified in the UFSAR as the Catahoula Formation. The rebound was estimated to be about 4 inches and was observed to be approximately 2 inches.

2.5.4.5.3 Lateral Earth Pressures and Hydrostatic Loading

Design of the structure will take account of the fact that short-term lateral earth pressures will be increased by heavy compaction of the backfill. Should the plant be embedded below the water table, hydrostatic and dynamic loadings will be evaluated during the COL phase using currently accepted standards of practice.

2.5.4.6 Design Criteria

Design criteria for plant foundations and excavations will be developed during the COL phase of the project, and will be based on additional subsurface exploration, laboratory testing, and geotechnical analysis. Bearing capacity analysis will be performed during the COL project phase. Refer to Section 2.5.4.5.1 for a general discussion of bearing capacity.

2.5.5 Stability of Slopes

The site is relatively flat, and not subject to large-scale landsliding or slope failures (Figure 2.5-70). The location of the proposed new facility encompasses two flat graded surfaces that are separated by an approximately 22-foot high, 3:1 (20 degrees) cutslope in loess soils. The cutslope is inclined at an angle less than laboratory-determined internal friction angle of the loess (32 to 34 degrees), and is stable without evidence of instability since it was constructed in the early 1970's. Although the entire proposed location of the new facility lies within the graded flat areas and cut slope, the area is bounded on the west by the 65-foot high erosional escarpment (bluff) that descends to the Mississippi River floodplain. Portions of the bluff are subject to surficial slumps and creeping soils that are confined within the loess soils in the face of the bluff slope. A possible slump scar on the bluff extends approximately 100 feet into the southwest corner of the site (Figure 2.5-70). No evidence of active or incipient slope movements, such as ground cracks or distressed facilities, were observed above or around the possible slump scar. Because the surficial slumping and erosion in the bluff slope are restricted to the loess soils, future instability in the bluff slope should not affect the planned facilities. It is likely that the future plant footprint will be sited at least 100 feet from the top of this possible slump feature, and the plant foundations would extend through the loess soils into underlying Upland Complex alluvium or old alluvium well below the elevation of the possible slide planes or toe of the bluff slope.

Specific stability analyses will be performed during the COL phase to evaluate the stability of deep foundation excavations for future facilities at the proposed site. However, no unstable conditions or materials were found underlying the site that should cause unusual stability problems for excavations, and standard shoring techniques were successfully used to stabilize deep foundations through the loess and alluvial soils at the operating GGNS site. Because foundation levels for the proposed new facility likely will be over 80-feet below grade in the area near the river bluff to reach suitable foundation materials, and the height of nearby slopes are less than about 60 feet, it is unlikely that any future slope failures would undermine or encroach within the foundation zone of the facility. Engineering solutions can be developed for any potential slope instability at the proposed site location and the hazard due to slope instability at the proposed new facility location is considered to be low. Potential hazards due to encroachment of slope failures will be evaluated during the COL phase of the project. It is not anticipated that there will be any permanent excavated slopes that might adversely affect the stability of the plant. Design of excavated slopes and /or tieback walls or other forms of temporary construction support are not anticipated to pose any obstacles to construction. Specific stability analyses will be performed during the COL phase to evaluate the stability of deep foundation excavations for future facilities at the proposed site. However, no unstable conditions or materials were found underlying the proposed site that could cause unusual stability problems for excavations, and standard shoring techniques were successfully used to stabilize deep foundations through the loess and Upland Complex alluvial soils at the operating GGNS site.

2.5.6 Embankments and Dams

Within the Site Location, there are no earth, rock, or earth and rock fill embankments used for plant flood protection or for impounding cooling water that could affect the safety of the proposed new facility. Furthermore, there are no impoundment structures within the Site Area that could pose a hazard to the proposed new facility. Therefore, the hazard due to embankment failure and surface water inundation of the proposed location of the new facility at the Grand Gulf Nuclear Station is negligible.

2.5.7 References

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