DRAFT REPORT

SEISMIC HAZARD ANALYSIS FOR THE SAVANNAH RIVER PLANT, SOUTH CAROLINA

Submitted to:

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TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE AND SCOPE

In this report, TERA Corporation presents the results of a detailed seismic hazard analysis of the U.S. Department of Energy (DOE) site of Savannah River Plant (SRP), South Carolina.

The scope of this study was limited to the gathering, evaluation and use of information of interest available during the analysis. This information pertains to geology, seismology, earthquake history, attenuation characteristics and soil conditions at the sites. A seismicity model was developed from this information, and the model was exercised with the TERA seismic hazard computer code.

This study, which was performed under contract to the DOE Lawrence Livermore National Laboratory (LLNL), was managed by R. C. Murray, with technical review from D. L. Bernreuter, both of the Nuclear Test Engineering Division. At TERA Corporation, the analysis was directed by C. P. Mortgat.

1.2 SUMMARY

To ensure credible results, sophisticated, well-accepted techniques were employed in the analysis of the seismic hazard. The calculational method we used, which is based on Mortgat's work (1977), has been previously applied to seismic exposure evaluation of diverse regions. This model has been extensively tested and compared with those developed by Cornell, McGuire and Der Kiüreghian (TERA, 1978).

The historical seismic record was established following a review of the available literature. The resulting seismic record, covering the period 1800-1977, was used to identify all possible sources of seismicity that could affect the site. Inadequacies and incompleteness in this record were explicitly considered in the definition of source regions and their activity rates.

The acceleration attenuation relations used, which had been developed by TERA for previous studies, proved to be applicable in this analysis.

The results of our analysis, which include estimates of the uncertainty, are presented in Figure 1-1. Our best estimate curve indicates that the SRP site will experience 4 percent g with a return period of 100 years, and 10.5 percent g with a return period of 1,000 years. The curves on either side of our best estimate represent lower and upper bounds confidence limits about those best estimate.

These curves provide a basis for selecting seismic design criteria for these sites in terms of free field peak ground acceleration. For those structures and equipment that could experience structural amplification, we have chosen the response spectral shape which we have determined to be most appropriate for the facilities. This spectral shape, scaled to 100 percent g for 5 percent damping ratio for SRP is shown in Figure 1-2.

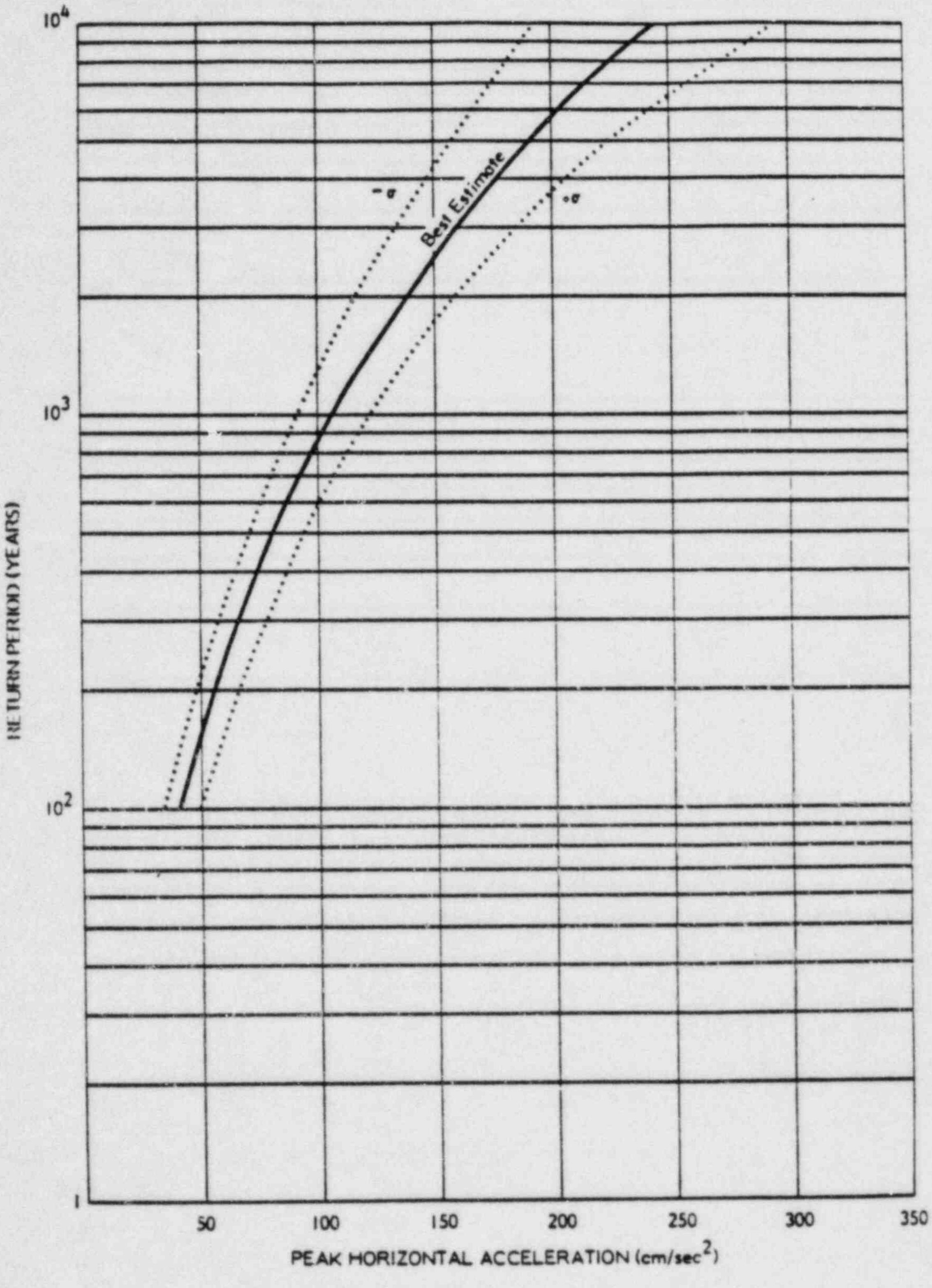

FIGURE 1-1

EARTHQUAKE HAZARD
AT SAVANNAH RIVER

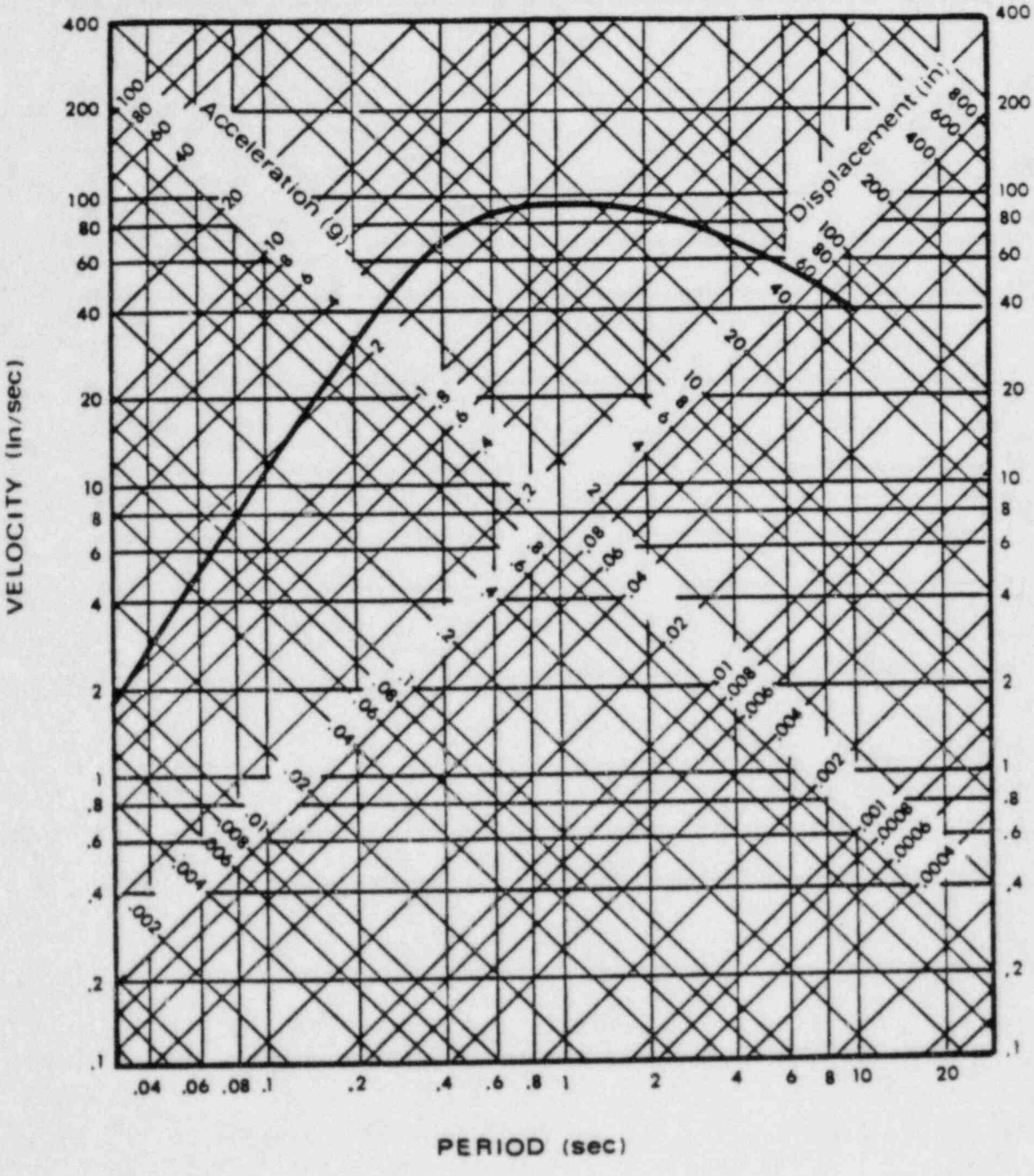

FIGURE I-2

DESIGN RESPONSE SPECTRUM SCALED TO 1.0 g
(5% OF CRITICAL DAMPING)

SAVANNAH RIVER

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2.0 SEISMIC RISK METHODOLOGY

A seismic risk analysis is only as credible as the input and methodology applied. This section presents the basis for our selection of a probabilistic Poisson model for the seismic hazard analysis at the Savannah River Plant DOE facility.

There are generally two, distinctly different approaches to seismic risk analysis: probabilistic and deterministic. Using the deterministic approach, the analyst judgmentally decides that an earthquake of a given magnitude or intensity occurs at a specific location. He then attenuates the ground motion from the earthquake source to the site and determines the effects of that earthquake. The main problem with this approach is that it is difficult to define the margin of safety or the degree of conservatism in the resulting design parameters. Analysts are often asked, for design purposes, to provide information on "maximum possible" or "most probable" earthquakes, but the deterministic approach does not easily provide those answers.

A probabilistic approach, on the other hand, quantifies the uncertainty in the number, size, and location of possible future earthquakes and allows an analyst to present the trade-off between more costly designs or retrofits and the economic or social impact of a failure. Because the product of a probabilistic approach is a measure of the seismic risk expressed in terms of return period, this trade-off can easily be quantified.

Although the probabilistic approach requires significantly more effort than the deterministic approach, it has the following advantages:

- It quantifies the risk in terms of return period.
- It rigorously incorporates the complete historical seismic record.
- It can incorporate the judgment and experience of the analyst.
- It accounts for incomplete knowledge regarding the location of faults.

- It has the flexibility to assess the risk at the site in terms of spectral acceleration, velocity, displacement, or earthquake intensity.

The credibility of the probabilistic approach has been established through detailed technical review of its application to several important projects and areas. Recent applications include assessments of the seismic risk in Boston (Cornell, 1974), the San Francisco Bay Area (Vagliente, 1973), the Puget Sound Area (Stepp, 1974), the country of Nicaragua (Shah, et al., 1975), the continental United States (Algermissen and Perkins, 1976), and the country of Costa Rica (Mortgat, et al., 1977). Results of these studies have been applied to, for example:

- Development of long-range earthquake engineering research goals.
- Planning decisions for urban development.
- Environmental hazards associated with the milling of uranium.
- Design considerations for radioactive waste repositories.

This diversity of application demonstrates the inherent flexibility of the risk assessment approach.

2.1 THEORY

The risk calculations can be fundamentally represented by the total probability theorem

$$P\left[A\right] = \iint P\left[A/m \text{ and } r\right] f_M(m)\, f_R(r)\, dm\,dr$$

where P indicates probability, A is the event whose probability is sought, and M and R are continuous, independent random variables which influence A. The probability that A will occur can be calculated by multiplying the conditional

probability of A, given events m and r, times the probabilities of m and r, and integrating overall possible values of m and r.

In our assessment of these facilities, A will be taken as maximum acceleration, and therefore

$$P\left[A/m \text{ and } r\right]$$

will be derived from data relating peak acceleration to epicentral distance and earthquake magnitude. Often known as attenuation data, these data are usually lognormally distributed around a mean relationship of the form (McGuire, 1977a).

$$A = C_1 e^{C_2 M} (R+r_o)^{C_3} .$$

In describing the seismicity of the sources, we are hindered by having incomplete historical data that are limited to a short time span. Reliance on frequency data alone can result in erroneous conclusions. The inclusion of geological and seismological opinions can increase the reliability and predictability of the seismicity. For this reason, a Bayesian approach for representing these opinions is used in the model.

The distribution of earthquake magnitude, $f_M(m)$, is obtained by combining a model for earthquake occurrence with a model for earthquake magnitude.

The Poisson model is used to estimate earthquake occurrence. It implies the following assumptions:

- Earthquakes are spatially and temporally independent.
- The probability that two seismic events will occur at the same time and at the same location approaches zero.

It has been shown (Gardner and Knopoff, 1974) that those assumptions are reasonable and applicable to situations where extremely large events are not expected.

In short, the model gives $P(n/\lambda)$ the probability of having n events in time t, given that λ is the mean rate of occurrence per unit time.

Thus, if the measured rate of occurrence λ is known, the probability distribution function is completely defined.

Information on magnitude is obtained using a Bernoulli process. This model aims at estimating the number of successes given a number of trials. It is applied to earthquakes in the following way: The magnitude scale is discretized in a finite number of fixed magnitude bands M_i (i=1,n) beginning with the smallest magnitude of interest (1), and up to the largest possible (n). Each magnitude band (M_i) is analyzed independently of all the others.

The trials are the occurrence of any event irrespective of magnitude. Considering a given magnitude band M_i, the successes are the occurrences of earthquakes of the given magnitude M_i; the failures are the occurrences of any other magnitude earthquake. Given that one earthquake has occurred (trial), p_{M_i} is the probability that it is of magnitude M_i (success); $q_{M_i} = 1 - p_{M_i}$ is the probability that it is of any other magnitude (failure).

Hence, the model determines

$$P_R(r_{M_i}/n, p_{M_i})$$

which is the probability that r_{M_i} events of magnitude M_i will occur out of a total of n events given that the probability of occurrence of M_i at each trial is p_{M_i}. A similar probability distribution function is obtained for each of the magnitude bands M_i to cover the whole range of possible magnitudes. These distributions are totally defined when the number of trials n and the probability of success p_{M_i} are determined.

In order to obtain the probability of any number of earthquakes of a fixed magnitude, regardless of the total number of occurrences, one removes the condition on the number of occurrences (n) by taking the summation over all the events:

$$P_R(r_{M_i}) = \sum_{n=o}^{\infty} P_R(r_{M_i}/n)\, P_N(n)$$

This distribution describes totally the seismicity of the source considered in terms of two parameters: magnitude (M_i) and number of occurrences (n).

The Bernoulli model has the advantage that the probability of occurrence of an earthquake of a given magnitude can be established independently of any other magnitude. It also offers greater flexibility in the use of historical seismicity data by combining them with subjective information through a Bayesian approach.

The distribution on distance, $f_R(r)$, depends on the geometry of the problem under consideration. For simple geometries, the distributions can often be integrated analytically. Realistic geometries, however, require numerical evaluation of the integral. A very versatile computer program has been developed (Mortgat, 1977) that incorporates the theory presented above with a numerical integration scheme that allows for evaluating very complex source-site geometries.

The overall approach to performing seismic risk assessments using this theory is summarized below. First, the historical earthquake record and local attenuation data are combined with the experience of the analyst to produce the functional relationships applicable to the area under consideration. The source regions are divided into small rectangular segments. The total probable activity of the segment is evaluated in terms of magnitude and occurrences of each magnitude. Using the transfer function from the segment to the site, the total effect of the activity on the segment is calculated at the site by the number of discrete peak ground accelerations and the corresponding probabilities exceeding these accelerations.

Assuming independence between events, the cumulative effect of additional segments is obtained until all the seismic sources modeled in the region have been covered. It follows that the return period is simply the reciprocal of the annual hazard.

3.0 REGIONAL AND SITE GEOLOGY

A study of the site geological setting is not within the scope of this analysis; however, for completeness we present herein a brief summary based on a study by D'Appolonia.

3.1 REGIONAL GEOLOGY

The Savannah River Plant site is located in the Upper Atlantic Coastal Plain, approximatively 31 miles southeast of the Fall Line and the city of Augusta, Georgia. The Atlantic Coastal Plain extends southwestward from Cape Cod to southern Georgia, Florida and Alabama where it continues as the Gulf Coastal Plain. It is underlain by a wedge of seaward-dipping unconsolidated and semiconsolidated sediments which increase in thickness from zero, at the contact with the Crystalline Piedmont at the Fall Line, to a thickness in excess of 3,100 feet near the coast of South Carolina (Rankin, 1977). The upper coastal plain slopes from a maximum elevation of 650 feet at the Fall Line to about 250 feet on the southeastern boundary. The major physiographic divisions in the site region are the Aiken Plateau and the Congaree Sand Hills. The surface of the Aiken Plateau is highly dissected and characterized by broad interfluvial areas with narrow steep-sided valleys. The Congaree Sand Hills trend along the Fall Line northwest and north of the Aiken Plateau and are characterized by gentle slopes and rounded summits.

West of the Atlantic Coastal Plain lies the Piedmont physiographic province. The Piedmont province is a broad plateau sloping gently seaward which is the easternmost physiographic and structural province of the Appalachian Mountains. It is composed predominantly of crystalline metamorphic rocks which were deformed several hundred million years ago during the Appalachian orogeny.

The site regional geology, within 200 miles of the sites, also includes portions of the Blue Ridge and Valley and Ridge physiographic provinces. The Blue Ridge province extends from Pennsylvania southwestward to northern Georgia. It is composed predominantly of crystalline metamorphic rocks and is lithologically

similar to the Piedmont. The Valley and Ridge province is composed of a sequence of Paleozoic sedimentary rocks which were folded and faulked during the Late Paleozoic. In its southern portian, a long zone of thrust faults is the predominant structural feature, and the ridge and valley topography is less obvious.

3.2 SITE CONDITIONS

The principal sedimentary units of the Coastal Plain in the vicinity of the Savannah River Plant are, in the order in which they are encountered, the Barnwell, McBean, Congaree, Ellenton, and Tuscaloosa Formations.

The Barnwell Formation extends from the surface to a depth of approximately 80 feet. It is characterized by layers of silt and clay at the surface underlain by a layer of sand to clayey sand (20 to 40 feet thick) and a layer of sandy silt recognized as the "tan clay." The Barnwell soils are in a generally loose condition, and D'Appolonia computed factors of safety against liquefaction close to 1 during high intensity earthquakes.

The McBean Formation is primarily sand to clayey sand with lenses of sandy silt and several calcareous zones. Its thickness is approximately 70 feet. Density in the McBean ranges from very loose to very dense.

The McBean is separated from the Congaree Formation by a layer of sandy silt known as "green clay." The Congaree Formation consists of sand to silty sand in a very dense condition; it is approximately 70 feet thick.

The Ellenton and Tuscaloosa Formations underlie the Congaree Formation. The Ellenton Formation consists of dense layers of silty sand and sandy silt. The Tuscaloosa Formation consists primarily of fluvial and estuarine deposits of cross-bedded sand and gravel with lenses of silt and clay. Its thickness can be estimated at approximately 600 feet beneath the Savannah River Plant.

4.0 SEISMOLOGY

The detailed elements of the seismic hazard assessment are discussed in Section 5.0. However, the seismic data base used to zone the region is of such significance that it is discussed in detail in this section. We focused on the instrumental data and felt earthquake reports, the so-called macroseismicity.

4.1 MACROSEISMICITY

A complete evaluation of the historical macroseismic report is the keystone to the hazard assessment because it contains important information on time and spatial distribution. With respect to time, the record provides detailed historical information on earthquake frequency. Further, the spatial distribution of earthquakes around the site can often be used to delineate seismic source regions within which earthquakes have common characteristics.

Several major earthquakes have been felt at the site during the last century; they are the Charleston earthquake of 1886 and the New Madrid earthquakes of 1811 - 1812.

The great Charleston, South Carolina, earthquakes of August 31, 1886, caused the highest historical site intensity. This earthquake was felt over the entire eastern United States and had a maximum Modified Mercalli Intensity of X. The epicentral area was approximately 145 km east-southeast of the site. There is one report of intensity VI for a location close to the site and several reports of intensity VIII at different locations within 30 km from the site (Bollinger, 1977). Bollinger's isoseismal map for this earthquake places the site in an isoseismal zone of outersites VII to VIII.

The New Madrid earthquakes of 1811-1812 (I_{MM} = XII, 36.6°N - 89.8°W) were the largest earthquakes ever experienced in the central and eastern United States. Aftershocks continued for two years. These earthquakes are associated with the fault along the Mississippi River Valley; the epicentral area was

approximately 850 km from the site. Judging by their effects, the magnitudes were estimated at 7.2, 7.1 and 7.4 for the three main shocks (Nuttli, 1973a). From isoseismal maps, one can infer that the intensity at the site was probably V, or possibly VI.

A number of other earthquakes are known or can reasonably be inferred to have been felt at the site. They are moderate events that occurred at relatively short distances from the site. An annotated list of the most important ones follow:

> The January 13, 1811, Burke County earthquake (I_{MM}=V, 32.2°N - 82.2W) occurred approximately 50 km from the site which probably experienced an intensity II to III. The November 2, 1875, Lincolnton, Georgia, earthquake (I_{MM}=VI, 33.8N - 82.5W) occurred 100 km northwest of the site. The intensity at the site was III to IV. The May 31, 1897, Giles County Virginia earthquake (I_{MM}=VII-VIII, 37.3N - 80.7°W) was felt over 230,000 square miles and generated an intensity III at the site (Hopper and Bollinger, 1971). The January 1, 1913, Union County, South Carolina, earthquake (I_{MM}=VII, 34.7N - 81.7W) was felt over an area of 43,000 square miles. The epicentral area was located 160 km from the site which experienced an intensity less than IV.
>
> The August 2, 1974, earthquake (I_{MM}=VI, 33.9N - 82.5W) was centered near Willington, South Carolina and was felt over an area of 14,000 square miles. The site intensity was IV. The event was followed by a series of microearthquakes; this seismic activity has been shown to be related to the water level in the Clark Hill Reservoir (Talwani, 1976).

This list of earthquakes is not exhaustive, and several other earthquakes can be inferred to have been felt at the Savannah River site; they were all small to moderate events which did not generate intensities greater than IV at the site.

4.2 MAGNITUDE AND INTENSITY RELATIONSHIP

Although most data are already available in terms of magnitude, an important part of the data is described in terms of intensity. In general, the subjective nature and the wide range of uncertainty of the Modified Mercalli intensity scale are such that they cannot be meaningfully compared to the Richter magnitude. This has led to the use of empirical relationships between magnitude and intensity. We have used a widely accepted linear relationship in the form:

$$m_b = a + b\, I_o$$

where

m_b = Body Wave Magnitude

I_o = Epicentral MM intensity

with the values

a = 1.75

b = 0.50

This relation has been derived separately for Central U.S. by Nuttli (1974). This relationship is used to estimate magnitudes when only intensity is given.

4.3 EARTHQUAKE SPATIAL DISTRIBUTION

The spatial distribution of seismic events recorded between 1800 and 1977 is shown in Figure 4-1. Several main centers of activity can easily be identified in the eastern United States:

- The New Madrid Seismic Zone is the most important of the seismic regions. It is part of the Upper Mississippi Embayment and has been active seismically since historical time. A few great earthquakes and thousands of light-to-moderate strong shocks have been centered in this region.

- Northeast of the New Madrid Seismic Zone, a cluster of earthquakes has been located along the Illinois-Indiana border. These epicenters are related to the Wabash Valley Fault Zone. This zone is an extension of the Upper Mississippi Embayment area.

- The cluster of epicenters along the Illinois-Missouri border defines a seismic region located in the belt between the Cap au Gres Fault and the Ste. Genevieve Fault.

- In South Carolina, a zone of seismic activity extends from southeastern Charleston, South Carolina, northwestward across the piedmont. The large 1886 Charleston earthquake and a number of minor-to-moderate events have occurred in this region. Due to the short distance that separates the earthquake source from the site, its contribution will be very important.

- West of the site lies the Southern Appalachian Tectonic Province. This zone extends from south Virginia to central Alabama from the western edge of the Piedmont across the Cumberland Plateau. Light to moderate shocks occur at an average frequency of one or two per year, with periods of several shocks a year followed by periods of no perceptible shocks.

In addition to these areas, other zones of seismic activity can be distinguished in the eastern United States. Among those are:

- Appalachian Plateau
- Central Virginia
- Adirondack Plateau
- Attica
- Anna
- Northern Illinois

These regions have displayed low-to-moderate rates of activity over the last 100 years. This, together with their distance to the site, makes their contribution to the seismic exposure at the Savannah site negligible.

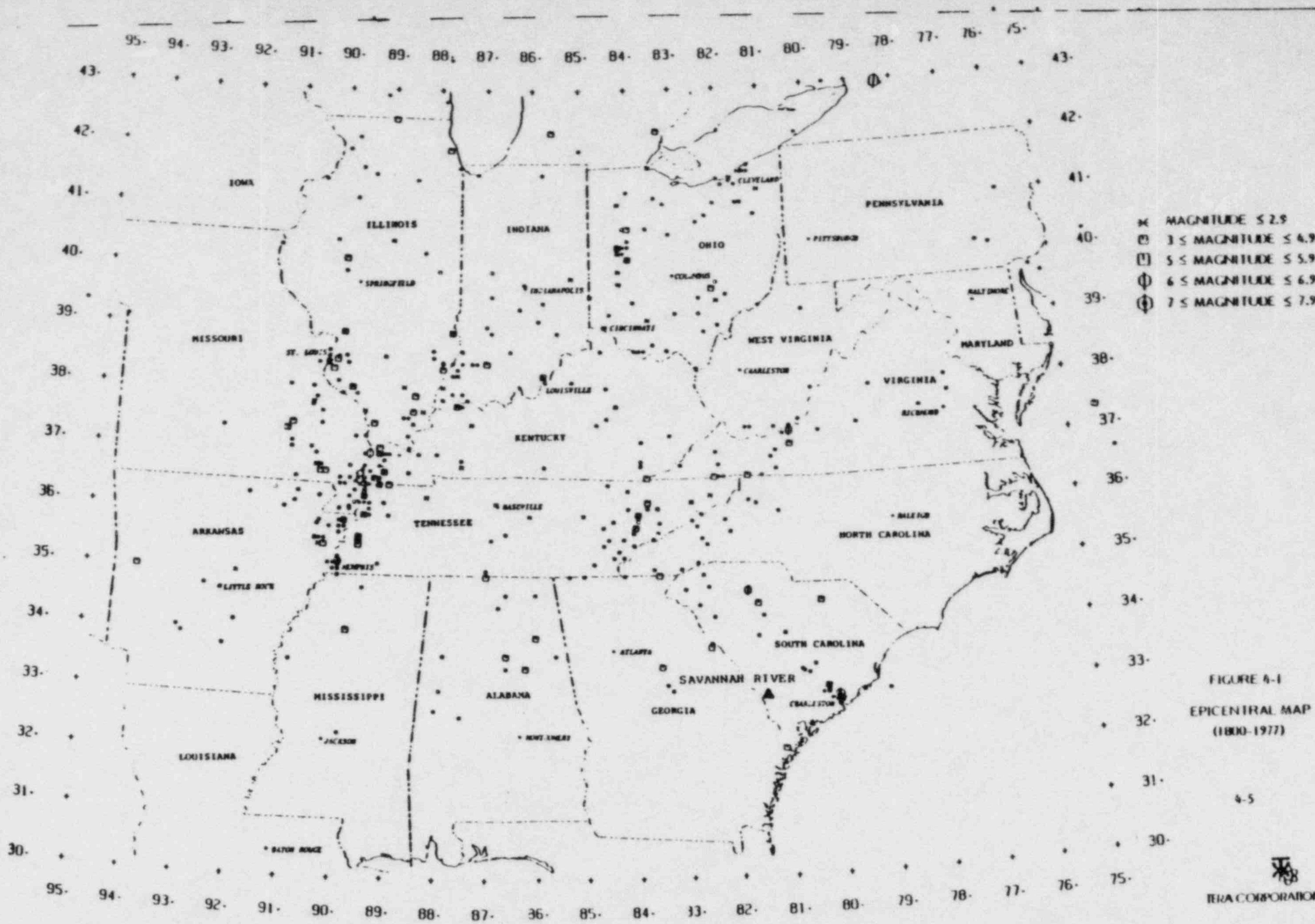

FIGURE 4-1

EPICENTRAL MAP

(1800-1977)

5.0 CALCULATIONS AND RESULTS

5.1 INPUT

As described in Section 2.0, Seismic Hazard Methodology, the input to a probabilistic seismic hazard assessment consists of:

- A geometric specification of local seismic regions
- A description of past seismic activity in terms of earthquake occurrence frequency (possibly modified by subjective input to remove incompleteness or bias in the data)
- An earthquake occurrence model
- A ground motion model
- An exposure evaluation model to determine the probability of exceedance of peak ground acceleration

The earthquake occurrence and exposure models used in this analysis have been described in Section 2.0. The other components of the model are presented in the following subsections.

5.1.1 SOURCE REGIONS

The definition of the source regions was based on a recent study by TERA (1979). These source zones synthesize the available historical seismicity data, the state of knowledge of the relationship between geologic structure and historical seismicity, and the information provided by nine experts on the configuration of seismic regions in the Eastern and Central United States. The final definition of the source regions' boundaries was based on a synthesis of the expert input. It resulted in the global map in Figure 5-1 which encompasses the Eastern and Central United States. Most of the sources presented in Figure 5-1 are not relevant to the present analysis because they are of low seismicity and/or at a great distance from the sites. A detailed description of the seismic zones which are of significant importance to our study follows:

- Sources 1 and 2 - New Madrid (Missouri)

  The New Madrid region is the most highly seismic and has been the site of several very large earthquakes in the past, the latest of which occurred in 1811 and 1812. A continuous moderate seismicity in the region confirms its activity and its potential danger. This study distinguishes between the Inner New Madrid zone which encompasses the areas of greatest activity in the last 200 years and the Outer New Madrid zone which has a lower activity. The differences in activity are apparent in the epicentral map in Figure 4-1. The Outer New Madrid zone includes the Wabash Valley, Cap au Gres and Ste. Genevieve Fault zones.

- Sources 3 and 4 - South Carolina (Georgia)

  The most destructive earthquakes in the history of the southern United States took place in this region (Charleston-Summerville, 1886). The oldest recorded earthquake occurred in 1750, and this region has continually displayed a higher seismic activity than the rest of the southern United States. Extensive studies have been made of the 1886 event and of the area in general (Bollinger, 1973, 1975, 1977). The eastern part of South Carolina, around the epicentral area of the Charleston earthquake, is recognized to be more active than the western part; as a consequence, both an eastern and a western South Carolina zone are present in our base map. The western zone is the host region for the Savannah site.

- Source 5 - Southern Appalachia

  The Southern Appalachia region coincides with the Valley and Ridge province of the northern Alabama and eastern Tennessee. Its activity has been moderately high and fairly uniform in time.

- Source 6 - Central Virginia

  This region has displayed a relatively low rate of activity uniformly over the last 100 years. Its low seismicity and its distance to the site reduce its importance considerably.

Considering past activities of these regions and their distances to the sites, it appears that regions 3, 4 and 5 will govern the hazard at the Savannah River site. Due to their proximity to the site, sensitivity analysis was performed on the boundaries of regions 3 and 4.

5.1.2 EARTHQUAKE STATISTICS

In this section we analyze the seismicity of each of the source zones presented in Section 5.1.1 in order to estimate the recurrence relationship for earthquakes. The expected activity of the zones is based on the reasonable assumption that future earthquake occurrences will have the same general statistics as past earthquake occurrences after introducing pertinent modifications to eliminate incompleteness or bias in the data.

The past earthquake activity varies greatly among the seismic regions presented in Figure 5-1. Such differences are not due to inconsistencies in the record but are rather fundamental tectonic variations supported by geological evidence.

The basic parameters of an earthquake occurrence model are the upper magnitude cutoff and the recurrence relationship. The recurrence relationship used in this study is the well-known relation:

$$\log N_c = a + b\, m_b$$

where N_c is the cumulative number of earthquakes of magnitude greater than or equal to m_b; and a and b are the parameters of the model. Ordinate a represents the total number of events in the area, whereas slope b is indicative of the relative frequency of different magnitude earthquakes.

The recurrence relationships for sources 1 to 6 are presented in Figures 5-2 through 5-7. These curves are based on data recorded in each region after modifications were made to correct the biases introduced by lack of recording capabilities during the preinstrumental period.

The upper magnitude cutoff is a rather uncertain parameter, particularly in the less seismic areas which were considered. For each source, it was obtained from reviews of expert opinion conducted by TERA (1979). The proposed values are intended to maximize the agreement among experts. Recognizing that there is no perfect consensus and that the m_b scale saturates at about m_b = 6.8, a sensitivity study was performed on the upper magnitude cutoff of the most important sources.

The values of parameters a and b and the upper magnitude cutoff are presented in Table 5-1.

5.1.3 GROUND MOTION MODEL

A keystone of a seismic analysis is the specification of decay of peak acceleration with respect to distance from the earthquake epicenter. Credible attenuation relations have in the past been difficult to develop for two reasons: first the large scatter in data makes a deterministic evaluation very difficult and secondly, data are very sparse in the near-field, thus allowing for a variety of interpretations.

The ground motion model used in this analysis is based on work done by TERA (1980), modified for applicabil'ty in the southeastern United States. Given the paucity of strong motion data and the availability of intensity data in the southeastern United States, a model for the attenuation of site intensity was first chosen (Bollinger, 1977), and then converted into a ground motion parameter (namely, peak ground acceleration) by using data from the western United States. Epicentral intensity, as a parameter in the attenuation model, is changed to body wave magnitude by using the correlation presented in Section 4.2. The local magnitude can be transformed to body wave magnitude by the relation:

$$m_b = 0.98\, M_L - 0.29$$

The recommended attenuation model is considered to be appropriate for soil sites such as SRP. The attenuation relation can be characterized by the following expression:

$$\ln A_H = 0.53 + 1.122\, m_b - 0.783 \ \ln R - 0.00033R \quad \text{for } R \geq 10 \text{ km}$$

$$\ln A_H = -1.28 + 1.122\, m_b \quad \text{for } R \leq 10 \text{ km}$$

where A_H = PGA (cm/sec^2)

m_b = Body Wave Magnitude

R = Epicentral Distance (km)

$\sigma_{\ln A_H}$ = 0.65

It is very important to consider data dispersion magnitudes relative to the mean recurrence relationship. The statistical properties of peak acceleration are usually characterized by the natural logarithm of acceleration, thus, dispersions are expressed in terms of the standard deviation of $\ln A_H$. Typical values of this parameter range from 0.51 (McGuire, 1974) to 1.2 (Esteva, 1970). We determined that a value of 0.65 is a conservative estimate for sigma and we associate this value with three standard deviation dispersions on acceleration.

The attenuation relationship of several magnitudes is plotted in Figure 5-8.

TABLE 5-1

RECURRENCE RELATIONSHIP USED IN THE ANALYSIS

	NUMBER OF OCCURRENCES GREATER THAN m_b = 3.875	IN YEARS	RECURRENCE SLOPE (b parameter)	UPPER CUTOFF MAGNITUDE
Source 1 - Inner New Madrid	190	175	.9	7.5
Source 2 - Outer New Madrid	130	175	.9	7.0
Source 3 - Eastern South Carolina	50	175	.9	7.0
Source 4 - Western South Carolina	33	175	.9	6.0
Source 5 - South Appalachia	165	175	.9	6.5
Source 6 - Central Virginia	33	175	.9	6.0

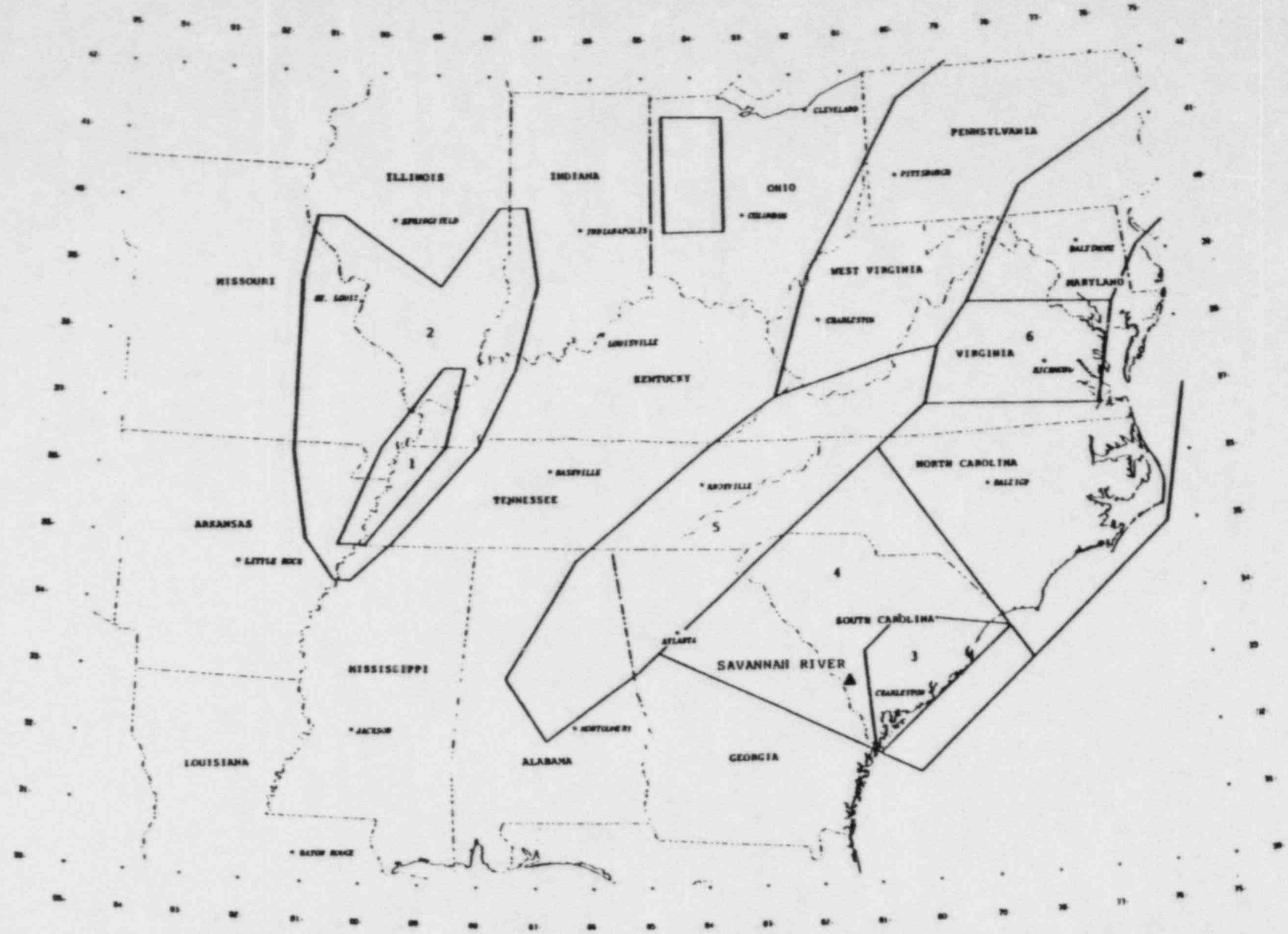

FIGURE 5-1
SEISMIC SOURCES

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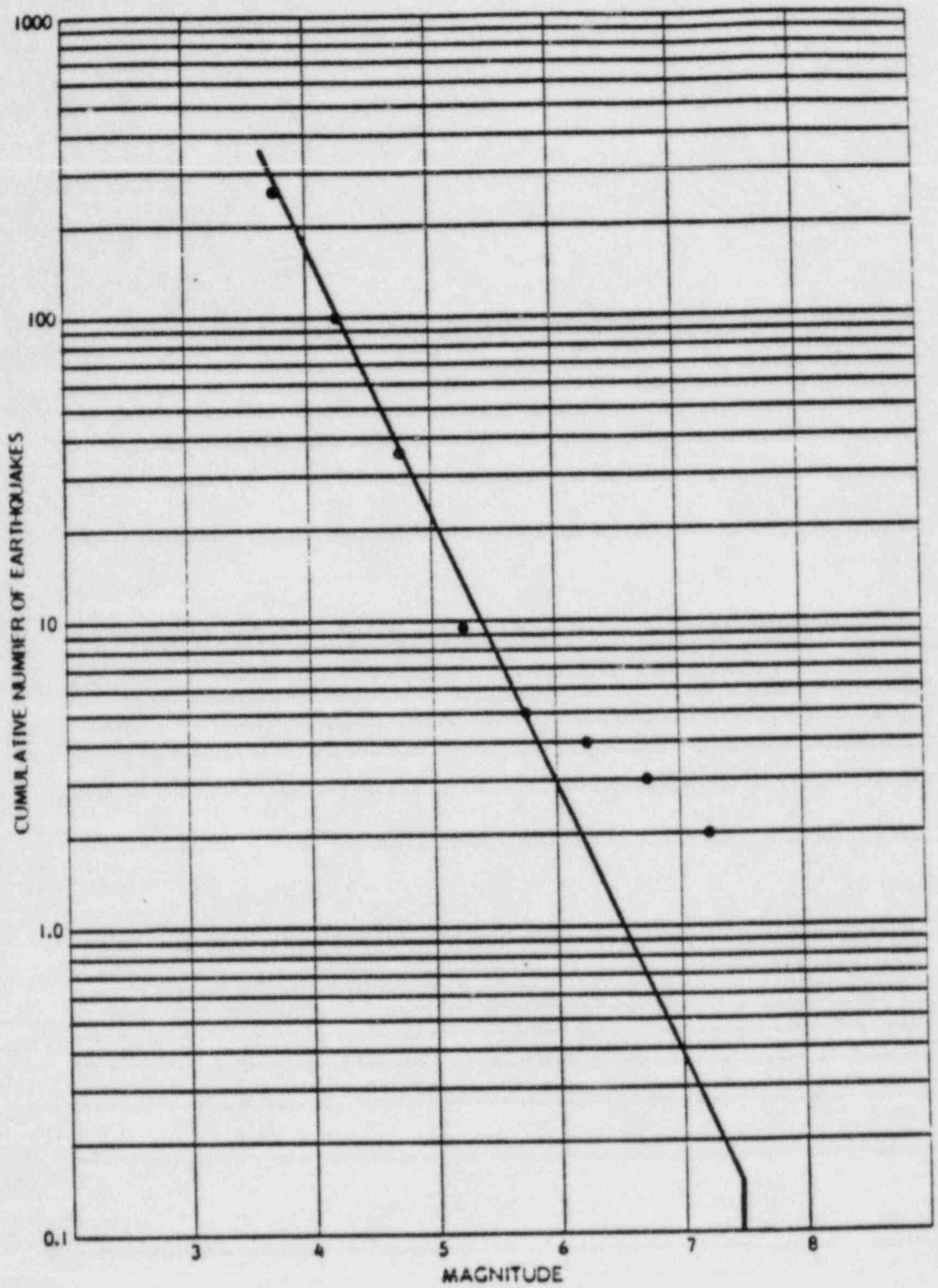

FIGURE 5-2

RECURRENCE RELATION FOR SOURCE 1
(Inner New Madrid)

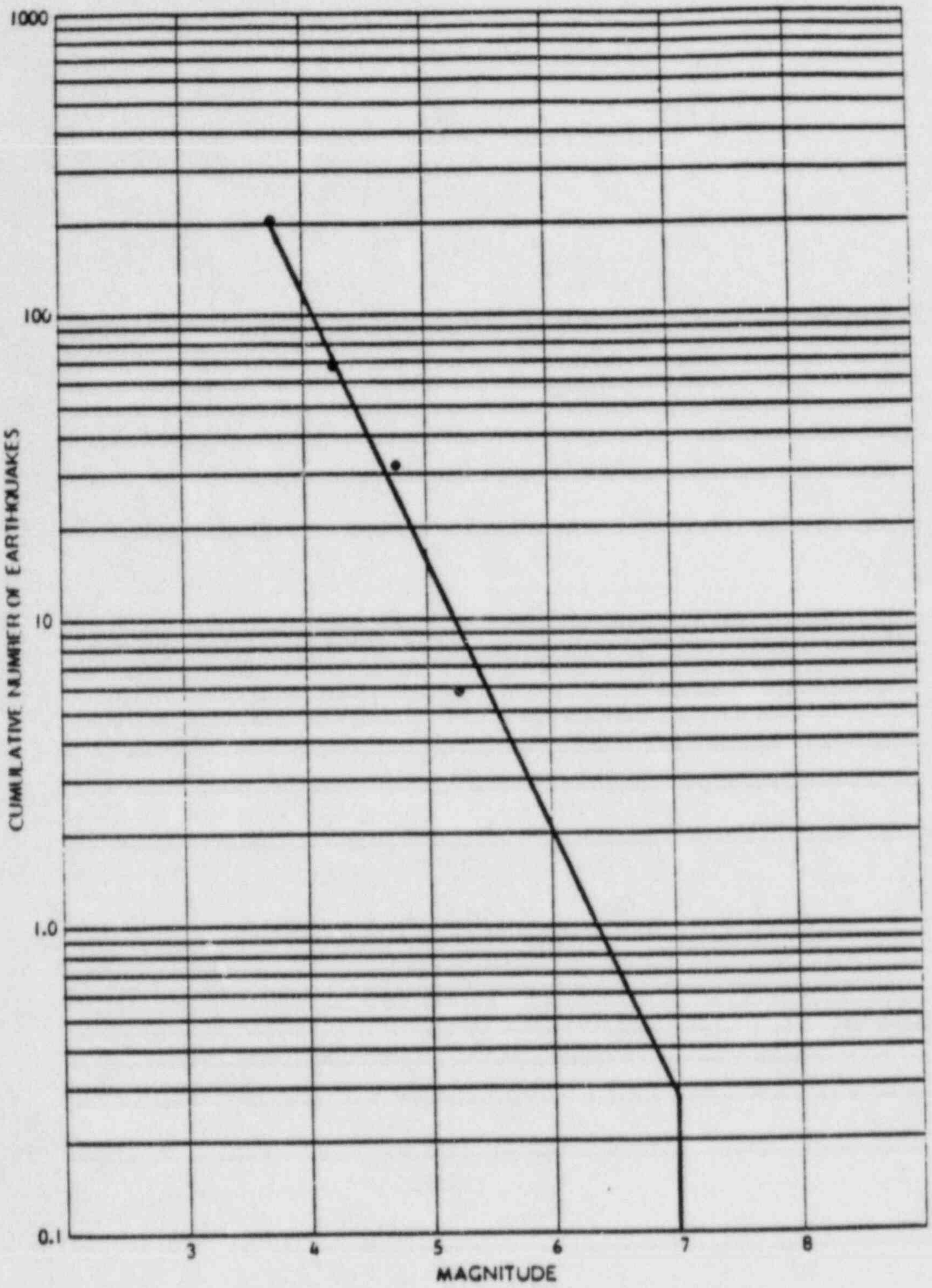

FIGURE 5-3

RECURRENCE RELATION FOR SOURCE 2
(Outer New Madrid)

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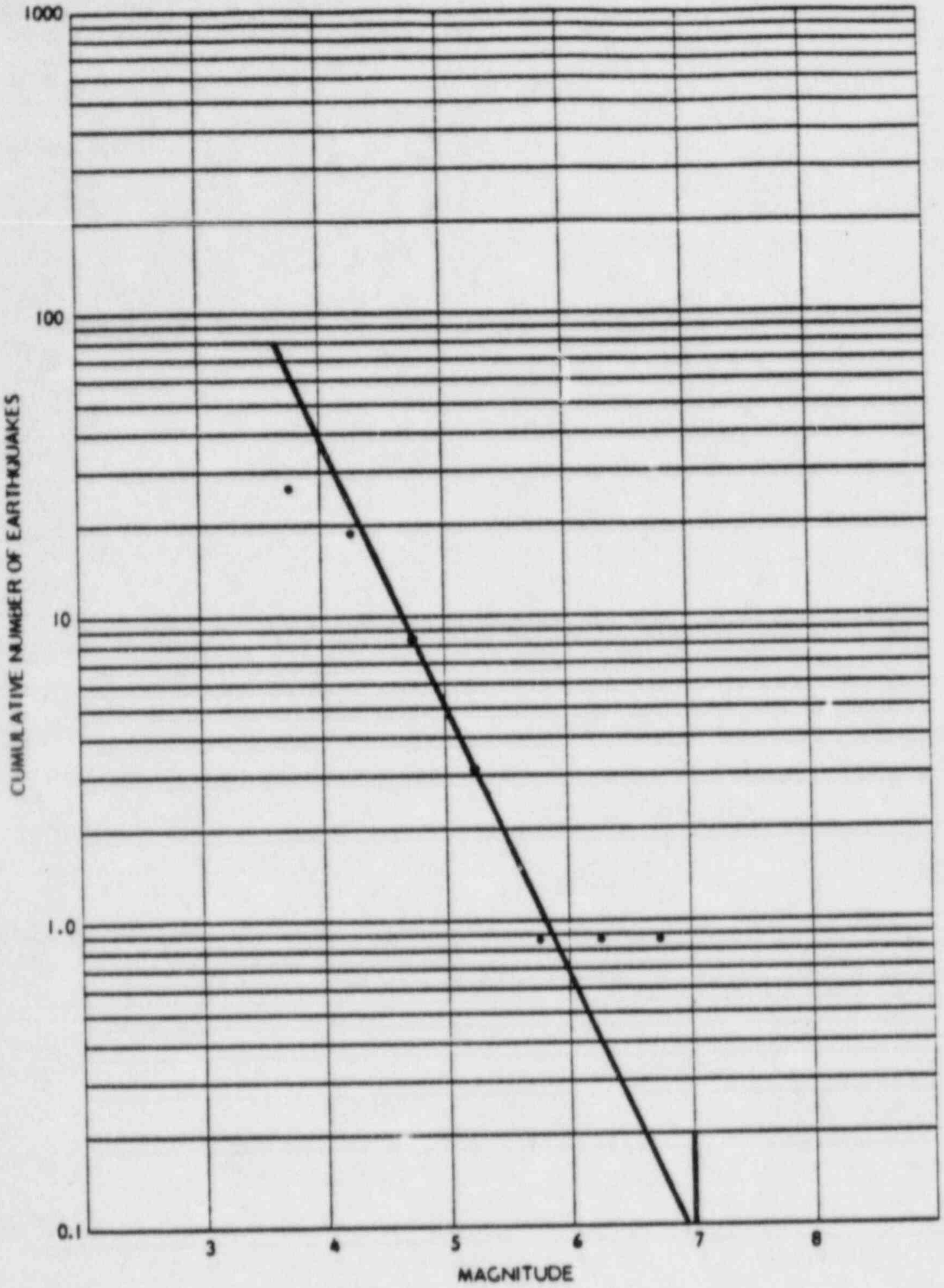

FIGURE 5-4

RECURRENCE RELATION FOR SOURCE 3
(Eastern South Carolina)

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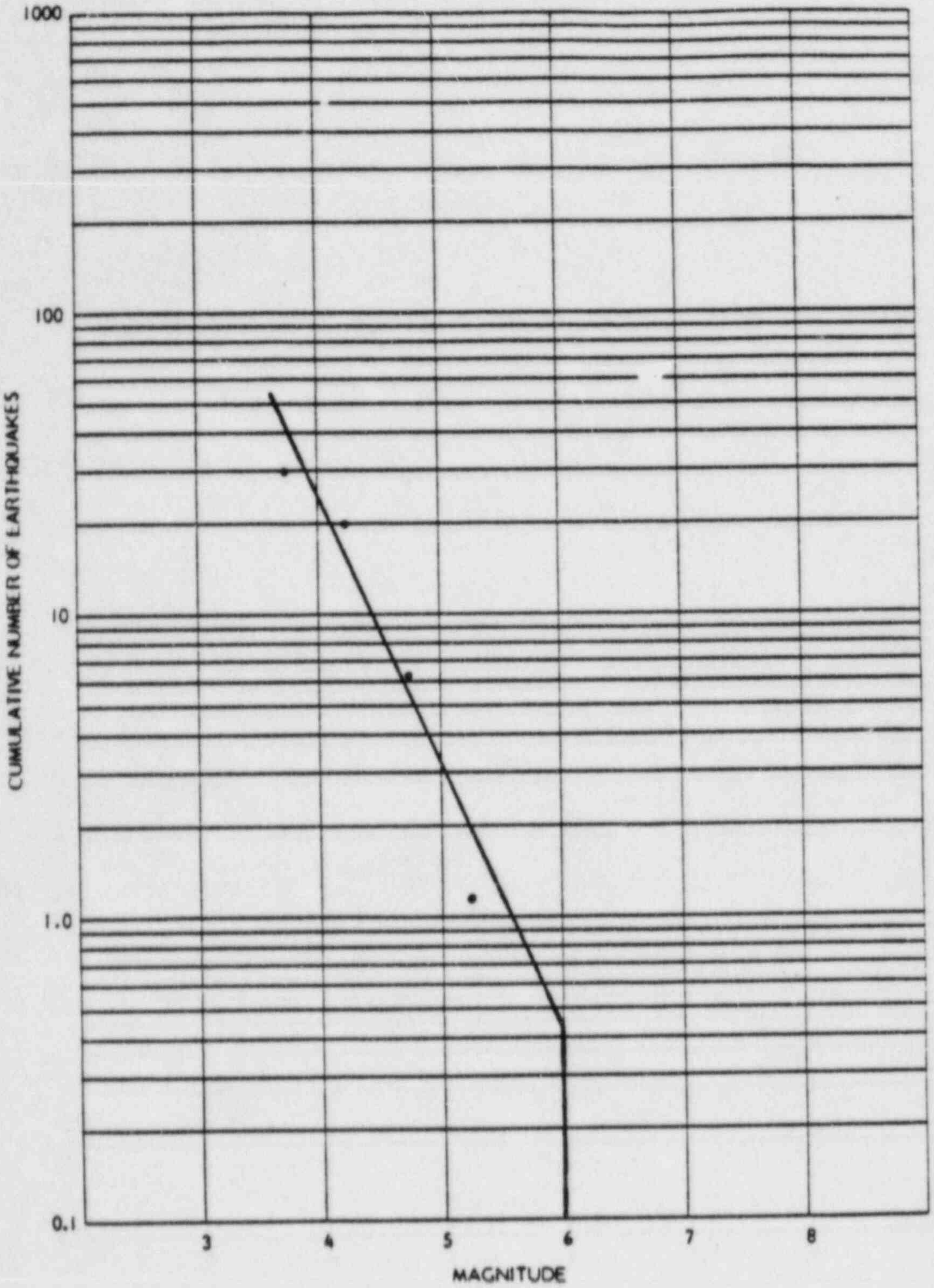

FIGURE 5-5

RECURRENCE RELATION FOR SOURCE 4
(Western South Carolina)

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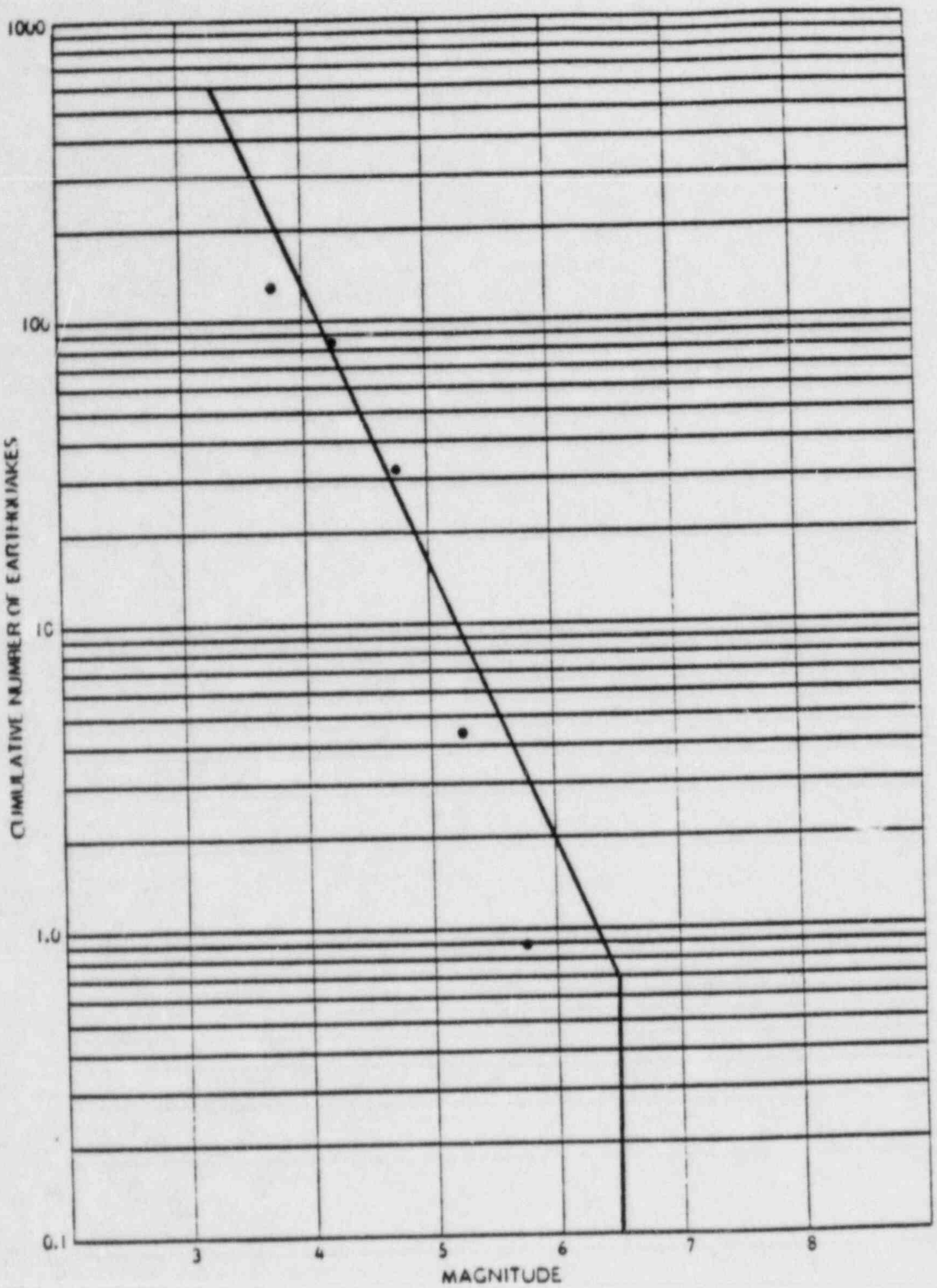

FIGURE 5-6

RECURRENCE RELATION FOR SOURCE 5
(Southern Appalachia)

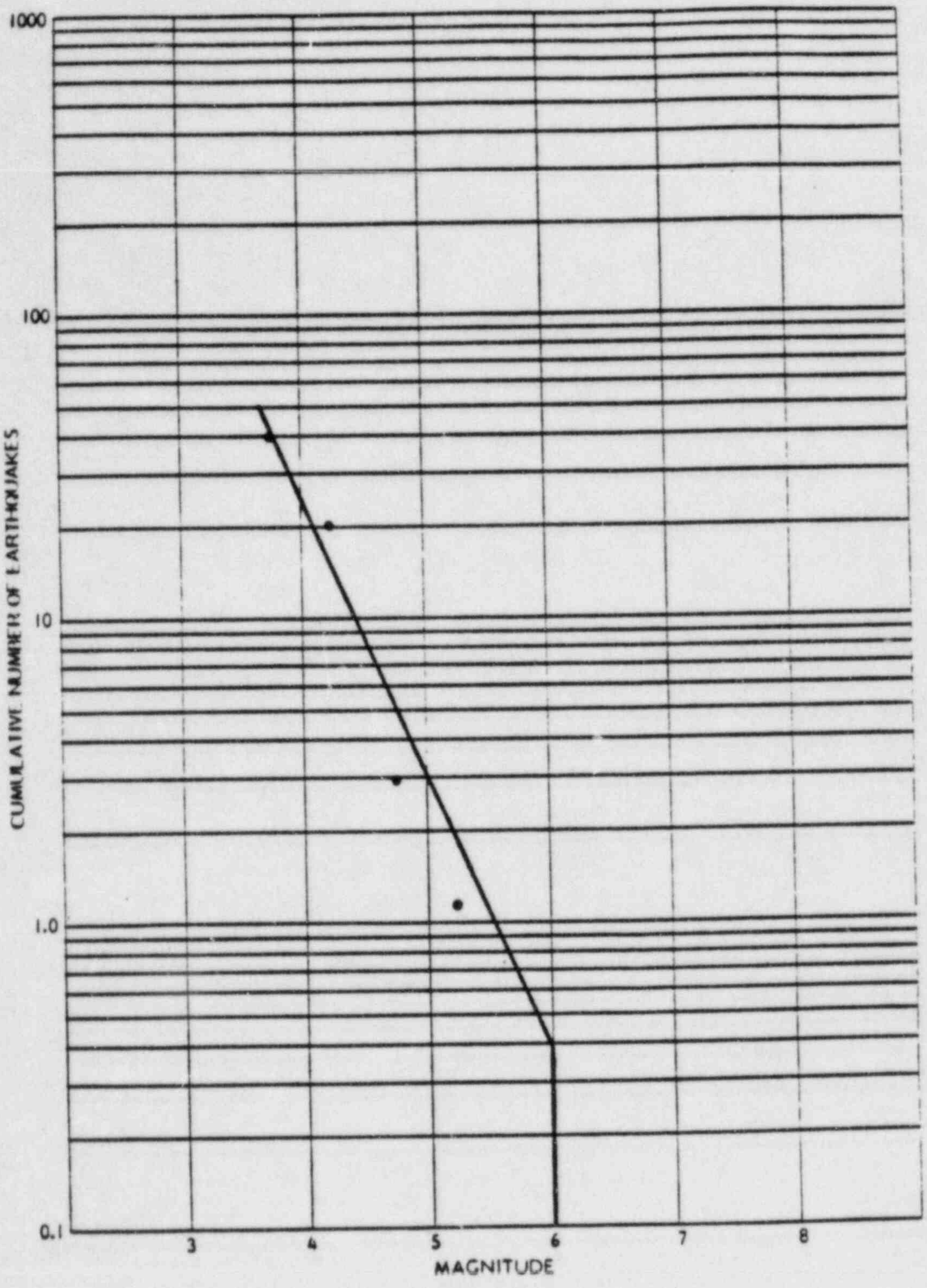

FIGURE 5-7

RECURRENCE RELATION FOR SOURCE 6
(Central Virginia)

TERA CORPORATION

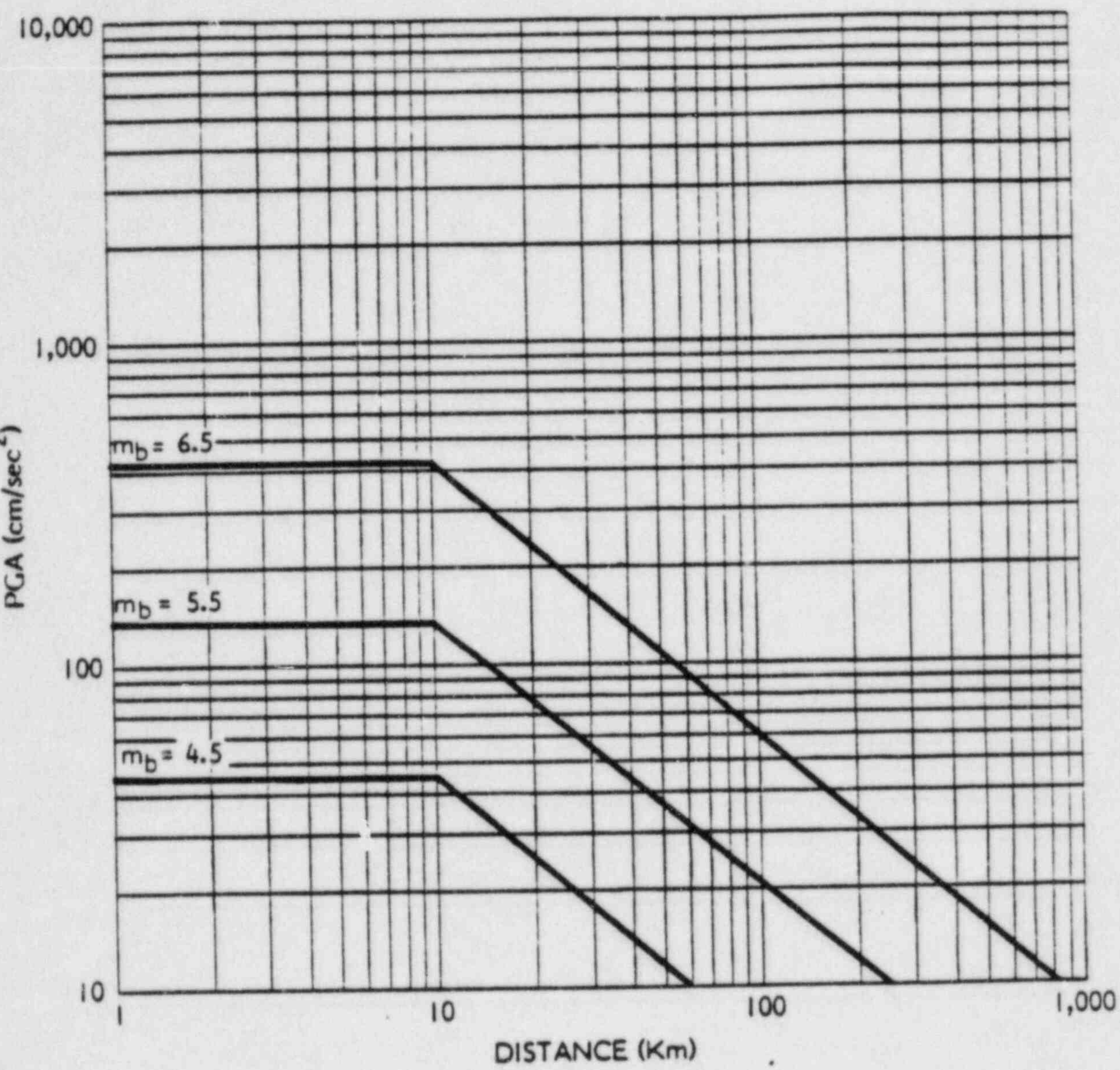

FIGURE 5-8

ATTENUATION RELATIONSHIPS

TERA CORPORATION

5.2 RESULTS

The results were obtained by computer calculations with a hazard analysis code (Mortgat, 1977). The basis for this approach was summarized in Section 2.0.

5.2.1 PEAK GROUND ACCELERATIONS

Our estimates of the risks represent the weighted results from 27 individual calculations. These cases represent the sensitivity analyses conducted regarding the boundary of the sources, the upper magnitude cutoff, and the attenuation functions. The perturbations are weighted by subjective estimates of probability of occurrence. The variations in these parameters represent the overall uncertainties in:

- Our ability to define the strain energy limit of the seismic sources
- The correlation between earthquake magnitude and intensity
- The uncertainty associated with the attenuation relation.

The South Carolina sources contribute to more than 90 percent of the hazard at the Savannah River site. To investigate the effect of source zone configuration we have modified the Charleston sources of Figure 5-1 into two other configurations.

a. The configuration in Figure 5-9 reduces the size of the eastern South Carolina source and centers it around the epicentral area of the Charleston earthquake of 1880. This zonation is similar to the South Carolina zone of the Hadley and Devine seismotectonic map of the eastern United States.

b. The configuration shown in Figure 5-10 does not distinguish between an eastern and a western South Carolina source, and events of the size of the great Charleston earthquake can occur at any location in this single source. This configuration considers that there is not enough physical information to restrict the larger events around the Charleston epicentral area.

The nine base cases were as follows:

CASE 1

- Base map configuration (Figure 5-1)
- Upper magnitude cutoff of the eastern South Carolina zone m_b = 7.00
- Upper magnitude cutoff of the western South Carolina zone m_b = 6.00

CASE 2

- Same as Case 1, but with the upper magnitude cutoff reduced to 6.75 and 5.50, respectively

CASE 3

- Same as Case 1, but the upper magnitude cutoff increased to 7.25 and 6.50, respectively

CASES 4, 5 and 6

- Same as Cases 1, 2, and 3, but with source configuration presented in Figure 5-9

CASES 7, 8 and 9

- Source configuration presented in Figure 5-10
- South Carolina zone upper magnitude cutoff m_b = 7.00, 6.75 and 7.25, respectively.

For these nine cases, the uncertainty about the attenuation relationship was modeled by a log-normal distribution with a standard deviation sigma ($\sigma_{\ln A_H}$) equal to 0.65. Sensitivity sigmas of 0.55 and 0.75 were also considered. The resulting 27 case studies were used to estimate the hazard at the Savannah River site. For this purpose, we assigned a weight to each of the cases described above:

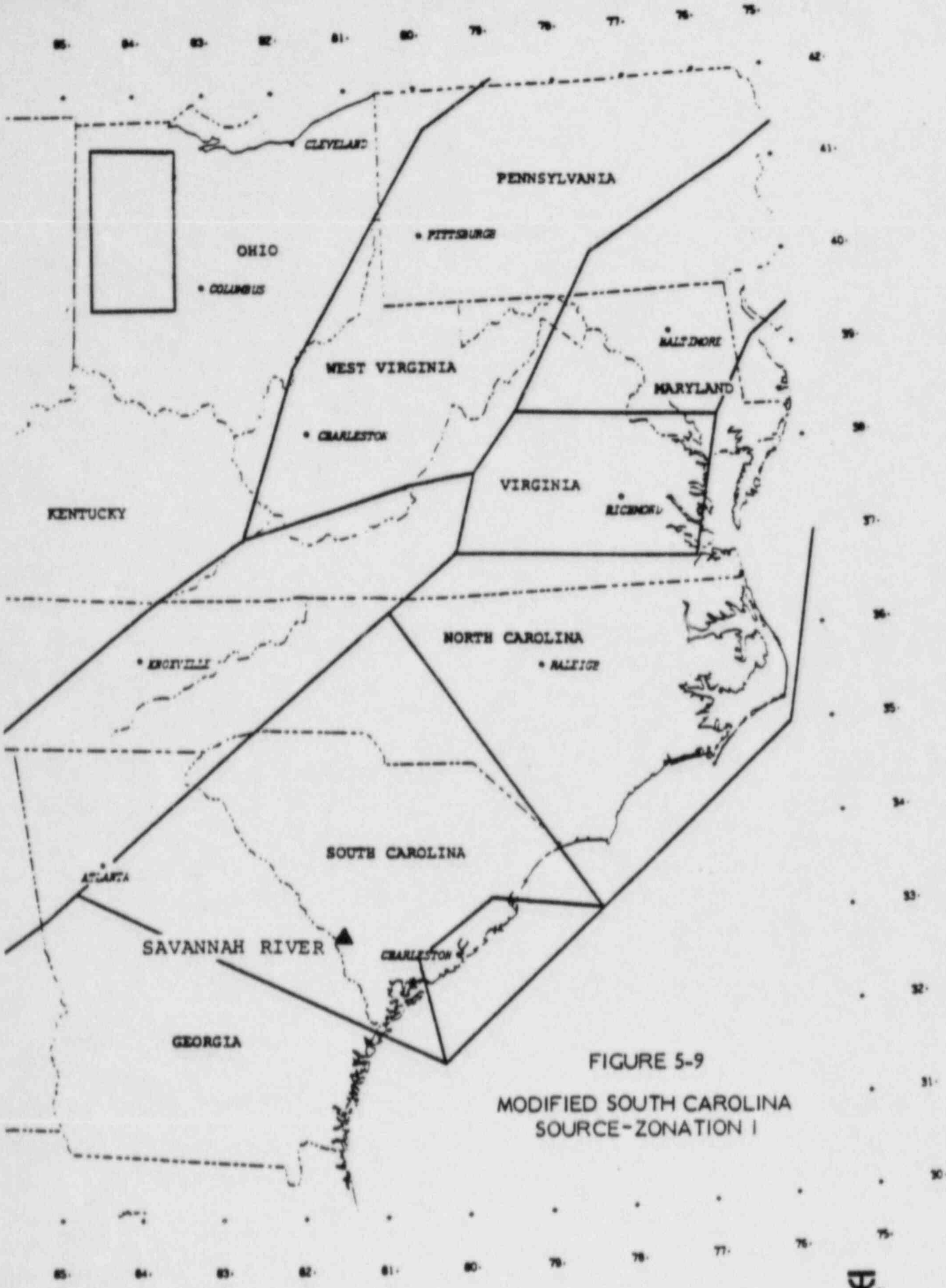

FIGURE 5-9

MODIFIED SOUTH CAROLINA SOURCE-ZONATION I

TERA CORPORATION

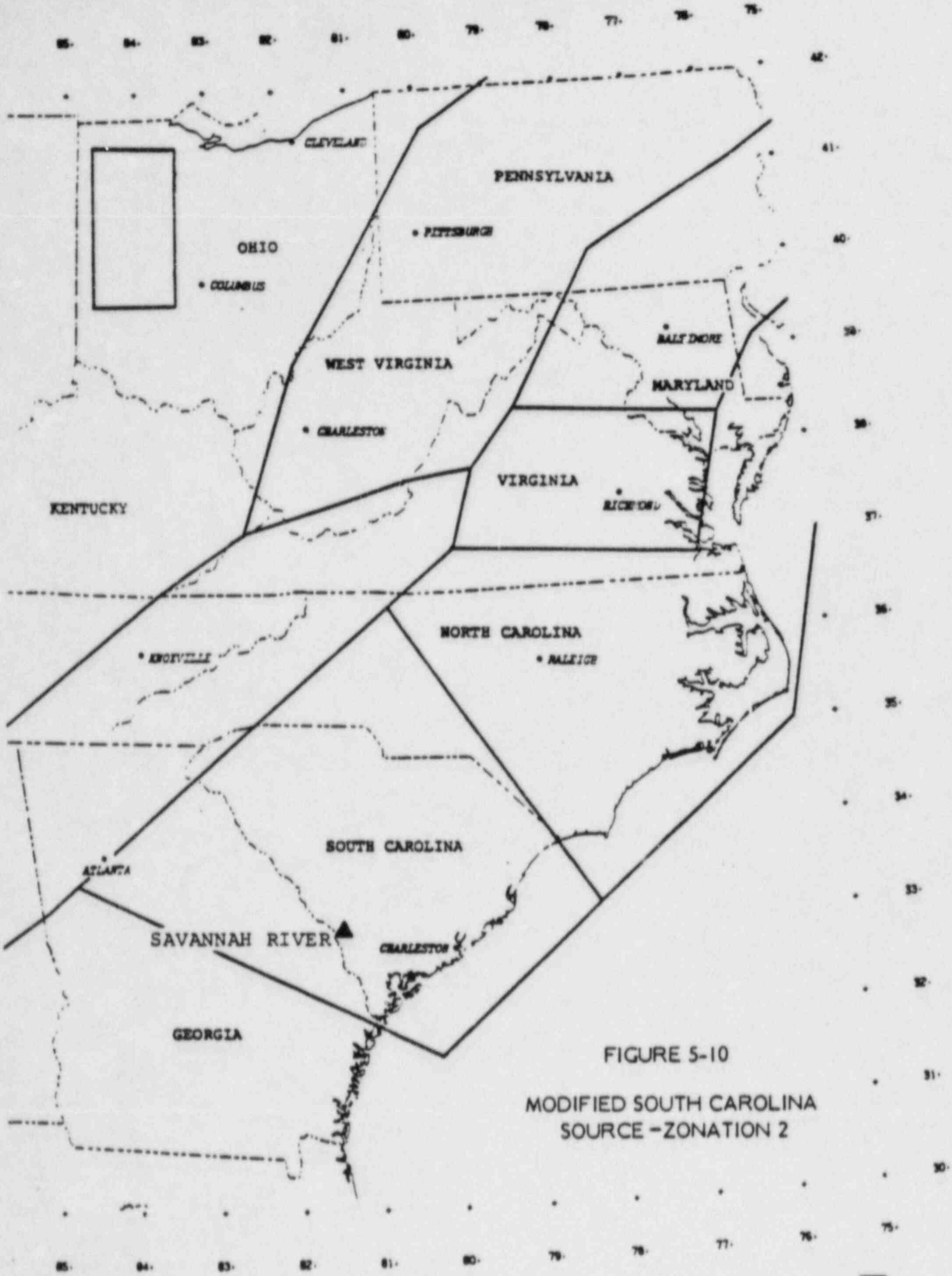

FIGURE 5-10

MODIFIED SOUTH CAROLINA SOURCE-ZONATION 2

- The South Carolina zonation of Figure 5.1 was assigned a weight of 0.50, and a weight of 0.25 was assigned to both sensitivity zonations of Figures 5-9 and 5-10

- We assigned a weight of 0.70 to the sigma = 0.65, and 0.15 to both sigma = 0.55 and sigma = 0.75

- For a given sigma value and a given South Carolina zonation, we considered the best estimate of the upper magnitude cutoff to be 70 percent probable and each of the reduced and increased values to be 15 percent probable.

The results are presented in Figure 5-11. This figure shows our best estimate, together with our estimate of the lower and upper limits. These limits can be roughly assumed to be the one standard deviation with respect to the best estimate. According to the best estimate the expected peak ground acceleration at the Savannah River Plant site is 4 percent g with a return period of 100 years, and 10.5 percent g with a return period of 1,000 years.

5.2.2 RESPONSE SPECTRUM

The results, given in the previous paragraphs, define the peak horizontal acceleration at the facility for various return periods. We have also determined an appropriate response spectrum for the site since some structures and equipment have sufficiently low fundamental frequencies to experience spectral amplification.

Our approach to the definition of a response spectrum is empirical; that is, we base our recommendation on the shape of response spectra of earthquakes of the type the site is likely to be subjected to. While sophisticated deterministic techniques exist which, through stress wave propagation calculations, can result in site specific spectra, such calculations are outside the scope of this analysis.

We recognize that the hazard at the site is generated by two types of events. In the host region, the near-field earthquakes of small to moderate magnitudes contribute to the greatest part of the hazard. Their energy is released at the

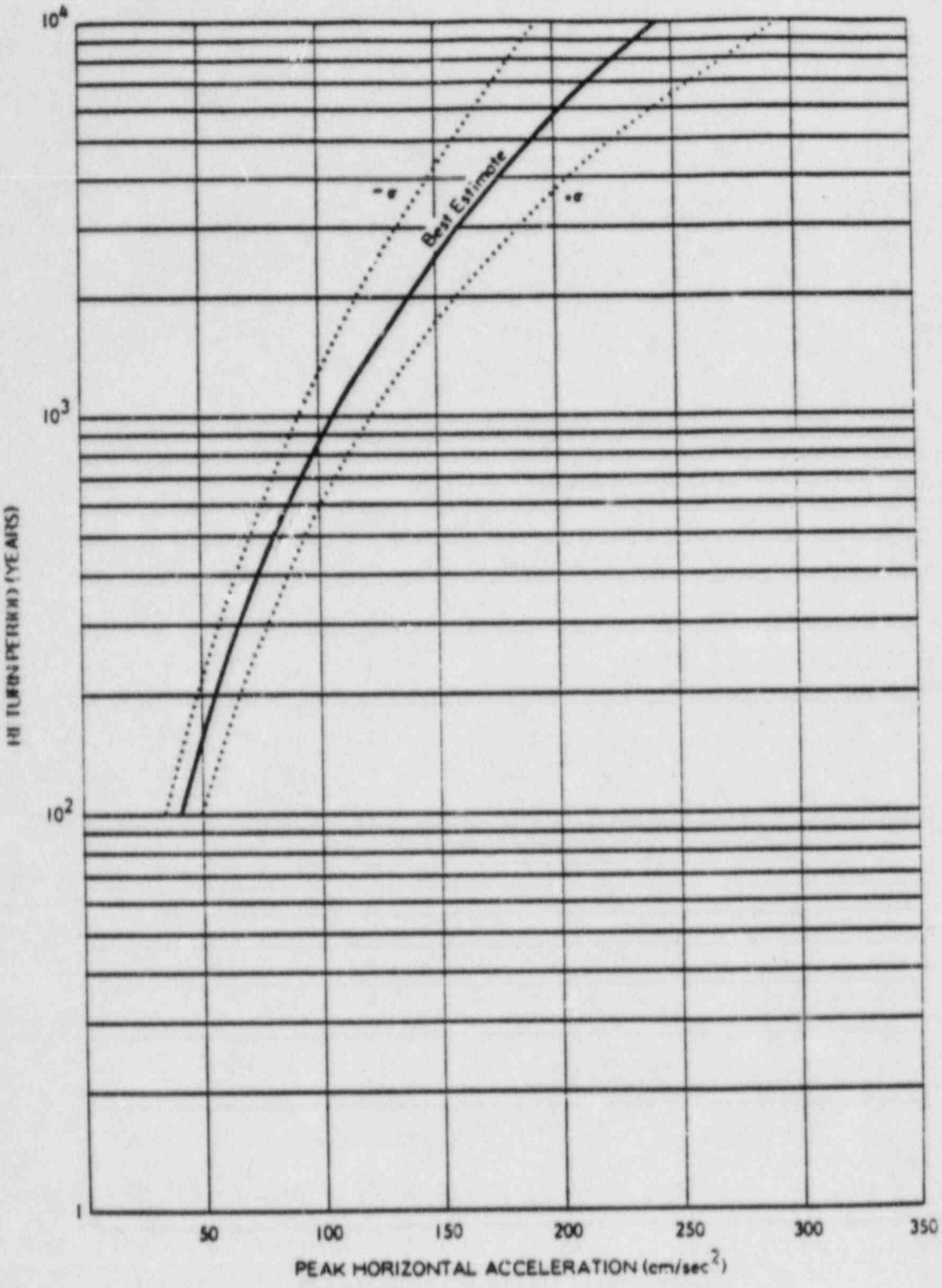

FIGURE 5-11

EARTHQUAKE HAZARD
AT SAVANNAH RIVER

TERA CORPORATION

site mainly in the high frequency range and their response spectra is governed by body waves. On the other hand, large earthquake motion from more distant sources, like Charleston, is transmitted by surface waves and contributes to the low frequency side of the spectrum. Even though their contribution to the total hazard is limited, these earthquakes must be considered since they are of long duration and may generate substantial damage on low frequency systems.

Unfortunately, the knowledge about earthquake mechanisms in the eastern United States is more qualitative than quantitative and the extent of the long period enhancement in the response spectrum compared to western events is not known. This, forces us to adopt a conservative approach.

We based our spectrum on the one recommended by D'Appolonia (1979) for SRP together with the following selected records:

1) The El Centro earthquake of May 18, 1940 (magnitude 6.7).

2) The Managua earthquake of December 23, 1972 (magnitude 5.6).

3) The Melendy Ranch earthquake of April 9, 1972 (magnitude 4.7).

In view of the broad frequency range of excitation to be expected at SRP site, this results in a fairly conservative spectrum envelope. This conservatism could not be eliminated without detailed site-specific spectra analyses beyond the scope of this project.

The resulting spectral shape, at five percent damping, is presented in Figure 5-12. The spectral acceleration, when scaled to a design peak acceleration, has a return period corresponding to the peak acceleration in Figure 5-11.

5.3 CONCLUSIONS

In summary, we have combined the best available input data with the most credible tools of seismic risk analysis to determine the return period of

acceleration at the DOE site of SRP. The results, shown in Figure 5-11 accounts for the dispersion of the data about the functional relationships used in the model. The results further account for variations in the upper magnitude cutoff and different tectonic models. Other design response spectra can be determined by scaling the 1.0 g response spectrum of Figure 5-12 to the desired peak acceleration.

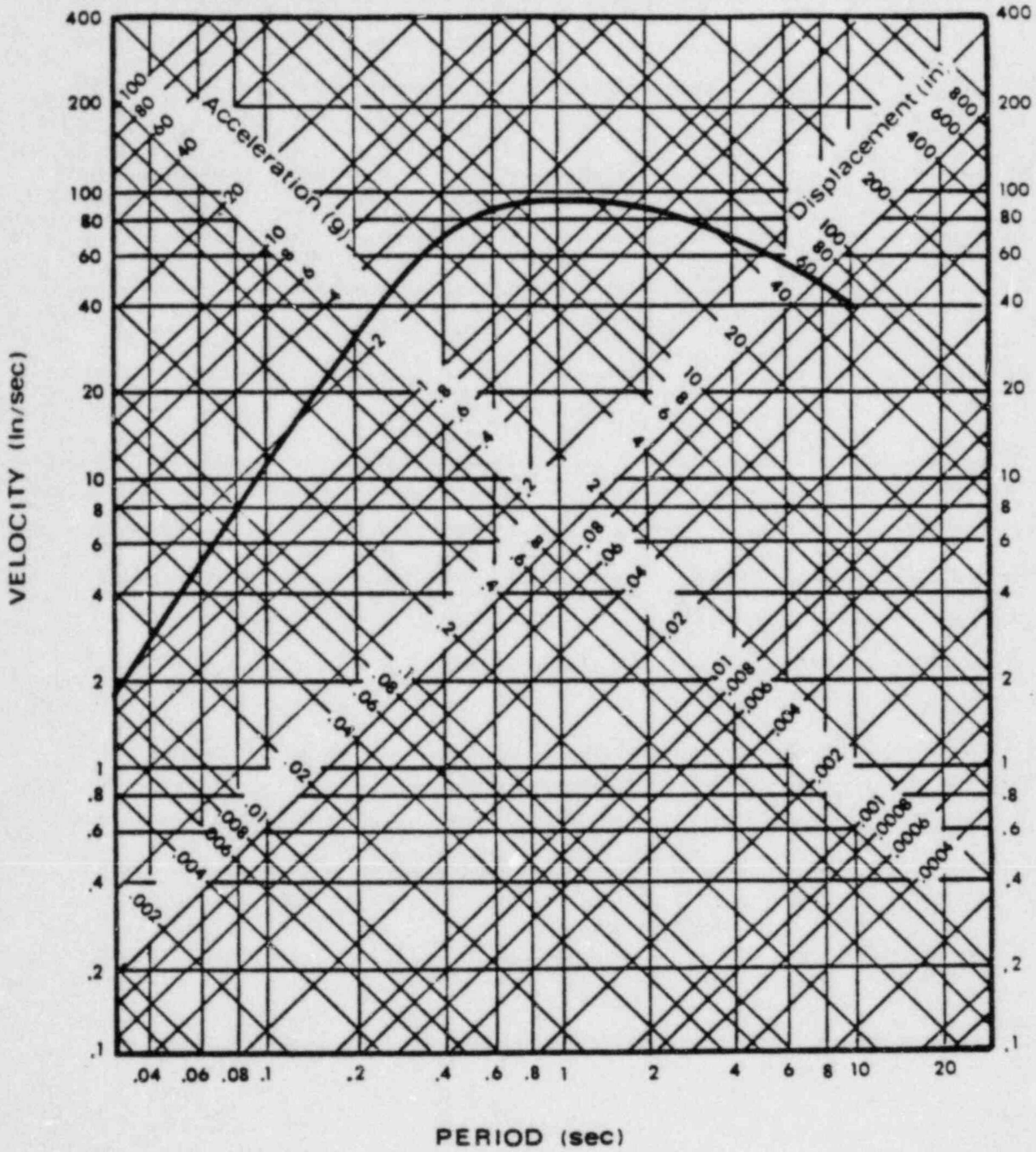

FIGURE 5-12

DESIGN RESPONSE SPECTRUM SCALED TO 1.0 g
(5% OF CRITICAL DAMPING)

SAVANNAH RIVER

TERA CORPORATION

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2 pages

July 25, 1977

To: Steve Varga
NRC
5.

From: GPCo.
Atlanta

United States Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
ATTN: Mr. Steven A. Varga, Chief
Light Water Reactors Branch 4
Division of Project Licensing
Washington, D. C. 20555

NRC DOCKET NUMBERS 50-424, 50-425
CONSTRUCTION PERMIT NUMBERS CPPR-108, 109
ALVIN W. VOGTLE NUCLEAR PLANT UNITS 1, 2
CATEGORY I BACKFILL

Gentlemen:

This will confirm the clarification and agreements reached with your NRC staff at the meeting in Bethesda on July 22, 1977 in connection with the Category I backfill at the Alvin W. Vogtle Nuclear Plant.

More specific details concerning the words used in the PSAR in connection with the Category I backfill were discussed. Specifically, a more detailed definition of the meaning of the words "select sand" was given and the manner in which "97 percent compaction" will be tested and evaluated in the field was defined.

"Select Sand"

The clarification of the terminology of "select sand" expressed in Section 2.5.1.7.3 of the PSAR is the sands and silty sands from required excavation, stockpiles and borrow areas. The sands and silty sands, regardless of the specific source from which they are obtained, are considered to be "select sands" as discussed in the PSAR and other relevant documents in connection with the Vogtle Plant.

Compaction Criteria

The average compaction shall be 97 percent of the maximum determined by ASTM D1557 with no tests below 93 percent and not more than 10 percent of the tests shall be below 95 percent in a set of 20 tests. These in-situ tests will be made at a depth not exceeding 24 inches.

Minimum Testing Frequency

In-situ density tests will be made at a minimum frequency of one test per 20,000 square feet of fill placed per foot of depth. The average compaction will be evaluated for each set of 20 field density tests made after placement in any area in which fill is placed.

U. S. Nuclear Regulatory Commission
ATTN: Mr. Steven A. Varga, Chief
Page two
July 25, 1977

All of the analyses and information presented in the PSAR are valid taking into account the clarifications presented above.

During the July 22, 1977 meeting, you were informed that a program is underway to analyze soils for backfill of different characteristics and different specifications for compaction which will conservatively meet the safety requirements for the Vogtle Nuclear Plant.

Presently it is expected to have the analyses completed and criteria established by November, 1977. At that time it is planned to request a meeting with the NRC Staff to present the bases for the modified criteria.

It is emphasized that the information presented above is merely a clarification of existing criteria and in no way represents any change in the commitments made in the PSAR.

Your arranging the July 22, 1977 meeting and your participation and that of your key staff personnel is very much appreciated.

Yours very truly,

W. E. Ehrensperger
W. E. Ehrensperger

WEE/JAB/nc

xc: Mr. D. L. McCrary
Mr. I. S. Mitchell, III
Mr. R. A. Thomas
Mr. J. A. Bailey
Mr. D. E. Dutton
Mr. Walter R. Ferris
Mr. L. T. Gucwa
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George F. Trowbridge, Esquire

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EFFECTS OF LATE CRETACEOUS AND CENOZOIC FAULTING ON THE GEOLOGY AND HYDROLOGY OF THE COASTAL PLAIN NEAR THE SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

By Robert E. Faye and David C. Prowell

Open-File Report 82-156

Doraville, Georgia

1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

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6481 Peachtree Industrial Boulevard, Suite B
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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who may prefer to use the International System (SI) of units, rather than inch-pound units, the conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric unit)
ft (foot)	0.3048	m (meter)
ft/s (foot per second)	0.3048	m/s (meter per second)
ft^2/d (feet squared per day)	0.0929	m^2/d (meters squared per day)
mi^2 (square mile)	2.590	km^2 (square kilometer)

EFFECTS OF LATE CRETACEOUS AND CENOZOIC FAULTING ON THE GEOLOGY AND HYDROLOGY OF THE COASTAL PLAIN NEAR THE SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

by

Robert E. Faye and David C. Prowell

ABSTRACT

Geologic and hydrologic investigations by the U.S. Geological Survey have defined stratigraphic and hydraulic anomalies suggestive of faulting within Coastal Plain sediments between the Ogeechee River in east-central Georgia and the Edisto River in west-central South Carolina. Examination of borehole cuttings, cores, and geophysical logs from test wells indicate that Triassic rocks and Upper Cretaceous and lower Tertiary Coastal Plain sediments near the Barnwell-Allendale County line near Millett, South Carolina, are offset by a northeast-trending fault downthrown to the northwest. The location of this suspected Coastal Plain fault generally coincides with the location of an inferred fault in basement rocks as interpreted from aeromagnetic surveys. Apparent vertical offsets range from about 700 feet at the base of Upper Cretaceous sediments to about 20 feet in strata of Late Eocene age. As a result, the Upper Cretaceous Middendorf Formation which directly overlies crystalline and Triassic rocks updip (northwest) of this fault, is absent immediately downdip of the fault. The thickness of Upper Cretaceous sediments is also sharply reduced from about 700 feet to about 180 feet across the fault.

Sediments of the basal Coastal Plain aquifer are largely truncated by uplifted Triassic rocks at the fault near Millett, South Carolina. Lateral ground-water flow near the Savannah River is consequently disrupted updip of the fault and ground water is transferred vertically into overlying sediments and possibly into the Savannah River. At several locations, abrupt changes in potentiometric head occur across this fault. Computed transmissivity of the basal Coastal Plain aquifer is also radically reduced downdip of the fault, sharply reversing a downdip trend of rapidly increasing aquifer transmissivity.

Other anomalous potentiometric data along a northeast-trending line between Statesboro, Georgia, and Fairfax, South Carolina, suggest the possibility of similar faulting in correlative geologic units. The location of the suspected fault near Statesboro, Georgia, generally coincides with the eastward extension of the Gulf Trough, a regional potentiometric anomaly in central Georgia.

INTRODUCTION

Investigations undertaken as part of the U.S. Geological Survey's Southeastern Atlantic Coastal Plain Regional Aquifer Systems Analysis (RASA) have defined anomalous geologic and hydraulic data suggestive of recurrent faulting within Coastal Plain sediments in east-central Georgia and west-central South Carolina. The general area of study is bordered to the west and east by the Ogeechee and Edisto Rivers, respectively (fig. 1). Potentiometric anomalies and radical changes in

Figure 1.--(Caption on next page) belongs near here.

aquifer transmissivity and in aquifer discharge to area streams were observed within parts of two regional Coastal Plain aquifers comprised of sediments of Late Cretaceous and early Tertiary age. Site-specific investigations of subsurface lithology were consequently undertaken to determine the origin and nature of the observed anomalies. Detailed analyses of borehole cuttings, geophysical logs, and palynological data at well sites adjacent to and along a line generally parallel to the Savannah River indicated the presence of faulting of Triassic rocks and Coastal Plain sediments near Millett, S.C. Cretaceous sediments are vertically offset approximately 700 ft, probably by en echelon reverse faulting similar to that previously observed along the Belair fault zone near Augusta, Ga., by Prowell and O'Connor (1978). Northeast-trending potentiometric anomalies and limited geologic data imply the presence of another fault which offsets correlative Coastal Plain sediments between Statesboro, Ga., and Fairfax, S.C.

Figure 1.--Location of study area.

The purpose of this paper is to describe and, where possible, quantitatively document the geologic, hydrologic, and hydraulic effects of faulting of Coastal Plain sediments within the study area. The geology and hydrology of regional aquifers are briefly described to provide bases for interpretation. Data sources and interpretive methods unique to various aspects of this study are discussed selectively in the text. Methods pertinent to the map location of well-data points are described in the Supplemental Information section at the end of the report.

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GEOLOGY

The emerged Coastal Plain in the vicinity of the Savannah River is a southeastward thickening wedge of semiconsolidated to unconsolidated strata of Cretaceous to Holocene age. The strata, in general, dip gently to the southeast; hence, "down dip" as used in this report means "southeastward". Outcrop areas of Cretaceous through middle Eocene sediments critical to this study are shown in figure 2. The inner margin of the Coastal

Figure 2.--(Caption on next page) belongs near here.

Plain noted in figure 2 is the updip limit of Upper Cretaceous and lower Tertiary sediments and is defined by the exposed unconformable contact between crystalline rocks and Coastal Plain sediments. The stratigraphic correlation of Coastal Plain sediments within the study area to contemporaneous sediments of the Atlantic and Gulf Coastal Plains is illustrated in table 1. Lithologic units described in table 1 pertinent to

Table 1.--(Caption on page 8) belongs near here.

the Savannah River area refer to the geologic section of Coastal Plain sediments shown in figure 3.

Figure 3.--(Caption on page 9) belongs near here.

ERA	PERIOD	Duration m.y.	Age m.y.
CENOZOIC (65)			65
MESOZOIC (160)	CRETACEOUS	71	136
	JURASSIC	54	190
	TRIASSIC	35	225
PALEOZOIC (345)	PERMIAN	55	280
	CARBONIFEROUS	65	345
	DEVONIAN	50	395
	SILURIAN	35	430
	ORDOVICIAN	70	500
	CAMBRIAN	70	570
PRECAMBRIAN	UPPER PRECAMBRIAN		
	MIDDLE "		
	LOWER "		

Figure 2.--Outcrop areas of Upper Cretaceous through middle Eocene sediments and critical data-collection sites.

Table 1.--Generalized correlation of stratigraphic, lithologic, and aquifer units

Figure 3.--Geologic section along line A-A'.

Regional Stratigraphy and Lithology

Crystalline Rocks

Paleozoic crystalline rocks that include gneiss, schist, quartzite, and granites of the Kiokee belt and metavolcanic rocks of the Little River Series of Crickmay (1952) underlie Coastal Plain sediments within the updip parts of the study area (LeGrand and Furcron, 1956; Siple, 1967; Prowell and O'Connor, 1978; Marine, 1979). The age of the Belair belt of the Little River Series was established as Paleozoic (probably Cambrian) from a trilobite found near Augusta, Ga. (Maher, 1981). The ages of the Kiokee belt and the remaining Little River Series are also considered Paleozoic. Crystalline rocks crop out within the study area north of the inner margin of Coastal Plain sediments and downdip in the channels of larger streams (fig. 2). Crystalline rocks unconformably underlie Cretaceous Coastal Plain sediments downdip to a line extending approximately from Wadley in southern Jefferson County, Ga., to Williston in Barnwell County, S.C. The upper 10 to 100 ft of the crystalline rock both in the exposed Piedmont and in the subsurface northwest of this line is typically saprolite. Saprolite is formed by the in place weathering of crystalline rock with the preservation of the relict texture of the parent rock. Saprolite can be distinguished from the overlying poorly consolidated Coastal Plain sands and gravels by mineralogy and texture and commonly by abrupt changes in the trends of electrical resistivity and spontaneous potential curves of bore-hole geophysical logs.

South of the line from Wadley to Williston, drill-hole data defining the nature of the crystalline rocks are unavailable. Drill holes penetrating the Cretaceous strata in this region bottom in unmetamorphosed red beds.

Triassic Rocks

Moderately to well-indurated interlayered dark-red claystones, siltstones, sandstones, and fanglomerates are present in the subsurface between the crystalline basement and the Cretaceous Coastal Plain strata generally southeast of the line between Wadley, Ga., and Williston, S.C. These rocks are interpreted as river and lake deposits formed in a continental environment. The fanglomerate layers, particularly those in the cores from well P5 and the cuttings from well AL-66 (fig. 3), contain an assortment of rock fragments that have been derived from other rock units. Greenschist clasts similar in lithology to the rocks labeled Pz_3 on figure 3 have been found in the samples from AL-66 and they indicate the presence of an exposed crystalline terrane during erosion and deposition. No fossils have been recovered from these red beds but by analogy with similar rocks in the Eastern United States, they are probably of Triassic to Early Jurassic age. In this report, these red beds are referred to as Triassic rocks, or rocks of Triassic age.

A weathered zone typically less than 50 ft thick is commonly present at the top of the Triassic red beds. The contact between Triassic rocks and overlying sediments can be distinguished by lithologic changes and is commonly characterized on electric logs by a relatively sharp reduction in electrical resistivity and spontaneous potential compared to the poorly consolidated overlying Cretaceous sands and gravels.

The geology and hydrology of Triassic rocks which underlie the SRP (Savannah River Plant) have been extensively investigated to evaluate

their storage potential for radioactive wastes. Results of these studies are described by Christl (1964), Marine (1973; 1979), and Marine and Siple (1974). Lithologic and geophysical drill-hole data in U.S. Geological Survey files from South Carolina and Georgia were examined by the authors to determine the altitude of the base of Cretaceous Coastal Plain sediments. Individual data points with designation of pre-Cretaceous rock type in the drill holes are shown in figure 4.

Figure 4.—(Caption on next page) belongs near here.

Coastal Plain Sediments

Coastal Plain sediments within the study area range in age from Late Cretaceous through early Tertiary and form a seaward thickening, wedge-shaped section of poorly consolidated lithologic units. Successively

Figure 4.--Altitudes at the base of Coastal Plain sediments.

younger sequences of sediments crop out generally seaward of older sediments and generally dip at a correspondingly smaller angle. Only Upper Cretaceous through middle to upper Tertiary sediments are considered in detail in this study.

Upper Cretaceous fluvial and marine sediments of Santonian to Maestrichtian age unconformably and continuously overlie Paleozoic crystalline or Triassic sedimentary rocks throughout most of the study area. These sediments were formerly considered contemporaneous with the Tuscaloosa Formation of Alabama and southwest Georgia (LeGrand and Furcron, 1956; Siple, 1967), but are now known to be younger and contemporaneous with the Middendorf, Black Creek, and Peedee Formations of South Carolina (Raymond A. Christopher, U.S. Geological Survey, written commun., 1980-81). Sediments of Campanian and Maestrichtian age correlative with the Black Creek and Peedee Formations are subsequently termed the Black Creek (?) Formation in this report. Sediments of the Upper Cretaceous Middendorf Formation (table 1) comprise the basal part of the Coastal Plain downdip to approximately the southern boundaries of Burke County, Ga., and Barnwell County, S.C., where they are abruptly terminated (fig. 3). Downdip from this area, for an undetermined distance, the basal Coastal Plain is probably comprised of sediments correlative with those of the Black Creek Formation of eastern South Carolina.

Sediments of the Middendorf and Black Creek(?) Formations are difficult to differentiate updip of the SRP and are characterized by poorly consolidated, kaolin-rich, fine- to coarse-grained sands and

gravels. These sediments are irregularly crossbedded and commonly contain discrete, generally discontinuous layers of kaolin and lenses of well-rounded quartz gravel. A zone of oxidation and weathering marks the Middendorf-Black Creek(?) contact. Sediments of the Black Creek(?) Formation are typically marine and are comprised of well-bedded, fine- to coarse-grained, clayey sand containing significant quantities of carbonaceous material. This unit is generally a fining-upwards sequence of sands and silty clays the upper part of which contains thin commercial grade kaolin deposits.

Basal sediments of the Middendorf Formation at the SRP and probably elsewhere consist of a semiconsolidated sandy clay overlying a tan to buff-colored indurated silty to sandy clay (Marine and Siple, 1974). The entire basal section of semiconsolidated clay ranges in total thickness from about 40 to 150 ft and is characterized on electric logs as a zone of low electrical resistivity which contrasts sharply with overlying highly resistive, poorly consolidated coarse sands. The basal and upper units of the Middendorf Formation and the sediments of the Black Creek(?) Formation are designated UK1, UK2, and UK3, respectively, in table 1 and in figure 3.

Unconformably overlying the Upper Cretaceous sediments throughout most of the study area is a continuous dark-gray to black, sandy, lignitic micaceous clay. The basal part of this unit consists of gray to bluish-gray, clayey quartz sand and gravel. Downdip of the SRP, these sediments

change facies to a carbonaceous marl. Siple (1967) formally named this unit the Ellenton Formation and suggested that it is probably contemporaneous with youngest Upper Cretaceous or lower Paleocene sediments observed elsewhere in South Carolina. Core samples of what is probably the Ellenton Formation were obtained from the site of Georgia Power Company's Plant Vogtle in Burke County, Ga., near TW-1 (figs. 2 and 3). Palynological analyses of these samples establish the age of the sediments as early to middle (Midwayan) Paleocene (Norman O. Frederiksen, U.S. Geological Survey, written commun., 1980) which is the age assignment used for the Ellenton Formation in this report.

Lower to middle Paleocene sediments occur only in the subsurface within the study area, generally seaward of a line between Louisville in Jefferson County, Ga., to Jackson in Aiken County, S.C., and range in thickness from a few feet to more than 150 ft. The upper contact of these Paleocene sediments is distinguished lithologically by the generally massive, lignitic clay in the upper part of the unit and on geophysical logs as a zone of low electrical resistivity and relatively high natural gamma radiation. Sediments of early to middle Paleocene age are labeled P1 in table 1 and in figure 3.

Sediments of late Paleocene to early Eocene(?) age occur only in the subsurface, generally seaward of a line between Perkins in Jenkins County, Ga., and Barnwell in Barnwell County, S.C. These sediments are characterized by calcareous, partially glauconitic, fine- to coarse-grained quartz sand within a matrix of light-gray to off-white calcareous clay.

Downdip these sediments undergo a facies change to sandy limestone and limestone. The maximum thickness of this unit within the study area is about 100 ft. Sediments of late Paleocene and early Eocene(?) age are designated P2 in table 1 and in figure 3 and are possibly contemporaneous with the Black Mingo Formation described by Siple (1975).

Sediments of middle Eocene (Claibornian) age unconformably and discontinuously overlie Upper Cretaceous sediments throughout updip parts of the study area and continuously overlie Paleocene sediments downdip in the subsurface. These sediments are contemporaneous with the Hatchetigbee, Tallahatta, and Lisbon Formations of southwest Georgia (Cederstrom and others, 1979, table 1), the Huber Formation of central Georgia (Buie, 1978), and the "Claiborne undifferentiated" unit and the McBean Formation in South Carolina described by Siple (1955; 1967). The McBean Formation as defined by Herrick and Counts (1968) is contemporaneous only with the uppermost outcropping sediments of middle Eocene age. Updip of McBean Creek (Burke County, Ga.), sediments immediately underlying the McBean Formation of Herrick and Counts (1968) were formerly considered part of the Upper Cretaceous. They are now known to be middle Eocene and are assigned to the Huber Formation. Sediments of youngest middle Eocene age (McBean Formation) crop out in eastern Georgia in the valley of McBean Creek near its confluence with the Savannah River in Richmond County and in the valley of Brier Creek in northern Burke County. Older sediments of middle Eocene age (Huber Formation) crop out within a belt extending from northern Jefferson County, Ga., to northern Aiken County, S.C. (fig. 2). Undifferentiated sediments of middle Eocene age crop out in South

Carolina in the valleys of Holley Creek, Upper Three Runs Creek, Town Creek, Tims Branch, and Tinkers Creek in Aiken and Barnwell Counties (fig. 2).

Within updip parts of the study area (fig. 2) the lowermost sediments of middle Eocene age are lithologically similar to the underlying Upper Cretaceous sediments and consist of fine- to medium-grained, unconsolidated kaolinitic quartz sand, clayey silt, and beds and lenses of commercial grade kaolin. The uppermost middle Eocene sediments consist of green glauconitic, sandy marl and beds of impure and silicified, fossiliferous limestone. Downdip in the vicinity of the SRP, sediments of middle Eocene age are comprised largely of calcareous sands and sandy limestones. Generally south of Burke and Jefferson Counties, Ga., and Barnwell County, S.C., middle Eocene sediments undergo abrupt facies changes to a sandy limestone and limestone, reaching a maximum thickness of about 300 ft. Where possible, sediments of middle Eocene age are subdivided lithologically in table 1 and in figure 3 into units E1 and E2, E3, and E4.

Sediments of late Eocene (Jackson) age overlie middle Eocene sediments in most of the study area. These upper Eocene sediments are contemporaneous with the Ocala Limestone (Herrick and Counts, 1968; Siple 1955, 1967: Huddleston and Hetrick, 1979) and the Santee Limestone (Hazel and others, 1977) and have traditionally been called the Barnwell Formation. Upper Eocene sediments updip are characterized by red to tan clayey sands, green to gray carbonaceous clay, and calcareous sands containing thin fossiliferous limestone beds. Updip the calcareous sands and limestones which form the basal part of the upper Eocene sequence are lithologically distinct

from the underlying green sandy marl of youngest middle Eocene age. Downdip this distinction is less apparent as both middle and upper Eocene sediments undergo facies changes to sandy limestone and limestone. Upper Eocene sediments are designated E5 and E6 in table 1 and in figure 3.

Geologic Section

Borehole cuttings, cores, and geophysical logs from selected control wells were analyzed to delineate the lithologic and stratigraphic characteristics of geologic units along the line A-A' shown in figure 2. The geologic section shown in figure 3 illustrates the stratigraphic and structural relationships derived from the data analyses. Control wells not directly on the line of section were projected to the line over the shortest horizontal distance. Structure contour maps by Siple (1967) and Prowell and O'Connor (1978) indicate that the Coastal Plain strata strike northeast and the line of section is generally parallel to true dip in the Coastal Plain strata northwest of well P5. Southeast of well AL-66, however, beds strike more easterly reflecting the influence of the Cape Fear arch (not shown in fig. 2). This change in strike and the northward divergence of control wells AL-19 and AL-23 from the section line results in an apparent but false flattening of sedimentary units seaward of well AL-66.

Geologic units of similar lithology, texture, and age are represented on the section by informal letter and number designations. This method of classification designates specific geologic units without the geologic connotations of regional formation names. For purposes of comparison, however, the names of correlative geologic formations have been included in the geologic section explanation and in table 1. Various geophysical logs used in conjunction with the examination of the borehole cuttings and in the extrapolation of geologic contacts between wells are shown with the control wells on the section. In the preparation of the geologic section, lithologic logs of borehole cuttings were compared with the corresponding

geophysical logs to better establish the position of lithologic contacts and to provide information about sample contamination due to downhole caving. The inaccuracy of the samples, however, may result in a + or - 10-foot error in the position of any contact shown in figure 3. Paleontologic control points are shown on well columns P-1 and TW-1 in the section but evidence of the age of other units is commonly derived by extrapolation of data from surface outcrops and other drill holes.

Two previously reported faults and their related lithologic discontinuities are shown in figure 3. The Belair fault, previously described by Prowell and O'Connor (1978), is a zone of reverse faults which vertically offset Santonian (Upper Cretaceous) sediments about 40 ft near well MZ-1 (fig. 2). At this locality, Piedmont crystalline rocks are faulted over Coastal Plain strata along a high angle reverse fault trending to the northeast. Subsequent erosion has removed the Coastal Plain strata from the upthrown block exposing metavolcanic crystalline rocks. The crystalline rock - Triassic rock contact in the subsurface at the SRP was described by Christl (1964), Siple (1967), and Marine and Siple (1974) as a normal fault of undetermined total displacement. This fault forms the northwestern border of the "Dunbarton" Triassic basin (Marine and Siple, 1974) but it displaces only pre-Cretaceous rocks. Therefore, the line on the geologic section representing this fault terminates at the base of the Cretaceous Coastal Plain strata. The following section of this report contains a more detailed discussion of structural features within the study area.

The positions of correlative sedimentary contacts at control wells P5 and AL-66 (fig. 3) initially indicated anomalous dip changes

and AL-66 is not known, but its position in figure 2 was determined by available potentiometric data (figs. 6 to 9) and the abrupt change in the meander pattern of the Savannah River. The proposed Millett fault displaces the Triassic-Cretaceous contact approximately 700 ft vertically and is shown as a reverse fault suggesting a geometric similarity to the Belair reverse fault at Augusta, Ga., and the Cooke and Helena Banks reverse faults reported near Charleston, S.C. (Behrendt and others, 1981). The amount of displacement suggested by correlative geologic contacts has been estimated by projecting the contacts to the fault line at the same dip recognized in the equivalent contacts updip of well P5. As discussed previously, the dip of the Coastal Plain strata southeast of well AL-66 is not true dip and, therefore, the slope of the contacts could not be used in the extrapolation of units from AL-66 to the fault plane. Localized changes in the dip of the Coastal Plain strata may shift the position of the intersections of the geologic contacts with the suggested fault plane and the value of any displacement measurement may vary by 10 to 20 ft.

The correlation of units between wells P5 and AL-66 suggests that successively younger strata are displaced to a lesser degree. Unit UK_1 on the geologic section (fig. 3) and probably all of unit UK_2 are not represented in the sedimentary sequence on the southeast (upblock) side of the Millett fault. This suggests that these units either never existed on the upblock or they were eroded after some stage of Cretaceous faulting. Similarly, subsequent movement along the fault has resulted in the thickening of some units on the northwest (downblock) side of the fault, but the displacements were too small to completely exclude their upblock counterparts. These conditions suggest that the Millett fault was active spasmodically, if not continuously, from the Cretaceous through the late Eocene.

Structure

Contour maps by Siple (1955, figs. 4 and 9: 1967, pls. 4 and 5) and Prowell and O'Connor (1978, figs. 2 and 3) show the configuration of the unconformity at the surface of "basement rocks" and the top of Upper Cretaceous sediments in most of Aiken and Barnwell Counties, S.C., and Richmond County, Ga. The strike of the basement rock surface in this region is about N. 66° E. and the dip is about 30 to 35 ft/mi to the southeast. The top of Upper Cretaceous sediments strikes similar to the basement surface but dips at a rate of about 15 to 20 ft/mi to the southeast.

Altitudes of the base of Cretaceous Coastal Plain sediments and designations indicating underlying rock types are shown in figure 4. Many of the irregularities shown in figure 4 are probably the result of erosion and deposition. However, abrupt changes in the altitude of the basal Coastal Plain unconformity provided a basis for Prowell and O'Connor (1978) to delineate the Belair fault zone near Augusta, Ga. Similar abrupt changes in the altitude of this unconformity near the Barnwell County-Allendale County line in South Carolina provided initial evidence for the existence of the Millett fault.

Faulting

The Belair fault zone near Augusta, Ga. (Prowell and O'Connor, 1978) is a zone of northeast-trending, high angle, en echelon reverse faults that displace Upper Cretaceous and younger sediments near the inner margin of the Coastal Plain (fig. 2). A segment of the Belair fault zone is shown on the geologic section near well MZ-1 (fig. 3). Southwest of this locality, Prowell and O'Connor (1978) reported that the fault displacements

reach a maximum of about 100 ft in Upper Cretaceous strata and about 40 ft in upper Eocene strata. This evidence suggests at least two episodes of fault movement. Prowell and O'Connor (1978) also reported that the fault plane dips about 50° to the southeast and is marked by a thick, clayey gouge zone.

Southeast of the Belair fault zone, Marine and Siple (1974) described the northwest contact of Triassic and crystalline rocks at the SRP as a Triassic basin border fault and reported seismic reflection data which indicated no offset of the basal Cretaceous unconformity. The seismic data substantiated previous examinations by Marine (1973) of lithologic and geophysical data from boreholes across the fault. Seismic reflection data on the southeast side of the SRP, however, were reported by Marine (1973) to show some apparent discontinuities at the Cretaceous-Triassic unconformity.

Siple (1967) considered the radical changes in natural gamma radiation levels shown on the aeromagnetic map of Petty and others (1965) at the southern end of the SRP to be indicative of faulting at the southeastern border of the buried Dunbarton Triassic basin of Marine and Siple (1974). Based on essentially the same aeromagnetic data supplemented with seismic refraction data, Daniels (1974) inferred the location of a basement fault in the same general location. The fault noted by both Siple and Daniels is generally coincident with the proposed Millett fault.

Unlike the northwestern border fault of the Dunbarton basin, the Millett fault offsets Cretaceous, Paleocene, and Eocene strata overlying the Triassic red beds. Evaluation of the drill-hole samples of these sub-horizontal Coastal Plain units provides evidence related to the vertical

movement of the fault but there are no critical markers to define amounts of horizontal movement. Measurement of the vertical displacement of the dated geologic units shown in figure 3 indicates that movement has diminished through geologic time. The 700-foot offset at the base of the Santonian (80 m.y. old) unit UK_1 suggests a displacement rate of about 8 or 9 ft per million years, whereas the 220-foot offset at the base of the late Campanian (70 m.y. old) unit UK_3 suggests a displacement rate of about 3 ft per million years. Similarly, the suggested 20-foot offset of the upper Eocene (40 m.y. old) unit E_6 suggests a displacement rate of only 0.5 ft per million years. These rates are very similar to rates calculated for other Cretaceous and younger faults in the Southeastern United States (Wentworth and Mergner-Keefer, 1981).

The Cooke fault and the Helena Banks fault (not shown on figures) of Behrendt and others (1981) are northeast-trending reverse faults near Charleston, S.C. The Cooke fault has been recognized by seismic reflection profiling northwest of Charleston and the Helena Banks fault has been recognized in offshore seismic surveys. The geometry of these faults and the reported characteristics of the Belair fault zone (Prowell and O'Connor, 1978) provided a basis for describing the geometry of the Millett fault, which is shown in figure 3 as a reverse fault steeply dipping to the southeast. The Millett fault strikes about N. 50° E. and probably exceeds 40 mi in length. If the Millett fault is similar to the Belair fault zone, the Coastal Plain strata should be drag-folded adjacent to the fault plane, particularly in units UK_1, UK_2, UK_3, and P_1 (fig. 3).

By analogy, the Millett fault plane in these units is probably marked by a clayey gouge zone 0.5 to 1.5 ft thick. The characteristics of Cretaceous and younger reverse faults in carbonate rocks are unreported.

The position of the Millett fault at the southeastern margin of the Dunbarton Triassic basin suggests that it may be a reactivated zone of weakness that formed in pre-Cretaceous time. However, the margins of Triassic basins, such as the northwest border of the Dunbarton basin, are characteristically normal faults and the evidence from regional fault studies mentioned previously would strongly suggest that the Millett fault is a reverse fault. Reverse reactivation of a normal fault at the southern margin of the Dunbarton basin would require that the area be downthrown to the southeast whereas the geologic section (fig. 3) indicates that the area is upthrown to the southeast. Therefore, simple reactivation of an old normal fault seems unlikely. An alternate explanation would be that the Dunbarton basin was a half-graben during the early to middle Mesozoic with a fault at the northwest border. Subsequent Cretaceous and Cenozoic reverse fault movement along the Millett fault would have resulted in the present basin geometry as a full graben.

Anomalous potentiometric data in Bullock and Screven Counties, Ga., and in Hampton County, S.C., (figs. 6 to 9) seem to be extensions of and coincident with a northeast-trending band of potentiometric anomalies extending across most of the Georgia Coastal Plain. This feature was first recognized as part of the principal artesian aquifer of Georgia by

Herrick and Vorhis (1963) and was referred to as the Gulf Trough. Geologic investigations of the Gulf Trough by Gelbaum (1978) and Cramer and Arden (1980) described the trough as a narrow, fault-bounded, excessively thick, belt of Cretaceous and younger sediments characterized through most of its length by abrupt, downdip changes in potentiometric head and to some degree by downdip changes in ground-water quality (Zimmerman, 1977).

Downdip projection of the base of the Coastal Plain sediments shown in the geologic section (fig. 3) to the vicinity of the potentiometric anomaly described above suggests that the top of pre-Cretaceous rocks in the vicinity of the Screven-Effingham County line in Georgia should be approximately 2,100 ft below sea level. Examination of borehole cuttings from test well GGS-855 (fig. 2) in southern Screven County, Ga., indicates that the well was drilled to a depth of 2,547 ft below sea level but did not bottom in "basement" rocks as reported. The hole probably bottomed in the indurated unit UK_1 shown in figure 3. This increase in thickness of the Coastal Plain strata and the similarity of the potentiometric data to that along the general strike of the Gulf Trough suggests that at least one side of the Gulf Trough may extend as far east as Hampton County, S.C.

Such an extension implies that geologic conditions near the Screven-Effingham Co. line in Georgia are similar to those at the Millett fault and suggests that a similar fault is present in this area with the southeast block downthrown. This proposed fault is informally named the "Statesboro" fault in this report for its proximity to the town of Statesboro in Bulloch County, Ga. The Millett and Statesboro faults thus border a

relatively upthrown block approximately 40 mi wide and of unknown length. The upward motion of this block from the Cretaceous through the Eocene has affected both the distribution and lithology of strata overlying the block. Such effects, in turn, should influence aquifer hydraulics and regional patterns of ground-water flow.

HYDROLOGY

Aquifer Definition

The sediments described previously can be subdivided into regional aquifers and confining zones based on lithology, areal extent, and stratigraphic and lithologic continuity. Regional aquifers of interest to this study include a basal Coastal Plain aquifer comprised almost entirely of Upper Cretaceous sediments of the Middendorf and Black Creek(?) Formations and an overlying aquifer comprised of sediments of late Paleocene through middle Eocene age. The basal Coastal Plain aquifer is, to a large degree, spatially equivalent to the occurrence of Upper Cretaceous sediments and is bounded at the bottom by contact with crystalline rock saprolite, the weathered Triassic rocks, or the semi-consolidated and indurated silty clay of the basal Middendorf Formation. The upper boundary of this aquifer is generally coincident with the occurrence of lower Paleocene sediments. In the vicinity of the SRP, basal sands and gravels of early Paleocene age are considered part of the basal Coastal Plain aquifer.

The relatively thick lignitic clay of early Paleocene age is an areally continuous confining zone which separates the basal Coastal Plain aquifer from the overlying aquifer comprised of upper Paleocene through middle Eocene sediments. This overlying aquifer is, in turn, partially confined at the top by the glauconitic clay and marl of youngest middle Eocene age (McBean Formation).

Where sediments of middle Eocene age directly overlie Upper Cretaceous sediments in updip parts of the study area, the basal Coastal Plain aquifer is discontinuously confined by thick beds and lenses of kaolin and other clays near the base of the middle Eocene sediments. The aquifer comprised of middle Eocene sediments in this area is locally confined by basal clays of the upper Eocene Barnwell Formation.

For discussion purposes, the regional aquifers and confining zone will be designated as A1, A2, and C1. Correlation of this nomenclature with defined lithologic units is listed below and shown in table 1.

Aquifer and Confining Unit	Description	Lithologic correlation [Refers to table 1 and figure 3]
A2	Regional Coastal Plain aquifer, lower Tertiary sediments of late Paleocene to middle Eocene age	P2, E1
C1	Regional confining zone, lower Tertiary sediments of early and middle Paleocene age	P1
A1	Basal regional Coastal Plain aquifer, largely sediments of Late Cretaceous age	UK2, UK3, basal P1

Aquifer Parameters

Aquifer-test data pertinent to the A1 aquifer in Richmond and Burke Counties, Ga., were reported by Bechtel Corporation (1973), J. E. Sirrine Co. (1980), and W. G. Keck and Associates (1965). Corresponding data for Aiken and Barnwell Counties, S.C., were reported by Mayer (1972) and Siple (1955; 1967). Hydraulic parameters pertinent to the A2 aquifer and younger lower Tertiary sediments at the SRP are described by Siple (1975), Marine and Root (1976; 1978), and Root (1977). Additional time-drawdown data pertinent to wells in both Georgia and South Carolina were obtained from U.S. Geological Survey data files. Hydraulic characteristics of Paleozoic and Triassic rocks at the SRP are described by Christl (1964) and Marine (1979).

Point values of transmissivity of the A1 aquifer are shown in figure 5. All values were computed using time-drawdown or time-recovery data. Although these data are pertinent only to discrete parts of the

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Figure 5.--(Caption on next page) belongs near here.

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aquifer they are considered representative of relative spatial changes in transmissivity within the study area. In Georgia, A1 aquifer transmissivity increases rapidly downdip from about 3,000 ft^2/day in northeastern Richmond County to about 30,000 ft^2/day in east-central Burke County. Similarly, in South Carolina, A1 aquifer transmissivity changes from about 12,000 ft^2/day in Aiken Co. to about 30,000 ft^2/day at the SRP.

Figure 5.--Point transmissivity of the A1 aquifer.

Transmissivity of the A1 aquifer seems to be greater than 20,000 ft^2/day throughout most of the SRP. Transmissivity of the restricted A1 aquifer downdip of the Millett fault is about 6,000 ft^2/day based on measurements near Martin and near Millett in Allendale County. Thus an established downdip trend of rapidly increasing aquifer transmissivity is sharply reversed across the Millett fault; probably due, in large part, to the observed "fining upward" character of the Black Creek (?) Formation and the 60-percent reduction in aquifer thickness which occurs across the fault (fig. 3).

Results of aquifer tests pertinent to the A2 aquifer at the SRP are reported by Siple (1955) and by Root and Marine (1978). Transmissivity of this aquifer seems to be variable and ranges from about 8,000 ft^2/day to about 13,000 ft^2/day. The larger transmissivities were observed in wells open to limestone and sand. Transmissivity of the McBean Formation, which comprises the upper zone of confinement of the A2 aquifer, is probably less than 100 ft^2/day.

Potentiometric Surfaces

Potentiometric maps in this report are intended to portray predevelopment or unstressed conditions. Potentiometric data actually used were collected during 1945 to 1981. Where data were available for multiple time periods, only the earliest data or data otherwise believed to be most representative of predevelopment conditions were used in this study. Additionally, the authors believe that, with minor exceptions caused by local pumping or long-term natural stress, potentiometric heads changed little or not at all within the study area during 1945 to 1981. Unpublished water-

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level records which indicate that A1 aquifer potentiometric heads within Georgia have changed little from 1945 to present (1981) support this belief. Similarly, in South Carolina, long-term water-level hydrographs published by Marine and Routt (1975) and Root and Marine (1978) indicate annual water-level fluctuations of about 5 to 10 ft occurred in the A1 aquifer from 1951-77 due to local pumping and seasonal stress, but no long-term water-level changes were observed in the vicinity of the SRP or near Williston, S.C. These published hydrographs are considered indicative of seasonal and long-term A1 aquifer potentiometric changes in the vicinity of the SRP in South Carolina and Georgia and are probably indicative of A1 aquifer head changes throughout most of the study area. Local water-level changes within the A1 aquifer at the SRP observed in production wells or in wells near production wells ranged only from about 5 to 30 ft and were generally less than 15 ft from 1952-60 (Siple, 1967). The SRP is probably the major single user of ground water within the study area.

Local declines in potentiometric heads related to the industrial use of ground water have been recognized within the A1 aquifer, near the cities of Hampton and Varnville in Hampton County, South Carolina. Similar water-level declines within the A1 aquifer have likely occurred near the city of Allendale, S.C.

Potentiometric heads pertinent to the A2 aquifer also have remained generally constant with time. Continuous water-level hydrographs published by Siple (1967) and Root and Marine (1978) indicate that seasonal

water-level changes of about 10 ft occurred in sediments of middle Eocene age at the SRP during the periods 1951-60 and 1973-77. Siple (1967) indicates that local pumping and long-term natural stress from 1952-60 resulted in total water-level changes within the A2 aquifer ranging from about 10 to 18 ft. Unpublished water-level records for eastern Georgia also indicate generally constant A2 aquifer potentiometric heads. However, since 1979 local water-level declines have occurred west of Waynesboro in Burke County and northwest of Louisville in Jefferson County, probably in response to the use of ground water for crop irrigation.

Potentiometric data for both aquifers within and immediately downdip of their respective outcrop areas indicate that direct or nearly direct hydraulic continuity exists between the aquifers and larger streams. Consequently, in these areas, stream altitudes determined from 7 1/2-minute topographic maps were utilized to provide additional definition of the potentiometric surfaces.

Al Aquifer

The altitude of the Al aquifer potentiometric surface at individual control wells is shown in figure 6. These data suggest that the Al aquifer regional potentiometric surface within and proximate to the outcrop areas of aquifer sediments (fig. 2) is generally symmetrical to the axis of the Savannah River and is, to a large degree, a subdued expression of surface topography. Potentiometric heads within this area range in altitude from about 500 ft near the inner margin of the Georgia Coastal Plain to about 150 ft near the Savannah River. Corresponding values in South Carolina range in altitude from about 300 to 150 ft, respectively. Potentiometric gradients are consistently toward the larger streams and are generally greatest within the outcrop areas and proximate to the larger streams. Lateral potentiometric gradients toward the Savannah River northwest of the Millet fault only gradually decrease downdip toward the fault and range from about 30 ft/mi in the outcrop area to about 5 ft/mi at the SRP.

The configuration of the inferred predevelopment potentiometric surface shown in figure 6 is based entirely on control well data and the

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Figure 6.--(Caption on next page) belongs near here.

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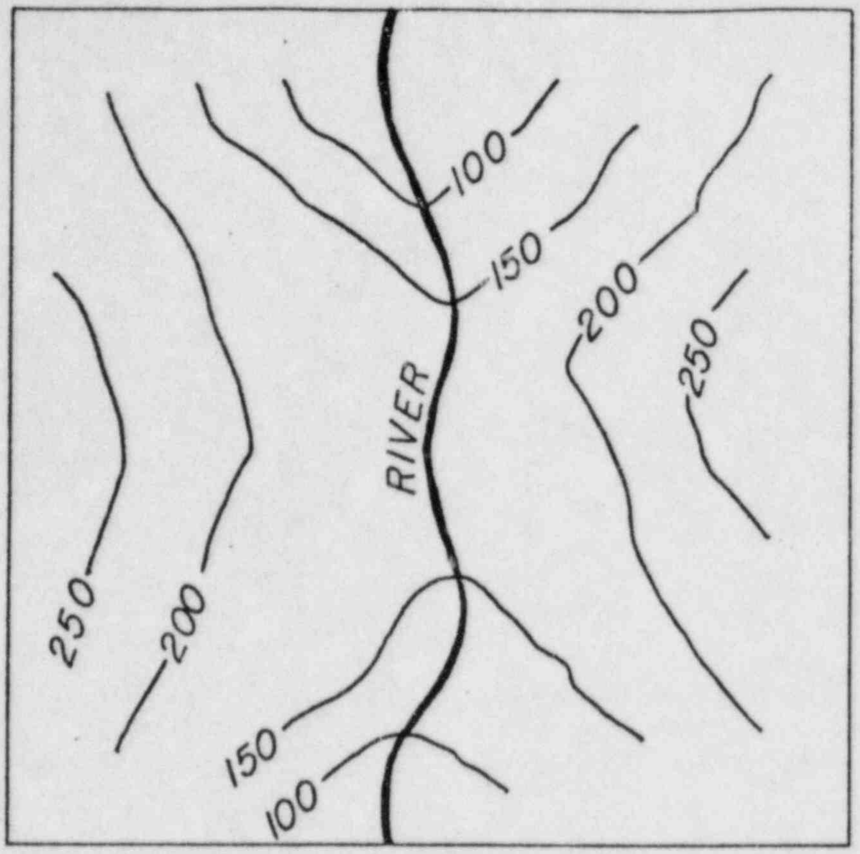
observed sensitivity of potentiometric altitudes to the proximity of the rivers and streams. Potentiometric contours were drawn disregarding geologic evidence of faulting and aquifer truncation described previously, and the Millett and Statesboro faults are shown on the map only for reference purposes.

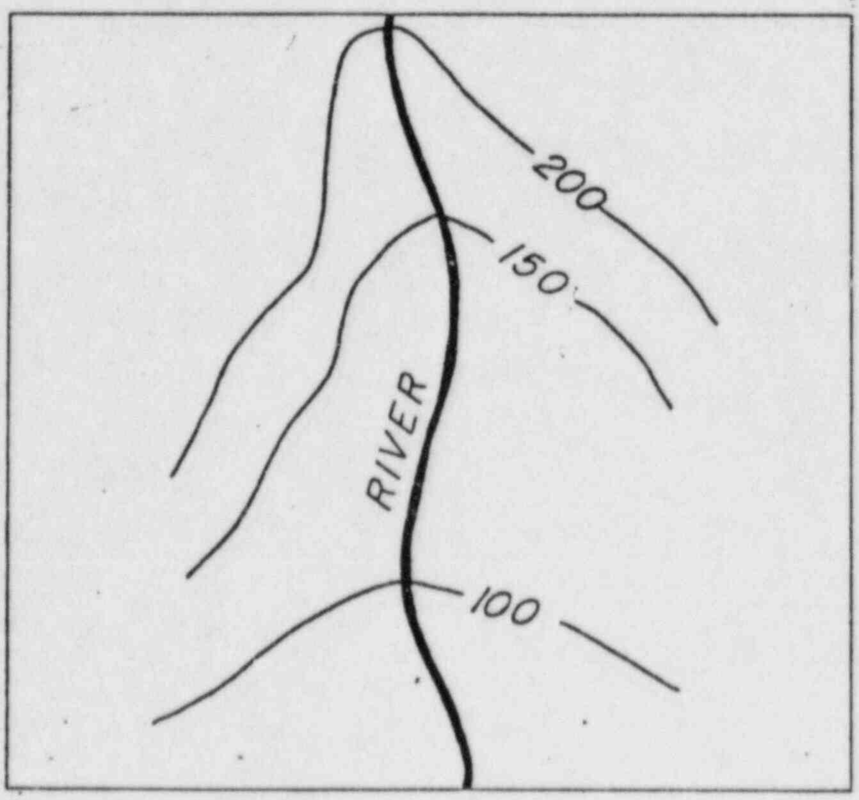
Figure 6.--Inferred predevelopment potentiometric surface of the A1 aquifer disregarding effects of faulting on ground-water flow, based on 1945-81 water-level data.

The potentiometric surface near the Savannah River northwest of the Millett fault is not well defined by point potentiometric data. Available data do, however, indicate a downdip narrowing of contours in the vicinity of central Burke County, Ga., that requires the 150-foot contour to either cross the Savannah River near the Millett fault or closely parallel the river channel to the southeast. Potentiometric contours less than 150 ft cross the river upstream of the Millett fault and form a distinctive "V" pattern symmetrical to the river. Downstream, potentiometric contours less than 150 ft cross the Savannah River and form an inverted "V" pattern also generally symmetrical to the river. This distinctive contour pattern near the Savannah River is shown diagrammatically below and was first described by Siple (1960; 1967) as a "saddle" pattern. More recently, LeGrand and Pettyjohn (1981) utilized the same description of a potentiometric "saddle" (Siple, 1960) to demonstrate a model of confined groundwater flow through undisturbed, homoclinally arranged Coastal Plain sediments and postulated the widespread existence of "saddles" within Coastal Plain aquifers of the Southeastern United States and elsewhere.

Potentiometric maps of the principal artesian aquifer in Georgia have been compiled by Mitchell (1981) and Johnson and others (1980; 1981). Pollard and Vorhis (1980) published potentiometric maps of the Cretaceous aquifer system in Georgia. Unpublished potentiometric maps pertinent to aquifers comprised of sediments of Late Cretaceous and early Tertiary age in eastern Alabama, Georgia, and western South Carolina have been compiled by ongoing Southeastern Coastal Plain RASA investigations. With the exception of the Savannah River area, the potentiometric contour configuration delineated



"SADDLE" PATTERN



INVERTED "V" PATTERN

by each of these maps near large rivers and streams is an inverted "V" pattern, shown in a generalized form in the drawing below. These maps and related potentiometric data suggest that the A1 aquifer contour configuration along the Savannah River valley southeast of Augusta is atypical with respect to corresponding patterns pertinent to correlative and lithologically similar aquifers along other large rivers within and proximate to the study area. Particularly atypical are the narrowing of potentiometric contours near the Savannah River and the resulting relatively large lateral potentiometric gradients toward the river northwest of the Millett fault.

The anomaleous A1 aquifer potentiometric contour patterns southeast of Augusta may be associated with the suggested fault displacements near Millett, S.C. The truncation of aquifer sediments by the suggested uplift of Triassic rocks (fig. 3) probably affects both the lateral and vertical flow of ground water through the A1 aquifer near and updip of the fault. A steeply-dipping clayey gouge zone in the clastic sediments along the Millett fault plane similar to that observed at the Belair fault zone (Prowell and O'Connor, 1978) could also influence the lateral and vertical movement of ground water. Similar conditions may also exist along the proposed Statesboro fault but the geologic evidence regarding this fault is very limited.

The potentiometric data shown in figure 6 were reevaluated by the authors to indicate the suggested effects of faulting on lateral ground-water flow within the study area. The authors' interpretation of the predevelopment A1 aquifer potentiometric surface is shown in figure 7.

Figure 7.--(Caption on next page) belongs near here.

Rather than extend potentiometric contours continuously across the Millett and Statesboro faults, the contours were offset at both faults. Displacement of contours across the Statesboro fault was suggested by pairs of potentiometric data points indicating abrupt lateral changes of potentiometric head ranging from about 25 ft near Fairfax, S.C., to about 40 ft near the Savannah River. Although disruption of the potentiometric surface directly across the Millett fault is not well-defined by point potentiometric data, changes in head of as much as 30 ft are implied by the paired data northwest of Millett, S.C.

Given the suggested effects of faulting on ground-water flow, the steepness and possibly the orientation of A1 aquifer potentiometric gradients between the Millett and Statesboro faults are somewhat changed from updip areas. In South Carolina, southeast of the Millett fault, potentiometric heads seem to be lowest near the fault and toward the Savannah River (figure 7). Potentiometric gradients near Barnwell are about 1.0 ft/mi to the southwest and toward the river. Near the west-central part of Allendale County potentiometric gradients seem to be generally to the north and to the northwest, toward the Millett fault and the Savannah River. Although data are incomplete, potentiometric gradients northwest of the Statesboro fault seem to be small and oriented only from the southwest toward the northeast. Potentiometric data between

Figure 7.--Map showing inferred predevelopment potentiometric surface of the A1 aquifer indicating suggested effects of faulting on ground-water flow, based on 1945-81 water-level data.

Fairfax, S.C., and the Savannah River are not available, however, and gradients may alternatively be oriented toward the Savannah River in South Carolina as well as in Georgia. Potentiometric gradients southeast of the Statesboro fault seem to be small and generally oriented only toward the Savannah River.

A2 Aquifer

The inferred predevelopment potentiometric surface of the A2 aquifer shown in figure 8 is contoured without regard to effects of faulting on ground-water flow. Regional potentiometric symmetry and subdued topographic expression are also common to this surface and characterize the potentiometric surfaces of both the A1 and A2 aquifers (figs. 6 to 9). Updip of the Millett fault in Georgia, potentiometric heads range in altitude from about 400 ft in the most updip areas to about 100 ft near the Savannah River. Corresponding values in South Carolina range in altitude from about 300 ft to 100 ft. Compared to the A1 aquifer, A2 aquifer potentiometric gradients seem to be somewhat lower updip of the Millett fault and greater within the wedge of sediments between the Millett and Statesboro faults. The A2 aquifer potentiometric surface within this wedge is characterized by a subdued expression of topography and by pronounced regional symmetry axial to the Savannah River, which sharply contrasts with the corresponding A1 aquifer surface.

Figure 8.--(Caption on next page) belong near here.

Figure 8.--Inferred predevelopment potentiometric surface of the A2 aquifer disregarding the effects of faulting on ground-water flow, based on 1945-81 water-level data.

The authors consider ground-water flow through the A2 aquifer to also be affected by faulting, although to a lesser degree than corresponding flow through the A1 aquifer. The authors' interpretation of the inferred predevelopment potentiometric surface of the A2 aquifer indicating suggested effects of faulting on ground-water flow is shown in figure 9.

Figure 9.--(Caption on next page) belongs near here.

Abrupt changes in potentiometric head ranging from about 20 to 30 ft are indicated across the Millett fault near Perkins, Ga., and in South Carolina near the Savannah River. Corresponding changes across the Statesboro fault are about 50 ft near Statesboro, Ga. The drop in A2 aquifer potentiometric head across the Statesboro fault between Statesboro and Brooklet in Bulloch County, Ga., supplements and reinforces the corresponding A1 aquifer potentiometric data, which originally led to the suggestion of this fault.

Hydraulic differentiation between the A1 and A2 aquifers is caused, to a large degree, by the confining characteristics of the carbonaceous clay of Paleocene age designated previously as C1. In updip areas, C1 is discontinuous or nonexistent and, depending on local confinement, A2 aquifer potentiometric heads may be similar to or greater than A1 aquifer heads.

Hydraulic differentiation between the aquifers generally increases downdip with the occurrence and increasing areal extent of C1 and is probably greatest near the Savannah River and other large streams.

Figure 9.--Inferred predevelopment potentiometric surface of the A2 aquifer indicating suggested effects of faulting on ground-water flow, based on 1945-81 water-level data.

North of Midville in southwest Burke County, Ga., observed potentiometric heads in adjacent wells screened individually in the A1 and A2 aquifers are offset 11 ft in altitude, with the A1 aquifer head being greater. In east-central Burke County, Ga., at the site of Plant Vogtle near TW-1 (fig. 2), A1 aquifer potentiometric heads are about 170 ft in altitude and A2 aquifer heads range from about 80 to 120 ft. Within the central part of the SRP southeast of Jackson in Aiken County, S.C., A2 aquifer potentiometric heads seem to be similar to or slightly less than A1 aquifer heads. Similar relations generally occur to the southeast, across the central part of the SRP to near the Millett fault.

Generally southeast of the SRP, sediments of the A2 aquifer and overlying sediments of late Eocene and younger age are comprised largely of limestone and sandy limestone. Such lithologies facilitate the vertical movement of ground water and direct or nearly direct hydraulic continuity exists between the A2 aquifer and ground water within overlying sediments. Consequently, surface recharge to the A2 aquifer is direct or nearly direct in interstream areas and A2 aquifer potentiometric heads in these areas may be greater than corresponding A1 aquifer heads. Relatively high A2 aquifer heads at the SRP, near Sardis in southeast Burke County, Ga., and near Swainsboro in Emanuel County, Ga., may be the result of interstream surface recharge to the A2 aquifer.

Generally south of the Millett fault in South Carolina and the Statesboro fault in Georgia, reversal of vertical potentiometric gradients seems to be everywhere complete and hydraulic differentiation between the aquifers is pronounced. At Statesboro in Bulloch County, Ga., measurements at various depths in a single test well indicate that potentiometric

heads in the A1 and A2 aquifers are at altitudes of 201 ft and 117 ft, respectively. Similar measurements at AL-27 (fig. 2) near Martin in Allendale County, S.C., indicate corresponding altitudes of 171 ft and 133 ft. At Savannah, predevelopment head differentials between the A1 and A2 aquifers probably were about 100 ft.

Ground-Water Flow

Lateral Flow

The directions of lateral flow within aquifers are indicated by their respective potentiometric maps (figs. 7 and 9). Lateral flow within the A1 and A2 aquifers northwest of the Millett fault is down gradient from interstream areas of recharge (fig. 2) toward large streams and rivers. In Georgia, Brier Creek and the Ogeechee and Savannah Rivers are shown to be major regional flow boundaries, receiving water directly from both aquifers in updip areas and indirectly by leakance through overlying sediments where the aquifers are deeply buried. Similar flow conditions exist in South Carolina with respect to Upper Three Runs Creek and the Savannah River. The A1 aquifer discharges directly into Horse Creek and Hollow Creek in Aiken County, S.C. Lateral flow in the vicinity of the Savannah River is generally directly toward the river in both aquifers. The A1 aquifer potentiometric configuration northwest of the Millett fault, particularly the narrowing of contours near the Savannah River, has been previously described as a possible manifestation of faulting. The potentiometric gradients suggested by these contours and the A1 aquifer transmissivities described previously (fig. 5) indicate that lateral flow through the A1 aquifer toward the Savannah River between Augusta and the Millett fault is probably relatively large.

Although a significant component of lateral ground-water flow through the A1 aquifer near and northwest of the Millett fault is somewhat parallel to the fault, there is also a smaller component of lateral flow generally toward or against the strike of the fault. As indicated in figure 3,

the downdip continuity of sediments within the A1 aquifer has been disrupted at the Millett fault such that thick sections of aquifer sediments are juxtaposed directly against relatively impermeable Triassic rocks. Thus, lateral flow toward the fault must move vertically upward through C1 into the A2 aquifer, or flow into the restricted part of the A1 aquifer southeast of the Millett fault. In the vicinity of the Savannah River, about 60 percent of total A1 aquifer thickness is truncated at the Millett fault (fig. 3) and lateral flow that would otherwise move as underflow down the potentiometric gradient must move vertically upward. In addition, the Savannah River is a potentiometric sink and ground-water movement toward the fault is increasingly vertical with proximity to the river. Thus, significant vertical as well as lateral flow components probably occur within the A1 aquifer northwest of the Millett fault near the Savannah River. As a result, any large-scale lateral transfer of ground water within the A1 aquifer from the northwest to the southeast across the Millett fault probably occurs largely in this area.

Consider that the transmissivity of the A1 aquifer is significantly and immediately reduced downdip of the Millett fault (fig. 5). A complete lateral transfer of water across the fault (no vertical discharge through C1), therefore, would require a large increase in potentiometric gradient near the fault and for some distance downdip. The A1 aquifer potentiometric gradients seem to increase significantly across the fault in South Carolina in the vicinity of the Savannah River; however, this

increase is local and generally reverses downdip. In addition, A1 aquifer potentiometric gradients within the wedge of sediments between the Millett and Statesboro faults were described previously as very small and trending north to northwest in the west-central part of Allendale County, directly opposite to the direction expected if ground water was moving laterally across the fault from the northwest. Thus, large quantities of lateral flow are probably not transferred across the Millett fault, near the Savannah River. Rather, most ground water within the A1 aquifer approaching this fault is probably discharged vertically through C1 into the A2 aquifer and, to some degree, into the Savannah River. Prowell and O'Connor (1978) observed 10-inch wide gouge zones in unit UK_2 at the Belair fault (fig. 3). The likelihood that a similar gouge zone of low lateral hydraulic conductivity has formed at the Millett fault restricting lateral ground-water flow, further reinforces the argument that lateral flow through the A1 aquifer across the Millett fault is minimal.

The disruption and truncation of aquifer sediments and the probable occurrence of gouge at the Millett fault indicate that ground-water flow through the A1 aquifer within the wedge of sediments between the Millett and Statesboro faults is probably hydraulically discontinuous from flow within contemporaneous sediments updip. Thus recharge to the A1 aquifer within this wedge probably occurs largely at the northeast and southwest

extremities of the Millett fault and at the southwest extremity of the Statesboro fault.

The sediments that comprise the A2 aquifer are offset only slightly at the Millett fault relative to the A1 aquifer (fig. 3) and the hydraulic effects of this offset are consequently probably less severe. Most flow within the A2 aquifer near the fault probably continues laterally across the fault, with some degree of interruption caused by fault gouge and the juxtaposition of offset limestones, sands, and clays. hypothesis - not observed

Within the wedge of sediments between the Millett and Statesboro faults, lateral flow through the A2 aquifer seems to be largely toward Brier Creek and the Ogeechee and Savannah Rivers in Georgia and toward the Savannah and Salkehatchie Rivers in South Carolina.

Vertical Flow

Vertical flow conditions within and between the A1 and A2 aquifers in the vicinity of the Millett fault have been described. Where faulting does not significantly disrupt ground-water flow, the potential for vertical leakance between aquifers is largely dependent on sediment lithology and the direction and size of the vertical potentiometric gradient. Thus, within most of the study area vertical potentiometric differentiation suggests that some water is transferred vertically upward from the A1 aquifer, through C1, and into the A2 aquifer. Such transfers are probably relatively large in the vicinity of potentiometric sinks, particularly near the Savannah River northwest of the Millett fault.

disruption of g.w. flow not observed - only hypothesized

Similarly, within updip parts of the study area, some ground water probably is transferred vertically downward from the A2 aquifer, across or around local confining zones, and into the A1 aquifer. The replica relation of each aquifer to topography has been described previously and also implies some degree of continuity of vertical flow.

Data describing vertical hydraulic differentiation within the A1 aquifer are available at several sites within the SRP and at AL-27 near Martin in northeastern Allendale County, S.C. Christl (1964) reported potentiometric heads in observation wells at the SRP where three clusters of three wells each are individually screened across a 10-foot section of sediments near the bottom, center, and top of the A1 aquifer. Differences in potentiometric head between the bottom and top of the aquifer (about 600 ft) were less than 3 ft in each cluster, indicating only a slight vertical hydraulic gradient within the aquifer. Similarly, at AL-27 (fig. 2) potentiometric heads changed only about 4 ft across the lower two-thirds of total A1 aquifer thickness (about 200 ft). Thus, flow through the A1 aquifer seems to be predominantly lateral at the two sites where definitive data are available. Whether these data are regionally representative presently cannot be determined. Vertical hydraulic gradients within the A1 aquifer near the Savannah River and other large streams updip of the Millett fault probably trend upward and probably are relatively large.

Data describing vertical hydraulic gradients within the A2 aquifer are not available. Vertical flow, however, probably is insignificant within the study area except near regional flow boundaries such as Brier Creek or the Savannah River. This concept is reinforced by a large suite of potentiometric data for Screven County, Ga., which indicates nearly direct hydraulic continuity between the limestones of the A2 aquifer and overlying limestones of late Eocene age. Data reported by Warren (1945) indicate similar continuity near Savannah in Chatham County, Ga.

Based on data from observation and pumping wells located near Fourmile Branch and the Aiken-Barnwell Co. line, Siple (1967) reported the possibility of downward vertical leakance from the A2 aquifer in response to nearby long-term pumping from the A1 aquifer. Mayer (1972) reported little or no leakance between the aquifers as a result of long-term aquifer tests near Snelling in Barnwell County, S.C.

Aquifer Discharge to the Savannah River

The Savannah River has previously been described as a regional potentiometric sink for both the A1 and A2 aquifers. The atypical A1 aquifer potentiometric contour configuration near the Savannah River northwest of the Millett fault and the resulting, relatively large lateral flow toward the river have been described previously as a possible manifestation of faulting. The truncation of A1 aquifer sediments by the Millett fault at the Savannah River and the probable vertical upward transfer of ground water from the A1 aquifer to overlying A2 aquifer sediments have also been described. Northwest of the Millett

fault the A2 aquifer is in direct hydraulic continuity with the Savannah River. Consequently, lateral flow from the A1 aquifer toward the Savannah River combined with vertical upward discharge from the A1 aquifer near the Millett fault and the river could contribute anomalously large quantities of ground water to river discharge upstream of the Millett fault. The Ogeechee River, Brier Creek, and the South Fork of the Edisto River are also potentiometric sinks relative to both aquifers.

Contemporaneous gaging-station data have been routinely collected on the Savannah River at Augusta, Ga. (station 02197000), at Burtons Ferry Bridge, Ga. (station 02197500), and near Clyo, Ga. (station 02198500). Corresponding data were collected on Brier Creek near Thompson, Ga. (station 02197520), and at Millhaven, Ga. (station 02198000). Ogeechee River stations of interest to this study are near Louisville, Ga. (station 02200500), at Scarboro, Ga. (station 02202000), and near Eden, Ga. (station 02202500). Data from gaging stations on the South Fork of the Edisto River near Montmorenci, S.C. (02172500) and near Denmark, S.C. (02173000) were also utilized (fig. 2).

Table 2 lists 30-day, 2-year (30-day Q_2) low flows for each station during the indicated period of record. Although the 30-day minimum flow probably does not occur simultaneously at each of the stations of interest, differences in streamflow between the stations are considered indicative of average, predevelopment rates of aquifer discharge to the given reach.

Baseflow is computed as aquifer discharge per square mile of drainage area. Baseflow to Brier Creek and between the two most upstream stations on the Savannah, Ogeechee, and South Fork of the Edisto Rivers is largely contributed from drainage updip of the Millett fault.

Aquifer discharge is contributed to the Savannah River between Augusta and Burtons Ferry Bridge at the rate of 0.74 $(ft^3/s)/mi^2$, which exceeds by a factor of 4 the corresponding discharge to the Ogeechee River between Louisville and Scarboro and exceeds by a factor of 1.6 and 2.0 the corresponding discharges to the South Fork of the Edisto River and to Brier Creek. Within their defined reaches, each of the streams receive discharge from contemporaneous sediments of similar lithologies. The Savannah and Ogeechee Rivers receive discharge from about the same incremental drainage areas (1,200 mi^2). Although the Savannah River is slightly more incised into Coastal Plain sediments than the other streams listed in table 2, differences in incisement are probably not significant where discharge to the river occurs from deeply buried aquifers. Thus, aquifer discharge to major rivers and streams within the study area contributed largely updip of the Millett fault from contemporaneous and lithologically similar sediments is shown to increase both eastward and westward to a maximum at the Savannah River.

Table 2.--Thirty-day, 2-year low flows at selected stations on the Savannah River, Brier Creek, and Ogeechee River, Ga., and the South Fork of the Edisto River, S.C.

U.S. Geological Survey Station No.	Station name	Drainage area (mi^2)	Period of record	30-day Q2 (ft^3/s)	Baseflow ($(ft^3/s)/mi^2$)
02197000	Savannah River at Augusta, Ga.	7,508	1960-70	6,300	
					0.74
02197500	Savannah River at Burtons Ferry Bridge, Ga.	8,650	1960-70	7,150	
					.33
0198500	Savannah River near Clyo, Ga.	9,850	1960-70	7,540	
02197520	Brier Creek near Thomson, Ga.	55	1970-80	2.35	
					.37
02198000	Brier Creek at Millhaven, Ga.	646	1960-70 1970-80	260 220	
02200500	Ogeechee River near Louisville, Ga.	800	[1]1937-49	170	
					.17
02202000	Ogeechee River at Scarboro, Ga.	1,940	1937-71	360	
					.11
02202500	Ogeechee River near Eden, Ga.	2,650	1938-74	440	
02172500	South fork of Edisto River near Montmorenci, S.C.	198	1939-65	117	
					.46
02173000	South fork of the Edisto River near Denmark, S.C.	720	1931-65	358	

[1] Adjusted to 1937-71, see Carter and Putnam (1978).

Aquifer discharge to the Savannah River downstream between Burtons Ferry Bridge and Clyo occurs at the rate of 0.33 $(ft^3/s)/mi^2$ or about 45 percent of the baseflow contributed between Augusta and Burtons Ferry Bridge. Baseflow to the corresponding reach of the Ogeechee River between Scarboro and Eden is 0.11 $(ft^3/s)/mi^2$ and amounts to about 65 percent of the flow contributed between Louisville and Scarboro. More than half the flow contributed to the Savannah River between Burtons Ferry Bridge and Clyo is contributed by Brier Creek (table 2) and is derived largely from sediments updip of the Millett fault (fig. 3). Baseflow to the lower reach of the Savannah River without the contribution from Brier Creek is 0.23 $(ft^3/s)/mi^2$, about twice the rate of baseflow contributed to the comparable reach of the Ogeechee River and only 32 percent of the baseflow contributed to the Savannah River between Augusta and Burtons Ferry Bridge. Thus, downstream trends of baseflow contributed along similar reaches of the Savannah and Ogeechee Rivers indicate that anomalously large aquifer discharges to the Savannah River occur generally upstream of the Millett fault. Similar east-west trends were discussed previously. Thus both east-west and downstream trends indicate anomalously high aquifer discharges to the Savannah River upstream of the Millett fault. Such discharges are possibly an indirect manifestation of the lateral truncation of aquifer sediments by the Millett fault (fig. 3) and the resulting atypical ground-water flow patterns northwest of the fault as well as the suggested vertical movement of ground water updip of the fault near the Savannah River.

SUMMARY AND CONCLUSIONS

Structural, lithologic, and hydraulic data strongly indicate faulting of Coastal Plain sediments near Millett in Allendale, County, S.C. Analysis of cuttings from boreholes immediately updip and downdip of the fault indicate that Upper Cretaceous and lower Tertiary sedimentary contacts show increasing displacement with increasing depth. Vertical offsets range from about 700 ft at the base of Upper Cretaceous sediments to about 20 ft in beds of late Eocene age. In addition, the Upper Cretaceous Middendorf Formation which comprises the basal 500 ft of Coastal Plain sediments on the downblock side of the fault seems to be entirely missing on the adjacent upblock.

Hydraulic discontinuities across the Millett fault include abrupt, large reductions in aquifer transmissivity and local decreases in potentiometric head. Transmissivity of the basal Coastal Plain aquifer is reduced about 75 percent across the fault, largely due to changes in sediment lithology and large reductions in aquifer thickness. Linearly aligned potentiometric anomalies beteen Statesboro, Ga., and Brunson, S.C., and the unusual thickness of Coastal Plain sediments in southern Screven County, Ga., are evidence of the suggested Statesboro fault. Ground-water flow within the basal Coastal Plain aquifer between the Millett and Statesboro faults is probably largely hydraulically discontinuous from contemporaneous sediments updip. Ground-water flow southeast of the Millett fault, is largely toward the Savannah River and to the north and northwest. Near the Statesboro fault, potentiometric gradients are small but flow seems to be from the southwest in Georgia toward the northeast to South Carolina. Lateral ground-water flow within the basal Coastal Plain aquifer is largely disrupted at the Millett fault because of the juxtaposition of hundreds of feet of aquifer sediments against relatively impermeable Triassic rocks. Thus vertical flow probably occurs within the basal Coastal Plain aquifer updip of the fault, especially near the Savannah River and may contribute to the anomalously large quantities of baseflow noted in the Savannah River between Augusta, Ga., and Burtons Ferry Bridge, Ga.

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SUPPLEMENTAL INFORMATION

Map Location of Well-Data Points

Potentiometric, lithologic, and structural data described in this report pertain almost exclusively to well-data points. Location of well-data points in Georgia and South Carolina utilized original source material, when availale, from which described locations were transferred to 7 1/2-minute or 15-minute topographic maps. Such material, for Georgia, consisted largely of well-location maps and well schedules and a drawn and(or) written description of the well location. Wells listed by LeGrand and Furcron (1956) were located using a published well-location map in combination with well-schedule data. A large number of well locations for Georgia were transferred directly from corresponding locations shown on county road maps, topographic maps, and municipal street maps. Well-location maps printed in consultants' reports were utilized extensively in Richmond and Burke Counties. To some degree the accuracy of well locations in Georgia is dependent upon when the well was drilled. The locations of most wells drilled during 1960-81 are known with a high degree of accuracy, and data pertinent to these wells comprise the majority of the data base. The locations of many of the wells listed by LeGrand and Furcron (1956) are known less accurately. Field checks of a representative sample of such wells have indicated, however, that location transfers from the published map and well schedules to quadrangle maps were generally accurate.

The transfer of well-location data to quadrangle maps for South Carolina largely paralleled corresponding efforts for Georgia. The accuracy of well locations in South Carolina, based on U.S. Geological Survey file data, is compromised to a large degree because of the nearly total lack of suitable well-location maps. Consequently, written location descriptions and Army Map Service coordinates listed on well schedules were utilized conjunctively to locate a large number of wells in Aiken, Barnwell, and Allendale Counties. Army Map Service coordinates and given land-surface altitudes were utilized almost exclusively to locate the large number of wells within the SRP listed in Siple (1955) that could not be found in U.S. Geological Survey data files. Well-data points in Orangeburg County were located using well schedules and a published well-location map from Siple (1975). Well-data points in Bamberg and Hampton Counties were located exclusively from well schedules and other pertinent information obtained from U.S. Geological Survey data files. Modern (post-1960) well data pertinent to the SRP are located with a high degree of accuracy based on reported latitudes and longitudes and SRP grid coordinates.

The accuracy of well locations in South Carolina is also somewhat dependent upon the period of time a particular well reconnaissance was conducted. Historical (pre-1960) data are the least accurately located. The lack of well-location maps has been compensated for in this study by carefully applying location descriptions written on well schedules or

other original source data to comtemporary county maps and modern quadrangle maps. These efforts in conjunction with Army Map Service coordinates, which commonly are listed on original source materials, have provided locations cf historical well-data points of sufficient accuracy to be utilized in this or similar studies. If considered doubtful, the locations of critical well-data points were field checked in both Georgia and South Carolina, wherever and whenever possible.

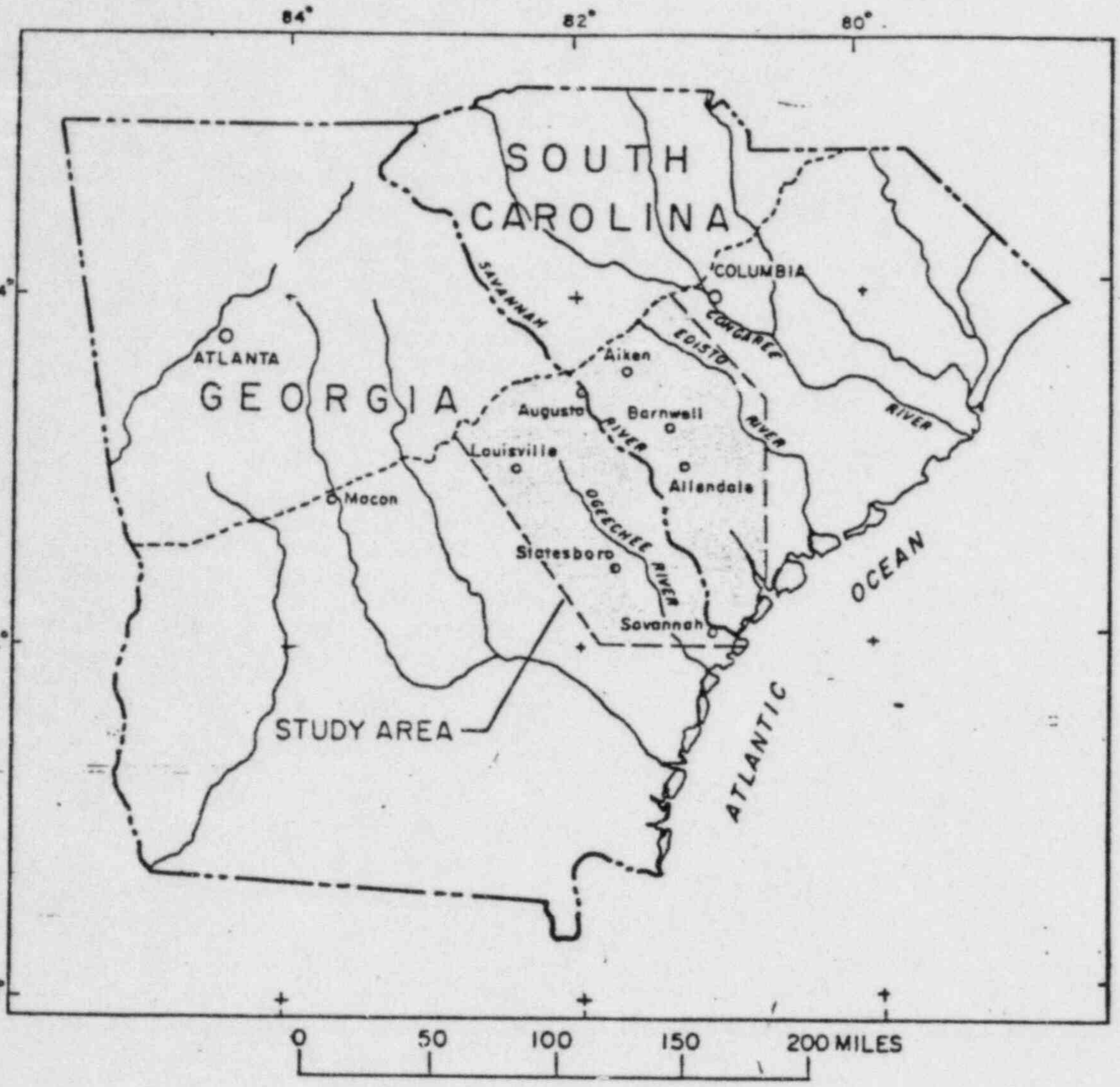

Figure 1.—Location of study area.

Table 1.—Generalized correlation of stratigraphic, lithologic, and aquifer units

Series	European Stage	Provincial Stage	New Jersey	North Carolina	Clubhouse Crossroads core South Carolina	This Report: Savannah River area Georgia and South Carolina	This Report: Lithologic unit 1/ (see fig. 3)	This Report: Aquifer-confining unit 1/	Chattahoochee River area Georgia and Alabama
OLIGOCENE	Chattian	Chickasawhayan		Trent Marl (part)	Upper part of Cooper Formation				
	Rupelian	Vicksburgian							
	Lattorfian								
EOCENE	Bartonian	Jacksonian		Castle Hayne Limestone	Lower part of Cooper Formation Santee Limestone	Barnwell Formation	E_6 E_5		Ocala Limestone Moodys Branch Formation
	Lutetian	Claibornian	Shark River Formation			McBean Formation Huber (?) Formation	E_2,E_3,E_4 E_1		Lisbon Formation Tallahatta Fm.
	Ypresian	Sabinian	Manasquan Formation					A_2	Hatchetigbee Formation
PALEOCENE	Thanetian		Vincentown Formation		Black Mingo Formation	Black Mingo Formation	P_2		Tuscahoma Fm. Nanafalia Fm.
	Danian	Midwayan	Hornerstown Sand	Beaufort Formation	Beaufort (?) Formation	Ellenton Formation	P_1	C_1	Clayton Formation
UPPER CRETACEOUS	Maestrichtian	Navarroan	Red Bank Sand Navesink Formation Mount Laurel Sand	Peedee Formation	Peedee Formation				Providence Sand Ripley Fm.
	Campanian	Tayloran	Wenonah Fm. Marshalltown Fm. Englishtown Fm. Woodbury Clay Merchantville Formation	Black Creek Formation	Black Creek Formation	Black Creek (?) Formation	UK_3	A_1	Cusseta Sand Member Blufftown Formation
	Santonian	Austinian	Magothy Fm.	Middendorf Formation / Cape Fear Formation	Middendorf Formation / Cape Fear Formation	Middendorf Formation	UK_2 UK_1		Eutaw Fm.
	Coniacian								
	Turonian	Eaglefordian							
	Cenomanian	Woodbinian	Raritan Formation	Unnamed Tuscaloosa equivalent	Unnamed Tuscaloosa equivalent				Tuscaloosa Formation

1/ Tentative age correlation

Modified from Hazel and others, 1977

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FAULTING AFFECTS COASTAL PLAIN SOUTH OF AUGUSTA, GA

Faulting of Coastal Plain sediments near the Savannah River south of Augusta, Ga., has vertically offset sediments by as much as 700 feet sometime during the past 85 million years and causes the discharge of relatively large quantities of ground water to the Savannah River, according to a recent U.S. Geological Survey, Department of the Interior, report.

Prepared as part of the USGS Southeastern Atlantic Coastal Plain Regional Aquifer Systems Analysis, the report describes vertical offsets of as much as 700 feet at the base of the Coastal Plain sediments near Millett, S.C. Intermittent vertical movement of this fault has continued through geologic time to at least the late Eocene (about 40 million years ago).

Whether the fault has moved in the last 40 million years cannot be determined with available data. There is no evidence of ground deformation or recent seismicity along the fault zone that would prove that the fault is currently active.

Truncation of the basal Coastal Plain aquifer (water-bearing rock unit) by the Millett fault "short circuits" regional ground-water flow and causes relatively large ground-water discharges to the Savannah River. Potential development of the ground-water resource southeast of the Millett fault may also have been adversely affected due to reductions in aquifer thickness.

The 73-page USGS report includes maps showing fault locations and the level to which water from the aquifer would rise in tightly cased wells (potentiometric surface) and describes regional geologic and hydrologic effects of suggested faulting near Millett, S.C., and Statesboro, Ga. The Millett fault is located about seven miles southeast of the Savannah River plant facility near the southern boundary of the plant grounds in Barnwell County, S.C.

The report, "Effects of Late Cretaceous and Cenozoic Faulting on the Geology and Hydrology of the Coastal Plain near the Savannah River, Georgia and South Carolina," released as U.S. Geological Survey Open-File Report 82-156 by R. E. Faye and D. C. Prowell, is available for inspection at the U.S. Geological Survey district office in Doraville, Ga. (6481 Peachtree Industrial Boulevard, Suite B), and at the USGS library in Reston, Va. (Room 4A100, USGS National Center, 12201 Sunrise Valley Dr.).

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