UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
GEORGIA POWER COMPANY, et al.	)	Docket Nos. 50-424 (OL)
	)	50-425 (OL)
(Vogtle Electric Generating Plant, Units 1 and 2)	)	

AFFIDAVIT OF THOMAS W. CROSBY
AND LEWIS R. WEST

County of San Francisco)
) ss.
State of California)

Thomas W. Crosby and Lewis R. West, being duly sworn according to law, depose and say as follows:

1. We are geologists employed by Bechtel Civil and Minerals, Inc. Cur business address is Bechtel Civil and Minerals, Inc., P. O. Box 3695, San Francisco, California 94119. Summaries of our professional qualifications and experience are attached hereto as Exhibits A and B.

2. The purpose of this affidavit is to authenticate and sponsor the report entitled "Geotechnical Verification Work -- Report of Results: Vogtle Electric Generating Plant" (August

1985). We authored this report. We have personal knowledge of the matters stated therein and believe them to be true and correct.

Thomas W. Crosby

Thomas W. Crosby

Lewis R. West

Lewis R. West

Subscribed and sworn to before me
this 4th day of September, 1985

My commission expires:
April 26, 1989

OFFICIAL SEAL
MAVIS M. LYNDE
NOTARY PUBLIC — CALIFORNIA
San Francisco County
My Commission Expires April 26, 1989

EXHIBIT A

PROFESSIONAL QUALIFICATIONS

Thomas W. Crosby

My name is Thomas W. Crosby. I graduated from Oregon State University with a Bachelor of Science degree in Geology in June 1973. For the past twelve years I have been employed by Bechtel as an engineering geologist. My responsibilities have been the field and office studies for the siting, design, and construction of major engineering projects, including nuclear power plants, hazardous waste facilities, dams, and tunnels.

I have been responsible for field exploration, data interpretation, report preparation, and regulatory review on nuclear power sites in Georgia, Pennsylvania, Washington, California, and Taiwan. My ground water experience includes supervision of monitoring well construction and testing at hazardous waste sites in New York, Tennessee, and Arizona. I have also supervised the installation and testing of large capacity production wells in Senegal, West Africa and Washington State.

I am a Registered Geologist and a Certified Engineering Geologist in the State of California, and a Licensed Geologist in the State of Oregon.

EXHIBIT B

PROFESSIONAL QUALIFICATIONS

Lewis R. West

My name is Lewis R. West. I have a B.S. degree in Geology from the University of Southern Mississippi and some graduate studies in geology at University of Nevada, Las Vegas.

I was employed by the Ground Water Branch of the U.S. Geological Survey for seven years. During this period, I worked in Alabama for four years and at the U.S.A.E.C. Nevada Test Site for three years.

From 1964 to 1973, I was employed by Environmental Research Corporation in Las Vegas, Nevada as field geologist and field office manager. I was responsible for the liaison between the home office in Virginia and the AEC's Nevada Operations Office. My duties involved investigations of tunnels and drill holes for input to determine containment and ground motion effects in relation to atomic bomb testing.

For the past 12-1/2 years, I have been employed by Bechtel as a Hydrogeologist. My responsibilities include all aspects of ground water occurrence and interaction in respect to foundation, dam sites, retention ponds and engineering geology design criteria as well as development of industrial ground water supply systems.

I am a Registered Geologist in the State of California.

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Vogtle Project

August 23, 1985

Director of Nuclear Reactor Regulation
Attention: Ms. Elinor G. Adensam, Chief
Licensing Branch #4
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

File: X7BC35
Log: GN-695

NRC DOCKET NUMBERS 50-424 AND 50-425
CONSTRUCTION PERMIT NUMBERS CPPR-108 AND CPPR-109
VOGTLE ELECTRIC GENERATING PLANT - UNITS 1 AND 2
SER CONFIRMATORY ITEM 5: GROUNDWATER MONITORING
SER CONFIRMATORY ITEM 8: CLAY MARL STRATUM

Dear Mr. Denton:

Enclosed for your staff's review is a copy of "Geotechnical Verification Work - Report of Results." This document was prepared to report our findings from the recently completed field and laboratory studies. In summary, these studies have verified previous findings on site characteristics:

- The core holes in the Blue Bluff marl have confirmed that the marl is a competent, firm, preconsolidated stratum, without voids or secondary openings.

- The permeability tests, both in situ and laboratory, verify that the marl is nearly impermeable.

- Additional observation wells, installed as part of this study, will allow acquisition of the data required by the "Ground Water Monitoring Program" submitted in June 1985.

- Preliminary water levels measured in these wells are consistent with previous results.

- The laboratory studies on cation exchange capacity and distribution coefficients for the backfill, have shown the previous assumptions for the accidental spill analysis to be conservative.

This report should allow closure of confirmatory items listed in Sections 2.4 and 2.5 of the SER.

- Section 2.4.12.6 - Design Basis for Subsurface Hydrostatic Loading
  The additional wells installed in the water table aquifer during this study will provide the required data for the monitoring program.

- Section 2.4.12.7 - Ground Water Monitoring Program
  The program previously submitted to the staff has been implemented. Georgia Power Company is recording water levels in each aquifer on the schedule discussed in the program. The results, along with the site specific rainfall data, are being submitted to Bechtel geohydrologists for tabulation, technical review, aud data management. This review includes a determination between the relationship of ground water levels to precipitation.

  The data will be submitted to NRC for review after the first six month reporting period at the end of 1985, without reduction in the monitoring frequency.

- Section 2.5.4.5 - Instrumentation and Monitoring
  This report provides the data on the six wells installed in the marl, the results of the in situ permeability testing, and detailed geologic logs of the core holes. NRC staff reviewers from hydrology and soils engineering visited the site to inspect marl core and well construction.

If your staff requires any additional information, please do not hesitate to contact me.

Sincerely,

J. A. Bailey

J. A. Bailey
Project Licensing Manager

JAB/sm
Enclosure
xc: D. O. Foster
R. A. Thomas
J. E. Joiner, Esquire
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Vogtle Project File

0112V

Geotechnical Verification Work
Report of Results

Vogtle Electric Generating Plant
August 1985

Geology Group
San Francisco

Geotechnical Verification Work
Report of Results

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San Francisco

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GEOTECHNICAL VERIFICATION WORK

REPORT OF RESULTS

1.0 INTRODUCTION

A program of geotechnical verification work was conducted at Plant Vogtle during the summer of 1985 to resolve several licensing issues and to acquire supplementary data on site characteristics. The work consisted of Standard Penetration Testing of the backfill, core drilling and in situ permeability testing of the marl, observation well installation, and laboratory testing.

Standard Penetration Testing was performed to verify the backfill compaction with respect to liquefaction potential.

Core drilling of the marl underlying the plant facilities (the foundation bearing stratum) was conducted to resolve the Open Item discussed in Section 2.5.4.1.3 of the Draft Site Evaluation Report (DSER). Observation wells were installed, both in the marl and the water table aquifer, and permeability testing was conducted in the marl to resolve the Open Item on ground water monitoring discussed in Section 2.5.4.5 of the DSER. Continuous recorders were installed on two observation wells to resolve Open Item on hydrostatic loading discussed in Section 2.4.12.5 of the DSER. Laboratory tests included measurement of marl permeability, and measurement of the cation exchange capacity and distribution coefficient of the backfill. The tests were conducted to supplement existing data.

This report discusses the results of these studies, with the exception of the Standard Penetration Testing in the backfill. That information has been submitted in a report entitled, "Standard Penetration Test Results", and for completeness is submitted as Appendix A.

2.0 SCOPE OF STUDIES

The marl was cored in two areas adjacent to the powerblock, designated as well clusters A and B on Figure 1. A series of 3 wells were installed at each cluster to monitor hydrostatic pore pressure at representative depths in the marl. In situ (packer) permeability tests were conducted in these cored holes.

Six observation wells were installed in the water table aquifer to allow monitoring in the powerblock backfill and in the area northwest of the powerblock. Two of these replace wells damaged from construction activities. Continuous water-level recorders were installed on two water-table observation wells for determining magnitude and frequency of diurnal fluctuations of the water table.

The drilling, coring, in situ permeability testing and observation well installation was performed by Law Engineering Testing Co., under the supervision of a Bechtel Engineering Geologist.

Laboratory permeability tests on ten marl samples from the 900 series holes were conducted by Harding Lawson Associates. The distribution coefficients (Kd) of four backfill samples was done by Battelle Pacific

Northwest Laboratories. Cation exchange capacity measurements on ten backfill samples were made by Soil and Plant Laboratory, Inc. These laboratory tests were conducted to supplement and verify data from previous investigations.

3.0 SUMMARY OF RESULTS

The results of the geotechnical verification work supports the previous data on site characteristics of Vogtle.

- Core drilling of marl: The very high core recovery; lack of voids, altered zones, or fractures; and drilling rate results verify that the marl is a fine-grained, competent and firm material without secondary openings. The core from the holes confirm the results of the many marl core holes drilled previously in the powerblock area.

- Peameability testing of marl: Both the in situ (packer) tests and the laboratory tests of the marl support results of previous studies. Of the fifteen intervals tested for in situ permeability, none showed any water takes. The laboratory tests show the marl to be consistently very low to practically impermeable, ranging from 1.4×10^{-6} to $5.0 \times 10.^{-9}$ cm/sec. These data show that the marl is nearly impermeable.

- Observation well installation: The observation wells installed in the water table aquifer and the marl aquiclude during this study provide additional monitoring points in the immediate vicinity of the plant facilities. The initial water levels recorded in the new wells are consistent with previous data. Continued monitoring of those wells is part of the VEGP ground water monitoring program.

- Distribution coefficient (Kd) of backfill: In the SER, June, 1986, the NRC assumed Kd values of 5 ml/g for strontium and 49 ml/g for cesium. These assumed values are stated by the NRC as being conservatively low, based on the literature. The results of the laboratory measurements confirm that assumption. The measured values are approximately an order of magnitude greater than the assumed values.

4.0 CONDITIONS IN THE BLUE BLUFF MARL

The integrity of the marl as a foundation layer and a barrier to ground water movement was questioned. To provide data on the structure, lithology, and permeability of the marl, the following program was conducted.

4.1 Core Drilling

Two clusters of three wells each, were constructed on the southeast and northwest sides of the power block (Figure 1). The marl was core drilled for visual inspection to determine the integrity of the marl. The wells

designated 900, 901, and 902 are located to the southeast, inside the power block excavation and the wells designated 903, 904B, 905 are located to the northwest, outside the excavation, as shown on Figure 1. The geologic logs for these holes are included in Appendix B. From inspection of the core, zones to be monitored by the wells were selected.

4.2 <u>Well Cluster A (wells 900, 901, and 902</u>)

The first well drilled was 900. A hole, 9-7/8 inches in diameter, was drilled through the backfill to the top of the marl, using a tricone rock-bit and revert/water as the circulating fluid. The top 10 feet, from a depth of 92.6 ft to 102.6 ft. was cored using a 5-1/2 inch OD double tube, ball-bearing, swivel-type, split core barrel with a bottom (face) discharge bit. Clear water was used as the circulating fluid. The hole was then reamed to 9-7/8 inches diameter and 6-inch steel casing was installed to a depth of 102.6 ft. The casing was cemented in place using a tremie pipe, 1-1/4-inches diameter inserted outside the casing to a depth of 102.6 ft, and a grout mix of one part cement to one part water (by volume).

After allowing cement to set for four days, the casing was flushed with clean water, and coring was continued to a depth of 142.6 ft. (Approximately 5 feet above the base of the marl, based on data contained in the FSAR). After being logged by an engineering geologist, the core was boxed, photographed, placed in plastic sleeves for moisture

preservation, and stored. Permeability tests, in situ, were conducted in ten foot intervals as drilling progressed from 102.6 ft (bottom of casing) to 142.6 ft (bottom of hole). The data obtained from well 900 were used to locate, core, test and complete wells 901 and 902. Both of these wells were drilled, cored, and tested in the same manner and using the same equipment as well 900.

Well 901 was drilled with a tricone bit to a depth of 91.6 ft and cored from 91.6 ft to 128 ft (bottom of hole). Casing was cemented in place at a depth of 102 ft and a permeability test was conducted in the bottom ten feet (118-128 ft).

Well 902 was drilled with a tricone bit to a depth of 91.5 ft and cored from 91.5 ft to 108 ft (bottom of hole). Casing was cemented in place at a depth of 100 ft and a permeability test was conducted in the bottom eight feet (100-108 ft).

4.3 Well Cluster B (Wells 903, 904B, and 905)

The first well drilled at this location was well 903. A hole 9-7/8 inches in diameter was drilled through the Barnwell sediments with a tricone rockbit to the top of the marl. The hole was drilled, cored, and tested in the same manner and with the same or equivalent equipment used to drill wells 900, 901 and 902.

The top of the marl was encountered at a depth of 78 ft. The hole was cored from 78 to 133 ft (approximately 10 ft above the base of the marl). Steel casing, 6 inches in diameter was cemented by the tremie method at a depth of 85 ft.

Permeability tests were conducted, as drilling progressed, in ten foot intervals from 85 to 133 ft.

The data obtained from well 903 were used to locate, core, test, and complete wells 904B and 905. Holes 904 and 904A had to be abandoned due to split casing and encountering buried utilities, respectively, the logs for these holes are included in Appendix B.

Well 904B was drilled with a rockbit to a depth of 68.5 ft and cored from 68.5 ft to 96.7 ft (bottom of hole). Casing was cemented in place at a depth of 85 ft and a permeability test was conducted in the bottom 11.7 ft (85 - 96.7 ft).

Well 905 was drilled with a rockbit to a depth of 77 ft and cored from 77 ft to 116 ft (bottom of hole). Casing was cemented in place at a depth of 88.5 ft and permeability tests were conducted in the bottom 27.5 ft.

Following the in situ permeability tests, porous tube (Casagrande) piezometers were installed in each of these holes. The well construction details are discussed in Section 6.2.

5.0 PERMEABILITY TESTING

5.1 In Situ Permeability Testing

Permeability testing (in situ) was conducted in holes 900 through 905 using the single packer method according to procedures in designation E-18 of the U.S. Bureau Reclamation "Earth Manual" and in general compliance with the Corps of Engineers, RTH-381-80. (The latter reference was recommended by the NRC staff).

The validity of some of the previous in situ permeability tests conducted during site exploration (1971-1973) was questioned by NRC, since some of these holes were drilled with bentonite as the circulating fluid. The NRC was concerned that bentonite could have caused some plugging of permeable zones, thereby reducing the amount of water being injected, resulting in calculated permeabilities lower than actually existed. In order to alleviate this concern, all of the holes were drilled with a biodegradable drilling additive (Revert) and water when drilling in sediments above the marl, and only clear water was used as drilling in the marl.

When drilling holes that penetrated the marl, a 6-inch diameter casing was cemented 8 to 10 ft below the top of the marl. After allowing the cement to set a minimum of 48 hours, the Revert was broken down with chlorine and the casing flushed with clean water. The holes were cored using only potable water as the circulating fluid in the marl after casing was set.

The method of testing was as follows:

At each well cluster, the deep core hole (900 and 903) was advanced in 10 foot intervals and a permeability test was conducted at each interval. This drilling/testing procedure was followed until the total depth of hole was reached. The interval being tested (bottom 10 foot) was isolated from the remainder of the hole by a pneumatic inflatible packer.

In the remaining wells, (901, 902, 904B, and 905), the hole was advanced to total depth, which was predetermined from well 900 or 903 data, and the bottom interval tested. The interval being tested was isolated in the same manner.

Each permeability test was conducted for a total period of 40 or 50 minutes, as follows: After the packer was seated, water was pumped into the test section at a minimum pressure (i.e. 40 psi) and held for 8 or 10 minutes, while recording water meter readings. The pressure was increased to an intermediate pressure (i.e. 50 psi) and held for another 8 or 10 minute period, while recording water meter readings. The pressure was then increased to the maximum (i.e. 60 psi) and held for 8 or 10 minutes. The test was continued by decreasing pressure back to the intermediate and minimum pressures at the same time intervals.

In all of the tests conducted, the water takes were zero indicating an apparent permeability of zero. The permeability test data are shown on Table 2.

5.2 Laboratory Permeability Testing

In situ (packer) permeability tests cannot be used to quantify the permeability of materials with very low values, due to mechanical and control limitations. Packer tests at Vogtle in fresh marl have consistently shown no water take, implying the marl is impermeable. In order to quantify the permeability of the marl laboratory measurements were made. During coring, ten samples of the core were collected, wrapped in foil and sealed with wax for permeability testing in the laboratory. The laboratory tests were performed by Harding Lawson Associates. The results are summarized on Table 2, with the data included in Appendix C.

The range of permeability measurements is from 1.41×10^{-6} to 5.01×10^{-9} cm/sec. These data, combined with the in situ tests confirm that the marl is nearly impermeable.

6.0 OBSERVATION WELL INSTALLATION

In Section 2.5.4.5 of the Draft SER, NRC requested additional monitoring wells and more frequent measurements of the ground water levels. In order to develop a ground water monitoring plan to meet these concerns, the number and location of existing observation wells was first reviewed. This review revealed an adequate number and location of observation wells existed to monitor the confined aquifers. However, the

data indicated that for complete coverage of the water table aquifer, additional wells were required. Therefore, two additional observation wells were installed to monitor water levels in the Barnwell sediments, to the north and west of the power block, and two additional wells were installed to monitor water levels in the backfill to the east and south of the power block. These additions to the existing observation wells were incorporated in the proposed monitoring plan submitted to NRC on May 21, 1985. Also, three existing observation wells were found to be damaged. These were to be grouted, and two were to be replaced. NRC staff found the proposed plan acceptable, as stated in Section 2.4.12.7 of the Final SER.

Three piezometers in each of two well clusters were installed at various depths within the marl. These piezometers are installed at the request of the NRC to monitor distribution of hydrostatic pore pressure within the marl.

The location of all observation wells are shown on Figure 1. These wells are currently being used to monitor ground water conditions at Plant Vogtle.

6.1 Water Table Aquifer Wells

The NRC requested that two water table aquifer wells be equipped with automatic water level recorders, one in the backfill and the other in adjacent Barnwell sediments. Well 808 was chosen as the Barnwell monitoring well and well LT-13 as the backfill well for continuous

monitoring. To better accommodate installation of an automatic recorder these two wells were constructed with 4-inch diameter well casing and screen. The remaining wells were constructed with 2-inch diameter well casing and screen.

6.1.1 Wells 808 and 809

Wells 808 and 809 were drilled and completed as observation wells to monitor water levels in the Barnwell sediments. Well 809, located west of the power block was drilled with a 7-7/8-inch diameter, tricone rock bit, using Revert and water as the circulating fluid. The well was drilled to a depth of 90 ft, one foot below top of marl. The well was constructed by installing a 2-inch diameter PVC screen, 10 ft long with .020 inch slot size. The screen is located from 74.5 to 84.5 ft below ground level and gravel packed to a depth of 69.35 ft. A bentonite seal 2.5 ft thick, was installed above the gravel pack and the remainder of the annulus between the hole and 2-inch casing was grouted to ground surface with a 1:1 mixture of cement and water.

Well 808, located north of the power block, was drilled with a 6-7/8 inch diameter, tricone rockbit, using Revert and water as the circulating fluid. The well was drilled to a depth of 68 ft, 1.7 ft below top of marl. Well 808 was constructed by installation of 4-inch diameter PVC casing and screen. The well screen, 10 ft long with slot size of .020-inch is located between 50.5 and 60.5 ft depth and gravel packed to

a depth of 45.5 ft. A bentonite seal, 2 ft thick was installed above the gravel pack and the remainder of the annulus between the 4-inch casing and the hole was grouted to land surface with a 1:1 mixture of cement and water.

6.1.2 Wells LT-12 and LT-13

Wells LT-12 and LT-13 were drilled and completed as observation wells to monitor water levels in the backfill. Well LT-12, located south of the power block, was drilled with a 6 7/8-inch diameter tricone bit using Revert and water as the circulating fluid. The well was drilled to a depth of 79ft, top of marl. The well was constructed by installing a 2-inch diameter casing/screen assembly. The screen is 10 ft. in length with a .020-inch slot size, located from 63.1 to 73.1ft. below ground surface and is a gravel packed to a depth of 58.15 ft. A bentonite seal, 1.65 ft. thick, was installed above the gravel pack and the remainder of the annulus between the 2-inch casing and the hole was grouted to ground surface with a 1:1 mixture of cement and water.

Well LT-13, located near the east end of the turbine building, was drilled with a 7 7/8-inch diameter, tricone rockbit to a depth of 89 ft, top of marl. The well was constructed by installation of 4-inch diameter PVC casing and screen. The screen is 10ft long, with a slot size of .020-inch located from 73.55 to 83.55 ft. depth and is gravel packed to a depth of 68.10 ft. A bentonite seal, 2.27ft. thick, was installed above

the gravel pack and the remainder of the annulus between the 4-inch casing and the hole was grouted to land surface with a 1:1 mixture of cement and water.

In construction of all observation wells, the Revert was broken down with chlorine after casing/screen installation and before installation of gravel pack. Clean water was pumped through the PVC casing, exiting through the screen and returning to land surface through the well annulus during installation of the gravel pack. All of the wells were developed by washing with clean water followed by pumping with air.

6.1.3 Wells LT-1A, LT-7, and STA.

During backfilling of the powerblock excavation it was necessary to maintain the water table far enough below grade to assure design compaction. Several observation wells were installed around the powerblock to monitor this water level. As backfill operations progressed and eventually advanced several feet above the water table, all of the observation wells were grouted and abandoned, except three. Of the three wells, STA is no longer needed and LT-1A and LT-7 were made a part of the long term ground water monitoring program.

As backfilling advanced, these wells were damaged and could not be utilized as observation wells. All three of these wells were abandoned as part of this work by grouting from the bottom up, using a 1 1/2 inch diameter hose as a tremie with a 1:1 mixture of cement and water.

As stated above wells LT-1A and LT-7 were included in the long term ground water monitoring program, therefore they were replaced. Well LT-1A was replaced with well LT-1B located 4 ft. due east. The hole was drilled with a 5 7/8-inch diameter, tricone rockbit using Revert and water as the circulating fluid. The hole was drilled to a depth of 84.65 ft. which is 1.35 ft. below the top of the marl. The well was completed by installing a 2-inch diameter PVC casing/screen assembly to a depth of 84.65 ft. The screen is 10 ft. in length with .020-inch slot size, located between 72.65 and 82.65 ft. and gravel packed to a depth of 65.17 ft. A bentonite seal 2.17 ft. thich was installed on top of the gravel pack and the remainder of the annulus between the 2-inch casing and the hole was grouted with a 1:1 mixture of cement and water.

Well LT-7 was replaced with well LT-7A, located 7 1/2 ft. west. The hole was drilled with a 5 1/8-inch diameter, tricone rock bit using Revert and water as the circulating fluid. The hole was drilled to a depth of 87 ft, which is top of marl. The well was completed by installing a 2-inch diameter, PVC casing/screen assembly to a depth of 87 ft. The screen is 10 ft. in length with .020-inch slot size, located between 75 and 85 ft. and gravel packed to a depth of 65 ft. A bentonite seal, 2-ft thick, was installed on top of the gravel pack and the remainder of the annulus between the 2-inch casing and the hole was grouted with a 1:1 mixture of cement and water.

6.2 Marl Observation Wells (Piezometers)

Each of the holes cored in the marl (900 through 905) was completed by installation of a porous stone piezometer to measure hydrostatic pore pressure within the marl confining layer.

The porous stones are 2 1/2 inches diameter and 2 1/2-ft. overall length, with a 2 ft. length of 60-micron porous stone. The riser casing is 1-inch diameter schedule 80 PVC.

The sand used for the filter pack is "Ottawa 10-30" which is clean and well graded from No. 10 to No. 30 mesh, United States standard sieve sizes. This gradation was selected to match the 60-micron porous stones and prevent movement into the stone of fines in the clay. The sand pack and stone are much more permeable than the marl.

All of the piezometers were installed in accordance with Designation E-28, U.S. Bru. Rec. "Earth Manual", as follows. Upon completion of drilling, the bottom of the 5 1/2-inch diameter core hole was sounded. The bottom 2 ft of hole was filled with Ottawa sand through a tremie, and tamped. The porous stone, having been soaked in water from 24 to 48 hrs., was lowered to the top of the sand. A centralizer was attached to the stand pipe about 6-inches above the stone. Additional Ottawa sand was installed by tremie to fill the annulus between the stone and the hole and to cover the stone a minimum of 1.85 ft., followed by tamping.

A bentonite seal, minimum thickness of 2 ft, was placed on top of the filter and the remainder of the annulus between the 1-inch standpipe and the 5 1/2 inch hole and/or the 6-inch casing, was filled with a 1:1 mixture of cement and water. Details of the piezometer installations are on Table 1 and are shown schematically on Figures 2 and 3.

TABLE 1 - SUMMARY OF OBSERVATION WELLS

WELL NO.	COORDINATES N	E	GROUND ELEV.	TOP OF WELL ELEV.	DEPTH TO MARL	OPEN INTERVAL
808	9625	9300	207.0	216.47	66.3	45.5-68
809	8320	7860	222.8	224.23	89.0	69.35-90
900	7538	10119.5	216.3	218.05	92.6	113.8-140.7
901	7538	10104.5	215.58	220.75	91.6	122-128
902	7543.5	10110.5	215.97	221.11	91.0	101.5-108
903	8480	8900	215.75	216.73	78.0	127-133
904B	8464	8885	215.75	216.31	78.8	90-96
905	8450	8900	215.75	216.71	77.3	109.8-116
LT-1B	8388	9304	213.18	215.47	83.3	65.17-84.65
LT-7A	8151.3	9317.5	215.92	221.17	87.0	65-87
LT-12	7775	9600	209.0	219.27	79.0	58.15-79
LT-13	8135	10110	219.0	221.2	89.0	68.1-90

TABLE 2 - PERMEABILITY TESTS

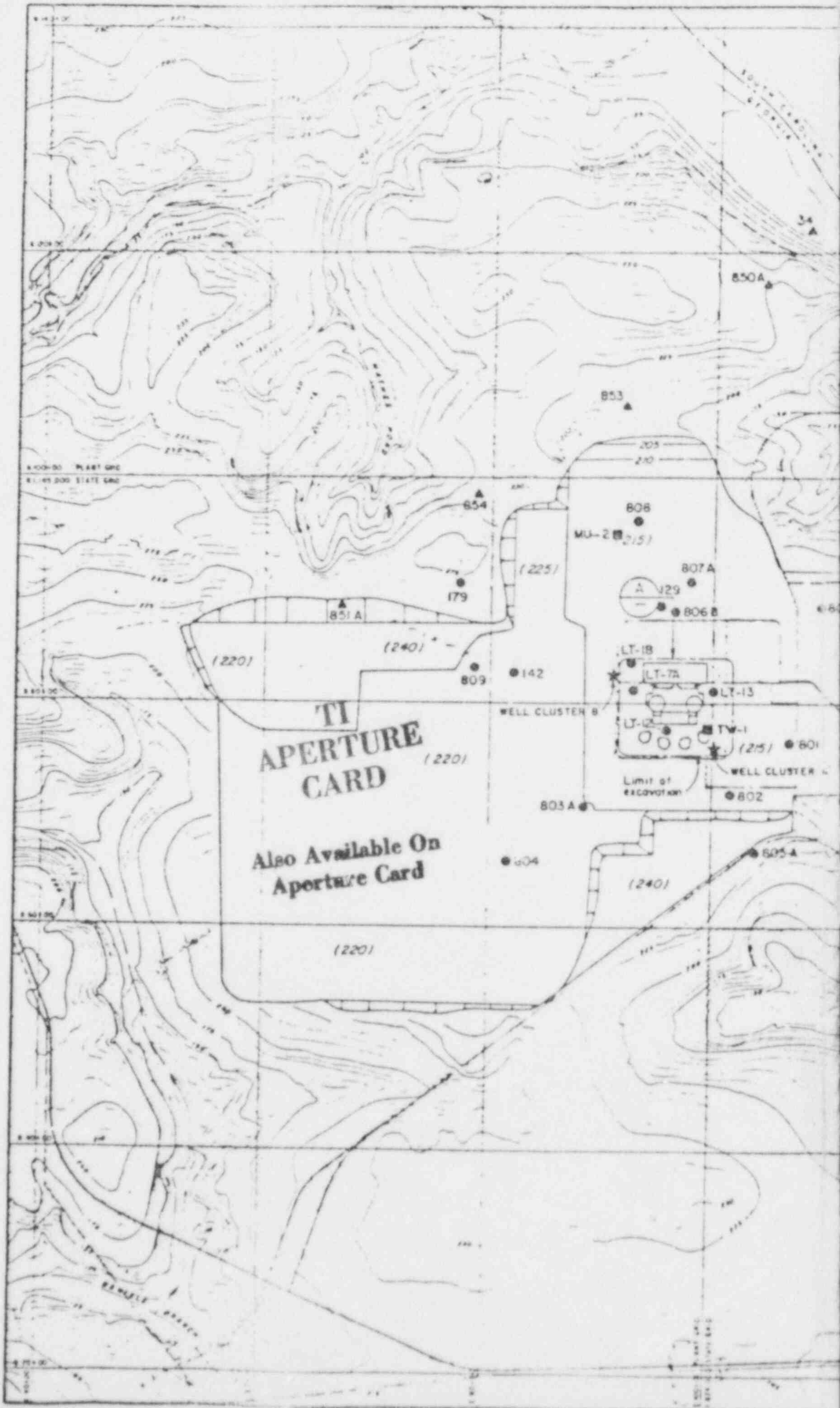
IN SITU PERMEABILITY TESTS

HOLE NO.	INTERVAL TESTED (FT.)	QUANTITY OF WATER INJECTED (GALS.)	PERMEABILITY (CALCULATED)
900	104.6-112.6	0	0
	112.6-122.6	0	0
	122.6-132.6	0	0
	132.6-142.6	0	0
	122.6-142.6	0	0
901	118-128	0	0
902	100-108	0	0
903	85-96	0	0
	96-106	0	0
	106-116	0	0
	116-126	0	0
	126-133	0	0
904B	85-96.7	0	0
905	88.5-102.5	0	0
	102.5-116	0	0

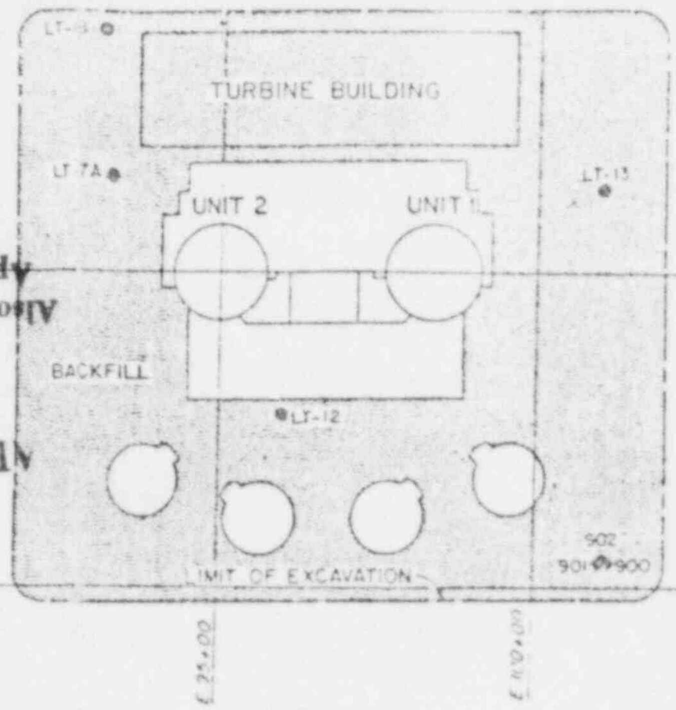
LABORATORY PERMEABILITY TESTS *

HOLE NO.	DEPTH (FT).	PERMEABILITY (CM/SEC)
901	119.0	5.01×10^{-9}
902	104.2	1.95×10^{-6}
903	108.2	1.94×10^{-7}
903	112.7	4.99×10^{-7}
903	128.4	2.06×10^{-6}
904B	92.3	2.42×10^{-6}
905	91.6	1.41×10^{-6}
905	96.7	8.49×10^{-6}
905	107.5	1.39×10^{-7}
905	114.0	7.81×10^{-8}

* - Tests were performed by Harding Lawson Associates (See Appendix B)



PLANT GRID
STATE GRID
850 A
853
854
806
MU-2
(215)
(225)
807 A
129
806 B
179
851 A
(240)
(220)
809
142
LT-18
LT-7A
LT-13
WELL CLUSTER B
LT-12
TW-1
(215)
801
WELL CLUSTER
Limit of excavation
803 A
802
805 A
804
(240)
(220)
(220)



DETAIL (A) PLANT SITE

100 0 100 200
SCALE IN FEET

EXPLANATION

- ★ Marl aquiclude well clusters
- 900 ◈ Marl aquiclude observation well
- 801 ⊕ Unconfined aquifer observation well
- 29 ▲ Confined (Tertiary) aquifer observation well
- TW-1 ▣ Confined (Cretaceous) aquifer observation well.

NOTE:

Site grading generalized from DWG. NO. CX2D46V003. Within graded area, approximate elevations shown in parentheses (215)

8509110281-01

REFERENCE:

Hancock Landing Project topographic map prepared by Clyde H. Eldridge Aerial Surveys Feb 25/71

SCALE IN FEET

Contour intervals 5 ft and 25 ft

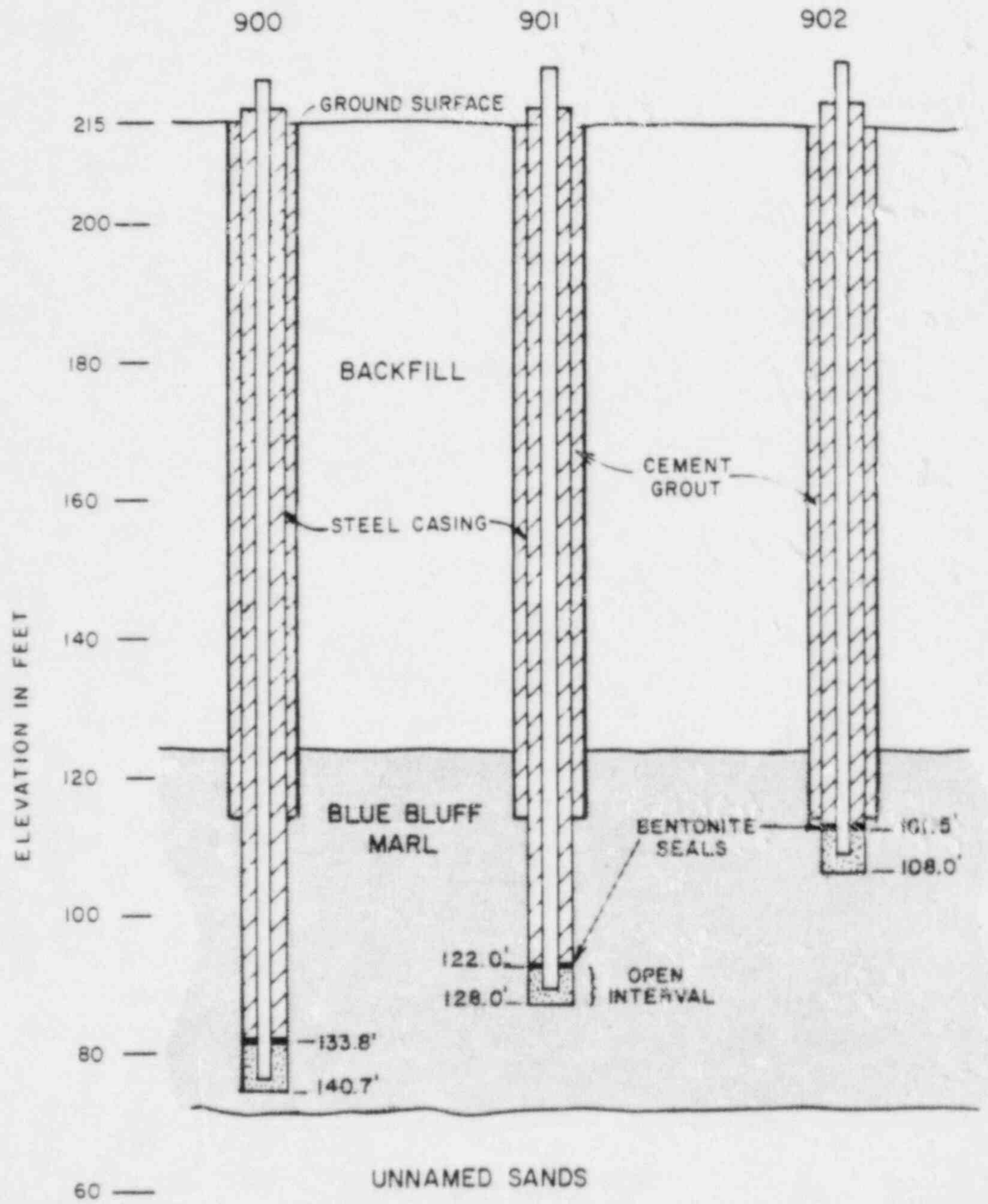
BECHTEL
LOS ANGELES

GEORGIA POWER COMPANY
ALVIN W. VOGTLE NUCLEAR PLANT

MONITORING PROGRAM
WELL LOCATIONS

SCALE: SHOWN

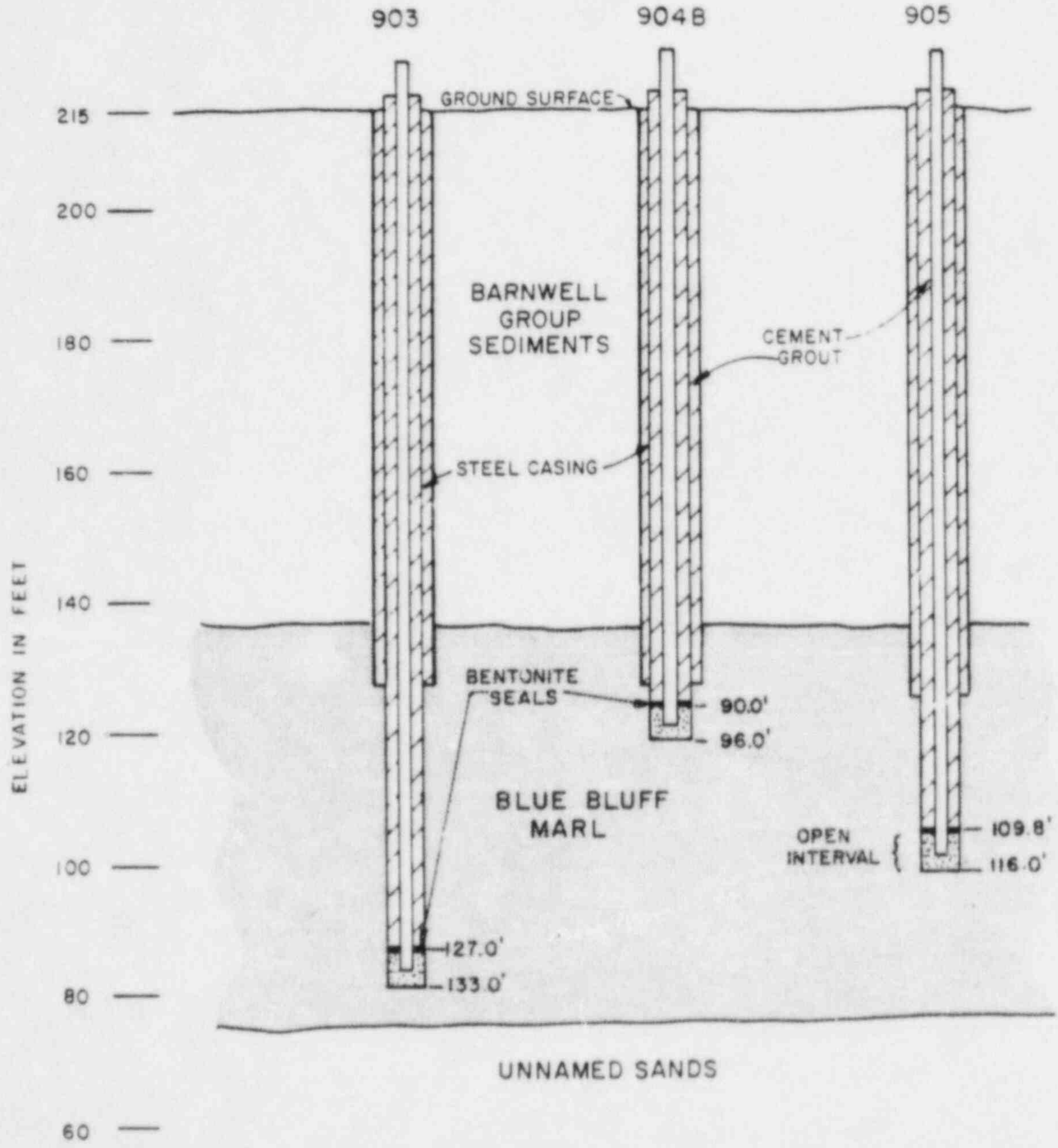
FIGURE 1



NOTES:

1. NO HORIZONTAL SCALE WAS USED, SCHEMATIC TO ILLUSTRATE WELL CONSTRUCTION.
2. SEE TEXT FOR DETAILS OF WELL CONSTRUCTION.

BECHTEL SAN FRANCISCO		
GEORGIA POWER COMPANY ALVIN W. VOGTLE NUCLEAR PLANT		
OBSERVATION WELL CLUSTER A SCHEMATIC SECTION		
JOB No.	DRAWING No.	REV
9510	FIGURE 2	



NOTES:

1. NO HORIZONTAL SCALE USED, SCHEMATIC TO ILLUSTRATE WELL CONSTRUCTION.
2. SEE TEXT FOR DETAILS OF WELL CONSTRUCTION.

BECHTEL
SAN FRANCISCO

GEORGIA POWER COMPANY
ALVIN W. VOGTLE NUCLEAR PLANT

OBSERVATION WELL CLUSTER B
SCHEMATIC SECTION

JOB No	DRAWING No	REV
9510	FIGURE 3	

APPENDIX A

STANDARD PENETRATION TESTS

H. Bolton Seed, Inc.

623 Crossridge Terrace. Orinda. California 94563 (415) 254-3036

July 3, 1985

Walter R. Ferris
106 Paseo Way
Greenbrae, CA 94904

Dear Mr. Ferris,

I have received from Zia Yazdani the results of the standard penetration test program carried out at the site of the Vogtle Nuclear Project. Ten SPT borings were drilled at locations distributed across the site and all show very high penetration resistance values in the compacted backfill.

My evaluation of the results indicates the following:

Top 10 ft. of fill : N-values range from about 30 to 97 with a conservative average value of about 50

Depth range 10 to 30 ft. : N-values range from about 62 to 200 with a conservative average value of about 100

Depth range 30 to 80 ft. : N-values range from about 100 to 200 with a conservative average value of 150.

I note that the SPT tests were carried out using a safety hammer and a rope and pulley technique, so that the procedure can be expected to deliver about 60% of the theoretical free-fall energy to the drill-stem (i.e. the Energy Ratio is about 60%).

Based on the above I interpret the results as follows:

Depth	Average N_{60} value	Effective Overburden Pressure	C_N	$(N_1)_{60}$
5 ft.	50	650 psf	1.6	80
20 ft.	100	2650 psf	0.87	87
60 ft.	150	7800 psf	0.53	80

Thus the $(N_1)_{60}$-values are reasonably consistent as would be expected for a reasonably uniform fill.

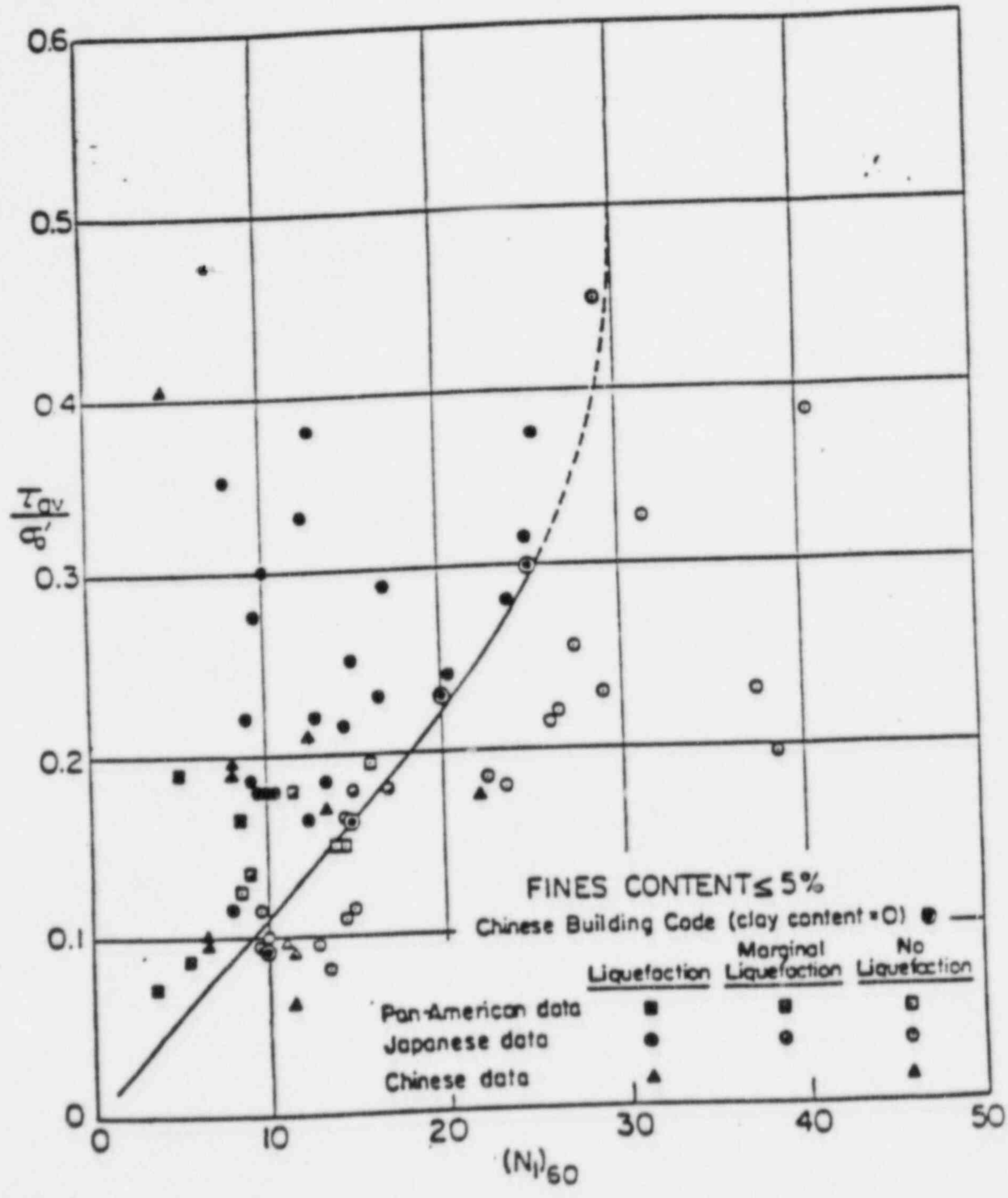
The field performance of sites which have and have not liquefied during earthquakes with Magnitude 7½, summarized on the attached figure, shows clearly that there is no possibility of

liquefaction occurring in this soil for any level of ground acceleration that may develop at the Vogtle site. In fact liquefaction is simply not a credible mode of failure for this fill.

Sincerely yours,

H. Bolton Seed

H. Bolton Seed



RELATIONSHIP BETWEEN STRESS RATIOS CAUSING LIQUEFACTION AND N_1-VALUES FOR CLEAN SANDS FOR M = 7-1/2 EARTHQUAKES

LAW ENGINEERING TESTING COMPANY
geotechnical, environmental & construction materials consultants
396 PLASTERS AVENUE, N.E.
P.O. BOX 13260 • ATLANTA, GEORGIA 30324
(404) 873-4761

July 26, 1985

GEOTECHNICAL SERVICES
NORWALK
JOB 9510
DATE 7/31/85
Z.1, S.1
A.W. X
X
M. PEROVICH X

Southern Company Services, Inc.
P.O. Box 2625
Birmingham, Alabama 35202

Attention: Mr. J. A. Bailey

Subject: Standard Penetration Soil Test Borings
For Category I Backfill
Vogtle Electrical Generating Plant
LETCo Job Number 7429

Gentlemen:

Law Engineering is pleased to submit boring logs for the soil test borings performed in Category I Backfill at Plant Alvin W. Vogtle.

The purpose of this exploration was to obtain specific subsurface data relative to backfill consistency and depth for Bechtel. Additional borings, testing and installation of piezometers were performed for Bechtel Power Corporation in accordance with their specification documents No. X2A P01, Division C2, Sections No. 18 and No. 19. However, since they are preparing a separate report, their data has not been included.

All drilling and sampling in the soil test borings was conducted according to applicable ASTM specifications and was performed by LETCo driller, Hezzie Collins.

Law Engineering's responsibilities in this work were limited to the execution of the requested drilling, laboratory testing and providing the necessary field engineering supervision so that the quality of work could be maintained.

Laboratory grain size testing of soil samples from the borings has been assigned by Bechtel and is presently underway in the laboratory.

We have enjoyed assisting Georgia Power in this work, and look forward to providing our services as the project continues. If you have any questions, do not hesitate to contact us.

Very truly yours,

LAW ENGINEERING TESTING COMPANY

Jose Perez
Geotechnical Engineer

William Allen Lancaster
Civil Engineer
Registered Georgia 7075

/cll

cc: Bechtel Power Corporation
Zia Yazdani

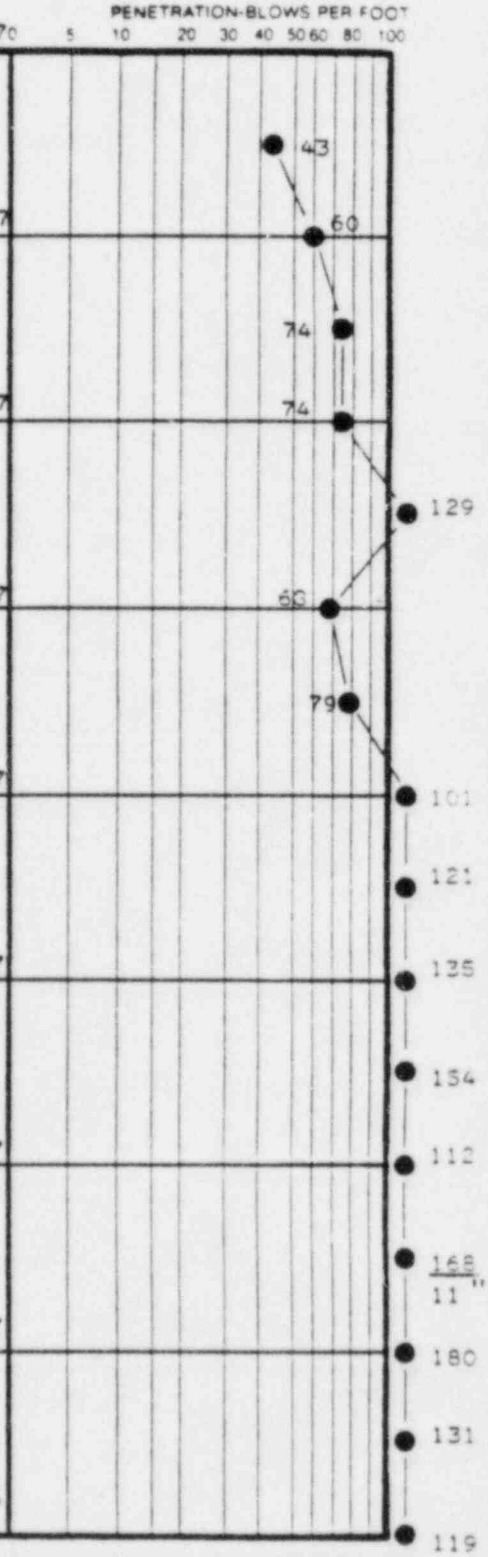
Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 75 + 50
E: 92 + 75

BORING NUMBER SPT-101
DATE DRILLED 6-4,5,&6-85
JOB NUMBER 7429
PAGE 1 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
0	BACKFILL-DENSE TO VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	201.70
		196.7
		191.7
		186.7
		181.7
		176.7
		171.7
		166.7
40		161.7



AF 35460

REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER: SPT-101
DATE DRILLED: 6-4,5,&6-85
JOB NUMBER: 7429
PAGE 2 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
40	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	161.7
		156.7
		151.7
		146.7
		141.7
		136.7
		131.7
73.5	OBSTRUCTION-CONCRETE FRAGMENTS	126.7
76	MARL-SAMPLED AS VERY HARD GRAY GREEN CLAYEY FINE SANDY SILT	
77.5	BORING TERMINATED	

PENETRATION-BLOWS PER FOOT (scale: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100)

Blow counts (top to bottom): 158; 159; 171; 182; 100/5''; 100/4½''; 110/1ST; 100/5; 100/5"; 107/1ST; 100/4"; 115/1ST; 100/3"; 100/1''; 163/8"

AF 35460

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

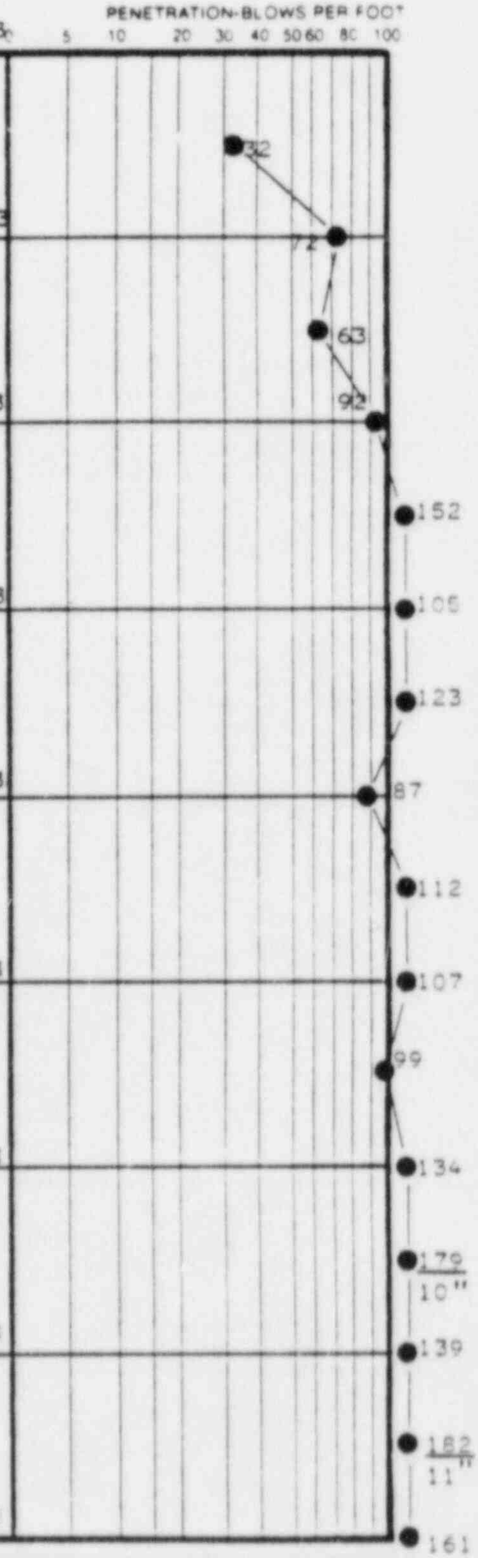
Soil Test Boring Record

BORING COORDINATES
N: 77 + 55
E: 93 + 00

BORING NUMBER SPT-102
DATE DRILLED 6-8&9-85
JOB NUMBER 7429
PAGE 1 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
0	BACKFILL-DENSE TO VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	204.3
		199.3
		194.3
		189.3
		184.3
		179.3
		174.3
		169.3
40		164.3

PENETRATION-BLOWS PER FOOT



REMARKS:

AF 35460

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER: SPT-102
DATE DRILLED: 6-8&9-85
JOB NUMBER: 7429
PAGE 2 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
40	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	164.3
		159.3
		154.3
		149.3
		144.3
		139.3
		134.9
74.0	MARL-SAMPLED AS HARD GRAY-GREEN VERY CLAYEY FINE SANDY SILT	130.3
75.7	BORING TERMINATED	128.3

PENETRATION-BLOWS PER FOOT: 5, 10, 20, 30, 40, 50, 60, 80, 100

Blow counts (top to bottom): 162; 179/11"; 193/11"; 100/6''; 100/5"; 100/4''; 100/4"; 100/5"; 100/5"; 100/5"; 88/10''; 100/5½"; 104/1ST 6'; 40

AF 35460

REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 81 + 50
E: 92 + 15

BORING NUMBER SPT-103
DATE DRILLED 5-26&27-85
JOB NUMBER 7429
PAGE 1 OF 2

DEPTH (FT) | DESCRIPTION | ELEV | PENETRATION-BLOWS PER FOOT (5, 10, 20, 30, 40, 50, 60, 80, 100)

Depth 0, Elev 203.2

BACKFILL-VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDUIM SAND

Penetration (blows per foot), top to bottom: 47, 79, 90, 131, 154, 126, 109/11", 124, 100/5", 100/3½", 100/5", 157, 184/10", 198/11", 179/11", 100/5½"

Elev
203.2
198.2
193.2
188.2
183.2
178.2
173.2
168.2
163.2

Depth 40

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REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-103
DATE DRILLED 5-26&27-85
JOB NUMBER 7429
PAGE 2 OF 2

DEPTH (FT)	DESCRIPTION	ELEV. 163.2	PENETRATION-BLOWS PER FOOT
	BACKFILL-VERY DENSE RED BROWN -SLIGHTLY SILTY TO SILTY FINE TO MEDUIM SAND		100/3"
		158.2	100/4"
			120/1ST 6
		153.2	100/6"
			100/4"
		148.2	100/3"
			130/1ST 6
		143.2	161/1ST 6
			136/1ST 6
		138.2	131/1ST 6
			100/5"
		133.2	131/1ST 6
72.0			
73.0	MARL-SAMPLED AS VERY HARD *		104
	BORING TERMINATED	128.2	

REMARKS

* GRAY-GREEN VERY CLAYEY FINE SANDY SILTY OR VERY SILTY FINE SANDY CLAY

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 77 + 00
E: 100 + 35

BORING NUMBER SPT-104
DATE DRILLED 6-10&11-85
JOB NUMBER 7429
PAGE 1 OF 3

DEPTH (FT)	DESCRIPTION				ELEV
0	BACKFILL-DENSE TO VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND				213.9
					208.9
					203.9
					198.9
					193.9
					188.9
					183.9
					178.9
40					173.9

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REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-104
DATE DRILLED 6-10&11-85
JOB NUMBER 7429
PAGE 2 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
60	BACKFILL-VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	173.9	
			100/5 1/2
		168.9	100/5"
			100/5 1/2"
		163.9	100/5 1/2"
			185/11"
		158.9	100/6"
			100/6"
		153.9	100/5 1/2
			100/5 1/2
		148.9	100/3"
			100/4"
		143.9	100/4"
			100/5"
		138.9	100/3 1/2
			100/5"
80		133.9	100/4"

REMARKS:

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SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-104
DATE DRILLED 5-10&11-85
JOB NUMBER 7429
PAGE 3 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
0		133.90	
	BACKFILL-VERY DENSE SILTY TO SLIGHTLY SILTY IFNE TO MEDIUM SAND		100/5''
85	CEMENT-PROBABLY LEAN FILL FOR LEVELING-LOW AREAS	128.9	100/5 1/2'
88	MARL-SAMPLED AS VERY HARD GRAY*		
89.5	BORING TERMINATED	123.9	62

Penetration scale: 5, 10, 20, 30, 40, 50, 60, 80, 100

REMARKS: *GREEN VERY CLAYEY FINE SANDY SILT

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 354

Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 75 + 60
E: 101 + 20

BORING NUMBER: SPT-105
DATE DRILLED: 5-27,28&29-85
JOB NUMBER: 7429
PAGE 1 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	216.3	114
		211.3	58
			88
		206.3	97
			195/10"
		201.3	154
			141
		196.3	175/11"
			187/10"
		191.3	157
			195/10"
		186.3	187/11"
			100/5"
		181.3	100/6 1/2"
			119/1ST 6
40		176.3	100/6"

Penetration scale: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100

AF 35460

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-105
DATE DRILLED 5-27,28&29-85
JOB NUMBER 7429
PAGE 2 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT 5 10 20 30 40 50 60 80 100
40	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	176.30	
			100/4"
		171.3	185/11"
			100/4"
		166.3	100/5"
			175
		161.3	100/1ST 6
			193/9''
		156.3	100/1ST 6
			100/5
		151.3	104*/1ST 6
			110*/1ST 6
		146.3	112*/1ST 6
			130*/1ST 6
		141.3	200*/1ST 5
			110*/1ST
80		136.3	147*/1ST

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REMARKS. *BLOWS IN EXCESS OF 100 WERE DELIVERED FOR ADVANCING THE SPLIT-SPOON SAMPLER THE FULL 6" OF THE FIRST SAMPLING INTERVAL IN ORDER TO OBTAIN SUFFICIENT RECOVERY TO PERMIT VISUAL INSPECTION OF THE SOIL

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-105
DATE DRILLED 5-27,28,29-85
JOB NUMBER 7429
PAGE 3 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
80.0	BACKFILL-VERY DENSE LIGHT BROWN SILTY FINE TO MEDIUM SAND	136.3	134* / 1ST 6
		131.3	130* / 1ST 6
			138* / 1ST 6
		126.3	178* / 1ST 6
91.0	MARL-SAMPLED AS GRAY GREEN VERY SILTY FINE SANDY CLAY WITH SEAMS**		140 / 11"
93.0	BORING TERMINATED		

AF 35460

REMARKS: ** CEMENTED FINE SAND
* BLOWS IN EXCESS OF 100 WERE DELIVERED FOR ADVANCING THE SPLIT-SPOON SAMPLER THE FULL 6" OF THE FIRST SAMPLING INTERVAL IN ORDER TO OBTAIN SUFFICIENT RECOVERY TO PERMIT VISUAL INSPECTION OF THE SOIL.

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

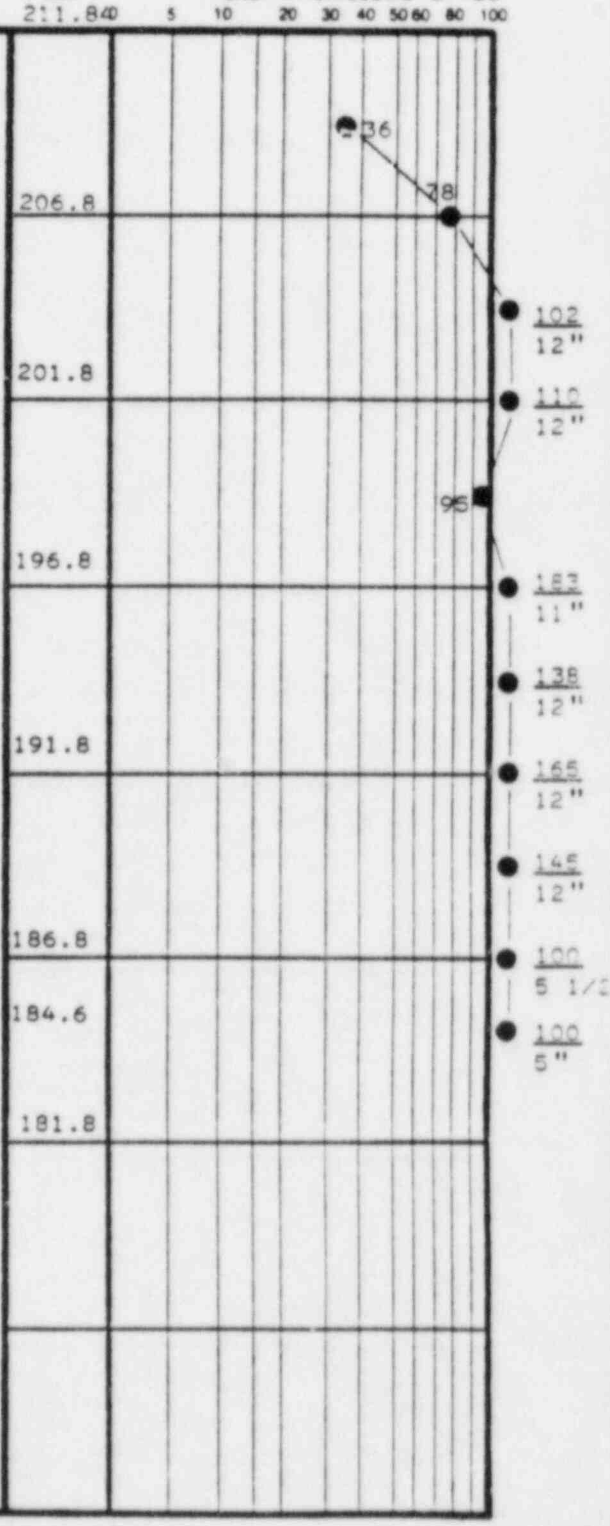
Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES:
N: 83 + 10
E: 92 + 70

BORING NUMBER SPT-106
DATE DRILLED 5-24-85
JOB NUMBER 7429
PAGE 1 OF 1

DEPTH (FT)	DESCRIPTION	ELEV
0	BACKFILL-VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	211.84
27.2	BORING TERMINATED*	184.6



REMARKS: *BORING TERMINATED DUE TO PRESENCE OF MECHANICAL DUCTS.
BOREHOLE WAS GROUTED WITH 3 BAGS OF CEMENT AND 22.5 GALS OF WATER.

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 3546D

Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 83 + 26.25
E: 92 + 82

BORING NUMBER SPT-106A
DATE DRILLED 5-24,25-85
JOB NUMBER 7429
PAGE 1 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
0	WASH BORING FROM 0 - 31.5 FEET	210.7	
		205.7	
		200.7	
		195.7	
		190.7	
		185.7	
		180.7	
31.5	BACKFILL-VERY DENSE RED BROWN SLIGHTLY TO SILTY FINE TO MEDIUM SAND		188/10½"
		175.7	100/5"
			100/4.5"
40.0		170.7	100/3"

REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-106A
DATE DRILLED 5-24,25-85
JOB NUMBER 7429
PAGE 2 OF 3

DEPTH (FT)	DESCRIPTION	ELEV
40.0	BACKFILL-VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	170.7
		165.7
		160.7
		155.7
		150.7
		145.7
		140.7
		135.7
80.0		130.7

PENETRATION-BLOWS PER FOOT: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100

Penetration (blows / inches), top to bottom:

- 100/3"
- 100/5 1/2"
- 100/5"
- 100/5"
- 100/3"
- 167/6"
- 100/4"
- 100/4"
- 100/3"
- 100/5"
- 100/3 1/2"
- 100/4"
- 100/3"
- 150/6"
- 130/6"
- 121/6"

AF 35460

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-106A
DATE DRILLED 5-24,25-85
JOB NUMBER 7429
PAGE 3 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
80.0		130.7	
81.0	BACKFILL-VERY DENSE RED BROWN*		
83.0	MARL-SAMPLED AS VERY HARD GRAY GREEN VERY CLAYEY F-NE SANDY**		67
	BORING TERMINATED	125.7	

REMARKS *TO SLIGHTLY SILTY FINE TO MEDIUM SAND
**SILT OR VERY SILTY FINE SANDY CLAY

AF 35460

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

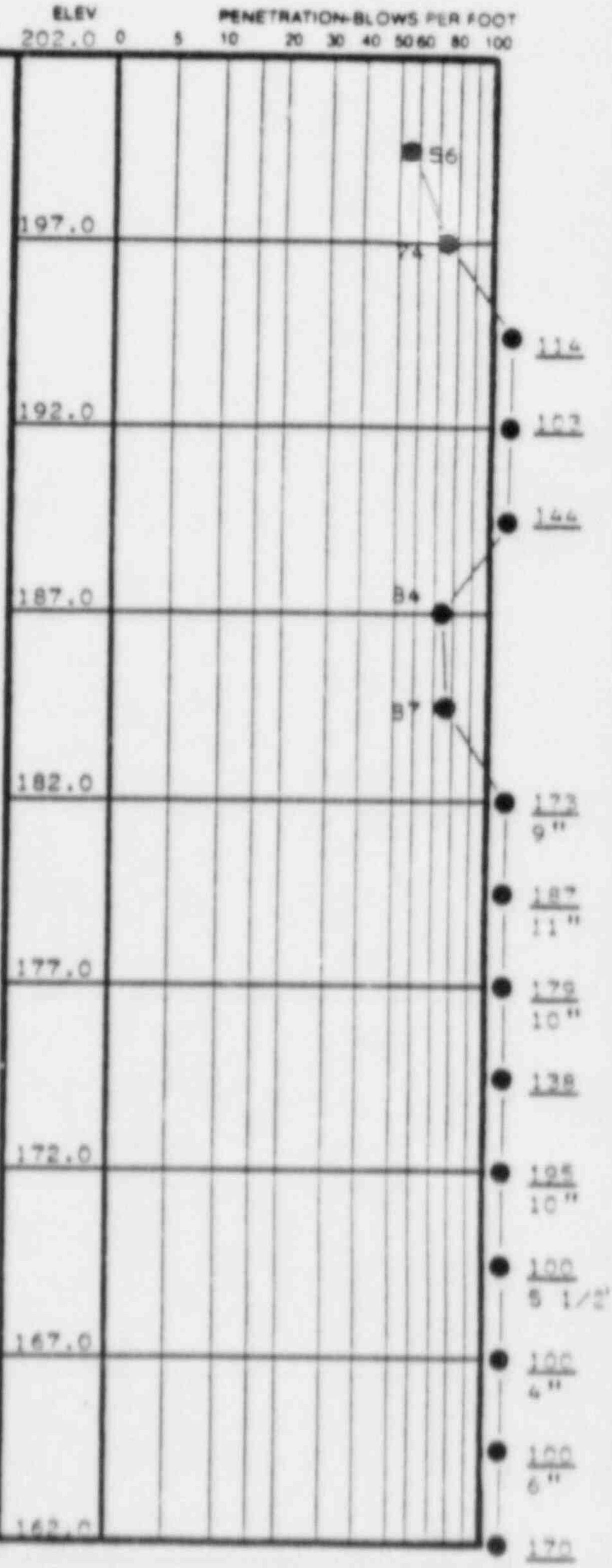
Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 76 + 70
E: 92 + 40

BORING NUMBER SPT-107
DATE DRILLED 5-21,22,23-85
JOB NUMBER 7429
PAGE 1 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
	BACKFILL - VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	202.0
40.0		162.0



REMARKS

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

BORING COORDINATES
N: 76 + 70
E: 92 + 40

BORING NUMBER SPT-107
DATE DRILLED 5-21,22,23-85
JOB NUMBER 7429
PAGE 2 OF 2

Soil Test Boring Record

DEPTH (FT.)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
40.0	BACKFILL-VERY DENSE SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	162.0	100/4 1/2
			100/5"
		157.2	100/5"
			100/5"
		152.2	100/5"
			100/4"
		147.2	100/4"
			100/3 1/2
		142.2	100/3 1/2
			100/5 1/2
		137.2	100/5"
			100/5"
		132.2	100/5"
		127.2	100/5 1/2
76.0	MARL-SAMPLED AS GRAY GREEN VERY*		185/10 1/2
77.0	BORING TERMINATED	125.2	

REMARKS *CLAYEY FINE SANDY SILT

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

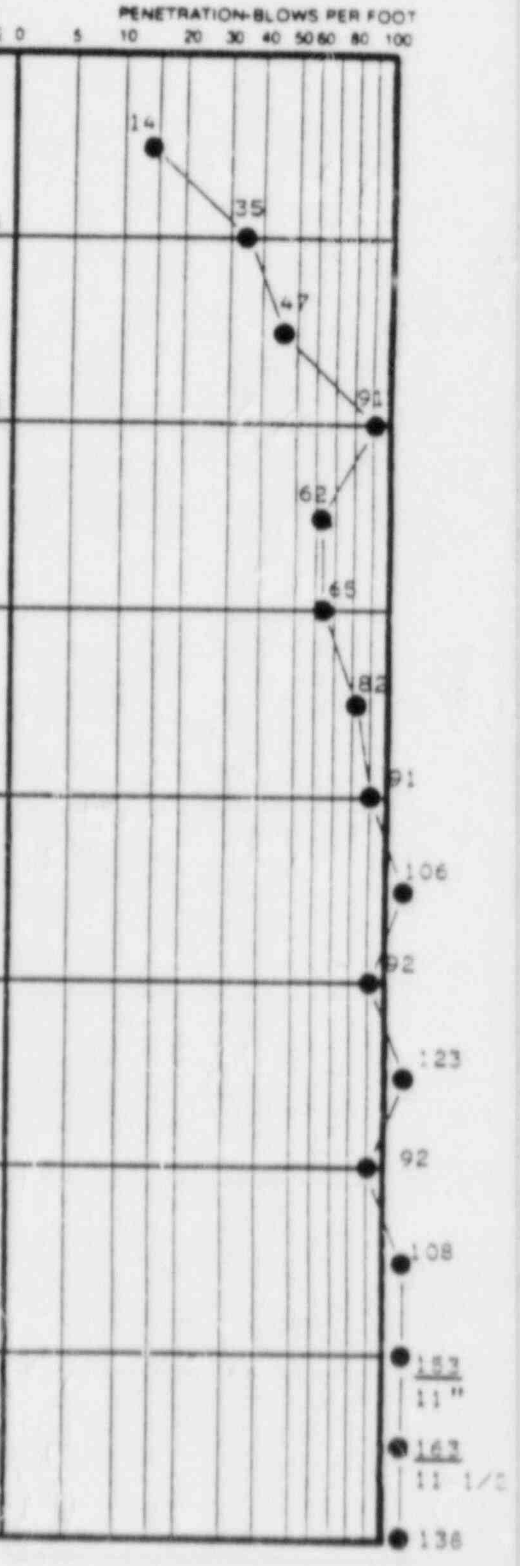
Soil Test Boring Record

BORING COORDINATES
N: 83 + 10
E: 101 + 00

BORING NUMBER SPT-108
DATE DRILLED 6-12 & 13-85
JOB NUMBER 7429
PAGE 1 OF 3

DEPTH (FT)	DESCRIPTION	ELEV
0.0	TEMPORARY BACKFILL - * FIRM RED - BROWN SLIGHTLY SILTY FINE TO MEDIUM SAND	220.5
3.5	BACKFILL - DENSE TO VERY DENSE RED BROWN SILTY TO SLIGHTLY SILTY FINE TO MEDIUM SAND	215.5
		210.5
		205.5
		200.5
		195.5
		190.5
		185.5
40.0		180.5

PENETRATION-BLOWS PER FOOT



AF 35460

REMARKS

* PLACED TO PROVIDE ACCESS TO BORING

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER: SPT-108
DATE DRILLED: 6-12&13-85
JOB NUMBER: 7429
PAGE 2 OF 3

DEPTH (FT.)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
40	BACKFILL-VERY DENSE RED-BROWN SLIGHTLY SILTY FINE TO MEDIUM SAND	180.5	
			121
		175.5	178/11 1/2"
			191/10
		170.5	179/11"
			173
		165.5	180/11"
			100/5 1/2
		160.5	100/5"
			100/6"
		155.5	100/4"
			100/4 1/2"
		150.5	100/5 1/2"
			100/4 1/2"
		145.5	100/4 "
			100/5 1/2"
80		140.5	100/5 "

PENETRATION-BLOWS PER FOOT scale: 0 5 10 20 30 40 50 60 80 100

REMARKS:

AF 35460

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-108
DATE DRILLED 6-12&13-85
JOB NUMBER 7429

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT (0, 5, 10, 20, 30, 40, 50, 60, 80, 100)
80	BACKFILL-VERY DENSE RED-BROWN SLIGHTLY SILTY FINE TO MEDIUM SAND	140.5	100/4"
		135.5	100/5"
			100/4"
59.3	MARL-SAMPLED AS VERY HARD GRAY GREEN VERY SILTY FINE SANDY CLAY	130.5	58
90.5	BORING TERMINATED		

AF 15460

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

Law Engineering Testing Company

Soil Test Boring Record

BORING COODINATES
N: 77 + 65
E: 96 + 100

BORING NUMBER SPT-109
DATE DRILLED 6-6,7&8-85
JOB NUMBER 7429
PAGE 1 OF 2

DEPTH (FT)	DESCRIPTION	ELEV
0	BACKFILL DENSE TO VERY DENSE RED-BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	209.0
		204.0
		199.0
		194.0
		189.0
		184.0
		179.0
		174.0
40		169.0

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER: SPT-109
DATE DRILLED: 6-6,7&8-85
JOB NUMBER: 7429
PAGE 2 OF 2

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
40	BACKFILL-VERY DENSE RED-BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	169.0	177/11; 180/10½''; 184/11''; 100/5''; 100/5''; 187/10''; 100/5''; 100/5''; 100/1ST 6; 100/1ST 5; 100/5; 100/4; 100/1ST 4; 125/1ST 6; 100/5''
		164.0	
		159.0	
		154.0	
		149.0	
		144.0	
		139.0	
		134.0	
79.0	MARL-SAMPLED AS VERY HARD GRAY*		65
80.5	BORING TERMINATED	129.0	

PENETRATION scale: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100

REMARKS: *Green very clayey fine sandy silt.

AF 3546AF 35460

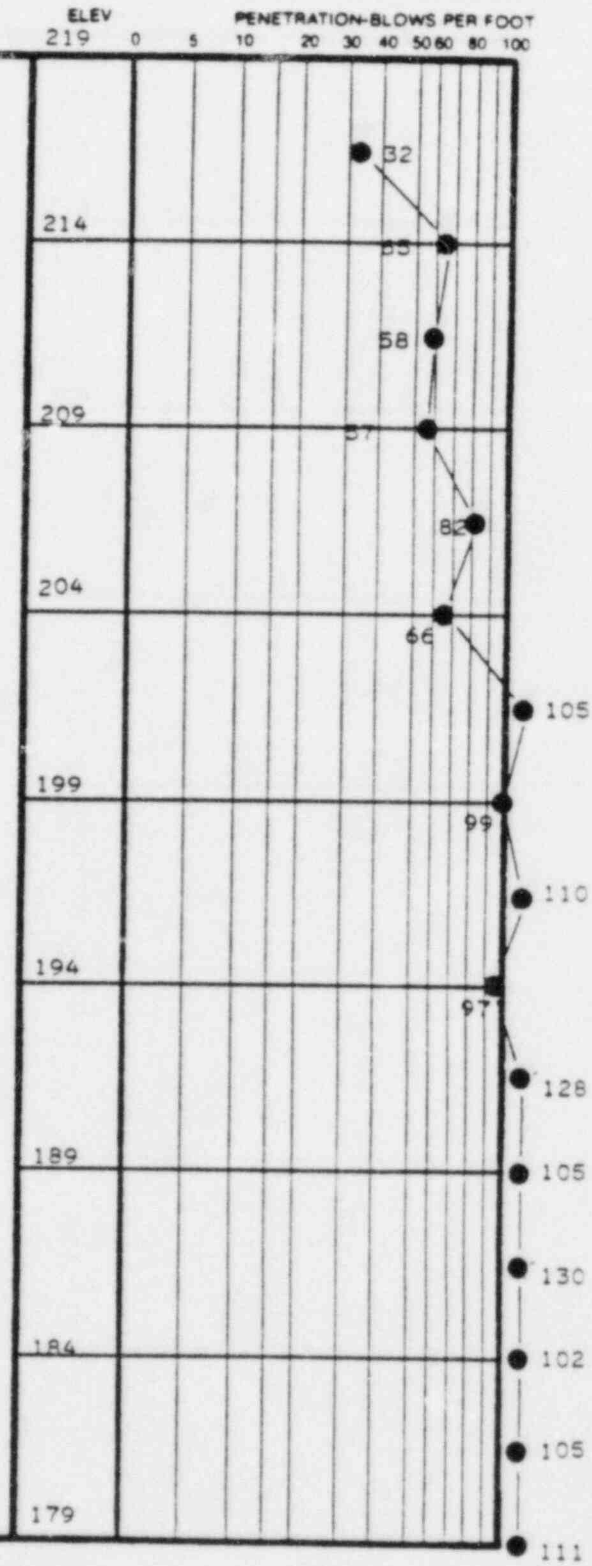
Law Engineering Testing Company

Soil Test Boring Record

BORING COORDINATES
N: 81 + 45
E: 100 + 80

BORING NUMBER SPT-110
DATE DRILLED 6-3&4-85
JOB NUMBER 7429
PAGE 1 OF 3

DEPTH (FT)	DESCRIPTION
0	BACKFILL-DENSE TO VERY DENSE - RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND
40	



REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-110
DATE DRILLED 6-3-84-85
JOB NUMBER 7429
PAGE 2 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
40	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	179	
			123
		174	154
			190/11
		169	156
			146
		164	159
			100/5''
		159	172/10½"
			100/4"
		154	195/11"
			115/1ST 6'
		149	167
			120/1ST 6'
		144	100/4"
			100/4''
80		139	100/5"

Penetration scale: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100

REMARKS:

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AF 35460

Law Engineering Testing Company

Soil Test Boring Record

BORING NUMBER SPT-110
DATE DRILLED 6-3&4-85
JOB NUMBER 7429
PAGE 3 OF 3

DEPTH (FT)	DESCRIPTION	ELEV	PENETRATION-BLOWS PER FOOT
80	BACKFILL-VERY DENSE RED BROWN SLIGHTLY SILTY TO SILTY FINE TO MEDIUM SAND	139	100/4½" ; 100/4½"
		134	
89.0			100/4"
90.0	MARL SAMPLED AS VERY HARD GRAY *	129	100/2"
	BORING TERMINATED AT 90.0 FEET		

REMARKS: * GREEN VERY CLAYEY FINE SANDY OF VERY CLAYEY FINE SANDY SILT

SEE KEY SHEET FOR EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ABOVE

AT 15460

APPENDIX B

GEOLOGIC DRILL LOGS

900	808	LT-1B
901	809	LT-7A
902		LT-12
903		LT-13
904		
904A		
904B		
905		

GEOLOGIC DRILL LOG

Field	Value
PROJECT	VOGTLE ELECTRIC GENERATING PLANT
JOB NO.	9510
SHEET NO.	1 OF 2
HOLE NO.	900
SITE	SOUTHEAST OF POWER BLOCK
COORDINATES	N 7538 E 10119.5
ANGLE FROM HORIZ.	90°
BEARING	--
BEGUN	6/6/85
COMPLETED	6/20/85
DRILLER	KEN THAMES/LAW ENGINEERING
DRILL MAKE AND MODEL	FAILING 1500
HOLE SIZE	9 7/8 IN.
OVERBURDEN (FT.)	92.6 FT.
ROCK (FT.)	50 FT.
TOTAL DEPTH	142.6 FT.
CORE RECOVERY (FT./%)	49.5/99%
CORE BOXES	8
SAMPLES	
EL. TOP OF CASING	218.05 FT.
GROUND EL.	216.3 FT.
DEPTH/EL. GROUND WATER	100.96 FT./117.20 FT. (7/16/85)
DEPTH/EL. TOP OF ROCK (MARL)	92.6 FT./123.7 FT.
SAMPLE HAMMER WEIGHT/FALL	--
CASING LEFT IN HOLE: DIA./LENGTH	SEE OBSERVATION WELL REPORT
LOGGED BY	L.R. WEST

0.0 – 92.6 ft (sample type: 9 7/8 INCH ROCKBIT)

Elevation: 210 · Depth marks: 5, 90

0.0 - 92.6 FT. BACKFILL:
SEE LOG OF SPT-105

Notes: ROCKBIT DRILLING WITH REVERT/WATER DRILLING FLUID

92.6 – 112.6 ft (sample type: 4-INCH CORE WITH 5 1/2 INCH OD BIT)

Sampler advance / length of core run	Sample recovery / core recovery	Percent core recovery	Drilling time (min.)	Water loss in G.P.M.	Pressure P.S.I.	Time in minutes
5.0	2.0*	40%	7.0			
			11.0			
			9.0			
			6.0			
			6.0			
2.0	4.6*	230%	2.5			
			1.3			
3.0	3.4*	101%	5.5			
			2.7			
			2.4			
5.0	3.5*	70%	6.6			
			6.1			
			11.3			
			9.7	0	20	8
			27.2	0	30	8
3.0	3.8*	127%	5.7	0	40	8
			5.9			
			5.8			
2.0	1.7*	85%	3.0			
			2.8			

Elevations: 123.7, 120, 110 · Depth marks: 95, 100, 105, 110

92.6 - 142.6 FT. MARL:
DARK BLUE GRAY, SILTY CALCAREOUS CLAY, FIRM TO MODERATELY HARD, LOCALLY FINE SANDY CLAY; THICK LIMESTONE NODULES AND LENSES, LOCAL OYSTERSHELL ZONES.

94.5 AND 96-97.2 FT. OYSTER SHELLS

100.0 - 100.8 FT. LARGE OYSTER SHELL FRACTURED FROM DRILLING 94.2 FT. AND 97.05 FT.

102.6 - 103.5 FT. HARD SANDY LIMESTONE

103.5 - 104.0 FT. FINE SANDY MARL

104.0 - 108 FT. MODERATELY SOFT MARL OYSTER SHELL CLAY - BROKEN ON REMOVAL FROM CORE BARREL

108 - 109 FT. LIMESTONE, HARD, SANDY FRACTURED DUE TO CORING AT 108 FT., 109 FT., 109.8 FT. AND 110 FT.

112 - 112.6 FT. SANDY LIMESTONE CORING FRACTURES AT 111 FT. AND 111.6 FT.

Notes: CORE DRILLING WITH CLEAR WATER AS DRILLING FLUID

CEMENTED 6 IN. STEEL CASING TO DEPTH OF 102.6 FT.

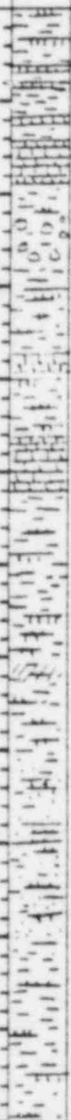
*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 2	900

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH	SAMPLE	NOTES ON WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
4 INCH CORE - 5 1/2 INCH OD BIT				1.5							
				2.7							
	5.0	5.3*	106%	2.9					115		
				3.1	0	40	10	100			
				3.3							
				2.9	0	50	10				
				3.0	0	60	10				
	5.0	5.0	100%	3.8					120		
				4.6							
				3.4							
				4.8							
				4.5							
	5.0	5.0	100%	4.9					125		
				3.6	0	50	8	90			
				3.3	0	60	8				
				2.9							
				4.5	0	70	8				
	5.0	5.0	100%	1.8					130		
				1.1							
				2.9							
				1.6							
				2.7							
	5.0	4.8*	96%	1.5					135		
				1.6	0	50	10	80			
				1.5	0	60	10				
				1.4							
				1.3	0	70	10				
	5.0	5.4*	108%	1.8					140		
				1.9							
				2.5				73.7			

GRAPHIC LOG



DESCRIPTION AND CLASSIFICATION

LIMESTONE AT 114 FT., 114.4 FT., 115.5 FT., 116 - 117.2 FT.

FRACTURES FROM CORING 118 FT., 119 FT., 119.3 FT., AND 119.4 - 123.2 FT.

118.2 FT. - 119.2 FT. LIMESTONE NODULES

121.8 - 122.2 FT. LIMESTONE

123.4 - 123.5 FT. SILTY, HARD MARL

124 - 125.5 FT. LIMESTONE

127.6 - 128 FT. SILTY, HARD MARL

128 - 129.7 FT. LIMEY

129.7 - 130.6 FT. SOFT PLASTIC

130.6 - 132.6 FT. SILTY MARL

132.6 - 137.6 FT. FIRM, SANDY

LIMEY AT 133.4 FT., 134.5 - 135 FT.

137.6 - 142.6 FT. FIRM, SILTY

BOTTOM OF HOLE 142.6 FEET

POROUS STONE (CASAGRANDE) PIEZOMETER INSTALLED IN HOLE, OPEN INTERVAL 133.8 FEET - 140.7 FEET.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: SOUTHEAST OF POWERBLOCK

HOLE NO. 900

GEOLOGIC DRILL LOG

Field	Value
PROJECT	VOGTLE ELECTRIC GENERATING PLANT
JOB NO.	9510
SHEET NO.	1 OF 2
HOLE NO.	901
SITE	SE OF POWER BLOCK
COORDINATES	N 7538 E 10104.5
ANGLE FROM HORIZ.	90°
BEARING	--
BEGUN	6/21/85
COMPLETED	7/7/85
DRILLER	H. COLLINS/LAW ENGINEERING
DRILL MAKE AND MODEL	MOBILE 53
HOLE SIZE	9-7/8 IN.
OVERBURDEN (FT.)	91.62 FT.
ROCK (FT.)	37.4 FT.
TOTAL DEPTH	128.0 FT.
CORE RECOVERY (FT./%)	33.8/93%
CORE BOXES	5
SAMPLES	
EL. TOP OF CASING	220.75 FT.
GROUND EL.	215.58 FT.
DEPTH/EL. GROUND WATER	101.57 FT./119.18 FT. (7/16/85)
DEPTH/EL. TOP OF ROCK (MARL)	91.62/123.96 FT.
SAMPLE HAMMER WEIGHT/FALL	--
CASING LEFT IN HOLE: DIA./LENGTH	SEE OBSERVATION WELL REPORT
LOGGED BY:	L.R. WEST

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9-7/8 IN. TRICONE BIT									0–5	0.0 - 91.62 FT. BACKFILL: SEE LOG OF SPT-105	ROCKBIT DRILLING WITH REVERT/WATER DRILLING FLUID.
									90		
5.5 IN. CORE BIT	2.5	2.2*	88%	3.0 / 5.2 / 14.7						91.62 - 128.0 FT. MARL: BLUE GRAY, SILTY, CALCAREOUS CLAY, FIRM TO MODERATELY HARD; LOCAL LIMESTONE NODULES AND LENSES. 93.15 - 94.1 FT. LIMESTONE, GRAY, HARD.	CORE DRILLING WITH CLEAR WATER AS DRILLING FLUID.
	5.0	4.8*	96%	2.8 / 5.5 / 2.0 / 2.3 / 2.3					95	95.25 - 95.75 FT. SANDY CLAY, CALCAREOUS, HARD. 95.75 - 99.1 FT. OYSTER SHELLS.	
	2.9	3.2*	110%	5.0 / 4.0 / 3.1					100	99.6 - 100.3 FT. LIMESTONE NODULES. SMALL LIMESTONE NODULE AT 100.5 FT. 100.5 - 102.0 FT. OYSTER SHELLS. LIMESTONE NODULE AT 102.5 FT.	CEMENTED 6 IN. STEEL CASING TO DEPTH OF 102.7 FT.
	3.0	1.4*	47%	7.5 / 19.1 / 9.0						OYSTER SHELLS AT 103.0 FT.	
	1.0	0.8*	80%	10.5					105	105.0 - 106.5 FT. SOFT, PLASTIC. 105.0 - 105.3 FT. SILTY	
	4.2	4.4*	110%	3.2 / 9.0 / 2.7 / 5.3						107.3 - 107.9 FT. LIMESTONE, SILTY AT TOP AND BOTTOM. 109.0 - 109.6 FT. LIMESTONE NODULES. SHELLS AT 109.6 FT.	
	5.0	5.0	100%	2.2 / 3.1					110	110.0 - 110.35 FT. SILTY LIMESTONE NODULE AT 110.7, 111.4, 111.7, 112 .0 - 112.4. LIMESTONE 112.9 - 113.2 FT. LIMESTONE TO 114.8 FT.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: SE OF POWER BLOCK

HOLE NO. 901

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 2	901

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
5.5 INCH BIT - 4 INCH CORE				4.7									
				4.3									
				2.4					115			115.0 - 115.4 FT. LIMESTONE NODULES	
	4.0	4.0	100%	2.0								115.4 - 117.0 FT. LIMEY AND SILTY NODULE AT 117.0 FT. AND 118.6 FT.	
				2.6									
				2.3									
				6.6	0	40	10						
	5.0	5.0	100%	13.2								119.0 - 120.5 FT. LIMESTONE, HARD, SOLID	
				7.3					120			SILTY - 121.0 - 122.2 FT.	
				2.1	0	50	10					PLASTIC - 122.2 - 123.0 FT.	
				2.0								SILTY - 123.5 - 124.0 FT.	
				3.2	0	60	10					LIMESTONE NODULE AT 124.2 FT.	
	4.0	3.8	95%	3.7					125			HARD SANDY LIMESTONE 125.0 - 126.0 FT.	
				7.5								SOFT TO SILTY - 127.0 - 128.0 FT.	
				8.3									
				3.4									

BOTTOM OF HOLE 128.0 FT.

POROUS STONE (CASAGRANDE) PIEZOMETER INSTALLED IN HOLE.
OPEN INTERVAL 122.0 - 128.0 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: SE OF POWER BLOCK

HOLE NO. 901

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	902

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
SE OF POWER BLOCK	N 7543.5 E 10110.5	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
6/23/85	7/3/85	H. COLLINS/LAW ENGINEERING	MOBILE 53	9-7/8 IN.	91.0 FT.	17.0 FT.	108.0 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
15.6/95%	2		221.11 FT.	215.97 FT.	94.85 FT./126.26 FT. (7/16/85)	91/124.97

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
	SEE OBSERVATION WELL REPORT	L.R. WEST

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH
9-7/8 IN. TRICONE ROCK BIT								215.97	0
5.5 IN. CORE BIT, 4 IN. CORE	5.0	4.7	94%	6.7				124.47	91
				5.8					
				12.3					
				3.0					95
				6.0					
	3.5	2.9	83%	5.0					
				6.3					
				7.1					
				11.7					
	5.0	5.0	100%	2.4					100
				2.0	0	40	10		
				9.3					
				3.0	0	50	10		
				2.0	0	60	10		
	3.0	3.0	100%	2.6					105
				2.8					
				3.0				107.97	108

DESCRIPTION AND CLASSIFICATION

0.0 - 91.0 FT. BACKFILL;
SEE LOG OF SPT-105.

91.5 - 108.0 FT. MARL;
BLUE GRAY, SILTY CALCAREOUS CLAY, FIRM TO MODERATELY HARD; LOCAL LIMESTONE NODULES AND LENSES.

93.4 - 95.0 FT. LIMESTONE, SANDY.
95.0 - 95.2 FT. CLAYEY, PLASTIC, FEW OYSTER SHELLS.
95.2 - 96.5 FT. FIRM, SANDY CLAY WITH ABUNDANT OYSTER SHELLS.
96.5 - 98.3 FT. HARD, ABUNDANT SHELLS. HIGHLY FRACTURED BY CORING.
98.7 - 100.0 FT. SOFT, PLASTIC.

100.0 - 100.3 FT. SILTY CLAY.

PLASTIC TO 102.25.

102.25 - 103.0 FT. LIMESTONE, SILTY CLAY.

103.0 - 105.0 FT. PLASTIC WITH ABUNDANT SHELLS.

105.0 - 105.2 FT. HARD SANDY CLAY.

105.2 - 108.0 FT. PLASTIC WITH SHELLS.

BOTTOM OF HOLE 108.0 FEET.

POROUS STONE PIEZOMETER INSTALLED IN HOLE. OPEN INTERVAL 101.5 FEET - 108.0 FEET.

NOTES ON WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

DRILLED WITH ROCK BIT AND REVERT/WATER DRILLING FLUID.

CORE DRILLING WITH CLEAR WATER AS DRILLING FLUID.

LEFT 1.3 FT. IN HOLE. PICKED UP ON SECOND TRY.

CEMENTED 6 IN. STEEL CASING TO DEPTH OF 100.0 FT.

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
SE OF POWER BLOCK	902

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: VOGTLE ELECTRIC GENERATING PLANT	JOB NO. 9510	SHEET NO. 1 OF 4	HOLE NO. 903	
SITE: NORTHWEST OF POWER BLOCK	COORDINATES: N 8480 E 8900	ANGLE FROM HORIZ. 90°	BEARING --	

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)MARL	TOTAL DEPTH
6/10/85	6/23/85	KEN THAMES/LAW ENGINEERING	FAILING 1500	9 7/8 IN.	78.0 FT.	55.0 FT.	133 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
56.0/100% (MARL)	8	4	216.73 FT.	215.75	109.61 FT./107.12 FT. (7/16/85)	78 FT./137.75 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	L.R. WEST/J.C. ISHAM

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES	ELEVATION 215.75	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9-7/8 - INCH TRICONE ROCK BIT									0–15			0.0 - 15.0 FT. SAND (SM): BROWN TO YELLOW BROWN, SILTY, MEDIUM TO COARSE SAND, SUBANGULAR. HARD DRILLING AT 6.9 FT. 0.0 - 10.0 FT. MEDIUM GRAIN SIZE 10.0 - 15.0 FT. MEDIUM TO COARSE GRAINED 0.0 - 12.0 FT. BROWN 12.0 - 15.0 FT. YELLOW BROWN	REVERT MIXED WITH WATER USED AS A DRILLING FLUID IN UPPER SANDS. LITHOLOGIC DESCRIPTION FROM 0.0 TO 35.0 FT. BASED ON WASH CUTTINGS.
									15–23			15.0 - 23.0 FT. CLAY (SC): TAN, SANDY CLAY, FINE TO MEDIUM SUBANGULAR SANDS. TRACE OF OYSTER SHELLS.	
									23–30			23.0 - 30.0 FT. SAND (SM): BROWN, SILTY, MEDIUM TO COARSE SAND, SUBANGULAR GRAINS, 1% OYSTER SHELLS.	
									30–35			30.0 - FT. SAND (SM-SC): TAN, SILTY CLAYEY SAND.	LOST 100% CIRCULATION AT 35.0 FT.

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: NORTHWEST OF POWER BLOCK — HOLE NO. 903

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 4	903

Columns: SAMPLE TYPE AND DIAMETER | SAMPLER ADVANCE LENGTH CORE RUN | SAMPLE RECOVERY CORE RECOVERY | PERCENT CORE RECOVERY | DRILLING TIME (MIN) | WATER PRESSURE TESTS: LOSS IN G.P.M., PRESSURE P.S.I., TIME IN MINUTES | ELEVATION | DEPTH | GRAPHIC LOG | SAMPLE | DESCRIPTION AND CLASSIFICATION | NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

Sample type (35–75 ft): 5.5-INCH OD/4.0 ID SPLIT TUBE CORE BARREL

Depth marks: 40, 45, 50, 55, 60, 65, 70, 75

Notes: DRILLED WITHOUT CIRCULATION 35.0 - 78.0 FT. LITHOLOGIC DESCRIPTIONS ARE BASED ON HOLE 905. CONTACTS ARE APPROXIMATE.

Description and classification:

44.5 - 77.3 FT. LIMESTONE: TAN TO CREAM, FOSSILIFEROUS (COQUINA), HARD TO VERY HARD, SOME SUBROUNDED, FINE TO MEDIUM GRAINED CEMENTED SAND.

57.0 - 58.0 FT. GRAYISH BLACK HARD SHALE.

62.2 - 62.8 FT. VERY HARD CEMENTED SANDSTONE LENSE.

62.8 - 77.3 FT. INTERBEDDED LIMESTONE AND SANDSTONE; 1 - 3 IN. LAYERS OF VERY HARD CEMENTED SANDS INTERBEDDED WITH 6 IN. - 1 FT. LAYERS OF HARD FOSSILIFEROUS LIMESTONE (SHELLS).

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

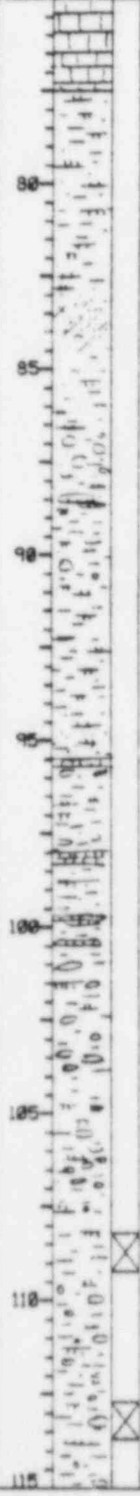
SITE: NORTHWEST OF POWER BLOCK

HOLE NO. 903

BECHTEL	GEOLOGIC DRILL LOG	PROJECT: VOGTLE ELECTRIC GENERATING PLANT	JOB NO. 9510	SHEET NO. 3 OF 4	HOLE NO. 903

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION
4-INCH SPLIT TUBE CORE BARREL/5.5-INCH OD	5.0	4.5*	90%	3.5				137.75
				5.0				
				4.0				
				5.5				
				4.0				
	3.0	3.5*	117%	3.0				
				8.0				
				13.0				
	5.0	3.8*	76%	9.0				
				10.0	0	30	8	
				6.0	0	40	8	
				13.0	0	50	8	
				4.0	0	40	8	
	4.0	3.1*	78%	12.0	0	30	8	
				11.0				
				4.0				
				6.0				
	1.0	0*	0%	5.0				
	1.0	4.1*	410%	30.0				
	5.0	5.0	100%	5.0				
				15.0	0	35	8	
				7.0	0	45	8	
				15.0	0	55	8	
				7.0	0	45	8	
	5.0	5.0	100%	7.0	0	35	8	
				8.0				
				7.0				
				9.0				
				10.0				
	5.0	3.2*	64%	14.0				
				9.0	0	40	8	
				20.0	0	50	8	
				13.0	0	61	8	
				12.0	0	50	8	
	3.0	3.4*	113%	8.0	0	40	8	
				10.0				
				12.0				
	2.0	3.4*	170%	11.0				

DEPTH / GRAPHIC LOG / SAMPLE



DESCRIPTION AND CLASSIFICATION

TOP OF MARL

73.0 - 133.0 FT. <u>MARL</u>:
BLUISH GREENISH GRAY, FIRM TO HARD, CALCAREOUS CLAY, UNFRACTURED, SOME FINE SANDY CLAY ZONES, LOCAL LIMESTONE NODULES AND LENSES, TRACE OF DARK BROWN ORGANIC MATTER, SOME OYSTER SHELLS.

82.5 - 84.5 FT. SOFT, MEDIUM GRAINED SANDY CLAY, TRACE OF SHELLS.

85.0 - 87.7 FT. 5% TO 10% SHELLS.

LIMESTONE NODULES AT 86.8 FT AND 87.70 FT.

LIMESTONE LENSES 88.2 - 88.8 FT.

88.8 - 90.0 FT. 10% TO 20% SHELLS.

90.0 - 91.9 FT. SEVERAL LIMESTONE NODULES.

91.9 - 94.8 FT. MORE CLAYEY, 10% TO 20% SHELLS.

94.8 - 95.4 FT. SANDIER, LESS THAN 5% SHELLS.

95.4 - 95.7 FT. LIMESTONE LENSE.

95.7 - 96.0 FT. SEVERAL LIMESTONE NODULES.

LIMESTONE LENSES AT 96.1 - 96.4 FT.; 97.9 - 98.25 FT.; 99.7 - 100.1 FT.; AND 100.5 - 100.6 FT.

LIMESTONE NODULES AT 97.2 FT.; 97.5 FT.; 101.1 FT.; 101.3 FT.; 101.8 FT.; 102.5 FT.; 102.9 FT.; 103.4 - 103.9 FT.

NOTES ON WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

CLEAR WATER USED AS DRILLING FLUID IN MARL.

6 IN. STEEL CASING CEMENTED TO A DEPTH OF 85 FT.

WAXED CORE SAMPLE *1 108.2 - 109.2

WAXED CORE SAMPLE *2 112.7 - 113.7 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: NORTHWEST OF POWER BLOCK

HOLE NO. 903

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	4 OF 4	903

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH
5.5 IN. SPLIT TUBE	2.0	3.4*	170%	9.0	TEST	*3			
	5.0	5.0	100%	3.0	0	45	8		
				8.0	0	55	8		
				5.0	0	66	8		
				5.0	0	55	8		120
				9.0	0	45	8		
5.5 IN. SOLID TUBE BARREL	5.0	5.0	100%	6.0					
				3.0					
				2.0					
				3.0					125
				3.0					
	5.0	5.0	100%	3.0		48	8		
				4.0		58	8		
				2.0		68	8		
				1.5		58	3		130
				1.5		48	8		
	2.0	2.0	100%	2.0					
				2.0				82.75	

DESCRIPTION AND CLASSIFICATION

LIMESTONE NODULES AT 104.9 FT.; 105.7 FT.; 106.0 - 109.2 FT. ABUNDANT LIMESTONE NODULES (20%).

106.0 - 116.0 FT. LESS THAN 5% SHELLS.

LIMESTONE NODULES AT 109.5 - 109.9 FT.; 110.8 - 111.1 FT.; 111.8 - 112.1 FT.; 112.5 - 112.7 FT.; 113.0 - 113.5 FT.; AND 114.7 - 115.0 FT.

CALCAREOUS ZONE 113.9 - 115.6 FT

116.0 - 133.0 FT. HARD CALCAREOUS ZONE

BOTTOM OF HOLE 133.0 FEET.

POROUS STONE PIEZOMETER PLACED TO A DEPTH OF 131 FEET. SEE OBSERVATION WELL REPORT. OPEN INTERVAL FROM 133 FEET TO 127 FEET.

NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

WAXED CORE SAMPLE *3 128.4 - 129.4 FT. 500 GRAMS IN GLASS JAR SAMPLE *4 FROM 131 FT.

DEEP GOUGES (1/2 IN.) CAUSED BY THE CORE CATCHER FROM 121.0 - 131.0 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: NORTHWEST OF POWER BLOCK

HOLE NO. 903

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 3	904

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NW OF POWER BLOCK	N 8465 E 8900	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7/2/85	7/9/85	K. THAMES/LAW ENGINEERING	FAILING 1500	9-7/8 IN.	78.8 FT.	(MARL) 9.2 FT.	88.0 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
9.2/100% (MARL)	2	0	—	215.75 FT.	—	78.8 FT./136.95 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
—	SEE OBSERVATION WELL REPORT	J.C. ISHAM

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9-7/8 INCH TRICONE ROCK BIT									0–5			0.0 - 5.0 FT. SAND (SM): RED, SILTY, SUBROUNDED, FINE GRAINED SAND (SM).	WATER MIXED WITH REVERT USED AS A DRILLING MUD FROM 0.0 - 88.0 FT.
									5–15			5.0 - 15.0 FT. SAND (SM): TAN, SILTY, SUBROUNDED, FINE TO MEDIUM GRAINED SAND (SM).	LITHOLOGIC DESCRIPTION FROM 0.0 - 77.0 FT. BASED ON WASH SAMPLES.
									15–35			15.0 - 35.5 FT. CLAY (SC): TAN, SANDY CLAY, SUBROUND, MEDIUM TO COARSE GRAINED SANDS.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 3	904

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9-7/8 INCH TRICONE ROCK BIT									40, 45			35.5 Ø 46.Ø FT. SAND (SM): TAN, SILTY, FINE TO MEDIUM, SOME COARSE GRAINED SAND; TRACE OF SHELLS.	
									50, 55, 60			46.Ø - 78.Ø FT. LIMESTONE: TAN TO CREAM, FOSSILIFEROUS (COQUINA), HARD TO VERY HARD, SOME SUBROUNDED FINE TO MEDIUM GRAINED CEMENTED SAND.	
									65, 70			VERY HARD, CEMENTED CALCAREOUS SANDSTONE FROM 62.Ø - 78.8 FT.	DRILL CHATTER 62.Ø - 78.8 FT. VERY HARD DRILLING. LOST ALL CIRCULATION FROM 67.Ø - 88.Ø FT. EXTREMELY HARD DRILLING 7Ø.Ø - 71.Ø FT. SOFT ZONE 71.Ø - 71.3 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 904

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	3 OF 3	904

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
5.5 INCH O.D., 4.5 INCH I.D. SPLIT TUBE CORE BARREL	2.0	0.4	20%	24.0 37.0								78.6 - 78.8 FT. VERY HARD LIMESTONE LENSE.	
	0.3	0.3	100%	10.0				136.95					
	4.7	4.5	96%	11.0 16.0 10.0 1.0 6.0					80			78.8 - 88.0 FT. <u>MARL</u>; BLUE GRAY, SILTY CALCAREOUS CLAY, FIRM TO MODERATELY HARD, LIMESTONE NODULES AND LENSES. 78.8 - 79.0 FT. TAN, SILTY CALCAREOUS CLAY, HARD, UNFRACTURED, TRACE OF DARK BROWN ORGANICS. 79.0 - 88.0 FT. GREENISH BLUISH GRAY.	CEMENTED 6 IN. STEEL CASING TO A DEPTH OF 88.0 FT. CASING SEPARATED AT A DEPTH OF 78.0 FT. CAUSING HOLE TO BE ABANDONED. GROUTED INSIDE AND OUTSIDE OF CASING TO GROUND SURFACE ON 7/9/83. INJECTED 28 CU. FT. OF 1:1 CEMENT/WATER GROUT. SEE GEOLOGIC LOG 904B FOR CONTINUATION.
	4.0	4.2*	105%	4.0 3.0 4.0 5.0				127.75	85			81.8 - 82.0 FT. SEVERAL 1/4-IN. DIAMETER PYRITE CRYSTALS. 83.2 - 84.4 FT. 10% SHELLS.	
									90			BOTTOM OF HOLE 88.0 FEET. HOLE GROUTED.	

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
NW OF POWER BLOCK	904

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	904A

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NW OF POWER BLOCK	N 8465 E 8890	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7/10/85	7/10/85	H. COLLINS/LAW ENGINEERING	MOBILE 53	9-7/8 IN.	15.0 FT.	--	15.0 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
--	--	--	--	215.75 F.T	--	--

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	NONE	J.C. ISHAM

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9 7/8-INCH TRICONE ROCK BIT									0			0.0 - 5.0 FT. SAND (SM): RED, SILTY, SUBROUNDED, FINE GRAINED.	WATER MIXED WITH REVERT USED AS A DRILLING MUD.
									5			5.0 - 15.0 FT. SAND (SM): TAN, SILTY, SUBROUNDED, FINE TO MEDIUM GRAINED.	
									10				ENCOUNTERED SEWER LINE AT A DEPTH OF 15.0 FT. HOLE ABANDONED. MOVED 5.0 FT. WEST AND STARTED HOLE 904B. SEE 904B FOR CONTINUATION.
								200.75	15			BOTTOM OF HOLE 15.0 FEET. HOLE GROUTED	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
NW OF POWER BLOCK	904A

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 2	904B

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NW OF POWER BLOCK	N 8464 E 8885	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.) MARL	TOTAL DEPTH
7/10/85	7/14/85	H. COLLINS/LAW ENGINEERING	MOBILE 53	9-7/8 IN.	76.5 FT.	20.2 FT.	96.7 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
14.7/100% (MARL)	3	5	--	215.75 FT.	93.8 FT./122.43 FT. (7/16/85)	76.5 FT./139.25 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	J.C. ISHAM

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION
ROCK BIT								
9-7/8 IN.								
4.5 IN. I.D. CORE BARREL, 5.5 IN. O.D.	5.0	2.4	48%	2.3				
				10.0				
				2.2				
				2.3				
				6.0				
	1.5	1.0	67%	34.0				
				38.8				
	4.5	3.2	71%	10.0				
				4.8				139.25
				5.7				
				4.0				
9-7/8 IN. ROCK BIT								
4.5 IN. I.D. CORE BARREL	5.0	3.6*	72%	5.9	0	30	8	
				3.8	0	40	8	
				5.6	0	50	8	
				3.8	0	40	8	
				2.3	0	30	8	

DEPTH: 5, 65, 70, 75, 80, 85

DESCRIPTION AND CLASSIFICATION

0.0 - 5.0 FT. SAND (SM): RED.

5.0 - 15.0 FT. SAND (SM): TAN.

15.0 - 35.5 FT. CLAY (SC): TAN, SANDY.

35.5 - 46.0 FT. SAND (SM): TAN.

46.0 - 76.5 FT. LIMESTONE: TAN, FOSSILIFEROUS (COQUINA).

62.0 - 76.5 FT. CEMENTED CALCAREOUS SANDSTONE, VERY HARD.

69.5 - 70.3 FT. VERY HARD LIMESTONE LENSE.

74.5 - 75.0 FT. TAN SILTSTONE LENSE, HARD.

76.5 - 96.0 FT. MARL: SILTY, CALCAREOUS CLAY, HARD, UNFRACTURED, SOME WHITE SHELLS.

76.5 - 78.8 FT. TAN.

78.8 - 96.7 FT. GREENISH, BLUISH GRAY.

87.6 - 88.3 FT. LIMESTONE NODULE.

NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

TRICONE DRILLING USING WATER MIXED WITH REVERT AS A DRILLING FLUID FROM 0.0 - 85.0 FT.

67.0 FT. LOST CIRCULATION, VERY HARD DRILLING.

CEMENTED 6 IN. STEEL CASING TO A DEPTH OF 85.0 FT.
WATER USED AS A DRILLING FLUID FROM 85.0 - 96.7 FT.

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 2	904B

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
6.5 IN. O.D. CORE BARREL	3.0	4.4*	147%	4.4									MARL SAMPLES:
				4.7								91.2 - 91.5 FT. LIMESTONE NODULE.	#1 92.3 (JAR)
				2.3							X		#2 92.3 - 93.0
	3.7	3.7	100%	7.0									#3 94.0 (JAR)
				5.2					95			94.7 - 95.5 FT. LIMESTONE NODULE.	#4 94.7 (JAR)
				3.1				119.05					#5 96.0 (JAR)
												BOTTOM OF HOLE 96.7 FEET.	
												POROUS STONE PIEZOMETER PLACED TO A DEPTH OF 94.7 FEET. OPEN INTERVAL FROM 90.0 FEET TO 96.7 FEET.	

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 904B

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 4	905

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NW OF POWER BLOCK	N 8450 E 8900	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
6/23/85	7/9/85	H. COLLINS/LAW ENGINEERING	FAILING 1500	9-7/8 IN.	77.3 FT.	MARL 38.7 FT.	116.0 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
37.6/96%	5	8	--	215.75 FT.	106.21 FT./110.5 FT. (7/16/85)	77.3 FT./138.45 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	J.C. ISHAM

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
9-7/8 IN. TRICONE ROCK BIT								215.75	0			0.0 - 5.0 FT. SAND (SM): RED, SILTY, SUBROUNDED, FINE GRAINED.	WATER MIXED WITH REVERT USED AS A DRILLING FLUID FROM 0.0 - 77.0 FT.
								210.75	5			5.0 - 15.0 FT. SAND (SM): TAN, SILTY, SUBROUNDED, FINE TO MEDIUM GRAINED.	
									10				
								200.75	15			15.0 - 30.0 FT. CLAY (SC): TAN, SANDY, SUBROUNDED MEDIUM SAND GRAINS.	LITHOLOGIC DESCRIPTION FROM 0.0 TO 77.0 FT. BASED ON WASH SAMPLES.
									20				
									25				
								185.75	30			30.0 - 44.5 FT. SAND (SM): TAN, SILTY, SUBROUNDED, FINE TO MEDIUM GRAINED.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
NW OF POWER BLOCK	905

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 4	905

Columns: SAMPLE TYPE AND DIAMETER | SAMPLER ADVANCE / LENGTH CORE RUN | SAMPLE RECOVERY / CORE RECOVERY | PERCENT CORE RECOVERY | DRILLING TIME (MIN.) | WATER PRESSURE TESTS: LOSS IN G.P.M., PRESSURE P.S.I., TIME IN MINUTES | ELEVATION | DEPTH | GRAPHIC LOG | SAMPLE | DESCRIPTION AND CLASSIFICATION | NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

Sample type and diameter: 9-7/8 IN. TRICONE ROCK BIT

Depth scale: 40, 45, 50, 55, 60, 65, 70

ELEVATION	DEPTH	DESCRIPTION AND CLASSIFICATION	NOTES
171.25	44.5	44.5 - 77.3 FT. LIMESTONE: TAN TO CREAM, FOSSILIFEROUS (COQUINA), HARD TO VERY HARD, SOME SUBROUNDED, FINE TO MEDIUM GRAINED CEMENTED SAND.	44.5 - 61.0 FT. FLUID LOSS APPROXIMATELY 5 GAL./FT. OF DRILL ADVANCEMENT.
	57.0	57.0 - 58.0 FT. GRAYISH BLACK HARD SHALE.	
	62.2	62.2 - 62.8 FT. VERY HARD CEMENTED SANDSTONE LENSE.	1 HOUR DRILLING TIME FOR SANDSTONE LENSE.
	62.8	62.8 - 77.3 FT. INTERBEDDED LIMESTONE AND SANDSTONE: 1 - 3 IN. LAYERS OF VERY HARD CEMENTED SANDS INTERBEDDED WITH 6 IN. - 1 FT. LAYERS OF HARD FOSSILIFEROUS LIMESTONE (SHELLS).	61.0 - 71.0 FT. FLUID LOSS APPROXIMATELY 10 GAL./FT. OF DRILL ADVANCEMENT.
	72.5		LOST ALL CIRCULATION AT 72.5 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 905

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	3 OF 4	905

SAMPLE TYPE AND DIAMETER: 4.5 IN. I.D. SPLIT TUBE CORE BARREL, 5.5 IN. O.D.

ELEVATION: 138.45

SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES
5.0	4.8	96%	8.0			
			6.0			
			4.0			
			3.0			
			4.0			
5.0	4.4	88%	14.0			
			7.0			
			3.0			
			3.0			
			3.0			
1.5	1.2	80%	3.0			
			1.0			
5.0	4.3*	86%	1.9	0	30	8
			1.8	0	40	8
			3.7	0	50	8
			4.8	0	40	8
			2.1	0	30	8
4.0	4.7*	118%	2.7			
			2.0			
			6.0			
			3.8			
5.0	4.3*	86%	4.8			
			3.5			
			3.3			
			3.7			
			2.5			
4.0	4.7*	118%	2.3	0	40	8
			3.0	0	50	8
			2.3	0	60	8
			3.7	0	50	8
5.0	4.6*	92%	3.0	0	40	8
			4.2			
			3.3			
			4.0			
			4.6			
4.5	4.9*	109%	3.7			
			2.9			
			3.3			
			2.0			

DEPTH: 80, 85, 90, 95, 100, 105, 110

DESCRIPTION AND CLASSIFICATION
77.3 - 116.0 FT. <u>MARL</u>; SILTY CALCAREOUS CLAY, HARD, UNFRACTURED, TRACE OF DARK BROWN ORGANICS.
77.3 - 78.3 FT. TAN.
78.3 - 116.0 FT. GREENISH BLUISH GRAY.
82.6 - 84.6 FT. 10% SHELLS.
84.6 - 88.5 FT. INTERBEDDED SILTY CALCAREOUS CLAY AND SILTY SANDY CALCAREOUS CLAY.
88.5 - 91.15 FT. 10% SHELLS.
91.15 - 91.5 FT. LIMESTONE LENSE.
91.5 - 92.4 FT. SEVERAL LIMESTONE NODULES.
92.4 - 93.9 FT. 10% SHELLS.
95.6 - 96.3 FT. LIMESTONE LENSE.
97.5 - 98.0 FT. LIMESTONE LENSE.
98.0 - 103.8 FT. SEVERAL LIMESTONE NODULES.
103.8 - 105.6 FT. CLAYEY.
105.6 - 112.0 FT. SEVERAL LIMESTONE NODULES.

NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
USED WATER AS DRILLING FLUID FROM 77.0 - 116.0 FT.
6 IN. STEEL CASING CEMENTED IN PLACE TO A DEPTH OF 88.5 FT.
SAMPLE #1 91.65 - 92.8 FT.
SAMPLE #2 96.7 - 97.5 FT.
SAMPLE #3 99.5 FT. (JAR)
SAMPLE #4 106.5 FT. (JAR)
SAMPLE #5 107.5 - 108.4 FT.
SAMPLE #6 113.3 FT. (JAR)
SAMPLE #8 114.0 - 115.0 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 905

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	4 OF 4	905

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
5.5 IN.	4.5	4.9*	109%	2.0 / 1.9				99.75	116				SAMPLE *7 116.0 FT. (JAR)
												BOTTOM OF HOLE 116.0 FEET. POROUS STONE PIEZOMETER PLACED TO A DEPTH OF 114.0 FEET. OPEN INTERVAL FROM 109.8 FEET - 116.0 FEET.	

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 905

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	808

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
SWITCH YARD	N 9625 E 9300	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
5/27/85	5/28/85	KEN THAMES/LAW ENGINEERING	FAILING 1500	6-7/8 IN.	66.3 FT.	MARL 1.7 FT.	68.0 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
—	--	—	216.40 FT.	207.0 FT.	57.16 FT./159.24 FT. (7/16/85)	66.3 FT./140.7 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	L.R. WEST

SAMPLE TYPE AND DIAMETER	ELEVATION	DEPTH	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
6-7/8 IN. TRICONE ROCK BIT	207.0	0	0.0 - 5.0 FT. SILTY CLAY: BROWN AND RED, 3% SMALL GRAVEL, BLACK.	LOG FROM DITCH SAMPLES DRILLED WITH E-Z MUD. COMPLETED AS OBSERVATION WELL. 4-IN. PVC CASING AND SCREEN.
	200		5.0 - 15.0 FT. SILTY CLAY: RED, TRACE BROWN; 1% SAND, FINE GRAINED.	
		10		
			15.0 - 20.0 FT. SILTY SAND: TAN, FINE GRAINED, 10% LIMESTONE, WHITE, WEATHERED.	
		20	20.0 - 28.0 FT. CLAY: TAN, PLASTIC, 10% OYSTER SHELLS. 25.0 FT. INCREASE IN OYSTER SHELLS.	
	180		28.0 - 35.0 FT. SAND: FINE GRAINED, 40 - 50% OYSTER SHELLS.	
		30		
			35.0 - 36.0 FT. CLAY: PLASTIC, TAN, SANDY; 30% OYSTER SHELLS.	
			36.0 - 45.0 FT. OYSTER SHELLS: TRACE CLAY, TAN, SHELLS CAVING FROM 40.0 - 42.0 FT.	
		40		
			45.0 - 46.0 FT. SILTY SAND: TAN TO BROWN, OYSTER SHELLS (FROM ABOVE).	
	160		46.0 - 50.0 FT. SAND: SILTY - DECREASE IN OYSTER SHELLS.	
		50	50.0 - 60.0 FT. SAND: SILTY, FINE GRAINED; 1% OYSTER SHELLS. 58.5 FT. SILT, TAN	
		60	60.0 - 66.3 FT. SILTY SAND: BROWN WITH BLACK SPECKS, 10% OYSTER SHELLS.	
	140.7		66.3 FT.- 68.0 FT. MARL: GREEN, CALCAREOUS CLAY, FIRM.	OBSERVATION WELL INSTALLED IN HOLE. OPEN INTERVAL 45.5 TO 68.0 FT.
	139.0		BOTTOM OF HOLE 68.0 FEET.	

Columns also printed on form (blank): SAMPLER ADVANCE / LENGTH CORE RUN; SAMPLE RECOVERY / CORE RECOVERY; PERCENT CORE RECOVERY; DRILLING TIME (MIN.); WATER PRESSURE TESTS (LOSS IN G.P.M.; PRESSURE P.S.I.; TIME IN MINUTES); GRAPHIC LOG; SAMPLE.

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE: SWITCH YARD — HOLE NO. 808

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 2	809

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NW OF POWER BLOCK	N 8320 E7860	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
5/24/85	5/26/85	KEN THOMAS/LAW ENGINEERING	FAILING 1500	7-7/8 IN.	89.0 FT.	1.0 FT.	90.0 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
--	--	--	225.25 FT.	222.8 FT.	72.51 FT./152.74 FT. (7/16/85)	89.0 FT./133.8 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	L.R. WEST

Column headings: SAMPLE TYPE AND DIAMETER; SAMPLER ADVANCE LENGTH CORE RUN; SAMPLE RECOVERY CORE RECOVERY; PERCENT CORE RECOVERY; DRILLING TIME (MIN.); WATER PRESSURE TESTS (LOSS IN G.P.M.; PRESSURE P.S.I.; TIME IN MINUTES); ELEVATION; DEPTH; GRAPHIC LOG; SAMPLE; DESCRIPTION AND CLASSIFICATION; NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

Sample type: 7-7/8 IN. TRICONE ROCK BIT

Elevation at top: 222.8

Elevation	Depth	Description and Classification	Notes
222.8	0	0.0 - 10.0 FT. SAND: SILTY, VERY FINE GRAINED, RED 5.0 - 7.0 FT. CHANGE TO TAN, INCREASE IN SILT.	DRILLING WITH REVERT/WATER DRILLING FLUID.
	10	10.0 - 20.0 FT. SILTY SAND: FINE GRAINED, RED.	
200	20	20.0 - 37.0 FT. SAND: SILTY, MEDIUM GRAINED, QUARTZ, TAN. 25.0 FT. MEDIUM TO COARSE GRAINED. HARD ZONE AT 26.5 FT. 35.0 FT. TRACE LIMESTONE, WHITE AND BLACK.	
	30		
	37	37.0 - 40.0 FT. GRAVEL: SMALL, SUBROUNDED, QUARTZ, LIMESTONE, WHITE AND BLACK, 40% CLAY, TAN.	WATER LEVEL ON 5/25 - 38.0 FT.
180	40	40.0 - 55.0 FT. CLAY: PLASTIC, TAN, 5% GRAVEL, SMALL, SUB-ROUNDED, QUARTZ AND LIMESTONE.	
	50		
	55	55.0 - 60.0 FT. SANDY CLAY: BROWN, SAND IS FINE GRAINED, QUARTZ WITH 3 - 5% LIMESTONE, WHITE.	HARD DRILLING.
160	60	60.0 - 77.0 FT. SILTY SAND: QUARTZ, FINE GRAINED, SUBROUNDED, TRACE LIMESTONE, WHITE.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.	SITE: NW OF POWER BLOCK	HOLE NO. 809

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	2 OF 2	809

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS LOSS IN G.P.M.	PRESSURE P.S.I	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
7-7/8 IN. TRICONE ROCK BIT								145.8					
									80			77.0 - 89.0 FT. LIMESTONE; WEATHERED, ORANGE AND BROWN.	100% WATER LOSS AT 77.0 FT. 40% WATER RETURN AT 80.0 FT.
								131.8				89.0 - 90.0 FT. MARL;	
								132.8	90			BOTTOM OF HOLE 90.0 FEET.	COMPLETED AS OBSERVATION WELL. WATER TABLE AQUIFER. OPEN INTERVAL 69.35 TO 90.0 FT.

* APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: NW OF POWER BLOCK

HOLE NO. 809

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	LT-18

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
NORTHWEST OF UNIT 2 TURBINE	N 8388 E 9304	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7/5/85	7/5/85	H. COLLINS/LAW ENGINEERING	MOBILE 53	5-7/8 IN.	83.3 FT.	1.35 FT.	84.65 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
---	--	---	215.47 FT.	213.18 FT.	60.3 FT./155.16 FT. (7/16/85)	83.3 FT./129.88 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
---	SEE OBSERVATION WELL RECORD	L.R. WEST

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
5-7/8 IN. TRICONE BIT								200 (at ~15); 150 (at ~63)	10, 20, 30, 40, 50, 60, 70, 80			0.0 - 84.65 FT. <u>BACKFILL</u>: SAND, RED BROWN, SILGHTLY SILTY TO SILTY, FINE TO MEDIUM GRAINED.	DRILLED TO REPLACE HOLE LT-1A. DRILLED WITH REVERT/WATER DRILLING FLUID.
												BOTTOM OF HOLE 84.65 FEET. INSTALLED OBSERVATION WELL OPEN INTERVAL 65.17 TO 84.65 FEET.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
NORTHWEST OF UNIT 2 TURBINE BUILDING	LT-18

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	LT-7A

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
SOUTHWEST OF UNIT 2 TURBINE BLDG.	N 8151.3 E 9317.5	90°	--

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7/7/85	7/7/85	H. COLLINS/LAW ENGINEERING	MOBILE 53	5-1/8 IN.	87.0 FT.	0	87.0 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
--	--	--	221.17 FT.	215.92 FT.	63.19 FT./157.98 FT. (7/16/85)	87.0 FT./128.92 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
	SEE OBSERVATION WELL REPORT	L.R. WEST

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN.)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
DRILLED WITH 5-1/8 INCH TRICONE BIT												0.0 - 87.0 FT. <u>BACKFILL</u>: SAND, RED BROWN, SLIGHTLY SILTY TO SILTY, FINE TO MEDIUM GRAINED.	DRILLED TO REPLACE WELL LT-7. DRILLED WITH REVERT/WATER DRILLING FLUID.
									10				
								200					
									20				
									30				
									40				
									50				
									60				
								150					
									70				
									80				
												BOTTOM OF HOLE 87.0 FEET. INSTALLED OBSERVATION WELL OPEN INTERVAL 65.0 TO 87.0 FEET.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE LATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
SOUTHWEST OF UNIT 2 TURBINE BUILDING	LT-7A

GEOLOGIC DRILL LOG

PROJECT: VOGTLE ELECTRIC GENERATING PLANT		JOB NO. 9510	SHEET NO. 1 OF 1	HOLE NO. LT-12	
SITE: SOUTH OF AUXILIARY BLDG.	COORDINATES: N 7775 E 9600		ANGLE FROM HORIZ. 90°	BEARING: --	
BEGUN: 6/3/85	COMPLETED: 6/3/85	DRILLER: KEN THOMAS/LAW ENGINEERING	DRILL MAKE AND MODEL: FAILING 1500	HOLE SIZE: 6-7/8 IN.	OVERBURDEN (FT.): 79.0 FT.
ROCK (FT.): 0	TOTAL DEPTH: 79.0 FT.				
CORE RECOVERY (FT./%): --	CORE BOXES: --	SAMPLES: --	EL. TOP OF CASING: 219.27 FT.	GROUND EL.: 209.9 FT.	DEPTH/EL. GROUND WATER: 59.10 FT./160.17 FT. (7/16/85)
DEPTH/EL. TOP OF ROCK (MARL): 79.0 FT./130 FT.					
SAMPLE HAMMER WEIGHT/FALL: --	CASING LEFT IN HOLE: DIA./LENGTH: SEE OBSERVATION WELL REPORT	LOGGED BY: L.R. WEST			

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
DRILLED WITH 6-7/8 INCH TRICONE BIT									0			0.0 - 79.0 FT. <u>BACKFILL</u>: SAND, RED BROWN, VERY DENSE, SLIGHTLY SILTY TO SILTY, FINE TO MEDIUM GRAINED.	DRILLED WITH REVERT/WATER DRILLING FLUID.
								200	10				
									20				
									30				
									40				
									50				
								150	60				
									70				
									79			BOTTOM OF HOLE 79.0 FEET. INSTALLED OBSERVATION WELL OPEN INTERVAL 58.15 - 79.0 FEET.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE. PICKED UP ON FOLLOWING RUNS.

SITE: SOUTH OF AUXILIARY BUILDING

HOLE NO. LT-12

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
VOGTLE ELECTRIC GENERATING PLANT	9510	1 OF 1	LT-13

SITE	COORDINATES	ANGLE FROM HORIZ.	BEARING
EAST OF UNIT 1	N 8135 E 10110	90°	

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
5/28/85	5/28/85	KEN THOMAS/LAW ENGINEERING	FAILING 1500	7-7/8 IN.	89.0 FT.	1.0 FT.	90.0 FT.

CORE RECOVERY(FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK (MARL)
--	--	--	220.61 FT.	219.0 FT.	63.08 FT./157.53 FT. (7/16/85)	89.0 FT./130.0 FT.

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
--	SEE OBSERVATION WELL REPORT	L.R. WEST

SAMPLE TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	PERCENT CORE RECOVERY	DRILLING TIME (MIN)	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
7-7/8 IN. TRICONE ROCK BIT								200 (at 20); 150 (at 70)	10, 20, 30, 40, 50, 60, 70, 80, 90			0.0 - 90.0 FT. <u>BACKFILL</u>: SAND, RED BROWN, DENSE TO VERY DENSE, SLIGHTLY SILTY TO SILTY, FINE TO MEDIUM GRAINED.	DRILLED WITH REVERT/WATER DRILLING FLUID.
												BOTTOM OF HOLE 90.0 FEET. INSTALLED OBSERVATION WELL. OPEN INTERVAL 68.1 TO 90.0 FEET.	

*APPARENT CORE RECOVERY. CORE SLIPPED THROUGH CORE CATCHER, REMAINING IN HOLE, PICKED UP ON FOLLOWING RUNS.

SITE	HOLE NO.
EAST OF UNIT 1	LT-13

APPENDIX C

LABORATORY TESTS

Permeability Tests	-	Harding-Lawson Assoc.
Cation Exchange Capacity	-	Soils and Plant Laboratory Inc.
Distribution Coefficient	-	Battelle Pacific Northwest Laboratories

Harding Lawson Associates

August 12, 1985

3854,085.01

Bechtel Civil & Minerals, Inc.
P.O. Box 3965
San Francisco, California 94119

Attention: Mr. Thomas Crosby

Gentlemen:

Laboratory Testing Results
Vogtle Electric Generating Project
Contract No. 9510-091-SF-06

This letter presents the results of laboratory testing performed on samples of rock and soil received from Bechtel Civil & Minerals (BCM) from the Vogtle Electric Generating Plant. Harding Lawson Associates (HLA) work on this project was performed under Contract No. 9510-SF-06 dated May 9, 1985.

The samples were delivered to our Novato, California laboratory by a Bechtel carrier on July 3, 8, 15, and August 15, 1985. Selection of the tests was performed by BCM personnel and transmitted to HLA with the samples. During the course of the laboratory work, we communicated with Mr. Thomas Crosby regarding the testing and progress of the work.

The testing was done in accordance with the Specifications for Laboratory Testing and in accordance with the data transmitted in the above-mentioned letter. All of the work was performed using properly calibrated equipment under the supervision of the HLA laboratory manager or the laboratory director. The original data sheets and computations are available in HLA's files for review. These records will be retained for at least one year from the date of this report.

Permeability Tests

Ten falling head permeability tests were run in accordance with the procedure presented in the Department of Army Manual EM 1110-2-1906. The

Engineers
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Geophysicists

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Telephone
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Alaska
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Hawaii
Nevada

Texas
Washington

test equipment consists of permeameter chambers manufactured by Karol Warner, Incorporated and modified by HLA

Each 4-inch-diameter soil/rock core was trimmed, placed in a chamber, confining fluid was placed in the chamber surrounding the rubber membrane covered sample, and a seating pressure of 2 psi applied to the chamber fluid. The sample was then seepage-saturated and followed by back-pressure saturation until a "B" value of .95 or greater was obtained. (All saturation water is distilled and was de-aired before testing.) The test specimen was then consolidated to the required pressure. After consolidation was completed, the permeability test was run.

The permeability test results for the 10 samples area as follows:

Sample No.	Depth (ft)	Permeability (cm/sec)	Initial Conditions	
			Water Content %	Dry Density (pcf)
901	119.0	5.01×10^{-9}	2.9	160.9
902	104.2	1.95×10^{-6}	38.6	78.1
903	108.2	1.94×10^{-7}	21.3	103.6
903	112.7	4.99×10^{-7}	26.0	97.5
903	128.4	2.06×10^{-6}	23.0	99.7
904	92.3	2.42×10^{-6}	65.1	66.4
905	91.6	1.41×10^{-6}	24.1	102.0
905	96.7	8.49×10^{-6}	25.7	99.9
905	107.5	1.39×10^{-7}	38.9	81.2
905	114.0	7.81×10^{-8}	24.8	98.3

Cation exchange capacity tests were performed by Soil and Plant Laboratory, Inc., of Santa Clara, California. The results are attached to this letter.

Yours very truly,

HARDING LAWSON ASSOCIATES

Lyle E. Lewis by [illegible]

Lyle E. Lewis,
Civil Engineer - 16360

DMS/LEL/dm

Attachment: Cation Exchange Test Results

4 copies submitted

SOIL AND PLANT LABORATORY, INC.
Member of The California Association of Agricultural Laboratories

SANTA CLARA OFFICE
July 11, 1985
Lab No. 78035

HARDING LAWSON ASSOCIATES
P O Box 578
Novato, CA 94948

RE: SAMPLES REC'D : 6-27-85

Sample No.	Cation exchange capacity meq/100	Description
1	0.9	SS#1
2	1.3	SS#2
3	1.1	SS#3
4	1.1	SS#4
5	1.5	SS#5
6	1.3	SS#6
7	0.7	SS#7
8	0.9	13293
9	1.3	13298
10	1.3	13308

Data are supplied without recommendation or comment.

LORI LITTLEFORD
Analytical Laboratory Director

P.O. Box 11744, Santa Ana, California 92711 (714) 558-8333 Telex Number: IRIN 678401
P.O. Box 153, Santa Clara, California 95052 (408) 727-0330
P.O. Box 1648, Bellevue, Washington 98009 (206) 746-6665

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)
Telex 15-2874

July 16, 1985

Mr. Cliff R. Farrell
Bechtel Civil and Minerals, Inc.
P.O. Box 3965
San Francisco, CA 94119

Dear Mr. Farrell:

Subject: Final Letter Report for Vogtle Nuclear Power Plant Sediment Sorption Tests - Contract No. 23112/07049

In mid-June 1985, four sediment samples (designated 13293, 13298, 13308 and 11755) and one well water sample from the Vogtle Nuclear Power Plant (Georgia) were received. The four sediment samples were air dried in our laboratory, then gently disaggregated and each sample was well mixed. The well water was filtered through 0.45 μm membrane filters to remove suspended material. The pH and Eh of the filtered water were pH = 7.42 and Eh = 373 mv vs SHE.

Triplicate one-gram samples of each of the four air dried sediments were placed in individual 50 ml polycarbonate centrifuge tubes. Next, 30.0 mls of the filtered ground water that had been spiked with 15.6 μCi/ℓ ^{85}Sr and 242 μCi/ℓ ^{137}Cs were contacted with the sediments for 7 days. The slurries were continually gently agitated on a linear shaker. In addition, three blank centrifuge tubes were treated in a similar fashion excepting that they contained only the radionuclide traced well water. These samples were used to correct for any container adsorption.

After the 7-day contact period, the samples were centrifuged and the supernatant solution was filtered through 0.45 m membranes. Exactly 15.0 mls of the filtered samples were radiocounted on a Ge(Li) detector for the characteristic gamma-rays 514 kev (^{85}Sr) and 662 kev (^{137}Cs).

The distribution coefficient, Kd, for Sr and Cs was then calculated from the observed counts for the blank solutions and the supernatant solutions from the sediment samples using equation 1.

$$Kd = \left(\frac{Co-Ce}{Ce}\right)\frac{V}{W} \qquad \text{Eq. 1}$$

where

Co = counts/min in blank sample (average of three blanks)
Ce = counts/min in each supernatant solution
V = volume of solution (30.0 mls)
W = weight of sediment (1.0g)

Table 1 is a summary of the radiocounting data and Table 2 is a summary of the individual Kd values. The variability in the observed replicates is similar to past experience for Sr and perhaps a little higher for the Cs values on sediments 13293 and 11755.

Perhaps the Georgia sediments contain a mineral very specific to cesium adsorption that is present in small amounts such that one gram samples are not truly homogeneous. That is, one sample such as Sample B for sediment 11755 might contain more of this selective mineral than the other two replicates.

In general, the trend for greater Cs adsorption than Sr adsorption is typical of sediments I've worked with and the absolute range Cs (400 to 2100 mls/g) and Sr (40-95 mls/g) are typical of predominantly sand-sized sediments as the Georgia samples appear to be.

Sincerely yours,

Jeff Serne

R. Jeff Serne
Staff Scientist
Geochemistry Section
Earth Sciences Department

RJS:dw

Attach.

cc: Mr. Ken Abbot (Bechtel)

Table 1
Counting Data Counts/min

	^{137}Cs	^{85}Sr
Blank A	34628.4	2647.8
B	34035.4	2565.0
C	31538.6	2414.6
Ave.	33400.8	2542.4
Sediment 13293		
A	2280.8	1146.8
B	1860.6	986.2
C	3759.0	1111.6
Sediment 13298		
A	1060.2	588.4
B	793.6	598.0
C	931.6	652.2
Sediment 13308		
A	1850.2	693.6
B	1715.6	779.2
C	1915.4	692.6
Sediment 11755		
A	535.0	1192.0
B	352.6	734.6
C	564.0	841.2

Table 2
Kd Data (units mls/g)

	^{137}Cs		^{85}Sr
Sediment 13293			
A	409		36.5
B	509		47.3
C	237		38.6
Ave.	385 ± 138	Ave.	40.8 ± 6
Sediment 13298			
A	915		99.6
B	1233		97.5
C	1046		86.9
Ave.	1065 ± 160	Ave.	94.7 ± 6.8
Sediment 13308			
A	512		80.0
B	554		67.9
C	493		80.1
Ave.	520 ± 31	Ave.	76.0 ± 7.0
Sediment 11755			
A	1843		34.0
B	2812		73.8
C	1748		60.7
Ave.	2134 ± 589	Ave.	56.2 ± 20.3

ERDA-1537

Final Environmental Impact Statement

Waste Management Operations

Savannah River Plant
Aiken, South Carolina

Energy Research & Development Administration

September 1977

ERDA-[illegible]
UC-2, [illegible]

Final Environmental Impact Statement

Waste Management Operations

Savannah River Plant
Aiken, South Carolina

Responsible Official:

James L. Liverman
Assistant Administrator for Environment and Safety

Energy Research & Development Administration

September 1977

FOREWORD

This environmental statement was prepared to provide a detailed analysis of the actual and potential environmental effects associated with waste management operations at the Savannah River Plant. The Savannah River Plant (SRP) near Aiken, South Carolina is a nuclear material production facility of the Energy Research and Development Administration (ERDA).* This statement covers the management of both radioactive and nonradioactive gas, liquid, solid, and thermal discharges from current and projected SRP operations and accumulated waste from past operations. Alternatives to current waste management operations are discussed. Available data on past operations are presented for background and to help characterize the existing and expected future condition of SRP.

The Federal action under review is the interim management of SRP wastes in accordance with ERDA policies and standards that require continued efforts to reduce releases to values that are as far as practical below guidelines which minimize risk to the population, and to develop improved methods of waste storage. Thus, the descriptive material in this statement presents detailed background information that may be used as a basis for environmental assessments or statements on long-range plans as they develop. The status of the SRP long-range waste management research and development program is presented in Appendix I. ERDA presently is preparing technical documents for SRP, Hanford and Idaho installations on alternative methods for long-term management of high-level radioactive wastes at these sites (described in Appendix I). These documents, which will serve as the basis for environmental statements on long-range management, should be available for public review in 1977.

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* ERDA was created by the Energy Reorganization Act of 1974 (January 19, 1975) to assume the operational and research and development functions of the Atomic Energy Commission, which was abolished by the Act.

In accordance with ERDA regulations,[1] future statements will be written late enough in the development process to contain meaningful information, but early enough that whatever information is contained may be factored into the decision making processes. These statements will be prepared before the development process has reached a stage of investment or commitment to implementation likely to foreclose or restrict later alternatives. None of the possible options for long-range management of SRP wastes is being foreclosed by current or projected operations.

The scope of this environmental statement is limited to effluent control and interim defense waste management operations at SRP. In this respect, it is similar to the waste management operations environmental statements for two other major production sites of the ERDA. The final statement concerning the Hanford reservation at Richland, Washington, has been published (ERDA-1538),[2] and the draft statement for the Idaho National Engineering Laboratory (ERDA-1536)[3] was issued June 29, 1976.

In this environmental statement, possible combined effects of the effluents from SRP, the Barnwell Nuclear Fuel Plant (BNFP), and the proposed Vogtle Nuclear Plant (VNP) are considered. The BNFP is a chemical separations plant for processing commercial nuclear fuel now under construction by Allied-General Nuclear Services (AGNS) on a site adjacent to SRP on the east. The VNP was proposed by the Georgia Power Company as a possible nuclear power plant to be constructed across the Savannah River from SRP on the west. Environmental statements for these plants were prepared by the former Licensing Branch of the AEC, now the Nuclear Regulatory Commission (NRC), in conjunction with the normal licensing procedures for commercial nuclear plants. No effluents are expected from the commercial waste burial facility of the Chem-Nuclear Services, Inc., another nuclear facility adjacent to SRP and BNFP.

Future production operations at the Savannah River Plant may vary from their present level. However, the environmental impact will be of the same nature and order as for 1975. The

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1. *U. S. Code of Federal Regulations*, Title 10, Part 711.
2. *Final Environmental Statement, Waste Management Operations, Hanford Reservation*. USERDA Report ERDA-1538 (1975).
3. *Draft Environmental Statement, Waste Management Operations, Idaho National Engineering Laboratory*. USERDA Report ERDA-1536 (June, 1976).

trend will be toward further reductions in the releases of some materials, but some increases may occur due to changes in production requirements. The accumulation of radioactive liquid and solid wastes will also proceed at about the same rate as in 1975. Cumulative offsite effects to the surrounding population beyond the year of actual release will be small as discussed in Section III.A.4.

Because implementation of any program to provide improved methods of storage will take place over many years, new waste tanks are being planned to satisfy the needs for 1) storage space for new wastes generated during the 1970s and 1980s, 2) replacement of single-wall tanks, and 3) replacement of double-wall tanks that have a history of leakage from the primary into the secondary container. Before the publication of this statement, two environmental statements on specific additional waste handling and storage facilities at SRP were issued. The statements were in support of an FY-1974 project (WASH-1528)[4] for four waste tanks and an evaporator, and an FY-1975 project (WASH-1530)[5] for six waste tanks and an evaporator. Because of increased costs, these projects were revised to include only three and four waste tanks, respectively, with no evaporators. The environmental impact of additional tanks planned for the future will be of the same nature and order as that for the previous tanks.

All radionuclides released from the SRP site to the environment are discussed in this statement. The data are presented so as not to reveal classified production information, but this does not affect the estimation of offsite effects from the releases.

The notification of the preparation of this statement, published in the Federal Register on August 14, 1975 (38 FR 21958), invited suggestions from all interested persons. Comments were received from individuals and organizations and were answered by ERDA prior to preparation of the draft statement. Careful review of each comment letter resulted in identification of specific suggestions that were included into Draft ERDA-1537. The comment letters and ERDA's response, including discussion and action on specific comments, were published as Appendix K of Draft ERDA-1537.

4. *Environmental Statement, Future High Level Waste Facilities, Savannah River Plant, Aiken, South Carolina.* USAEC Report WASH-1528 (1973).

5. *Environmental Statement, Additional High Level Waste Facilities, Savannah River Plant, Aiken, South Carolina.* USAEC Report WASH-1530 (1974).

The issuance of the draft statement was announced in the Federal Register on October 29, 1976 (41 FR 27284), and public comments were requested within 90 days. A total of eleven comment letters were received from individuals and organizations. The issues raised by these comments have been considered in the preparation of this final statement and text changes have been made where appropriate. Moreover, the comments on the draft statement along with the responses by ERDA replace the previous Appendix K in the final statement. Copies of the final statement, the draft statement, and all written suggestions and comments received, as well as the documents referenced by this statement are available for inspection at ERDA Public Document Rooms at 1333 Broadway, Oakland, California; 20 Massachusetts Avenue, Washington, D.C.; and the Savannah River Operations Office at SRP.

C. CHARACTERIZATION OF THE EXISTING ENVIRONMENT

1. PLANT HISTORY

The Atomic Energy Commission (now ERDA) selected the location of the Savannah River Plant in November 1950 after study of over 100 potential sites. Factors in the selection of the site included the low population density, accessibility of a large cooling water supply, and freedom from floods and major storms. The Savannah River Plant was the largest construction job undertaken by the Atomic Energy Commission. Construction began in February 1951, and it eventually involved over $1 billion in expenditures and a peak construction force of 39,000 workers. The operating force includes about 5000 workers.

Uranium fuel fabrication began in M Area and extraction of heavy water (D_2O) began in D Area in 1952.

The first production reactor (R) was started up in December 1953. Other production reactors began operation in February 1954 (P), July 1954 (L), November 1954 (K), and March 1955 (C). The Heavy Water Components Test Reactor (HWCTR) began operation in U Area in March 1962. Recirculation of cooling water for R and P reactors through Par Pond began in 1958. Reactors were shut down in June 1964 (R), December 1964 (HWCTR), and February 1968 (L).

The separations areas began processing radioactive fuel assemblies from the reactor areas in November 1954 (F) and July 1955 (H). Solid radioactive waste was first sent to the burial ground in the first half of 1953 when waste uranium from fuel fabrication in M Area was disposed of in this facility. The first waste tank was completed in March 1954. Waste discharges to the seepage basins and waste tanks began shortly after startup of the separations areas

Baseline measurements of Savannah River conditions were made in 1951, before plant startup, by the Academy of Natural Sciences of Philadelphia. Since the baseline study, the Academy has maintained a continuous program of surveillance of river conditions.

During the period from 1951-1960, biologists from the University of South Carolina and the University of Georgia conducted surveys of biota and ecosystems on the SRP site for the AEC. The University of South Carolina described the major plant communities and collected data on comparison sites from nearby areas of South Carolina. Studies were made of plant succession in the abandoned fields. In addition, information was published on the effects of flooding of the vegetation along Steel Creek and on the environment in Steeds Pond which received effluent from the fuel fabrication facility.

The University of Georgia gathered information on the animal communities of the plantsite and produced studies of quantitative relationships within the old field ecosystems. In 1961, the Savannah River Ecology Laboratory was established to promote continuing ecological studies. It has been operated by the University of Georgia since its inception.

In 1972, SRP was declared the nation's first National Environmental Research Park.

2. SITE CHARACTERISTICS

INTRODUCTION

Characteristics of the SRP site that are pertinent to the operations of a waste management program include the geology, hydrology, meteorology, seismicity, biota, and background radiation. These characteristics are reviewed below. A more-detailed discussion may be found in DP-1323.[16]

GEOLOGY

SRP occupies an approximately circular site in South Carolina of about 300 square miles, bounded on the southwest by the Savannah River and centered approximately 25 miles southeast of Augusta, Ga. The plant is located in the Coastal Plain geologic province as can be seen on Figure II-38. This province is characterized by flat, mostly unconsolidated sediment of Cretaceous age or younger. About 20 miles northwest of the plantsite is the lower edge of the Piedmont Plateau (the other main geologic province in S. C.). The Piedmont Plateau is underlain by igneous and metamorphic rocks. The boundary between the two provinces is called the Fall Line. The Fall Line is not a sharp line of contact but a zone of transition from the typical land forms of one province to those of the other. It is often difficult to determine from the ground surface where the Piedmont Plateau ends and the Coastal Plain begins. Because the sediments of the Coastal Plain are more easily eroded than the hard crystalline rock of the Piedmont Plateau, the distinction is noticeable in river beds as the change in rock formation causes waterfalls or rapids. Figure II-38 also shows several other geologic provinces in the Appalachian Mountains.

The soil layers of the plantsite affect the migration rates and directions of ground water and of any radioisotopes present in the soils and ground water of the site. Geologic formations beneath the Savannah River Plant site are shown in Figure II-39, a cross section that originates at the Fall Line 20 miles to the northwest and bisects the plantsite. The formations are the

FIGURE II-38. Geologic Provinces of Southeastern United States

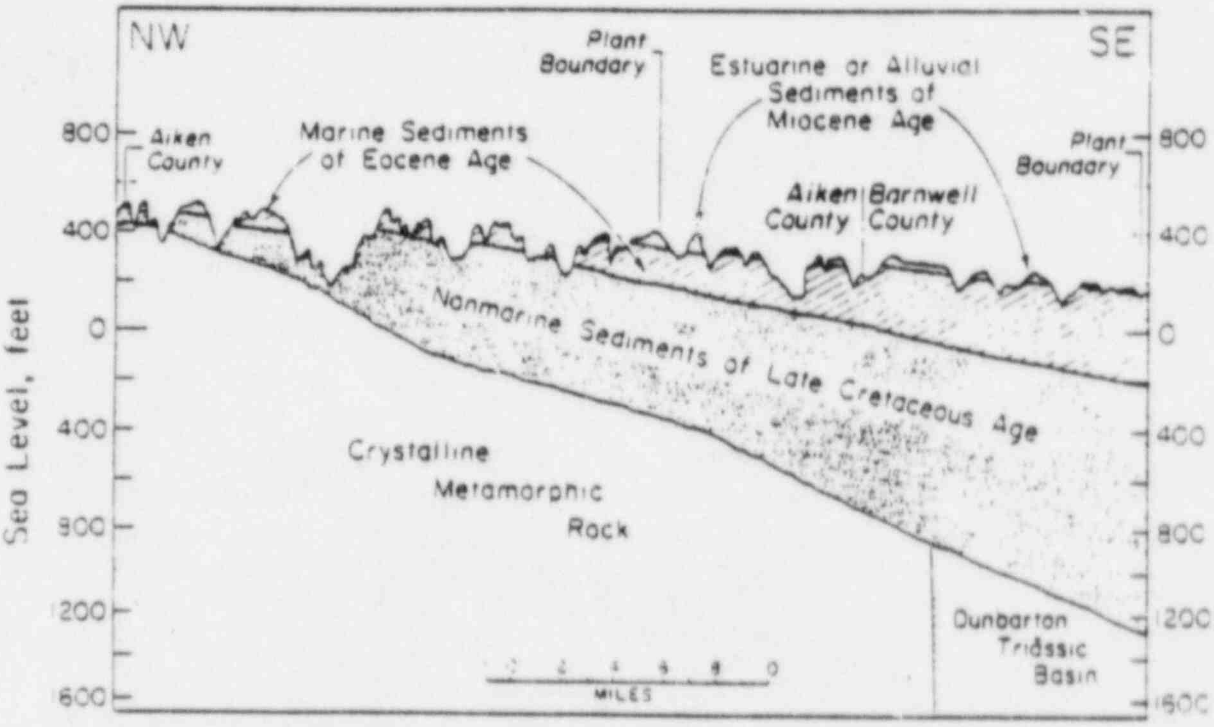


FIGURE II-39. Profile of Geologic Formation Beneath the Savannah River Plant

Hawthorn, Barnwell, McBean, Congaree, Ellenton, Tuscaloosa, and bedrock (crystalline metamorphic rock and the Dunbarton Triassic Basin).[17] The sediments that constitute the formations above bedrock are either unconsolidated or semiconsolidated. The crystalline metamorphic rocks outcrop at the Fall Line and dip approximately 36 ft/mi to the southeast underneath the Coastal Plain sediments.

A large Triassic deposit in a basin of the crystalline rock underlies one-third of the plant area and is located in the southeastern section of the site. This deposit consists of sedimentary material formed into sandstones, siltstones, and mudstones.

The geologic formation that immediately overlies the basement rock is called the Tuscaloosa Formation and is 500 to 600 ft thick below the plant. This formation consists of sand and clay and contains several prolific water-bearing beds, which supply over 1000 gal/min of water from each of several individual wells.

Overlying the Tuscaloosa Formation are several formations of the Tertiary Period that range in age from about 10 million to about 50 million years. These formations have a combined thickness of about 350 ft in the central part of the plant. They consist predominantly of compact clayey sand and sandy clay with a few beds of sand and a few beds of hard clay. At depths ranging from about 100 to 180 ft, there is a zone in which the sandy deposits include calcareous cement, small lenses of limestone, and some shells. At scattered discontinuous localities, slowly moving ground water has dissolved this calcareous material and left these lenses less consolidated than the sediments surrounding them. Some of these areas were filled with a concrete grout before major facilities were constructed. At some places on the Savannah River Plant, the rocks of the Tertiary Period are overlain by more recent terrace deposits of alluvium. These deposits are usually thin in the upland areas, but are of significant thickness in the valleys of the Savannah River and some of its larger tributaries.

The sediments form a wedge ranging in thickness from a few feet at the Fall Line to more than 1200 ft on the southeastern or downdip side of the plantside. They strike in an average direction of N60°E and dip from 6 to 36 ft/mi to the southeast. The sediments are unbroken by large displacement faults or severe unconformities.

HYDROLOGY

Surface Water

Surface waters provide a mechanism for transporting unavoidable releases of radioactive elements, stable elements, and heat offsite. These materials, if discharged by operating facilities to a plant stream, will move toward the Savannah River because almost all of the plantsite is drained by tributaries of the river (Figure II-2). Only one small stream (not shown on Figure II-2) in the northeastern sector of the site drains to the Salkehatchie River to the east, and this small stream has no operating facilities on it. Each of the tributaries is fed by smaller streams; therefore, no location on the site is very far from a continuously flowing stream. Knowledge of the flow in the streams is used to predict the offsite consequences of various routine and accidental releases.

In addition to the flowing streams, surface water is held in over 50 artificial impoundments covering a total of over 3000 acres. The largest of these, Par Pond, has an area of approximately 2700 acres. Water is held intermittently in marshes and over 200 natural basins, called Carolina Bays. A large swamp bordering the Savannah River receives the flow from several of the plant streams.

The source of most of the surface water on the plantsite is either natural rainfall or water pumped from the Savannah River to cool the nuclear reactors. The cooling water is discharged to the streams to flow back to the river or to Par Pond. Additional small amounts are discharged from other plant processes to the streams.

Savannah River

The Savannah River Plant adjoins the Savannah River for 17 miles. The headwaters of the river are in the Blue Ridge Mountains of North Carolina, South Carolina, and Georgia. Formed at the junction of the Tugaloo and Seneca rivers near Hartwell, Georgia (100 miles northwest of SRP), the river empties into the Atlantic Ocean near Savannah, Georgia. The Savannah River basin is one of the major river basins in the southeastern United States. It has a surface area of 10,580 square miles, of which 8100 are above the Savannah River Plant.

Two large reservoirs upstream of the Savannah River Plant provide power, flood control, and recreational areas. Clark Hill Reservoir, completed in 1952, is 35 miles (70 river miles) upstream. Hartwell Reservoir, completed in 1961, is 90 miles (150 river miles) upstream. Operation of these reservoirs

stabilized the river flow in the vicinity of the plant to a yearly average flow of 10,400 ±2900 cfs during 1961 to 1970. The minimum daily flow during this period was 6000 cfs. Figure II-40 shows monthly average flows for 1960 to 1970 for three locations on the river: at U. S. Highway 301 crossing (about 23 miles below SRP), at the SRP boat dock, and at Augusta. As the river flows by the Savannah River Plant, its nominal level drops 84 to 80 ft above mean sea level. River water requires a minimum of 3 days to reach the coast from SRP, and the average flow times of 5 to 6 days probably better represents the travel time.

The monthly average temperature of the river water measured at the SRP boat dock since July 1955 ranged from 6.8 to 26.8°C (Table II-20). The daily river temperature has reached 25.5°C or higher only during the months of June through September.

The Savannah River is used for fishing, both commercial and sport, and pleasure boating downstream of the plant, and also as a drinking water supply at Port Wentworth, Ga., for an effective consumer population of about 20,000, and at Hardeeville, S. C. (Beaufort - Jasper Water Treatment Plant), for a consumer population of approximately 50,000. Barge traffic is maintained on the 90-ft-wide and 9-ft-deep channel between Augusta and Savannah, Ga.

Onsite River Tributaries

The five main streams on the plantsite are Savannah River tributaries. These are Upper Three Runs, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs (Figure II-2). They arise on the Aiken Plateau and descend 100 to 200 ft before discharging to the river. On the plateau, the streams are clear except during periods of high water. Rainfall soaks into the ground, and seepage from the sandy soil furnishes the streams with a rather constant supply of water throughout the year. In addition, four of the streams have received reactor cooling water discharges. These discharges, many times the natural stream flows, cause the streams to overflow their original banks along much of their length.

Upper Three Runs

Upper Three Runs, the longest of the plant streams, differs from the other four streams in two respects: it is the only one with headwaters arising outside the plantsite, and it is the only one that has never received heated discharges of cooling water from the production reactors.

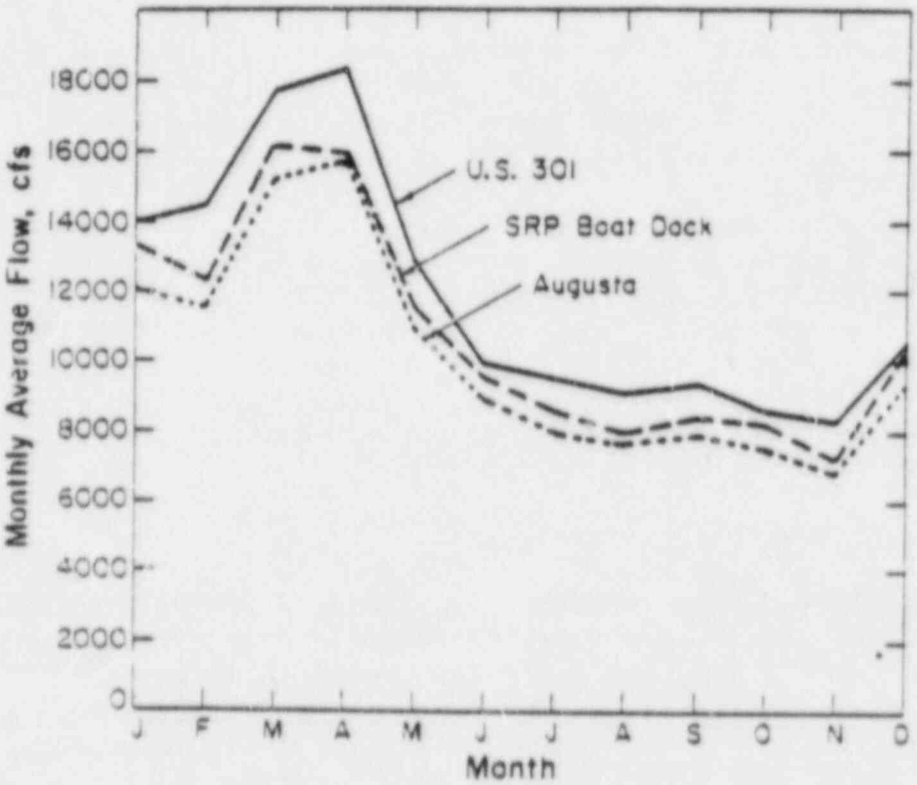


FIGURE II-40. Savannah River Average Monthly Flows for 1960-1970

TABLE II-20

Monthly Average River Temperatures at SRP Boat Dock, °C

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly Average
1955							25.6	26.8	25.2	21.4	15.7	11.2	-
1956	8.8	11.7	13.5	16.2	19.9	21.9	23.9	24.1	22.7	19.5	15.5	12.5	17.5
1957	10.2	12.6	13.0	17.6	19.5	22.6	24.2	24.9	25.0	19.2	15.8	11.2	18.0
1958	8.2	6.8	9.4	13.6	18.1	21.8	23.5	24.9	25.4	21.1	17.4	11.1	16.8
1959	9.6	11.2	12.8	17.7	20.9	21.8	23.3	26.3	24.9	22.3	16.3	11.7	18.4
1960	9.9	9.0	8.6	15.0	18.2	22.1	23.5	24.2	24.7	22.0	16.5	10.3	17.0
1961	8.4	9.3	12.7	14.4	19.5	22.1	22.5	22.9	22.6	19.6	17.8	12.7	17.0
1962	8.6	10.2	10.7	14.1	20.2	21.5	23.8	23.7	22.5	20.0	15.1	10.5	16.7
1963	8.4	7.5	11.0	16.7	17.5	20.8	22.4	23.6	21.8	20.1	16.4	9.6	16.3
1964	7.1	7.3	12.0	14.1	17.7	22.5	21.9	22.6	22.3	18.5	16.4	12.5	16.2
1965	9.8	9.6	10.[illegible]	14.4	18.4	19.3	21.8	22.0	22.1	20.2	17.8	13.7	16.6
1966	9.3	8.3	10.3	15.5	17.2	20.0	22.9	22.9	21.9	20.3	17.0	12.2	16.5
1967	9.5	9.7	13.1	16.6	18.4	18.7	22.2	22.9	21.7	19.9	15.6	12.7	16.7
1968	8.0	8.2	11.2	15.1	17.3	20.0	22.7	23.4	21.7	19.7	15.0	10.2	16.3
1969	7.8	7.9	9.8	15.2	19.3	21.9	23.2	22.3	21.9	20.6	15.0	11.5	16.4
1970	8.5	9.7	12.8	16.6	19.7	—	—	—	—	21.1	16.1	12.1	—
1971	9.8	9.3	10.8	14.7	16.8	20.4	21.9	22.7	22.2	20.3	16.3	12.6	16.5
1972	11.3	9.5	13.1	16.3	17.9	20.9	23.3	24.3	23.4	20.3	17.0	12.5	17.5
1973	9.7	8.8	13.2	15.1	18.8	20.2	24.2	23.5	24.8	23.0	19.8	14.5	18.0
1974	14.0	12.0	14.5	17.0	19.5	24.0	25.0	26.0	25.0	22.0	17.0	10.0	19.0
1975	10.0	11.0	11.3	13.0	16.0	19.5	22.4	23.3	25.2	23.0	18.8	14.6	17.3
MONTHLY AVERAGES	9.4	9.5	11.7	15.5	18.5	21.2	23.3	23.9	23.4	20.6	16.6	11.9	
											OVERALL AVERAGE		17.1
1935-1950 AVERAGE	11.5	10.0	14.0	19.0	23.5	26.0	28.5	28.5	26.5	21.5	-16.0	12.0	19.7

Upper Three Runs drains an area of about 190 square miles. Its significant tributaries are Tinker Creek, a rather lengthy headwaters branch, and Tims Branch, which receives industrial wastes from the fuel fabrication facilities (M Area) and the Savannah River Laboratory and flows through an impoundment, Steeds Pond. The M Area effluent flow averages about 1 cfs. Tims Branch flows at between 1-1/2 and 2 cfs below Steeds Pond and about 4 cfs just before discharge into Upper Three Runs.

The flow and temperature of Upper Three Runs have been monitored at the Highway 125 crossing (Figure II-2). Flow ranges between 190 to 520 cfs and averages 265 cfs. The average temperature for 1959 to 1966 was 16.9°C, with a maximum monthly average of 23.0°C in July.

Upper Three Runs was designated as a National Hydrologic Bench-Mark Stream by the United States Geological Survey in 1966. In Bench-Mark Streams the water quality, temperature, and flow are measured monthly to provide hydrologic data for a river basin in which the hydrologic regimen will likely be governed solely by natural conditions.

Four Mile Creek

Four Mile Creek follows a generally southwesterly path to the Savannah River for a distance of about 15 miles. In the swamp along the river, part of the creek flow empties into Beaver Dam Creek, a shorter stream that also discharges into the river. The remainder of the Four Mile Creek flow discharges through an opening in the levee into the river, or flows down the swamp and mixes with Steel Creek and Pen Branch.

Four Mile Creek and Beaver Dam Creek together drain about 35 square miles and receive discharges from four plant areas. Four Mile Creek receives effluents from F and H separations areas and the reactor cooling water discharge from C Reactor. The average flow upstream of any plant discharge is less than 0.5 cfs and is increased by drainage and F and H effluents to about 20 cfs just above the confluence with the C Reactor discharge. After the junction with the C Reactor cooling water, the creek flows about 7 miles before entering the river swamp. Beaver Dam Creek receives 65 to 130 cfs of effluent from the heavy water production process and the associated power generating plant in D Area.

Pen Branch

Pen Branch follows a path roughly parallel to Four Mile Creek until it enters the river swamp. The only significant tributary is Indian Grave Branch, which flows into Pen Branch about 3 miles above the swamp. Pen Branch enters the swamp about 3 miles from the river, flows directly toward the river for about 1.5 miles, and then turns and runs parallel to the river for about 5 miles before discharging into Steel Creek about 0.5 mile from its mouth.

Pen Branch with Indian Grave Branch drains about 35 square miles above the swamp. Indian Grave Branch receives the effluent cooling water from K Reactor. Above the K-Area discharge, Indian Grave Branch flow averages only about 1 cfs; above Indian Grave Branch, Pen Branch is also a small stream averaging 5 to 10 cfs.

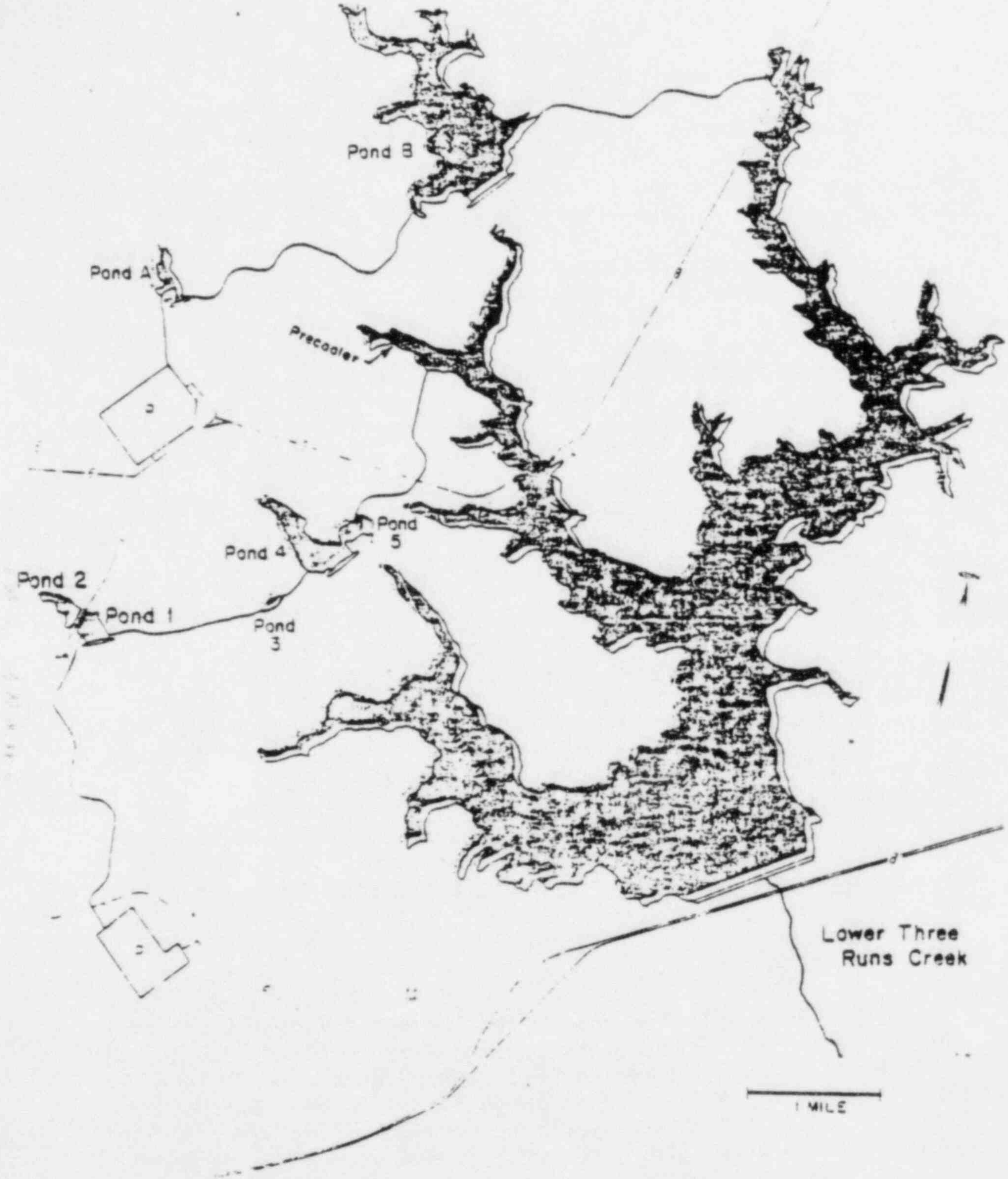
Steel Creek

Steel Creek flows southwesterly for about 4.5 miles, then turns to flow almost due south for about 5.5 miles, and enters the river swamp 2 to 3 miles from the river. In the swamp, it is joined by Pen Branch.

The drainage area of Steel Creek and its main tributary, Meyers Branch, is about 35 square miles. Steel Creek has received the cooling water discharges from two reactors, but it currently receives only about 15 cfs of water at about natural temperatures from P Area. The discharge of cooling water effluent from P Reactor to Steel Creek was discontinued in 1963 when this reactor was switched to cooling with recirculated water from Par Pond; L Reactor discharge ceased in 1968 when the reactor was shut down and placed in standby condition. Flow rates measured in Steel Creek at the Highway 125 crossing are about 30 cfs.

Lower Three Runs

Lower Three Runs has the second largest drainage area (about 180 square miles) of the plant streams (Figure II-2). Near its headwater a large impoundment, Par Pond (Figure II-41), has been formed by an earthen dam. The three main arms of the pond follow the streambed and drainage areas of the upper reaches of Lower Three Runs and its tributaries, Poplar Branch and Joyce Branch. From the dam, Lower Three Runs flows in a southerly, then southwesterly course for about 20 miles to the Savannah River. An arm of the plant follows the stream to the river. Several small tributaries arising off the plantsite flow into the creek in its lower reaches.



Par Pond and Effluent Canals

Before construction of Par Pond, effluent cooling water from R Reactor was discharged via Joyce Branch to Lower Three Runs. Since the pond filled in 1958, the overflow to Lower Three Runs has varied, depending on the utilization of the pond cooling water system by R and P reactors. In 1964, R Reactor was shut down and placed in standby condition. Even when both R and P reactors were utilizing the pond, the temperature of the pond overflow water was about natural. During periods of no dam overflow, about 5 cfs seeps through and under the dam to enter Lower Three Runs. When the pond is thermally stratified (primarily during the warmer months), this seepage is usually several degrees cooler than the surface water in the pond.

Par Pond

The Par Pond cooling water impoundment was formed in 1957-1958 by damming Lower Three Runs. The impoundment covers approximately 2700 acres to an average depth of about 20 ft. The maximum depth near the dam is about 60 ft. A 140-acre portion is separated from the main body by a dam to form the precooler, which is now considered part of the P-Reactor effluent canal system. There are three major arms in Par Pond (Figure II-41): the north or upper arm, the middle or warm arm, and the south or lower arm.

The canal systems for conducting the effluent cooling water from P to R reactors to Par Pond are also shown in Figure II-41. The P canal system is currently in use, but the R system has not received thermal discharges since 1964. From P Reactor, there are 4-1/4 miles of canals and 5 small impoundments. The largest impoundment besides the 140-acre precooler covers 36 acres; the total surface area of the small impoundments and canals is 227 acres. The now-unused R canal system consists of about 3.5 miles of canals and two impoundments, 7.4 and 260 acres in size, respectively. The total surface area of the system is 285 acres.

River Swamp

On the plantsite, a swamp lies in the floodplain along the Savannah River for a distance of about 10 miles and averages about 1.5 miles wide. A small embankment or natural levee has built up along the river from sediments deposited during periods of flooding. Next to the levee, the ground slopes downward, is marshy, and contains stands of large cypress trees and hardwoods. During periods of high river level, river water overflows the levee and stream mouths and floods the entire swamp area, leaving only isolated islands. When flow subsides, stagnant pools of water remain, but even with the pools and meandering channels, some of the land in the swamp is nearly dry.

Three breaches in the natural levee allow discharge of creek water to the river near the mouths of Beaver Dam Creek, Four Mile Creek, and Steel Creek. The Beaver Dam Creek discharge contains the effluent from the D-Area heavy water plant plus part of the Four Mile Creek flow. During swamp flooding, the water from these streams flows through the swamp parallel to the river and combines with the Pen Branch flow. Pen Branch does not discharge directly to the river, but flows through the swamp and joins Steel Creek about 0.5 mile above its mouth.

Figure II-42 shows the deltas of Four Mile Creek and Pen Branch where these streams flow into the swamp. Figure II-43 shows the deltas of Pen Branch and Steel Creek.

Chemical Composition of Surface Water

Knowledge of the chemical quality of surface waters is important for two reasons: it permits an estimate of alterations that have occurred as a consequence of plant operations and permits evaluation of the potential effects of releases into the aqueous environment.

Surface water on the plant and surrounding areas (Figure II-44) is very low in dissolved solids and iron and is very soft (Table II-21).[17] All surface water, except that from the Salkehatchie River near Barnwell, has pH values between 5 and 7; the pH of water from the Salkehatchie River is 7.3. Water from this river is also the hardest. The area around Barnwell is underlain by calcareous deposits; therefore seepage to the surface stream is characterized by the analogous chemical composition of water in the aquifer. Similarly, the composition of water from Holley Creek is characterized by the chemical composition of the water in the Tuscaloosa aquifer underlying this area.

Ground Water

Liquid materials discharged on the ground surface migrate slowly down to the ground water and then travel either with or slower than the ground water until emerging at a surface stream. The types of geological strata affect both the flow path and the velocity of the materials. The number, size, and shape of the openings in porous sediments and the degree of their interconnection determine the amount of water than can be stored in the openings and the effectiveness of any saturated geologic formation to transport water. A water-bearing bed or stratum of permeable rock, sand, or gravel capable of yielding considerable quantities

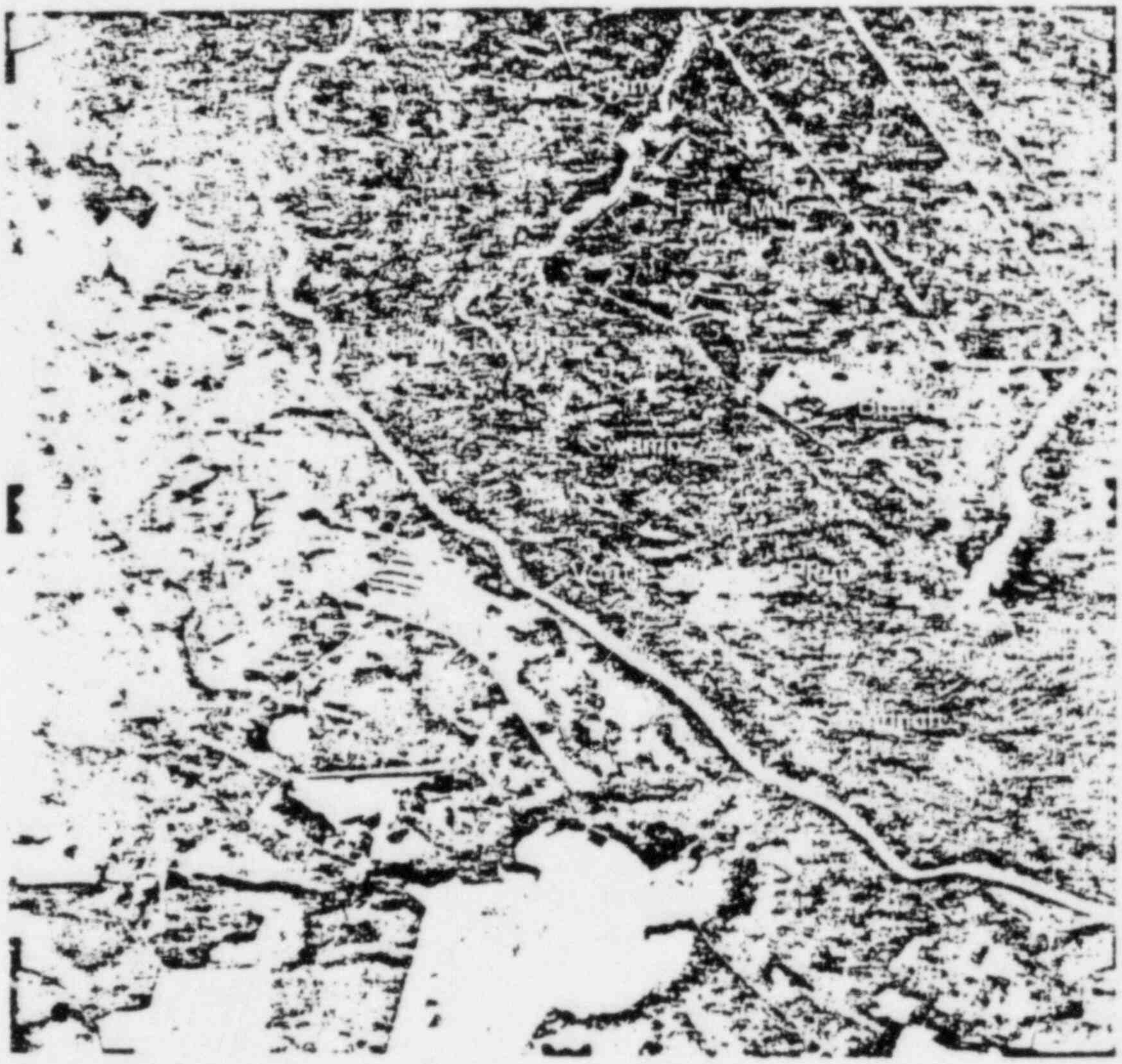


FIGURE II-42. Four Mile Creek and Pen Branch Deltas

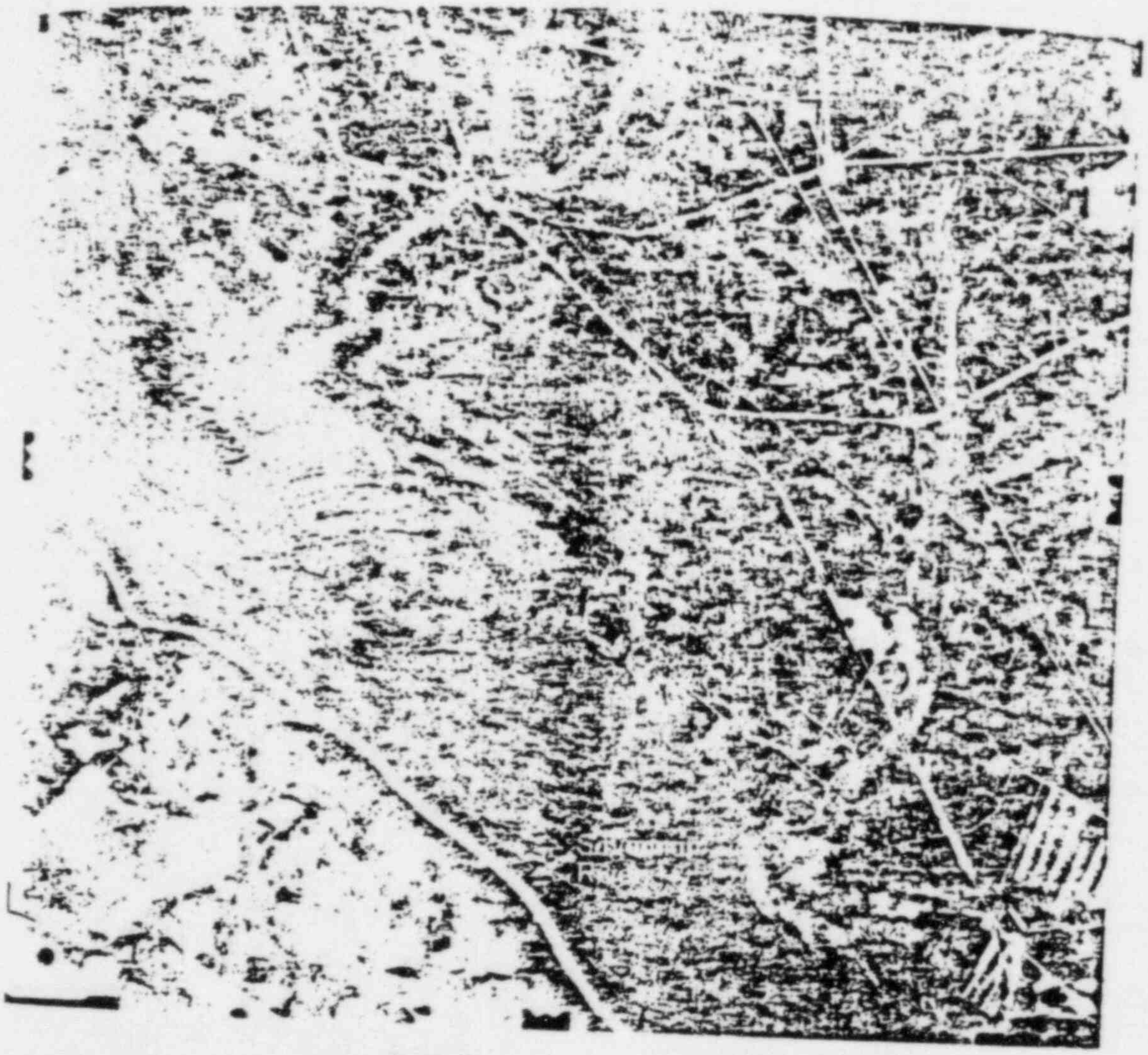


FIGURE II-43. Pen Branch and Steel Creek Deltas

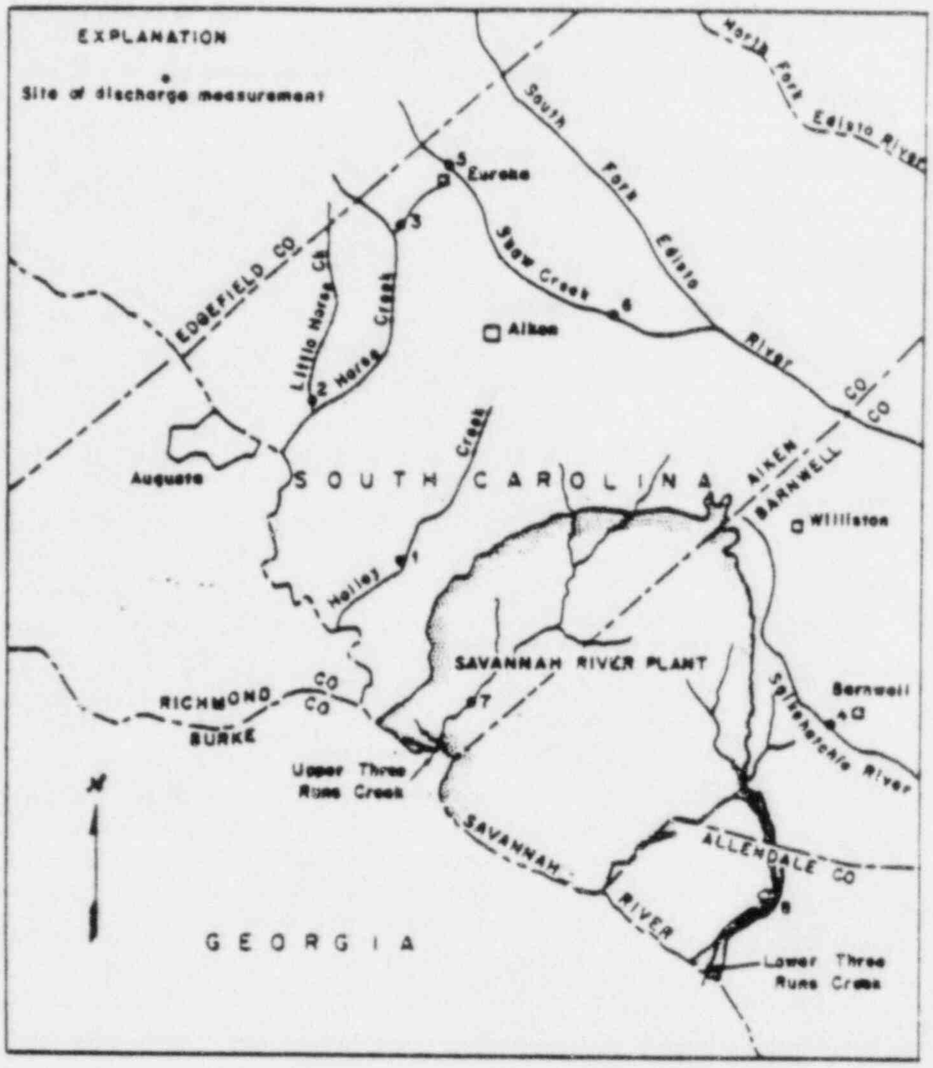


FIGURE II-44. Locations of Stream Discharge Measurements

TABLE II-21

Chemical Analysis of Surface Water in SRP Area[47]

Location (Fig. II-44)	ppm SiO_2	Total Iron	Calcium	Magnesium	Potassium plus Sodium	HCO_3^-	SO_4^{2-}	Cl^-	F^-	NO_3^-	Dissolved Solids	Hardness, $CaCO_3$	Specific Conductance (25°C) μmho	pH
1	6.7	0.14	0.6	0.4	2.4	3	1.7	2.5	0.1	0.5	17	3	15.5	6.[illegible]
2	5.4	0.14	1.0	0.5	2.2	4	1.4	2.5	0.1	1.0	18	5	21.2	6.3
3	4.9	0.06	0.6	0.3	2.2	3	1.0	2.1	0.1	0.9	13	3	14.7	5.4
4	8.9	0.05	8.8	0.6	2.0	27	1.1	3.4	0.1	0.5	48	24	63.6	7.3
5	6.3	0.20	1.3	0.7	4.8	7	1.2	5.1	0.1	2.7	28	6	34.8	5.8
6	6.6	0.31	0.8	0.5	3.[illegible]	5	1.5	3.6	0.1	1.2	23	4	24.5	5.8
7	2.0	0.30	0.5	3.0	2.0	35	0.8	0.8	-	0.5	12	13	25.0	5.5
8	1.4	0.30	3.0	7.0	10	17	3.0	1.3	-	0.5	50	37	60.0	6.9

of water to wells or springs is called an aquifer. Geologic formations that are adjacent to but less permeable than aquifers are called confining beds because they tend to restrict or retard the movement of ground water.

Within the zone of saturation, ground water occurs under either water-table or artesian conditions. Under water-table conditions, the ground water is not confined, and the upper surface of the saturated zone is free to rise and fall. Under artesian conditions, the ground water is confined between an upper and lower confining bed, and the piezometric surface of the aquifer is above the top of the aquifer. The piezometric surface is an imaginary surface that indicates the level to which the confined water rises in wells.

The results of detailed studies on the site reveal how the geology and hydrology of the plantsite affects ground water movement. Differences in the piezometric head (water pressure) measurements show the direction that ground water flow will take. Figure II-45 shows the vertical distribution of hydrostatic head in ground water near H Area, measured with six piezometers near the H-Area waste tank farm and four other piezometers outside H Area. Downward percolation of water from the water table is indicated by decline to minimum head in the Congaree formation. In the two piezometers (1E, 1D, Figure II-45) above the tan clay, the decline is probably fairly uniform with depth. Across the tan clay (1D to 1C), the decline is relatively abrupt (about 12 ft of head decline in 18 ft of depth). The tan clay, maximum 12 ft thick, is sufficiently impermeable to divert some of the water laterally to creeks, the nearest being several thousand feet away.

Within the fairly permeable sands of the McBean formation, the head declines only 2 ft in ~50 ft of geologic material (1C to 1B). The green clay shown on Figure II-45 is one of the more significant hydrologic units in the region; it is only 6 to 10 ft thick in H Area (although somewhat thicker elsewhere), and its importance is easily missed if only drilling information is available. The 30-ft decline in piezometric head (1B to 3B, 1A) across the green clay indicates that the clay is continuous over a large area and has low permeability. Thus the green clay also diverts water laterally to creeks that have eroded down into the McBean. These points of discharge are farther from H Area than the discharges from the Barnwell formation.

Ground water in the Congaree zone below the green clay also discharges into Upper Three Runs. This formation has the lowest hydrostatic head. The Ellenton formation has a head ~7 ft higher than the Congaree, thus indicating the Ellenton is not receiving water from the Congaree formation.

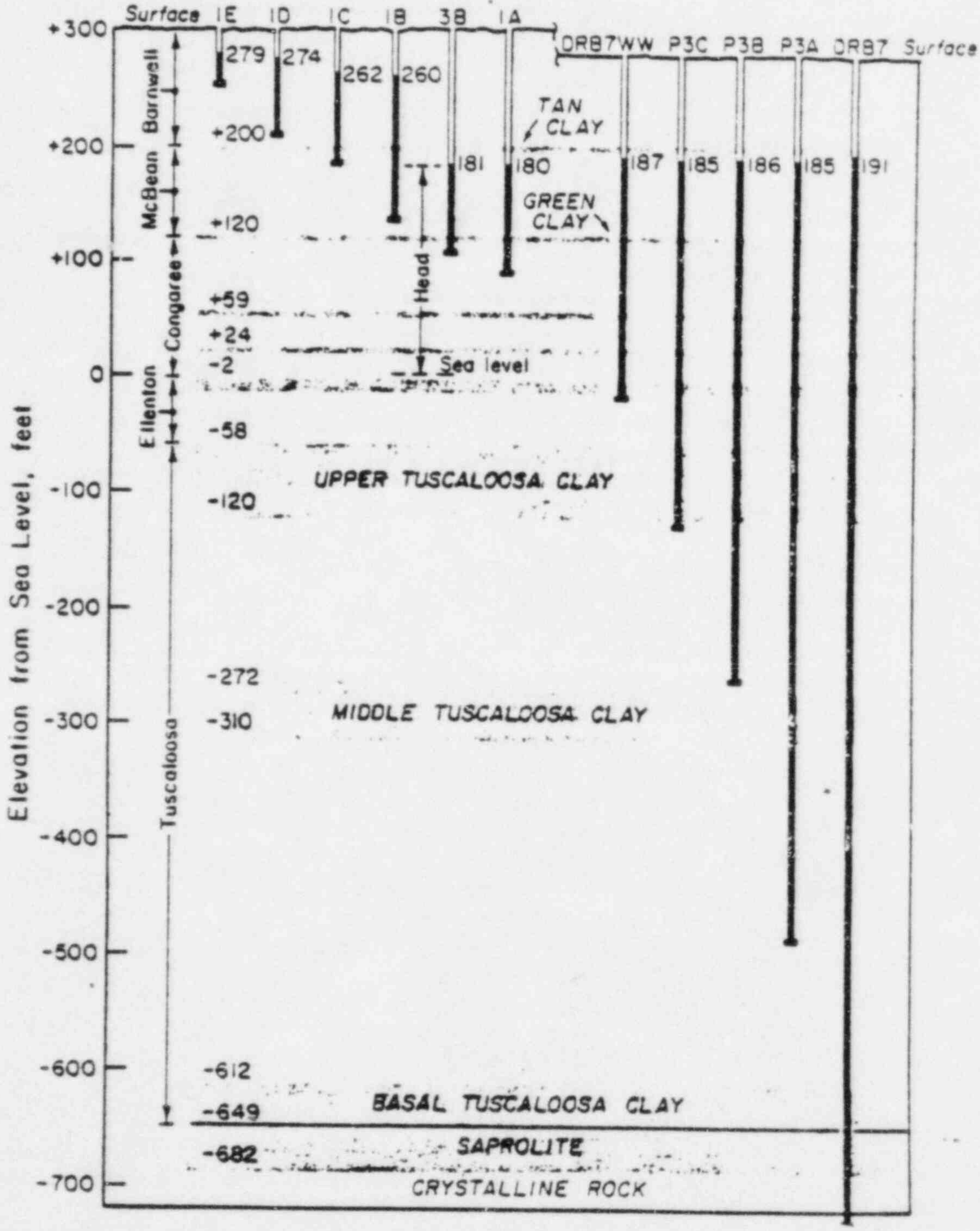


FIGURE II-45. Hydrostatic Head in Ground Water near H Area

Head is uniform in the three Tuscaloosa piezometers (P3C, P3B, P3A), lower than that in the Ellenton formation (DRB7WW), but higher than those in the Congaree. Both the recharge and discharge regions of the Tuscaloosa are principally off the plantsite, and they control its water level within the plantsite.

Piezometric contours for the Tuscaloosa formation (Figure II-46) indicate that the Tuscaloosa water flows from the Aiken plateau in a curved path to the Savannah River valley. This lateral flow through the very permeable formation supports the Tuscaloosa water level on the plantsite. Recharge by vertical percolation from above probably does not occur at SRP.

Any contamination entering ground water from H Area would be transported both downward and laterally, especially laterally at each clay barrier. Because water heads in the Tuscaloosa and Ellenton formations are higher than in the Congaree, such contamination would be discharged into Upper Three Runs before it could enter the Tuscaloosa.

LOCAL CLIMATE AND METEOROLOGY

The climate in the SRP area is tempered with mild winters and long summers. Augusta temperatures average 48°F in the winter, 83°F in summer, and 65°F annually. The average relative humidity is 70%. The average annual rainfall at SRP is 47 in. The recorded maximum annual precipitation in Augusta occurred in 1929 (73.82 in.); the minimum occurred in 1933 (28.05 in.).

Basic meteorological data needed to characterize atmospheric dispersion are wind speed and direction, horizontal wind direction variability, and vertical wind direction variability (standard deviations of these quantities), vertical temperature profiles, and vertical mixed depth. Empirically derived relationships are then necessary to relate the above parameters to atmospheric transport and dispersion.

Meteorological data applicable to the SRP are obtained at the WJBF-TV tower located near Beech Island, S. C., about 25 km northwest of the center of SRP. A 2-yr data base[18] was compiled from March 1966 until March 1968; the data consisted of measurements of wind speed, azimuthal and vertical wind direction, and temperatures. These data were taken from instruments at various elevations up to 1200 ft at about 3-min intervals. Data taken over a period of this length are assumed adequate to apply to any given year without serious error. A new system of seven additional towers is being erected on SRP to provide additional data.

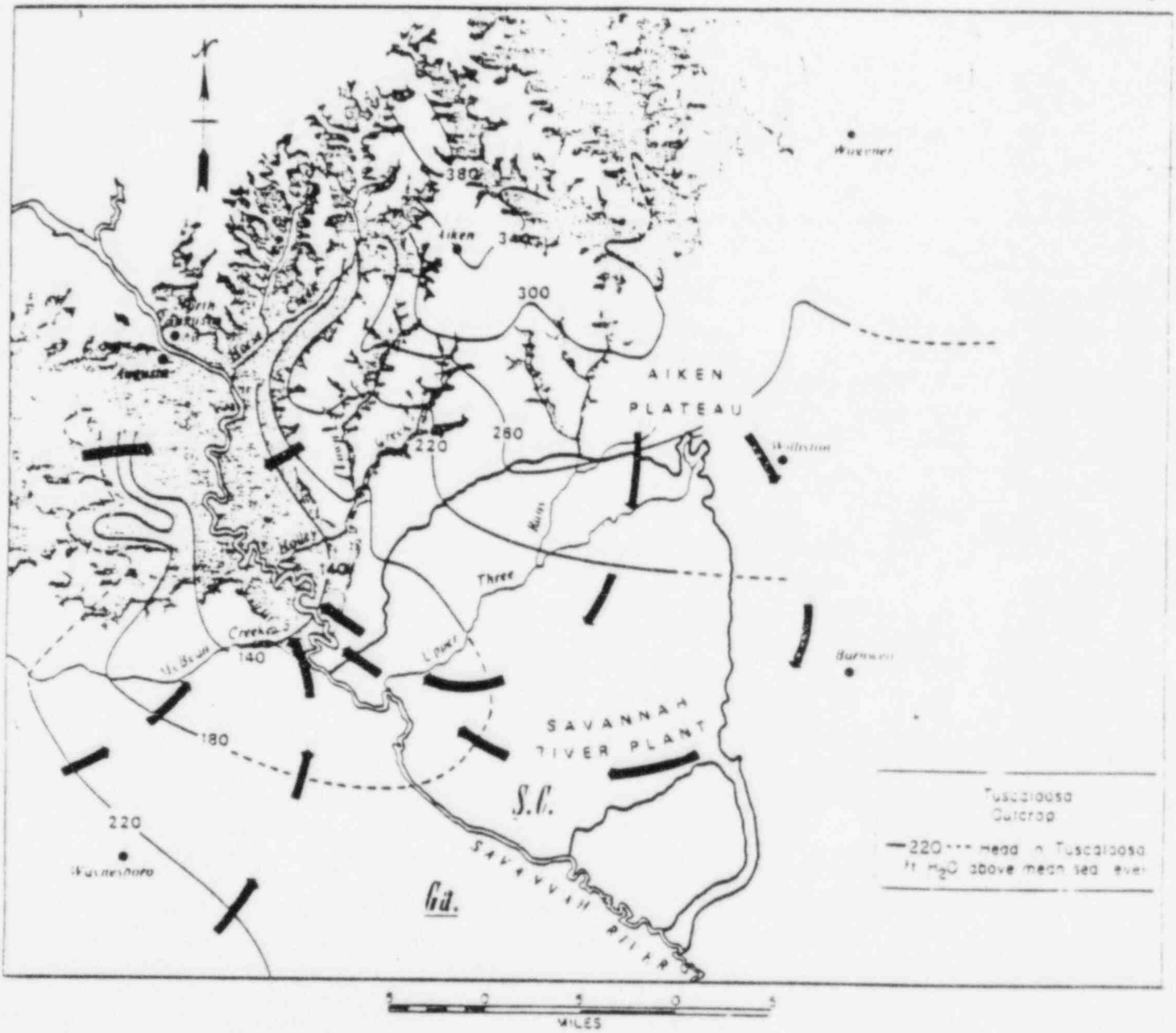


FIGURE II-46. Flow in Tuscaloosa Aquifer

When estimating dispersion, it is important to consider the meteorological conditions as they occur jointly. Using techniques similar to those described in DP-1163,[13] the SRP 3-min data from the 1966-1968 data base were reduced to averaged parameters which characterized dispersion properties over each 15-min period. An annual average mixing depth was imposed to normalize estimated dispersion with long-term measurements both onsite and offsite. A more-detailed discussion of methods for estimating environmental effects is presented in Appendix F.

To confirm the earlier assumption that the 1966-1968 data base could be used to estimate effects of releases in any given year, a second 2-yr data base was constructed for the period of 1974 and 1975. This data base was collected at 5-sec intervals between ground level and 1100 ft above ground level at the WJBF-TV tower. The results from using this new data base confirm the earlier assumption that a 2-yr data base can be used to calculate the effects of releases from other years without significant error.

Storms

The probability and magnitude of severe storms have been analyzed to determine their effects on waste management facilities. Two types of major storms, hurricanes and tornadoes, occur in South Carolina. The following sections describe these storms and discuss their frequency of occurrence.

Hurricanes

Fully mature tropical cyclones, called hurricanes in the Atlantic and typhoons in the Pacific, are large rotating storms of extraordinary violence. They are born over the warm waters of all the tropical oceans. Although hurricanes are neither the largest nor the most intense atmospheric storms, their considerable size and great intensity make them the most dangerous and destructive of all storms. The greatest damage and loss of life arise from storm surges that inundate low-lying coastal areas with wind-driven seawater in which all floating objects act as battering rams, from flooding caused by heavy rains, and from winds that frequently exceed 150 mph.

Tropical cyclones that do not mature into hurricanes are called tropical storms (winds <75 mph). A summary of all Atlantic-born tropical storms and hurricanes for the years 1959 to 1975 is listed in Table II-22 (data assembled by the National Hurricane Center, Miami, Fla.). Many of these storms did not strike land and thus caused little damage.

TABLE II-22

Atlantic Hurricanes and Tropical Storms

Year	*Number of* *Hurricanes*	*Tropical Storms*
1959	6	5
1960	4	3
1961	8	2
1962	3	5
1963	7	2
1964	6	6
1965	4	2
1966	7	4
1967	6	2
1968	4	3
1969	10	3
1970	3	7
1971	5	7
1972	3	1
1973	4	3
1974	4	3
1975	6	2
Annual Average	5.3	3.5

Thirty-eight hurricanes affected (caused damage to) South Carolina in the 275 years of record for an average frequency of 1 every 7 years.[13] The hurricanes that affect South Carolina occur predominantly in the months of August and September (Table II-23). Records during the 1700s and 1800s are not complete or totally accurate because of the lack of communications and a systematic method of identifying and tracking hurricanes at that time.[13]

The occurrence of a hurricane along the coastal region does not generally mean that the Savannah River Plant will be subjected to winds of hurricane force. SRP is 100 miles inland, and the high winds associated with hurricanes tend to diminish as the storms move over land. Winds of 75 mph were measured by anemometers mounted at 200 ft only once during the history of SRP, during passage of Hurricane Gracie to the north of the plantsite on September 29, 1959 (Figure II-47).

Tornadoes

Tornadoes are normally characterized as violently rotating columns of air in contact with the ground. Most tornadic winds rotate in a counterclockwise direction. The wind speeds often reach high speed within a relatively small storm. A distinguishing feature of a tornado is that the vortex is nearly always visible as a funnel-shaped pendant which appears to hang from a heavy cumulonimbus cloud. A tornado is usually accompanied by heavy rain and hail, and often by lightning and thunder. Although a few tornadoes destroy large areas, a typical tornado is on the ground for only one or two minutes and lightly damages an area 50 yards wide by one mile long. The translational speed averages 30 mph. In the extreme cases, the path may be one mile wide and 300 miles long leaving great destruction. The maximum recorded duration is over 7 hours. Less than 5% of all tornadoes which occur throughout the United States have wind speeds in excess of 200 mph. Tornadoes with wind speed of this magnitude may have several vortices rotating about a common axis. The maximum number of vortices observed in a single storm is 7. Generally the wind speed varies in intensity during the lifetime of a tornado and reaches the maximum wind speed and damage capability for 15% of their life cycle. Although tornadoes with wind speeds in excess of 200 mph comprise only 5% of all tornadoes, they are responsible for 97% of the fatalities.

The Savannah River Plant is in an area where occasional tornadoes are to be expected. National Weather Service records from 1916 to 1975 show that at least 300 tornadoes have occurred in South Carolina. In 1975, 12 tornadoes struck South Carolina and 22 struck in Georgia. More-accurate records of wind speeds

TABLE II-23

Month of Hurricane Occurrence
in South Carolina

Month	*% of Total*
June	3
July	3
August	37
September	47
October	10

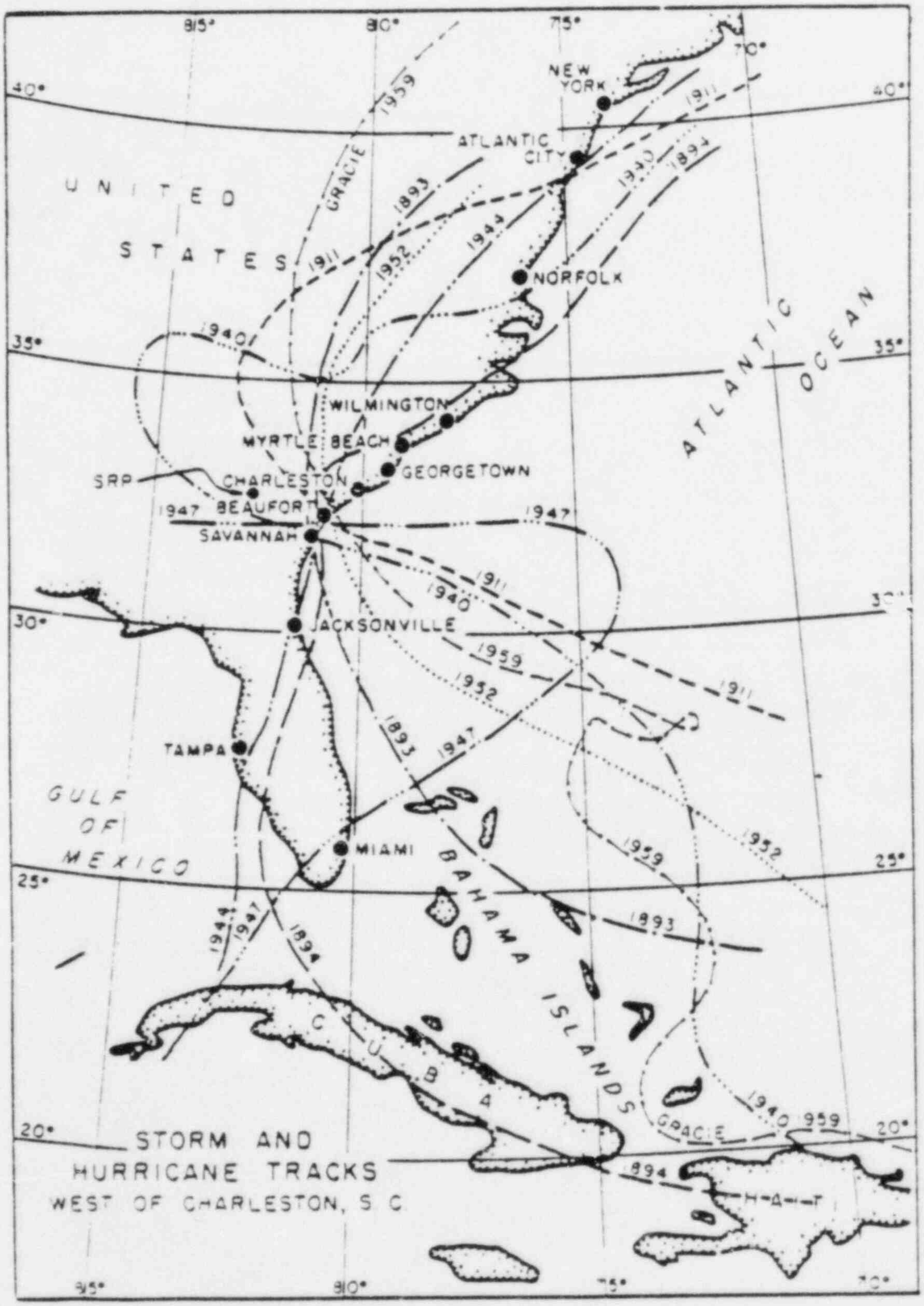


FIGURE II-47. Storm and Hurricane Tracks West of Charleston, South Carolina

and damage area have been kept since 1959. The Fugita-Pearson scale for assessing tornado wind speed and damage has been in use by the National Weather Service since 1971. Most tornadoes occur in South Carolina and Georgia during the period February through June and August to September (Table II-24) and travel in a southwest to northeast direction. The combined area of Georgia and South Carolina is struck by an average of 24.6 tornadoes per year.[20]

Tornado data from 1969 to 1975 show that Georgia and South Carolina may have extreme tornadoes with a maximum wind speed up to 260 mph. Tornadoes with winds up to 318 mph have been observed in the Midwest but not in the Southeast. The probability of a tornado with winds in excess of 250 mph striking a point within the SRP, is estimated to be less than 10^{-5} per year. During the 24-yr history of SRP, there has been no tornado damage to any production facility. On two occasions, light damage has occurred (displacement of light sheet metal roofing, window breakage, tree breakage, etc.). Several other tornado funnels have been sighted in unpopulated areas on the plantsite but investigations showed no damage; thus, the sighted funnels did not touch the ground. Investigation of tornadoes occurring near SRP in 1975-1976 showed damage from tornadic wind speeds varying from 100 to 175 mph.

TABLE II-24

Month of Tornado Occurrence, % of Total/Yr

	Georgia	*South Carolina*
January	9	1
February	8	5
March	18	12
April	33	24
May	7	19
June	5	13
July	2	2
August	4	9
September	3	8
October	<1	2
November	5	2
December	5	3

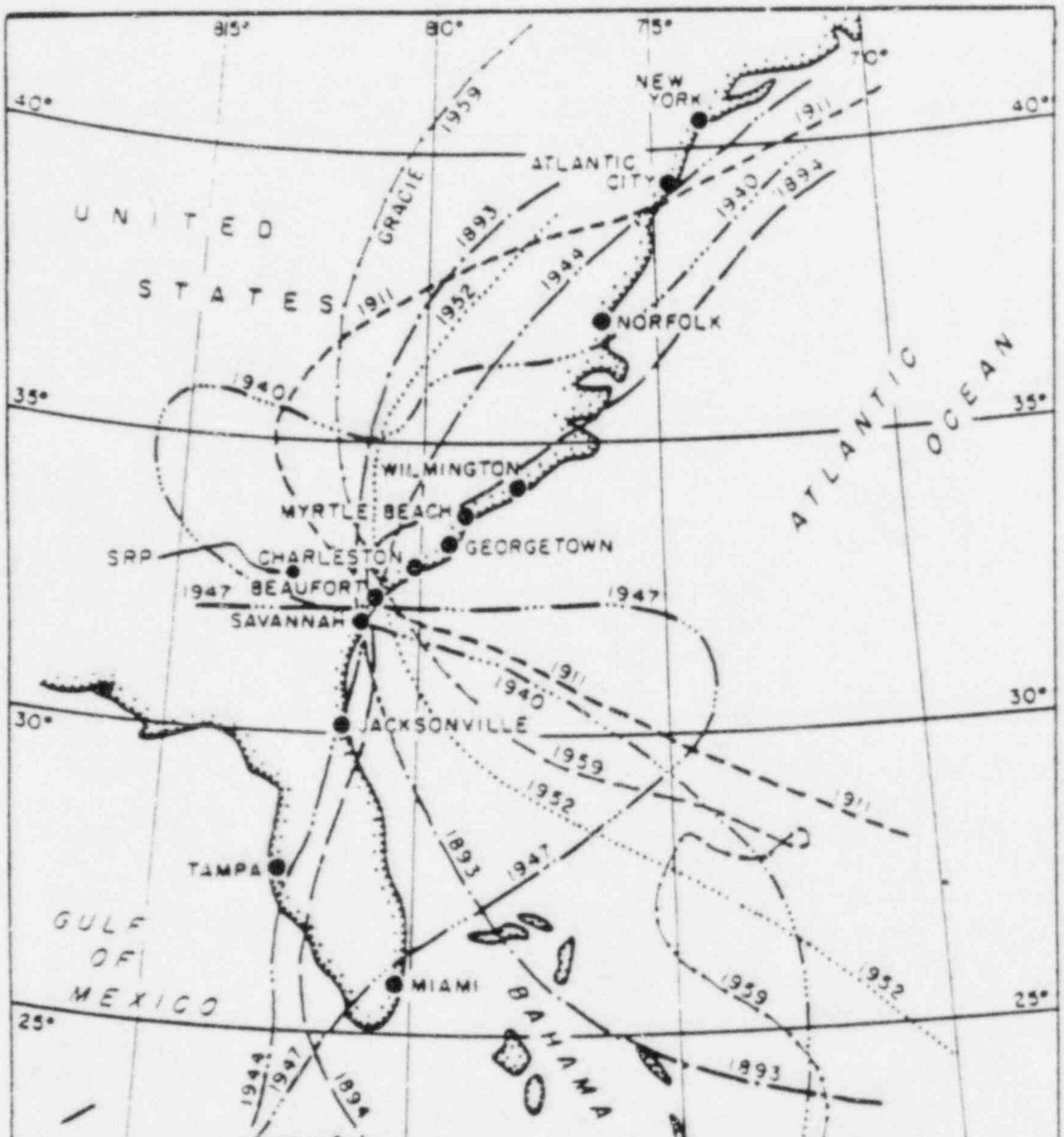


FIGURE II-47. Storm and Hurricane Tracks West of Charleston, South Carolina

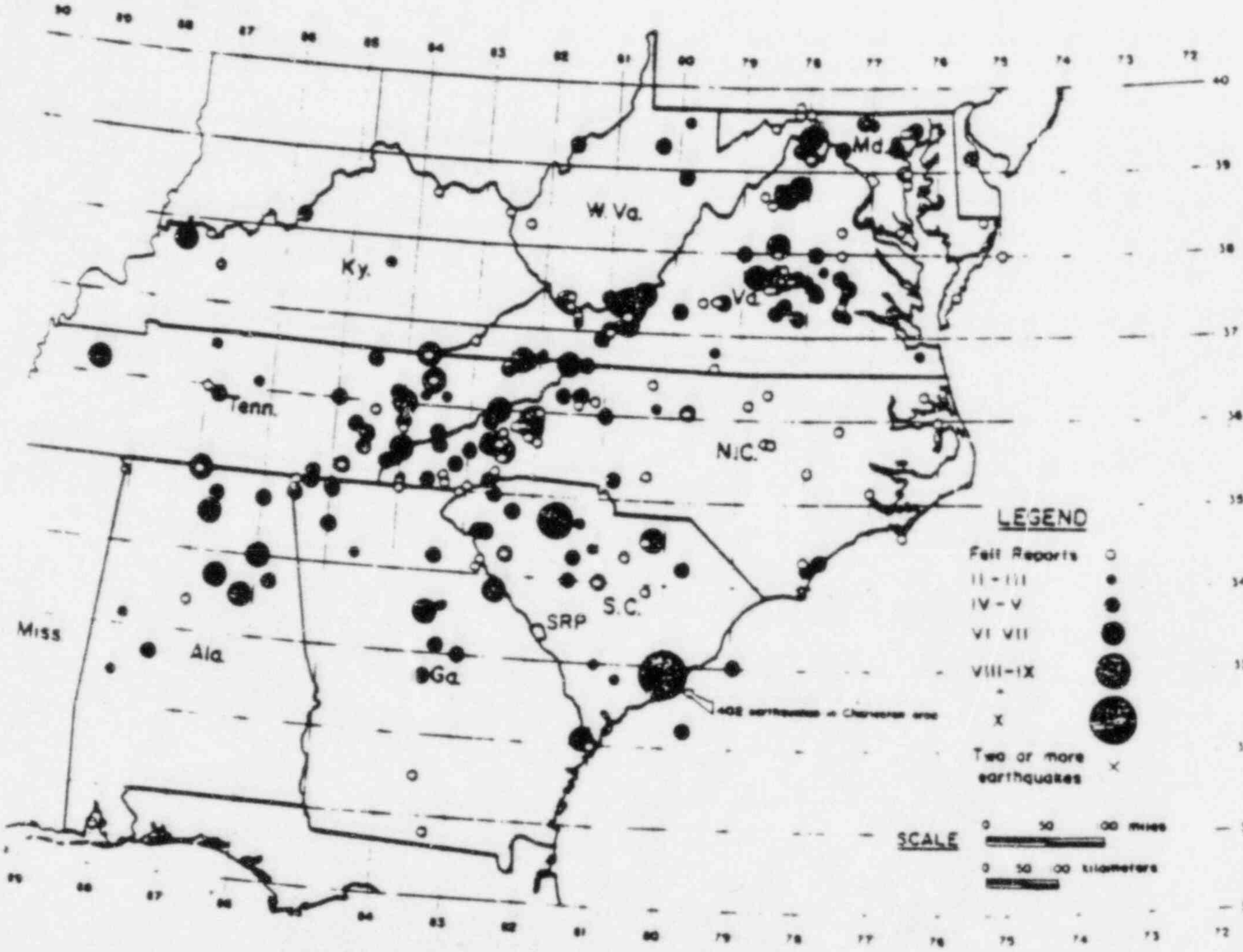


FIGURE II-49. Seismic Activity in Southern Appalachian Area Between 1754 and 1970

SEISMICITY

The Savannah River Plant is located in an area where moderate damage might occur from earthquakes, based on earthquake risk predictions by the U. S. Coast and Geodetic Survey (Figure II-48).[21] The spatial distribution of South Carolina earthquakes, with respect to southern Appalachian seismicity, is shown in Figure II-49.[22] On the basis of three centuries of recorded history of earthquakes, an earthquake above an intensity of VII on the Modified Mercalli (MM) scale would not be expected at the Savannah River Plant. Average acceleration from Reference 23 for intensity VII corresponds to 0.13 g. During the past 100 years, the area within a 100-mile radius of the Savannah River Plant has experienced one shock of intensity X, one shock of intensity VIII, two shocks of intensity VII, and 12 shocks of intensity V MM. Seismic monitors, which were installed in SRP reactor buildings between 1952 and 1955, are set to alarm at 0.002 g (intensity II) and have never indicated an earthquake shock of this intensity since their installation. The design basis earthquake (DBE) for SRP incorporates an acceleration of 0.2 g.

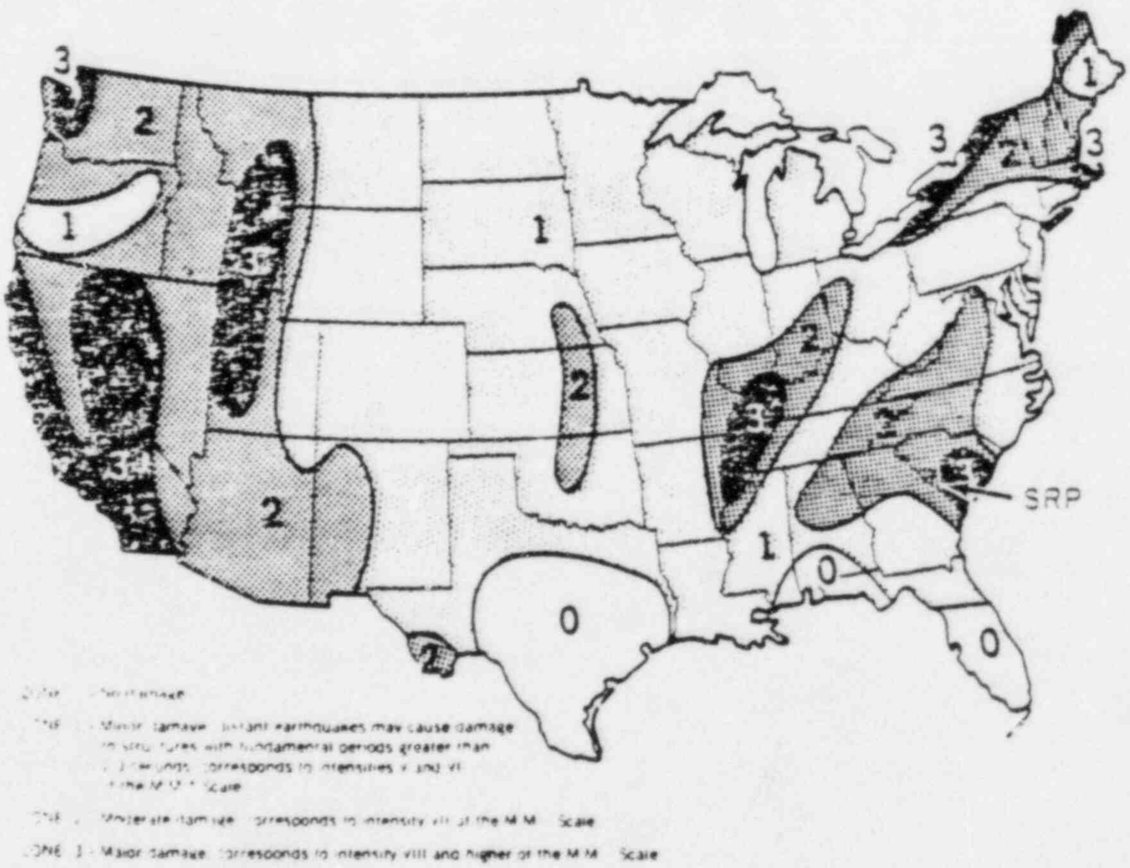


FIGURE II-48. Seismic Risk Map for United States

Before the 1886 Charleston earthquake, the seismic activity in the southeastern part of the United States was low. No severe earthquake shocks had their origin in South Carolina or Georgia from the time of settlement by colonists in about 1670 until the Charleston earthquake in 1886.[22] The only shocks of significance felt in the area during this 200-yr period were those connected with the New Madrid, Missouri, earthquake of 1811-1812. These shocks slightly damaged a few brick buildings in Columbia and elsewhere in the state of South Carolina.

The shock of intensity X MM was the Charleston earthquake of August 31, 1886. This earthquake was felt 800 to 1000 miles away. An area of about 2,000,000 square miles was affected (Figure II-50). In contrast, the 1906 San Francisco earthquake with an intensity of XI MM affected an area of only 373,000 square miles. With only minor exceptions, an earthquake of a given intensity in the eastern United States will be felt at much greater distances than a shock of the same intensity in the western United States. This effect is probably due to the more efficient propagation of certain seismic waves in the more uniform crustal structure of the eastern United States.

The Charleston earthquake caused only minor superficial changes to the ground surface. The epicentral region was broken by many fissures through which water issued, but the fissures seldom attained a width of more than one inch. In contrast, the San Francisco earthquake opened fissures up to 3 ft wide at a distance of 15 miles from the fault, and the fault was exposed at the surface. The Charleston earthquake was probably caused by a fault movement in basement rock beneath a half-mile thickness of unconsolidated sediments. There is evidence that the intensity at and near the Fall Line was slightly greater than that nearer to the epicenter of the 1886 Charleston earthquake. This presumably is due to the fact that the sands and clays of the coastal plain sediments provide greater attenuation to seismic waves than do the underlying basement rock. The effect may also be due to resonance of the soil column near the Fall Line.

Damage was greater at Augusta, Georgia, and Columbia, South Carolina, on the Fall Line, than at intermediate locations, as can be seen from Figure II-50.[24] Reports on the effects of the Charleston 1886 earthquake from towns in the vicinity of SRP were used to estimate earthquake intensities (Figure II-51).

Since the 1886 earthquake, Charleston has been the locus of continued seismic activity indicating that the earthquakes are associated with a tectonic structure even though it is obscured by the overlying Coastal Plain sediments. This tectonic structure is responsible for 98%* of all of the historic earthquake activity

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* Calculated from listing of earthquakes found in Reference 25.

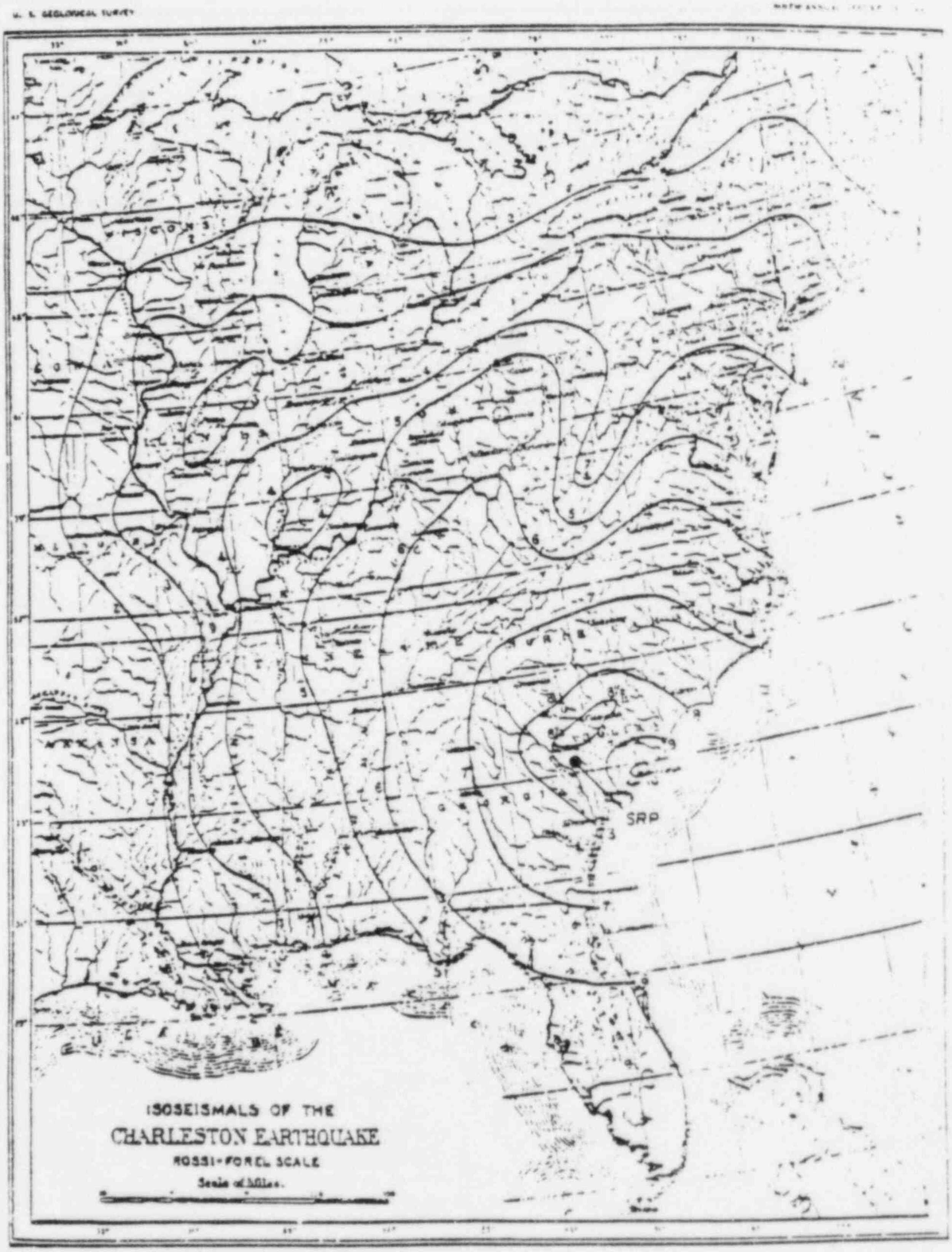

FIGURE II-50. Isoseismals of the Charleston Earthquake (Rossi-Forel Scale)

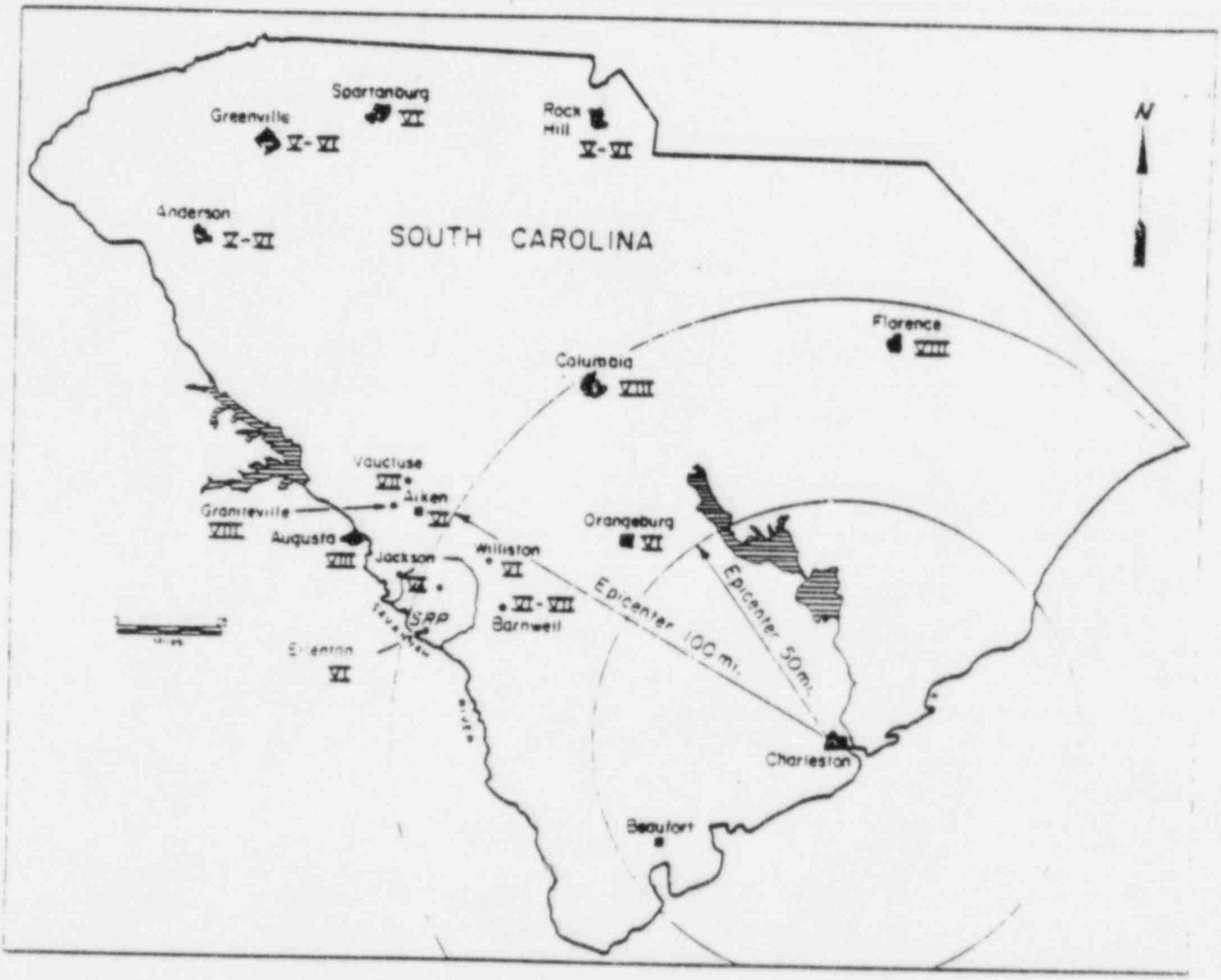

FIGURE II-61. Intensity of the 1886 Charleston Earthquake in the Vicinity of SRP

in the Coastal Plain province of South Carolina and 89% of the earthquake activity in South Carolina.[26] In evaluating the potential for ground motion at SRP, earthquakes of the intensity of the 1886 Charleston earthquake are not assumed to occur elsewhere in the tectonic province.[26]

Earthquakes associated with the Piedmont Province do not seem to be associated with tectonic structures and could thus be assumed to occur anywhere within the province. The maximum earthquake occurred in Union County on January 1, 1913. It occurred about 95 miles from SRP, and its intensity at SRP was about III MM. Since these earthquakes are not associated with a known tectonic structure, they can reasonably be assumed to occur anywhere in their tectonic province, which could be as close as 20 miles from waste management facilities at SRP. If an intensity VI-VII MM earthquake were to occur at this distance, the intensity at SRP would be V-VI MM. At the VI MM level the acceleration would be approximately 0.07 g. Using a similar logic, the maximum earthquake in the Blue Ridge Province and Valley and Ridge Province would result in an intensity of I-II MM and the acceleration would be <0.02 g.[26]

With the installation of many very sensitive seismographs on the South Carolina Coastal Plain and nearby Piedmont Plateau, a greater number of small earthquakes are being recorded. These additions to the statistical record of earthquakes in this area have not changed the conclusions drawn from the 300-yr and human observation of more easily detectable earthquakes. However, as these refined observations contribute to the understanding of crustal structure and tectonics in this area, they may permit a determination of the potential for strong earthquakes in this region.

Intensified geologic studies have revealed a fault northwest of Augusta, Georgia, along the Fall Line, in which crystalline metamorphic rocks are faulted up against sediments of the Tuscaloosa formation and in one area, against sediments that were reworked from the Tuscaloosa formation. Radiocarbon dating of slightly organic clays within the fault zone indicate that the age of the fault is less than 2450 years old. Dating of other organic clays in the vicinity but not actually cut by the fault, give ages as recent as 400 years. Thus, indications are that this fault should be considered in evaluating possible vibratory motion at SRP. The USGS has studied this fault, but the rate and character of its movement has not yet been resolved, nor has its significance to the tectonic framework of the eastern United States been determined. A rough estimate of the intensity of a postulated earthquake was made using available information on the fault,[27] and assuming sudden movement along the entire length of the fault.[28] This results in an earthquake with an

maximum intensity of IX MM. Estimates of the intensity at SRP (30 miles from the fault) would be VI-VII.3 MM.[29,30] The lower value was determined using data from Reference 29 that is based on extensive California attenuation data, and the higher value assumes attenuation to be similar to the Central United States.[31] This would be equivalent to vibratory ground motion of 0.07 to 0.16 g.[23] As more is learned about this fault, its significance will be reassessed.

BIOTA

Plants, birds, and animals must be considered in any waste management policy because of their ability to mobilize radioactivity present in the environment and thereby permit it to be dispersed and to enter the food chain of man. The Savannah River Plant site provides a wide variety of protected habitats; hence, the species diversity and populations are both large. In general, the plantsite is a natural preserve for biota typical of the southeastern Coastal Plain. The production and support facilities occupy only a small portion of the plantsite, and wildlife is little affected by them. Radioactive releases are limited to low levels in limited areas and have had no significant effect on the wildlife.

Habitat Conditions

Before construction of SRP in 1951-1952, Ellenton (population 600) and Dunbarton (population 231) were the only towns on the plantsite. The communities of Leigh, Hawthorn, Robbins, and Meyers Mill were isolated aggregates of families. After acquisition of the site by the Government, honeysuckle invaded these areas, and fruit trees and ornamentals grew wild. At the time of Government acquisition, about 67% of the land area was forested, and 33% was in croplands and pastures. Cotton and corn were the chief crops. Abandoned fields passed through the annual broadleaf vegetation stage into the perennial grass stage and gradually became more wooded. Most of these abandoned fields have subsequently been planted in pine. From the viewpoint of wildlife management, habitat conditions are considered fair-to-excellent over the plantsite.

The Savannah River swamp on the south, particularly that portion subject to periodic flooding, and the dry sandy soils in the north are areas of limited terrestrial wildlife support. Although the swamp is supporting many wildlife species, the composition and age of vegetational species limit carrying capacity.

The region between the sandy sites on the north and the Savannah River swamp on the southeast is best suited for most of

the wildlife species because of the soil fertility and resultant favorable species composition. Much of the area is in pine plantations. Sawtimber is increasing as the pines grow. Ecological succession in the area of old townsites has reached the stage of maximum forage production (for deer). Hedgerows, ornamentals, and fruit trees also provide excellent wildlife habitats.

Artificial water impoundments are numerous. Five natural streams drain to the Savannah River from the site, the largest streams are Upper Three Runs and Lower Three Runs. In addition to the normal occurrence of warm water species of fish, these streams provide spawning runs for striped bass. The Savannah River swamp provides excellent habitat for fish in the numerous stream channels and oxbow lakes.

Vegetation

The plantsite is about evenly divided between Coastal Terraces and the Aiken Plateau (Figure II-52). The Aiken Plateau is quite hilly and deeply dissected by small streams. There are extensive areas of scrub oak and longleaf pine forest along the ridges. Many of the farms in this region were marginal in agricultural productivity. Soils in the Aiken Plateau are mostly sandy and low in fertility. Most of the soil is too sandy and excessively drained to yield regular, profitable crops.

Sandy loams occur in the Coastal Terraces subregion. Fertility is much greater in this area than on the sandy soils of the Aiken Plateau. Fluvial belts of sandy loams also occur along the streams that cross the SRP site. Farming in this area before construction of SRP was confined to the Sunderland and Brandywine terraces bordering the Savannah River floodplain.

Before Federal acquisition, there was very little timber management in the area. Generations of exploitive logging had resulted in poor stands of timber except for hardwoods in the floodplains; timber cutting in the floodplain was not overexploited because of limited access. Although much of the Savannah River Plant site now consists of managed pine forests, the composition of the naturally seeded forests of the site is closely related to the moisture available to the trees. Habitats range from very sandy, dry hilltops to continually flooded swamps. This continuous range is broken into zones characterized by communities of tree species.

The dry sandy areas[11] are typically covered with a scrub oak community dominated by longleaf pine, turkey oak, blue jack oak, black jack oak, and dwarf post oak with ground cover of three awn grass and huckleberry.

On more fertile, dry uplands, oak-hickory hardwoods are prevalent. The most characteristic species are white oak, post oak, southern red oak, mockernut hickory, pignut hickory, and loblolly pine, with an understory of sparkleberry, holly, greenbrier, poison oak, and poison ivy.

On more-moist soils, often found along small streams or on old floodplains, the composition is more variable. Trees may include tulip poplar, beech, sweetgum, willow oak, swamp chestnut oak, water oak, loblolly pine, and ash. The understory may include dogwood, *Viburnum*, holly, and red buckeye.

Bottomland hardwood forest[32] borders the Savannah River swamp where it is subject to occasional flooding. Here, small variations in elevation strongly affect the kinds of trees present. Some common trees are sweetgum, swamp chestnut oak, red maple, ash, laurel oak, blue beech, river birch, water oak, willow oak, sycamore, winged elm, and loblolly pine. Palmetto, switch cane, greenbrier, grape, crossvine, and trumpet creeper are common.

In the Savannah River swamp, where standing water is present most of the year, bald cypress and tupelo gum are dominant trees. Black gum, water elm, and water ash are also present.

Examples of habitat types at SRP have been reserved for research purposes. Two of these areas are registered with the Society of American Foresters as Natural Areas for the preservation of forest cover types. These are Boiling Springs Natural Area, an example of loblolly pine-hardwood (9 acres), and Scrub Oak Natural Area, an example of scrub oak-longleaf pine forest type (52 acres). Ten other areas[33] have been set aside as typical of the major ecosystems present on the plantsite:

1. Sandhills - 67 acres
2. Cypress Grove - 22 acres
3. Loblolly Stand - 28 acres
4. Steel Creek Bay - 29 acres
5. Mixed Swamp Forest - 91 acres
6. Beech Hardwood Forest - 118 acres
7. Oak-Hickory Forest - 83 acres
8. Old Fields - 350 acres
9. Risher Pond - 4 acres
10. Savannah River Ecology Laboratory Area - 100 acres of fields and pine woods

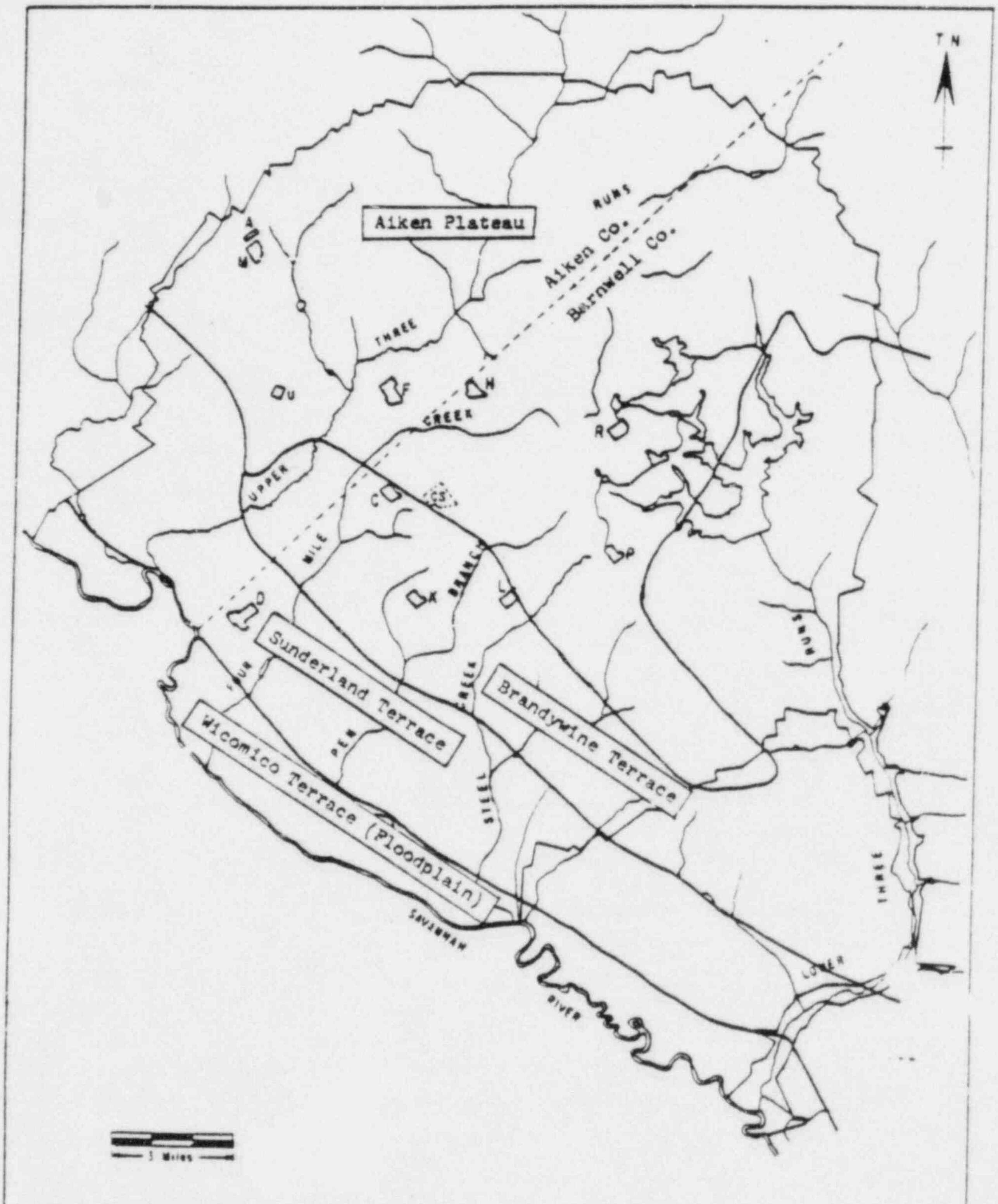

FIGURE II-52. Coastal Terraces on the Savannah River Plant

The ages of the major types of trees on the entire plantsite are summarized in Table II-25. Biologists[33-38] have recorded a variety (128 families, 871 species) of vascular plants on the plantsite.

TABLE II-25

Age of Major Types of Trees[39]

Age, years	*Acres*
Unclassified	640
1 - 10	21,720
10 - 20	77,080
20 - 30	24,560
30 - 40	15,400
40 - 50	19,560
50 - 60	13,760
60 - 80	17,360
80 +	8,440

Mammals

The populations of most species of mammals increased rapidly after the Savannah River Plant was officially closed to the public on December 14, 1952. Most notable expansion was in the deer herd, estimated to be about 20 animals in 1951. A virtual population explosion occurred; the present population is estimated to be greater than 20 deer per square mile or a total of about 5,000 to 8,000 deer on the plantsite. The greatest population densities occur on the southern and northeastern portions of the plantsite. Under protection, the populations expanded so rapidly that by the mid-1960s deer-vehicle collisions were common, and range deterioration was apparent. Controlled hunts, open to the public, were started in 1965. Approximately 10,000 deer have been killed in public hunts,[40] and about 500 have been killed for research purposes.

Domestic hogs, abandoned in 1952, reverted to the semiwild state and became detrimental to young forest plantations. A control program of hog removal was initially pursued by shooting and trapping. Currently, deer hunters are allowed to shoot the feral hogs, and about 125 have been killed since 1969.

Feral dogs and cats are present on the plantsite. Because the threat of rabies is always present and a few persons were chased by dogs, trapping is practiced and captured dogs without licenses are given to the S.P.C.A.

With the exception of deer, feral hogs, and feral dogs, there is no wildlife predation by man. Small mammals such as mice, rats, and shrews are common in favorable habitats. Animals that are common (C) or abundant (A) on the plantsite are:

Gray fox	(C)	Opossum	(C)
Raccoon	(C)	Cottontail rabbit	(A)
Wildcat	(C)	Gray squirrel	(A)
Red fox	(C)	Fox squirrel	(C)
Striped skunk	(C)	Beaver	(C)

Uncommon species found in favorable habitats include marsh rabbit and otter. Animals considered rare are spotted skunk, cane cutter rabbit, black bear, mink, and weasel.

Birds

Before acquisition of the plantsite by the Government, game birds, particularly quail and dove, were abundant due to extensive use of land for agriculture. The removal of land from agriculture did not decrease the quail population; the population increased and probably reached a record high in the early 1960s, but is declining because the conversion of agricultural fields to forest reduced the carrying capacity of the land for quail.[41]

Wild turkey, although present, were not very numerous. South Carolina Wildlife and Marine Resource initiated a program in 1972 using SRP as a breeding ground for wild turkey for stocking other parts of the state. Thirty-three birds were released on SRP by the end of 1974, and current estimates are that the turkey population has increased to about 200 birds.

Waterfowl are present but mainly during winter migrations. Winter waterfowl species increased in number and diversity after construction of Par Pond. An estimated 20,000 ducks and coots spend the winter on the site. Most of these are on Par Pond and several other large ponds and Carolina Bays. Perhaps 2,000 ducks spend the winter in the lower swamps and on the Savannah River. Wood ducks are the only waterfowl that commonly nest on the site.

Endangered species of birds that are protected on the SRP site are the bald eagle, the redcockaded woodpecker, and Kirtland's warbler. Biologists have identified 213 species of birds on the plantsite.[42]

ENVIRONMENTAL PARK

The plant was designated as a National Environmental Research Park in June 1972. The various portions of the plantsite offer unusual opportunities for observing interactions between large industrial complexes and the environment. There are extensive areas of land protected from heavy traffic patterns, casual visitors, real estate development, and other disruptive influences. Because the land area is owned by the U.S. Government, long-term ecological research can be based at the Park with confidence in the continuation of the existing habitats. Several of the unusual opportunities offered are for observing and comparing the ecosystem changes brought about by heated water, flooding, atmospheric and aqueous emissions from fossil fuel power plants, uptake and retention of low levels of radioactive materials, forest management activities, and other stresses on the environment. Researchers from universities and government agencies are currently taking advantage of these opportunities for study.

BACKGROUND RADIATION

Background radiation is the base radiation level to which is added any dose from plant operations. Offsite environmental radiation measurements must take into account this radiation and its variation as a consequence of activities conducted beyond the site boundary. Natural background radiation includes both cosmic and terrestrial sources. These sources vary with location but are assumed constant with time within the recorded span of human history.[48] Local penetrating radiation from artificial origins, both fallout from nuclear detonations and prescribed medical exposures, varies with time for the population as a whole, and doses from the latter source vary from one individual to another. External exposure from radioactive fallout appears to be decreasing with time as a result of the nuclear test ban treaty,[49,50] while that from medical sources appears to be increasing as a result of increased use of diagnostic X-rays.[51]

The calculated annual background radiation dose received by the average person living in the vicinity of the Savannah River Plant is approximately 120 mrem from natural sources. An additional 100 mrem may be received on the average from medical X-rays. Its distribution is shown in Table II-26. The wide range of exposures (excluding those incurred for medical reasons) results primarily from the geologic distribution of naturally radioactive elements near the surface in this region.

In the vicinity of SRP, low-concentration placer deposits of uranium and thorium occur in the Atlantic Coastal Plain.

Reptiles and Amphibians

The SRP site, with its wide diversity of aquatic and terrestrial habitats, supports a diverse population of reptiles and amphibians.[43-45] Species common to the southeastern Coastal Plain are found. Biologists[46,47] have identified 10 species of turtles, 10 species of lizards, 1 specie of alligator, 34 species of snakes, 15 species of salamanders, and 28 species of frogs and toads. Alligators, once rare, are now commonly seen in Par Pond and, to a lesser extent, in some of the effluent streams. This endangered species is protected on the SRP site.

Fish

Habitats for fish on the plantsite are numerous and diversified. They consist of natural and thermally stressed flowing streams, ambient temperature and thermally stressed reservoirs, Carolina Bays, abandoned farm ponds, swamp channels, and oxbow lakes. Fish are present throughout the thermally unaffected streams on the plantsite but are restricted to the lower reaches, near the Savannah River swamp and backwater pools, of streams carrying reactor cooling water.

Par Pond has been receiving heated reactor cooling water since 1958. Temperatures are elevated at one end and near ambient at the effluent end. The pond is connected to two reactor effluent streams (one reactor operating, one reactor shutdown since 1964) by a series of canals and smaller ponds (Figure II-41). Fish range throughout Par Pond and ponds on the canal network. However, due to the protected nature of the impoundment, populations are becoming unbalanced. Bass populations are excessively high, and other populations are declining. Major species occurring are largemouth bass, black crappie, bluegill, and redbreasted sunfish.

Most species not collected from the Par Pond system but reported in the effluent stream, Lower Three Runs, are those commonly considered to inhabit flowing waters. Two species have been collected from Par Pond but have not been recorded as present in Lower Three Runs. These are *Ictalurus platycephalus* (flat bullhead) and *Alosa aestivalis* (blueback herring). The latter commonly migrates up the Savannah River to spawn. An effort is being made to determine if this species is truly landlocked in the reservoir system. Recent evidence indicates that this species does become reproductive in this reservoir system. Species identified in streams number 36 in Upper Three Runs, 25 in Four Mile Creek, 16 in Pen Branch, 24 in Steel Creek, and 42 in Lower Three Runs. All streams except Lower Three Runs were sampled near the Savannah River swamp. Lower Three Runs was sampled 8 miles downstream from the Par Pond dam.

Cosmic Rays

Cosmic ray contribution to natural background dose varies with both latitude and altitude. SRP and the surrounding area out to 100 km lie between latitudes 33°N and 34°N with an altitude variation between sea level and roughly 300 meters (1000 ft).[53]

The ionizing component of cosmic radiation at sea level varies with latitude in the plantsite area by only about 0.5% of mean value,[54] less than the variation between measurements by different investigators (~3.7%).[55] The altitude effect on the ionizing component of cosmic radiation (based on doubling of the dose rate for every 1500-m increase in altitude[56]) causes an increase of from 1.4 to 5.8% over the sea level dose at the roughly 100- to 400-ft elevation of the general area surrounding the Savannah River Plant. The dose rate from this component of cosmic radiation is estimated at 29 mrad/yr based on a sea level rate of 28 mrad/yr.[57]

The dose equivalent rate from the neutron component of cosmic radiation is more difficult to estimate because of the wide variations in measurements[58] and the effect of self-shielding and secondary production in the body. Compared with the effects of these variations, the changes with latitude and altitude within the region of concern are negligible. Watt's experimental data[59] corrected for latitude and altitude give a value of 6 mrem/yr at SRP. Thus the total dose equivalent attributed to cosmic radiation in the vicinity of SRP is 35 mrem/yr.*

External Terrestrial Radiation

External terrestrial radiation in the vicinity of SRP is attributed primarily to gamma emitters in the natural radioactive series derived from uranium and thorium with some additional contributions from ^{40}K. Variation in the distribution of these minerals in local geologic formations and their inclusion in materials of construction commonly used in urban areas leads to a wide variation with location. Some typical values are shown in Table II-27. Because of the wide variation shown, the U.S. mean value of 55 mrem/yr[60] is chosen to represent the average external terrestrial background in the vicinity of SRP. Lowder and Condon[61] cite essentially the same rate, 1 mrem/week, for the average dose to persons living indoors.

* mrad is equivalent to mrem for the ionizing component of cosmic radiation and for external terrestrial radiation.

Slightly higher concentrations occur in the near-surface rocks of the Piedmont Plateau bordering the Coastal Plain on the northwest. These deposits cause substantial local variations in natural background radiation within the region. The radioactivity of these deposits on the plantsite and environs has been described in detail by Schmidt.[52]

TABLE II-26

Background Exposure Near SRP

	Estimated Whole Body Dose, mrem	
	Average[a]	*Range*[b]
Natural		
Cosmic Radiation	35	30–40
Terrestrial Deposits		
External	55	6–380
Ingested	27	25–30
Total Natural	117	61–450
Artificial		
Medical Diagnostic	101	*c*
Weapons Fallout		
External	1	
Ingested	4	3–8
Total Artificial	106	
Total Background	223	165–560

a. Central Savannah River Area (within 40 km of SRP perimeter)

b. Within 100 km of SRP perimeter

c. Only the average used in total range because of high individual variability

Internal Radiation

Internal radiation from natural sources arises primarily from ^{40}K, ^{14}C, ^{87}Rb, and daughters of ^{226}Ra. Contributions from these sources are shown in Table II-28. No estimate of variation with location is attempted because widespread distribution of fertilizers and foods as well as population mobility has an averaging effect for these natural long-lived radionuclides that produce the internal dose.

TABLE II-28

Estimated Average Annual Whole-Body Internal Radiation Dose from Natural Radioactivity

Nuclide	*Dose, mrem*	*Year*	*Source of Data*
^{3}H	<0.01	1962	Reference 66, p 217, paragraph 84
^{14}C	1.0	1962	Reference 66, p 216-216, paragraph 82
^{40}K	19	1962	Reference 66, p 216, paragraph 80
^{87}Rb	0.6	1966	Reference 66, p 27, paragraph 136 (QF[a] = 2)
^{210}Po	3.0	1966	Reference 67, p 35, Table XVI (QF = 10)
^{222}Rn	3.0	1962	Reference 66, p 212, paragraph 41 (QF = 10)
Total	27.0		

a. Quality factor.

TABLE II-27

External Gamma Fields from Natural Terrestrial Radioactivity[a], mrem/yr

	Aircraft Surveys	*SRP Mean (70)*	*Other*
Augusta, Ga.	17- 85 (58)		56 (71)
Waynesboro, Ga.	17- 46 (58)	26	
Aiken, S. C. (Airport)	17- 34 (58)	19	26 (63) 24 (65)
Barnwell, S. C.[b]	6- 51 (58)	35	
Edgefield, S. C.[b]	11-154 (58)		23- 95 (63)
Lexington, S. C.[b]	17-385 (58,63)		20-140 (63)
Columbia, S. C.	35-385 (63)		80 (58) 70 (71)

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a. Number in parentheses is year of measurement. Source of data is also given.

(58) Reference 52

The aeroradioactivity survey readings reported by Schmidt in counts per second (cps) at 500 ft altitude were corrected for background due to fallout (150 cps) and converted to mrem/yr at 3 ft by the factor 1 mrem/hr at 3 ft = 77,000 cps at 500 ft (Reference 52, p 13). This is considered a better conversion factor than the 1 μrem/hr = 37 cps derived from the correlation curve supplied by Schmidt (Reference 52, p 17) because the latter was based on ground readings in the μrem/hr range which are subject to considerable uncertainty.

Reference 59

(63) References 62 and 63

(65) Reference 64

(70) Reference 65

(71) Lawrence Livermore Laboratory measurements

b. 10-mile radius

When the baseline study was made, and continuing to the present time, the cities of Augusta and North Augusta contributed raw or partially treated sewage to the river. This was the major source of pollution within a short distance upstream. Since that time, a number of industries have located between Augusta and the Savannah River Plant, and many discharge effluents either directly or indirectly into the river. Some industries that were small at the time of the baseline survey have enlarged. The city of Augusta now treats all sewage before discharge.

Biological and chemical evidence indicates that the mineralized nutrient load increased in this section of the river during the study period. These conditions have produced a decrease in diversity and a change in the more common species. The changes have not been severe enough, however, to degrade the river below a healthy condition. There was no evidence in the areas studied of any effects of the slight increases in temperature of the river caused by the Savannah River Plant.

Savannah River Ecology Laboratory Studies of the SRP Site

The Savannah River Ecology Laboratory (SREL) of the University of Georgia was established in 1961 to study the ecology of the SRP site. It has conducted diversified studies of site characteristics to identify and follow natural changes since acquisition of the property in 1950 as well as to investigate the effects of SRP operations. Research is currently centered in three major programs: thermal ecology, mineral cycling, and radioecology of transuranic elements. Each of these programs is strengthened by the ongoing accumulation of knowledge of the basic ecology of the site.

Emphasis in all programs is placed on field-oriented research dealing with unique regional problems or those of local origin which have broad ecological significance. As examples of the latter, extensive research has been conducted in the Par Pond reservoir system and the Savannah River swamp, both of which have received thermal effluents and low levels of radioisotopes. Furthermore, the availability of low levels of plutonium and uranium in both terrestrial and aquatic environments on the Savannah River Plant has provided an unusual opportunity for field research in this area. SREL studies seek to document the effects and determine the extent of local environmental effects and establish predictable relationships which have regional applicability. A limited number of the SREL regional studies require data collected from several southeastern states. Studies in the natural, environmentally unaffected areas on the SRP are also a vital part of the overall program. The combination of thermally and isotopically altered natural environments in the immediate vicinity of unaffected areas has resulted in a unique field research facility.

ENVIRONMENTAL STUDIES BY OUTSIDE CONTRACTORS, UNIVERSITIES, AND RESEARCHERS

Academy of Natural Sciences of Philadelphia Studies of the Savannah River

Before the start of plant construction in 1951, the Limnology Department of the Academy of Natural Sciences of Philadelphia began a baseline study of the Savannah River in the vicinity of the Savannah River Plant. This study considered all the major groups of aquatic organisms (protozoa, lower invertebrates, insects, fish, and algae) together with the general chemical and physical characteristics of the river.[68] The purpose of this study was to provide a comprehensive picture so that future changes that might occur in the Savannah River could be measured. Such changes might be due to the activities of the Savannah River Plant or to changes in upstream river conditions.

Since the baseline study, the Limnology Department has carried on a continuous program of scientific investigation in the Savannah River, as follows:

1. Detailed surveys of the biological, chemical, physical, and bacteriological aspects have been made at 3- to 5-year intervals.

2. Checks on river conditions are made four times yearly; the general condition of algae, invertebrate, and fish populations are determined.

3. Diatometer studies were begun in 1953 to continuously record changes that may occur in river conditions as indicated by changes in the structure of the diatom community.

At the time the baseline study was made, the Savannah River was a typical Coastal Plain river receiving a moderate amount of city and industrial waste along its course. There was a heavy silt load. In 1952 shortly after the first study was made, Clark Hill Dam was put into operation upriver from the plant. This dam has had several effects on the river. Because of stabilized river flow, cave-ins of the banks due to rapidly rising and falling water no longer occur. The banks are vegetated with higher plants that hold the soil in place. Also, suspended solids tend to settle out behind Clark Hill Dam, with the result that downstream waters are clearer. Algal growth extends to a much greater depth, and populations of filter-feeding insects have increased, resulting in an increase in aquatic life in the Savannah River below the dam.

- To determine how individuals and species populations respond to artificial elevation of aquatic temperatures through differential thermal tolerances, behavior patterns, host-parasite relationships, genetic selection, and alteration of competitive interactions.

- To determine how communities respond to the artificial elevation of aquatic temperatures through changes in species composition and diversity.

SREL studies have revealed the following apparent effects of reactor thermal effluents on the environment of the SRP:

1) An assessment of the broad-scale effects of reactor effluents on the forest vegetation of the Savannah River swamp has revealed that:[69]

   a) The trees on 560 acres of the swamp forest have been killed by heated reactor cooling water. This represents 7.5% of the total swamp area into which effluents are released.

   b) One-third to two-thirds of the trees have been killed in another 650-acre area (8.7% of the total swamp), and the forest canopy is open.

   c) In an additional 3,450 acres (46.2% of the total swamp), mortality of swamp hardwoods includes fewer than one-third of the trees but more than that found in the natural swamp upstream of all heated effluents. The canopy is uneven.

2) Studies on aquatic vertebrates have revealed a number of effects on these groups of organisms. Among these are the following:

   a) Bass are attracted to the thermal areas in large numbers during winter.[70]

   b) Thermal tolerances of bluegill are increased in thermal areas.[71]

   c) Amphibian growth rates are increased but body sizes at metamorphosis are reduced in thermal areas.[72]

   d) Growth rate and body size of some turtle species are increased in thermal and post-thermal recovery areas.[73]

SRP Site Ecology

The forests and pine plantations of SRP are actively managed for pulp and timber production by the U.S. Forest Service, using management techniques which are standard throughout the southeast. The evaluation of forest management techniques in this region is a continuous process for numerous federal and state agencies. SREL is studying the nutrient cycle which exists in the soils of the southeastern Coastal Plain in order to effectively devise management techniques which are compatible with productivity and conservation.

In addition to the wood resources of the SRP, there are animal resources, such as an estimated 5,000-8,000 white-tail deer and 500-1,000 feral swine. These as well as other game and non-game species are managed by the Forest Service and studied by SREL. Special management of other species is required by the Endangered Species Act of 1973 (PL-93-205), that requires all Federal agencies be cognizant of those endangered species of wildlife and plants which occur on lands under their management, carry out programs for the conservation of endangered species, and take action necessary to ensure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of endangered species or result in the destruction or modification of critical habitat of such species. At least two endangered species, the American alligator (*Alligator mississippiensis*) and the redcockaded woodpecker (*Dendrocopos borealis*) are found on the Savannah River Plant, and both of these are being studied by SREL personnel.

Thermal Ecology

The following objectives have guided SREL research in thermal studies:

- To determine how elevated water temperatures resulting from reactor effluents affect selected physical parameters of the environment having direct effects on biological systems.
- To determine how elevated water temperatures influence the uptake and availability of nutrients, heavy metals, and other elements to organisms associated with aquatic ecosystems.
- To determine the effect of the artificial elevation of aquatic temperatures on primary and secondary productivity (including reproduction and growth processes) in aquatic communities.

- To determine the importance of interactions among energy flow, thermal environments, and mineral cycling processes on the rates of biomass buildup and transfer within southeastern ecosystems.

- To determine the extent to which transfer coefficients are modified by population processes that influence the temporal or spatial turnover of standing crops.

- To validate models of cycling processes in southeastern ecosystems at various sites on the southeastern Coastal Plain.

The Savannah River Plant provides opportunities to investigate various interactions of heavy metal and other stable element cycling between the biological and physical components of the environment. The broad list of available habitats includes reservoirs, ponds, swamps, streams, a major river system, abandoned agricultural land, forest plantations, and several natural forest types. Some of these habitats have received various radioisotopes and industrial pollutants from plant operations for many years. Because of the porous sandy soils of this area, many minerals normally held in the organic or clay fraction of soils become concentrated in the biota. This creates rather tightly closed mineral loops in the biota and reduces nutrient loss, but can also result in the accumulation of toxic pollutants.

The Savannah River Ecology Laboratory has conducted studies in contaminated habitats on the fate of radionuclides in the environment. The low activity levels of these radioisotopes in well-defined ecosystems provide a unique opportunity to study the fates of these isotopes under natural conditions.

Studies have been concentrated in the swamp ecosystem, especially in the Steel Creek area. Studies have also been done with radioisotopes in the Par Pond system. Because radiocesium is among the few long-lived isotopes that have been released and is biologically active, most of SREL's research efforts in this area have been focused on radiocesium.[78,79]

Radioecology of Transuranic Elements

Evaluation of potential hazards to the quality of the environment and health of man from low-level releases of the transuranium nuclides (e.g., ^{238}Pu, $^{239-240}Pu$, ^{241}Am, and ^{244}Cm) was initiated as a new program in 1974. This program is considered independent of general mineral cycling studies because of the unique properties of transuranic elements, their potential long-term persistence in the environment, and the potentially serious environmental problems they pose.

e) Some alligators, principally larger males, in the thermal areas, remain active throughout the normal period of winter dormancy.[7]

f) Diversity of fish and reptiles is decreased in areas of greatest thermal impact.[5]

g) Certain species of waterfowl avoid thermal areas while others do not.[76]

h) Several species of fish and turtles inhabiting thermal areas demonstrate significant changes in kinds and population densities of parasites.

3) Plant ecology studies have revealed several findings other than the general impact on the swamp.[77]

a) Tree species diversity is reduced in thermal and early post-thermal recovery areas.

b) Accompanying the shift from hardwood floodplain to freshwater marsh, the diversity of herbaceous shoreline and island plants remains high in thermal and post-thermal areas.

c) Diversity of submerged plants is greatly reduced in hot water. Periphyton communities have shifted from green algae to blue-green algae.

d) Species composition of plant communities is greatly changed in both thermal and post-thermal areas.

e) Cattails from the thermal areas have a lower biomass per unit area than those from normal temperature areas. Also, sexual reproduction is absent in heated areas.

Mineral Cycling

Research objectives for the mineral cycling program at SREL are:

- To determine the availability of stable elements and radioisotopes to the biota of the southeastern Coastal Plain.
- To determine the role of primary producers and consumers in cycling processes in southeastern ecosystems.
- To determine the factors that are limiting to rate processes in southeastern ecosystems.

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APPENDIX G

METHODS FOR DETERMINING ENVIRONMENTAL RADIATION DOSE

Most of the radionuclides released to the atmosphere and to the Savannah River from Savannah River Plant operations are not detectable by routine environmental monitoring due to the very low levels of released material. Therefore, mathematical models were developed to predict the fate of the radionuclides in the environment and the subsequent dose commitment to offplant population groups. A number of pathways (or vectors) have been identified by which radionuclides are introduced into or may affect the human body. These include air, drinking water, transfer in food crops, external radiation from deposited radioactivity, etc., and are included in the model. These same vectors are analyzed in the routine environmental monitoring program and verify that the mathematical models do not underestimate the population dose commitment. Because population dose cannot be measured (again because of the very low levels released, but with the exception of tritium which is released in quantities sufficient to measure the dose), the dose estimate calculated by the mathematical model cannot be attributed to have a high degree of precision; however, it is estimated that actual dose would not be less than one-half nor more than twice the dose figures given.

DOSE COMMITMENT

As used in this appendix, "dose commitment" means radiation dose equivalent[1] that will be received in a 70-year lifetime by population groups as a result of a given release of radioactive materials to the environment. This includes commitments from:

- External dose from radioactive materials in the atmosphere and on the earth's surface.
- Internal dose from radioactive materials entering the human body.

Vectors that do not result in significant doses to the population groups discussed in this statement are not included in the mathematical model. For example, global recycling of tritium, carbon-14 and krypton-85, after mixing with the earth's atmosphere, is not considered; the subsequent dose to the population groups discussed in this statement is significantly less than the initial dose from the release of these nuclides.

POPULATION

It is estimated that the population groups considered in this report have increased about 10% during the period of SRP operation. However, all dose commitment calculations in this report assume a constant population size, based on the 1970 census. This was done to simplify population dose calculations and is a reasonable approach considering the degree of precision of population dose calculations. The population doses calculated for the years prior to 1970 will be conservative (overestimated) due to the population increase since that time. The population distribution is shown in Figure G-1.

DOSE VECTOR MODELS

For members of the public to be exposed to radioactivity released from SRP, the radioactive material must be transported to the recipient population groups. The two basic transport media for SRP releases are air and water. From these arise numerous exposure vectors. Fourteen vectors were selected for atmospheric releases (Figure G-2) and sixteen vectors for liquid releases (Figure G-3), based on a study of demography, meteorology, topography, and agricultural practices. The numbered lines on the model diagrams are for purposes of identification and compilation of data and will be described in the sections which discuss each model.

ATMOSPHERIC RELEASES

The calculational technique used for determining atmospheric dilution or dispersion of radioactive gases, vapors, and particles is described in Appendix F. These procedures provide the following data for each radionuclide released to the atmosphere:

1. Integral external gamma dose from passage of gamma-emitting radionuclides in the atmosphere. (The passage of radioactive material may either by overhead, i.e., a plume that has not reached ground intercept, or at ground level, where it submerges a recipient in a radioactive cloud.) Uncollided gamma photon energy flux is corrected for buildup for the two conditions of passage. In addition, provision is made for calculating gamma dose from radioactive daughter nuclides born in transit. Calculations are made for each radionuclide in sixteen 22.5° azimuthal sectors and twenty 5-km radial increments from the geographic center of the Savannah River Plant, a total of 320 locations (Figure G-1).

2. Integral air concentrations [(Ci-sec)/m^3] of each radionuclide at the 320 locations described in 1.

3. Integral areal deposition [(Ci-sec)/m^3] of each radionuclide at the 320 locations described in 1. This is not applicable to noble gases.

For each radionuclide released, a dose conversion factor was calculated for dose vectors shown in Figure G-2. These factors are in terms of integral lifetime dose (70 years) per annual average air concentration [rem/(Ci-yr/m^3)] and areal deposition [rem/(Ci-yr/m^2)]. In the computer program for calculating dose, the dose conversion factors are divided by 3.15 x 10^7 (sec/yr) to be compatible with units of integral air concentration [(Ci-sec)/m^3] and integral deposition (Ci)/m^2, the output forms of the atmospheric dispersion calculations. The dose conversion factor, so modified, is used as a multiplier with output from the dispersion program. The lifetime dose commitment from each radionuclide released can be calculated for an individual at each of 320 areal segments (20 radial increments, 16 azimuthal sectors) within 100 km from the geographical center of the plant. This represents a land area in a circle extending 50 miles from the plant perimeter. Individual dose data for each areal segment is multiplied by the number of people in each segment, and the resultant doses from each of the 320 radial increments are summed to obtain total man-rem dose commitment. Provision is made for calculating whole body dose, skin dose, critical organ dose, and identification of the critical organ.

External gamma radiation dose from airborne activity (vector 01, Figure G-2) is calculated by use of dose conversion factors that are a function of the gamma energy being considered. Provisions are made in the MAN-REM program to calculate external gamma cloud dose from library data obtained from processing the meteorological data for various gamma energies.

Figure G-2 shows diagrammatically the vectors selected for use in the SRP atmospheric release model. A description of each follows:

01 *External Gamma Cloud or Plume.* This represents penetrating whole body gamma dose from submersion in an atmosphere containing radioactive materials or from passage overhead of a plume containing radioactive materials.

02 *External Beta Cloud.* This represents beta skin dose from submersion in an atmosphere containing radioactive materials. Because of the short range of beta particles in air, beta skin dose is not calculated for overhead passage of a plume where the receptor is not submerged in the plume.

03 *External Gamma Deposition.* This represents penetrating whole body gamma dose at 1 meter above ground level from radioactive materials deposited on the surface of the earth from passage of a cloud or plume containing radioactive materials. At each of the 320 geographical locations for which this is calculated, the surface deposition is treated as an infinite plane source uniformly contaminated. Uncollided gamma photon energy flux is corrected for buildup.

04 *External Beta Deposition.* This represents beta skin dose from radioactive materials deposited on the surface of the earth. Dose calculations are based on a finite plane disk source, uniformly contaminated; and the radius of this disk depends on the range of the energy of the beta particles for each radionuclide.

The vectors for external radiation, 01 through 04, do not take into account variables which attenuate the dose, such as shielding afforded by occupancy in buildings, reduction in beta dose by clothing worn, or roughness factors for the surface on which the radioactive materials are deposited. The beta skin dose is calculated at a skin depth of 0.07 cm (7 mg/cm^2) and thus overestimates exposure of the lens of the eye. The integrated beta depth dose to the testes was calculated, but was so small (less than 2% of the skin dose for the highest energy beta considered) that it was not included as an organ dose vector.

05 *Internal Dose - Critical Organ - Inhalation.* This represents the internal dose to the critical organ for each radionuclide that is taken into the body by inhalation. Dose is calculated as lifetime (70 years) commitment from an integral uptake of radioactive material.

06 *Internal Dose - Whole Body - Inhalation.* This is the same as vector 05 except it treats the whole body as the critical organ. Calculations use the simplifying assumption that the radionuclide is distributed uniformly throughout the human body. In those cases where distribution is not uniform or is unknown, the dose so calculated is conservatime (overestimates the body dose). This method is also used in other vectors for internal dose where whole body is treated as the critical organ, i.e., vectors 08, 10, 12, and 14.

07 *Internal Dose - Critical Organ - Deposition - Domestic Water Supply.* This represents integral dose to the critical organ received from consumption of surface water supplies, i.e., lakes, ponds, and streams, which have been contaminated by deposition of radioactive materials from airborne radioactivity.

This is not an important vector in the areas contiguous to the Savannah River Plant because most domestic water is obtained from deep wells or from the Savannah River upstream from SRP. The Savannah River upstream receives its water from a vast water shed extending to the Appalachian Mountain chain to the west, an area so distant that aerial deposition from SRP releases can be ignored.

08 *Internal Dose - Whole Body - Deposition - Domestic Water Supply.* This is the same as vector 07 except it treats the whole body as the critical organ.

09 *Internal Dose - Critical Organ - Consumption of Vegetation Containing Radioactive Materials.* This represents integral dose to the critical organ received from consumption of vegetative farm crops which contain radioactive materials as a result of foliar deposition and uptake from the soil. This vector contributes a very small portion of the population exposure because of the nature and quantity of releases of radioactive materials from SRP.

10 *Internal Dose - Whole Body - Consumption of Vegetation Containing Radioactive Materials.* This is the same as vector 09 except it treats the whole body as the critical organ.

11 *Internal Dose - Critical Organ - Consumption of Meat Products Containing Radioactive Materials.* This represents integral dose to the critical organ from consumption of meat products from herbivorous animals which have been fed on vegetative crops containing radioactive materials of SRP origin. This vector contributes a very small portion of the population exposure because of limited production of meat products in the near vicinity of SRP and because of the nature and quantity of radioactive materials released.

12 *Internal Dose - Whole Body - Consumption of Meat Products Containing Radioactive Materials.* This is the same as vector 11 except it treats the whole body as the critical organ.

13 *Internal Dose - Critical Organ - Milk Consumption.* This represents integral dose to the critical organ received from consumption of locally produced milk. Exposure is via the forage-cow-milk pathway. This is an important vector for three of the radionuclides released at SRP, tritium, iodine-129, and iodine-131.

14 *Internal Dose - Whole Body - Milk Consumption.* This is the same as vector 13 except it treats the whole body as the critical organ.

For vectors 07 through 14, population dose calculations depend largely on environmental monitoring data, i.e., analysis of foods available to the public. The dose model can be used to calculate specific individual dose commitments to persons who produce and consume their own food at any of the 320 geographical locations included in the computational program. It is for this group, i.e., small farmers, that the data for *individual* dose commitment apply.

All possible dose vectors have not been included in the dose model for atmospheric releases, but no important vectors have been omitted. Table G-1 presents a computer-calculated summary of man-rem doses for all radionuclides released to the atmosphere in 1975. The summary shows cumulative dose by radial increment from 20 km (plant perimeter) to 100 km (50 miles from the plant perimeter). Table G-2 shows dose contributed by individual radionuclides to population dose, to individuals, and to individual organs. An isopleth of whole body dose to the individual during 1975 from atmospheric releases is shown in Figure G-4.

RELEASES TO LIQUID EFFLUENTS

Radioactive materials enter the Savannah River or have the potential for future entry by four mechanisms resulting from current and past waste management practices. These mechanisms are:

1. *Direct discharge to effluent streams.* Low concentrations of radioactive materials in large volumes of water are discharged to surface streams flowing to the river. No practical method currently exists for removing these radioactive materials because they are generally aqueous flows that have already been decontaminated to as low a level as practical at the point of release. Tritium (oxide) cannot be removed from the effluents with existing technology. All of the radionuclides released in this manner are below the Concentration Guides (ERDAM 0524) at the point of departure from the SRP site and, after dilution in the Savannah River, are less than 1% of the Concentration Guides for uncontrolled areas.

2. *Discharge to and retention in effluent streams.* Some radioactive materials discharged to effluent streams do not flow directly to the Savannah River because of retention in the stream and stream components by complex chemical and biological phenomena. Most notable is cesium-137, which is partially retained by stream sediments, vegetation, and organic detritus. At SRP, less than 20% of the cesium-137 discharged reaches the Savannah River during the year of discharge. The remainder desorbs over tens of years. The cesium that is not lost through radioactive decay will contribute to discharges to the river in future years.

3. *Discharge to seepage basins.* Some low-level liquid wastes are discharged to earthen seepage basins to prevent surges of radioactivity in plant streams and to allow short-lived nuclides to decay. The water in these basins moves downward to the water table and then flows laterally with the ground water to outcrop areas near or along effluent streams. The movement of radioactive materials depends on the element, its chemical form, and its ion exchange characteristics in the soil. Tritium (oxide) moves at the same rate as the seepage and ground water. All other elements experience travel delays resulting from reduction in velocity and/or immobilization by ion exchange phenomena in the soil. Delays in transport to surface streams reduce the amount of radioactivity reaching the aquatic environment by radioactive decay. Currently, only tritium and strontium are reaching surface streams. However, other very long-lived radionuclides may eventually enter the streams and contribute to future dose commitment.

4. *Burial of solid wastes.* Solid waste, containing radioactive contamination, is buried in unlined earthen trenches above the water table. In 20 years of use of burial trenches, very little radioactivity other than tritium has been detected in the ground water. Some of the moderately long-lived radionuclides such as ^{90}Sr may reach the water table, but should decay to background levels within 100 ft of the point of entry into the ground water. The inventory of tritium in the ground water is 5×10^{4} Ci, and the projected population dose after migration to the nearest stream is less than 1 man-rem. It is estimated from measurements that the fastest moving radionuclidic compound, tritium oxide, would take approximately 70 years to reach a stream, once it has reached the ground water beneath the burial trenches. 98% of the long-lived transuranium elements in solid waste are buried in concrete containers for future retrieval and should not contribute to future population dose commitment.

The four mechanisms of release cannot be mathematically modeled with a satisfactory degree of precision because of many unknown parameters and variables in ground water and surface water transport of radionuclidic compounds. An aqueous transport model is being developed with the intent to be combined with a dose vector model (Figure G-3); these models will be used as a predictive tool for waste management programs.

As in the atmospheric release model, dose factors were calculated for each radionuclide for each important vector in terms of integral dose commitment per integral radionuclide concentration $\{rem/[(Ci\text{-}yr)/m^3]\}$. When used as multipliers for concentrations of radionuclides in the various aqueous vectors, the dose

commitment to critical population groups can be calculated for each radionuclide. Sixteen vectors are shown in the liquid release model. A description of these vectors follows:

21 *Internal Dose - Critical Organ - Untreated River Water Consumption.* This represents the integral internal dose to the critical organ for each radionuclide that is taken into the body by ingestion of untreated river water. No such population is known to exist and is included primarily to represent a maximum dose possible from river water consumption.

22 *Internal Dose - Whole Body - Untreated River Water Consumption.* This is the same as vector 21 except it treats the whole body as the critical organ.

23 *Internal Dose - Critical Organ - Treated River Water Consumption.* This is the same as vector 21 except that it applies to customers of the two water treatment plants downstream from SRP, i.e., the Beaufort-Jasper, S.C. Water Authority and the Cherokee Hill Water Treatment Plant, Port Wentworth, Georgia. See Tables G-3 and G-4 for a description of utilization of water from these plants. At present, these plants are the only significant dose vector for liquid releases of radioactive materials.

24 *Internal Dose - Whole Body - Treated River Water Consumption.* This is the same as vector 23 except the whole body is treated as the critical organ.

25 *Internal Dose - Critical Organ - Fish Consumption.* This represents integral critical organ dose from consumption of Savannah River fish. Bioaccumulation of radionuclides in fish flesh is taken into account. There is very little commercial fishing on the Savannah River. Thus, this vector is used only to calculate doses to individuals and is not applicable to any discrete population group. This vector is included in the hypothetical dose calculation to individuals but not in the man-rem calculations.

26 *Internal Dose - Whole Body - Fish Consumption.* This is the same as vector 25 except the whole body is treated as the critical organ.

27 *Internal Dose - Critical Organ - Consumption of Irrigated Food.* There is no known use of Savannah River water for irrigation purposes. This vector is included only for consideration of potential future utilization of river water.

28 *Internal Dose - Whole Body - Consumption of Irrigated Food.* This is the same as vector 27 except the whole body is treated as the critical organ.

29 *Internal Dose - Critical Organ - Consumption of Livestock Watered with River Water.* This represents critical organ dose from consumption of meat products from animals watered with river water. This vector is relatively unimportant because there are no known locations where river water is pumped for watering purposes, and the river is virtually inaccessible to livestock at most downstream locations because of heavy, swamplike growth and steep river banks. Farmers in this region generally depend on wells and farm ponds as a source of water for livestock.

30 *Internal Dose - Whole Body - Consumption of Livestock Watered with River Water.* This is the same as vector 29 except the whole body is treated as the critical organ.

31 *Internal Dose - Critical Organ - Consumption of Vegetative Crops Grown in Dredge Sediments.* The Savannah River is dredged periodically to maintain a navigable channel between Savannah, Georgia, and Augusta, Georgia. Most of the dredging occurs in the Savannah Harbor where heavy silting occurs when fresh river water mixes with tidal salt water intrusion. Spoil areas for the sediments have been placed in two locations, and some farming is currently done on the spoil area containing sediments up through 1957. These sediments contain ^{137}Cs concentrations ranging from 0.1 to 2.0 pCi/g. Food crops grown in the sediments (corn, cucumbers, and soy beans) all contain less than 0.6 pCi/g of ^{137}Cs[11] (sensitivity of analysis) and thus, are not a significant contribution to population dose.

32 *Internal Dose - Whole Body - Consumption of Vegetative Crops Grown in Dredge Sediments.* This is the same as vector 31 except the whole body is treated as the critical organ.

33 *External Gamma Dose - Whole Body and External Beta Dose - Skin.*
34 These vectors are to account for direct radiation received
35 from submersion in river water (swimming), living or working
36 at water surface, and living or working near exposed river
37 bank and dredge sediments. All of these vectors apply to
individuals rather than population groups.

During 1975, the only liquid release vectors affecting large population groups were 23 and 24, treated water consumption. The man-rem dose estimates for these vectors for customers of the Beaufort-Jasper, S.C., Water Authority and for the Cherokee Hill Water Treatment Plant, Port Wentworth, Georgia, were calculated

based on calculated concentrations of radionuclides in treated water in 1975.

DOSE CALCULATIONAL TECHNIQUES

Techniques for calculating dose were patterned after methods used by the ICRP.[3,4] Standard man data were used except where infants were critical members of the population. Equations were derived to provide a factor for converting integral concentrations of radionuclides in various media to lifetime dose commitment via the various vectors. Dose factors for atmospheric vectors are shown in Table G-5 and in Table G-6 for liquid release vectors. The method for calculating these factors is illustrated in this section by showing the derivation of some of the equations for atmospheric vectors.

Internal Dose: The dose rate to an organ or to the body is a function of the amount of radioactive material present. The amount q of radioactive material in the body at any time t can be expressed as

$$q_t = q_o e^{-\lambda t} \tag{G-1}$$

where

q_t = amount of radioactive material in the body at time t

q_o = initial amount of radioactive material (initial uptake)

λ = effective decay constant for the radionuclide, $days^{-1}$

The integral amount of radioactive material in an organ or the body can be obtained by integrating equation G-1

$$Q = q_o \int_o^T e^{-\lambda t}\, dt = q_o \left(\frac{1 - e^{-\lambda T}}{\lambda} \right) \tag{G-2}$$

For the inhalation route of uptake, the 70-year dose commitment can be calculated, using Equation G-2.

$$Dose_{70} = \frac{(365)(2x10^7)(C)(f)(3.7x10^4)(\varepsilon)(1.6x10^{-6})(8.64x10^4)}{(100)(m)(\lambda)} x$$

$$(1 - e^{-2.555x10^4 \lambda}) = \frac{3.7x10^{11} fC\varepsilon}{m\lambda} (1 - e^{-2.555x10^4 \lambda}) \tag{G-3}$$

where

365 = days/yr

2×10^7 = inhalation rate, cc/day

C = concentration of radionuclide in air, µCi/cc (or Ci/m^3)

f = fraction of radionuclide inhaled that reaches organ of interest

3.7×10^4 = dis/(sec-µCi)

ε = effective energy in organ of interest, MeV

1.6×10^{-6} = ergs/MeV

8.64×10^4 = sec/day

2.555×10^4 = days in 70 years

100 = ergs/(g-rad)

m = mass of organ of interest, g

λ = effective decay constant, $days^{-1}$

To obtain a dose commitment conversion factor, Equation G-3 is rearranged:

$$D_c = \frac{Dose_{70}}{C} = \frac{3.7\times10^{11} f\varepsilon}{m\lambda}\left(1 - e^{-2.555\times10^4\lambda}\right) \qquad \text{(G-4)}$$

Equation G-4 applies to any organ except the G.I. tract. The dose conversion factor, for any mode of uptake, can be generalized by:

$$D_c = \frac{Kf\varepsilon}{m\lambda}\left(1 - e^{-2.555\times10^4\lambda}\right) \qquad \text{(G-5)}$$

where

K = a constant related to rate of intake.

Some values of K used in derivation of dose conversion factors are listed in Table G-7.

Dose calculations for the G.I. tract are treated separately from other body organs because the various portions of this system are subject to a relatively constant elimination rate and are exposed to radiation only during passage of the contents. From ICRP,[3] dose conversion factors for an integral intake were derived.

$$D_c = \frac{Dose}{C} = \frac{fI(3.7x10^4)(8.64x10^4)(365)(1.6x10^{-6})(\varepsilon)(d\tau)e^{-\lambda_o t}}{(2)(100)(m)(d\tau/\tau)}$$

$$= \frac{9.3x10^3 fI\varepsilon\tau\ e^{-\lambda_o t}}{m} \qquad (G-6)$$

where

f = fraction of material reaching G.I. tract

I = intake rate, ml or g/day for liquids and foods and cc/day for inhalation

ε = effective energy in critical section of G.I. tract, Mev

m = mass of contents of portion of G.I. tract considered, g

τ = residence time in portion of G.I. tract involved, days

λ_o = radioactive decay constant, $days^{-1}$

t = time for ingested material to reach portion of G.I. tract considered; $e^{-\lambda_o t} \cong 1$ for half-lives greater than 4 days

Equation G-6 can be simplified to account for different modes of intake, i.e.,

$$D_c = \frac{Kf\ \varepsilon\tau\ e^{-\lambda_o t}}{m} \qquad (G-7)$$

where

K = a constant depending on mode of intake

Values for K for the G.I. tract are given in Table G-8.

Values for constants for various portions of the G.I. tract are listed in Table G-9.

External gamma dose from submersion is calculated in the meteorological program which takes into account dose from submersion and/or dose received by passage overhead of a plume of radioactive gases (before ground intercept). Skin dose is equal to whole body dose when the radioactive material approaches the receptor to nearer than 10 m because irradiation is then from gamma only. For submersion, skin dose increases significantly because of the contribution of beta radiation. In the case of

submersion, the receptor is assumed to be at the center of a hemispheric cloud having a radius equal to the range of beta particles. This method is the generally accepted practice.[4,5] The dose factor for beta irradiation by submersion in air can be derived as follows.

To obtain total skin dose, the gamma dose (calculated in other parts of the program) is added to the beta dose obtained from Equation G-8.

Radioactive materials deposited from the atmosphere on dairy pastures enter the grass-cow-milk vector. For two of the more important radionuclides released at SRP, tritium and iodine-131, reasonably consistent relationships have been observed between the concentration of these nuclides in air and their concentration in milk. The relationship can be expressed as follows:

$$C_m = (CF)C_A \qquad \text{(G-9)}$$

where

C_m = concentration in milk, Ci/ℓ

CF = concentration factor

C_A = concentration in air, μCi-sec/cc (or Ci-sec/m^3)

The value of CF for tritium is 30 and for iodine-131 is 400 for chronic releases encompassing a wide range of meteorological conditions.

$$D_c = \frac{\text{Dose}}{C} = \frac{\varepsilon(1.6\times10^{-6})(3.7\times10^{4})(8.64\times10^{4})(365)(1.13)}{(1.293\times10^{-3})(100)(2)} \qquad \text{(G-8)}$$

$$= 8.16 \times 10^{6}\varepsilon$$

where

1.13 = P_a/P_t = stopping power of air relative to tissue

1.293×10^{-3} = density of air (STP), g/cc

2 = correction for cloud being hemispheric

The atmospheric dispersion program assumes a deposition velocity of 1 cm/sec for both of these nuclides. From this, the following relationship is obtained:

$$C_A = 100\ C_d \tag{G-10}$$

where

C_d = areal deposition, Ci/m²

Substituting in Equation G-9

$$C_m = 100(CF)C_d \tag{G-11}$$

Equation G-11 can be used in calculating the dose from ^{131}I and ^{3}H by the grass-cow-milk vector as follows:

$$\text{Dose} = \frac{(365)(1)[100(CF)C_d](3.7x10^{10})(\varepsilon)(8.64x10^{4})(1.6x10^{-6})(f)}{(100)(m)(\lambda)}$$

$$= \frac{1.9x10^{12}(CF)C_d\varepsilon f}{m\lambda} \tag{G-12}$$

where

1 = milk intake, 1 ℓ/day

$100(CF)C_d$ = concentration of nuclide in milk, Ci/ℓ (from Equation G-11)

$3.7x10^{10}$ = dis/(sec-Ci)

Equation G-12 can be rearranged to obtain a dose conversion factor as follows:

$$D_c = \frac{\text{Dose}}{C_d} = \frac{1.9x10^{12}(CF)\varepsilon f}{m\lambda} \tag{G-13}$$

For the special cases of tritium and iodine-131, Equation G-13 becomes:

$$D_c(^{3}H) = \frac{5.7x10^{13}\varepsilon f}{m\lambda} \tag{G-14}$$

and

$$D_c(^{131}I) = \frac{7.6x10^{14}\varepsilon f}{m\lambda} \tag{G-15}$$

The grass-cow-milk vector for radionuclides released in particulate form was adopted from a method developed at LLL,[5] i.e.,

$$\text{Dose} = \frac{(365)(I)(C_d)(f_m)(f_w)(\varepsilon)(UAF)(3.7\times10^{10})(1.6\times10^{-6})(8.64\times10^{4})}{(100)(L_p)(m)(\lambda_v)(\lambda_e)}$$

$$= \frac{1.9\times10^{10}(1)(C_d)(f_m)(f_w)(\varepsilon)(UAF)}{(L_p)(m)\lambda_v\lambda_e} \qquad (G\text{-}16)$$

where

1 = milk intake, ℓ/day

C_d = integral areal deposition on forage, Ci/m^2

f_m = fraction of radionuclide ingested by cow appearing in milk

f_w = fraction of radionuclide ingested by man appearing in organ

UAF = utilized area factor, m^2/day (area utilized by foraging cow)

L_p = volume of milk produced per day by cow, ℓ/day

m = mass of organ, g

λ_v = effective decay constant on forage, $days^{-1}$

λ_e = effective decay constant in critical organ, $days^{-1}$

By rearranging Equation G-16, the dose conversion factor is obtained:

$$D_c = \frac{\text{Dose}}{C_d} = \frac{1.9\times10^{10} f_m f_w \varepsilon UAF}{L_p m \lambda_v \lambda_e} \qquad (G\text{-}17)$$

For dairies in the Central Savannah River Area, the UAF averages about 30 m^2/day and the L_p averages 16 l/day. Cows are on forage throughout the year, but their diet is supplemented with imported corn and oats (about 50% supplement by weight in spring and summer months and 85% during fall and winter). It is assumed that the UAF remains constant throughout the year.

Using these values, Equation G-17 becomes:

$$D_c = \frac{3.6\times10^{10} f_m f_w \epsilon}{m\lambda_v\lambda_e} \qquad \text{(G-18)}$$

VARIATIONS FROM THE DOSE MODEL

Dose calculations for the long-lived radionuclides carbon-14 and iodine-129 require the use of different techniques than those normally used for other radionuclides released to the environment from SRP operations. The modifications are necessary for calculating plant boundary dose to individuals and dose to the population within 100 km because transport data and dose conversion factors for these radionuclides are not available at this time to permit use of the "vector model." A conservative approach, called variously the "specific activity model" or the "equilibrium ratio model" is used. This approach assumes that carbon-14 and iodine-129 mix with their naturally occurring isotopes in the atmosphere, and that the presence of the SRP-made nuclides in man's body instantly comes into equilibrium with the ratio of SRP-made nuclide to natural nuclide abundance in the atmosphere. The bases and assumptions used for calculating dose from carbon-14 and iodine-129 are described in the following sections.

Carbon 14

Carbon-14 (half-life = 5730 years) is produced in SRP reactors by various reactions in the fuel, coolant, and core construction materials. The reactions accounting for most of ^{14}C production are:

$$^{17}O\ (n,\alpha)\ ^{14}C$$

$$^{14}N\ (n,p)\ ^{14}C$$

$$^{13}C\ (n,\gamma)\ ^{14}C$$

The (n,α) reaction with naturally occurring ^{17}O (0.039%) present in the heavy water coolant accounts for most of the ^{14}C produced at SRP. The nitrogen occurs as an impurity in the fuel, as dissolved

gas, as nitric acid, and as impurity in the core material. Natural carbon-13 is a minor constituent present in structural materials of the reactor and its core.

A small fraction of the carbon-14 produced at SRP is released to the atmosphere as $^{14}CO_2$ and ^{14}CO from the production reactors and from the fuel and target chemical processing areas. These gases mix with natural carbon-12, 13, 14 present in the atmosphere, and then enter the world's carbon cycle. In the carbon cycle, the radiocarbon (man-produced and natural) and the natural nonradioactive carbon are incorporated into living material. After sufficient time has elapsed, the ratio of radiocarbon to total carbon in living matter will approach equilibrium with the ratio existing in the atmosphere, provided the ratio in the atmosphere is a constant over long periods of time.

For purposes of calculating dose to individuals and the population within a 100 km radius of SRP, it is assumed conservatively that any SRP released carbon-14 instantaneously reaches equilibrium in man at the same ratio as exists in the local atmosphere. The radiocarbon is incorporated in the tissues of man through ingestion of food and inhalation of CO and CO_2 in the air. For carbon taken into the body in this manner, the ICRP[3] suggests an effective half-life in the body of 10 days, or a mean life of 14.4 days. This half-life would appear to be too short for the "equilibrium ratio model" because it may be assumed that a small fraction of the radiocarbon replaces nonradioactive carbon in organic matter in human tissues. Therefore, it is assumed arbitrarily that the lifetime dose commitment from radiocarbon in the body is two times the dose received during the year of release of carbon-14 from SRP.

Monitoring measurements show SRP releases average about 86 Ci/yr of carbon-14 to the atmosphere in the form of ^{14}CO and $^{14}CO_2$ (primarily as $^{14}CO_2$). The calculated annual average concentration of carbon-14 in air at the plant boundary is 2.3×10^{-14} μCi/cc. The average concentration of natural carbon in air (as CO and CO_2) is 1.56×10^{-7} g/cc. Thus, the SRP-released carbon will be present in air at the plant boundary in the ratio of (2.3×10^{-14} μCi/cc):(1.56×10^{-7} g/cc) or 1.47×10^{-7} μCi ^{14}C/g of total carbon. This is the average at the plant boundary during the year of release. If it is assumed that the 1.26×10^{4} g of carbon in the total body of "standard man" instantaneously reaches equilibrium with the ratio in air, it can be calculated that the total body of man contains an equilibrium content of 1.85×10^{-3} μCi of ^{14}C. This would result in a whole body dose of 0.025 mrem during the first year, and a lifetime dose commitment of 0.052 mrem (assuming lifetime dose commitment is twice the first year dose).

The average dose commitment to individuals in the population within 100 km of the center of SRP was calculated to be about 29%

of the dose commitment to the individuals at the plant boundary by methods described in Appendix F. Thus, the population dose within 100 km can be calculated:

$$\frac{(0.052 \text{ mrem})(0.29)(668{,}000 \text{ persons})}{1000 \text{ mrem/rem}} = 10.1 \text{ man-rem}$$

Carbon-14 is also produced in nature, primarily by the (n,p) reaction on nitrogen in the upper atmosphere. An estimated inventory of 2.4×10^8 Ci of ^{14}C exists in the environment from natural production. This material is in equilibrium, ~90% in the deep oceans below 100 meters, ~2% in the atmosphere, and ~8% in the surface waters, sediments, and biosphere.[7] An additional 6.4×10^6 Ci of ^{14}C has been produced by atmospheric tests of nuclear weapons through 1971.[7,8] The presence of naturally-produced carbon-14 in man's body results in an annual dose of 1.02 mrem.[9] Thus, the population within a 100 km radius of SRP receives an annual dose from natural carbon-14 of:

$$\frac{(1.02 \text{ mrem})(668{,}000 \text{ persons})}{1000 \text{ mrem/rem}} = 681 \text{ man-rem}$$

The estimated population dose commitment of 10.1 man-rem from a year of operation of SRP is about 2% of the annual dose from naturally occurring carbon-14.

Based on recent measurements correlated to SRP reactor operating history, it was calculated that a total of approximately 2139 Ci of carbon-14 was released to the environment since startup of SRP, resulting in an estimated maximum whole body dose commitment of 1.5 mrem to an individual at the plant boundary and a population dose commitment of 291 man-rem. This population dose is about 2% of the 22-year dose from naturally occurring carbon-14.

Iodine-129

Iodine-129 (half-life = 1.59×10^7 years), produced as a fission product in reactor fuels and targets, is released to the atmosphere from fuel and target element chemical processing areas and mixes with the natural iodine-127 present in the atmosphere. The major vector for exposure of man is the grass-cow-milk chain. Minor vectors are vegetative food crops, meat from herbivorous animals, and inhalation. Vegetative food crops contain iodine both from foliar deposition and from root uptake from the soil, the former being more important during initial release but the latter probably important over extended periods of time because of the very long half-life of iodine-129. Little is known about the ultimate fate of iodine-129 in soil, but it is expected to migrate to the ocean and be diluted with the large inventory of natural iodine-127.

Iodine-129 releases to the atmosphere from SRP have not been routinely monitored because the low specific activity of this nuclide (1.73×10^{-4} Ci/g) and the low energy of radiations emitted during decay (beta-0.14 MeV, max, gamma-0.038 MeV) make accurate measurements difficult. However, short-lived iodine-131 is measured routinely and efficiency of removal of this nuclide from ventilation exhaust (discharged from 200-ft exhaust stacks) has been determined for the various methods used at SRP for chemical processing of reactor fuels and targets. During the period from 1954 through 1975, an estimated total of 4.3 curies of iodine-129 was released from exhaust stacks to the environment, based on iodine-131 removal efficiency for each chemical process and calculated amounts of iodine-129 that entered each process. If this material were released uniformly over 22 years of operation, the average annual release would be 0.2 Ci. At this rate of release, the concentration of iodine-129 in air at the SRP site boundary would average about 5.9×10^{-17} μCi/cc or 3.4×10^{-13} g/m^3 (not corrected for depletion by surface deposition). This would mix with stable iodine-127 in air, which is typically present in concentrations of 10^{-8} to 10^{-9} g/m^3 in this area. Thus, taking the mid-point of this range, the ratio of $^{129}I/^{127}I$ in air at the plant boundary would be about 6.8×10^{-5}. Ratios of up to 1.2×10^{-5} were measured in grass and 4×10^{-6} in soils at the plant boundary in 1971.[10]

Because cattle consume large quantities of pasture foods, bovine thyroids should be good indicators of the upper limit of the $^{129}I/^{127}I$ ratio in foods. Ratios of 0.8×10^{-6} (South Carolina average) up to 3.5×10^{-6} have been measured in bovine thyroids obtained from locations near SRP[11] (samples taken during 1966-1968). Because grass and bovine thyroid samples were not taken at the same time or place, the conservative assumption is made that bovine thyroids will approach the maximum ratio of $^{129}I/^{127}I$ found in grass near the plant perimeter, i.e., about 1×10^{-5}. If it were further assumed that the ratio in man's thyroid approaches that in cattle, the dose would be 0.3 mrem to an adult thyroid and 0.20 mrem to an infant thyroid per year (dose calculations based on: adult thyroid mass = 20 g, total iodine content = 0.007 g, infant thyroid mass = 2 g, total iodine content = 0.00018 g).[8] In the equilibrium ratio model, the dose to an adult's thyroid is higher than the dose to an infant's thyroid because of the greater total iodine (and iodine-129) concentration per unit mass of thyroid tissue. A large degree of conservatism is inherent in the calculations. The dose calculated by this approach is highly unlikely because man receives much of his iodine from sources other than local food crops, i.e., iodized table salt, imported foods, etc., and the $^{129}I/^{127}I$ ratio in man's thyroid would be lower than in bovine thyroids. However, for conservatism it was assumed that the thyroid dose at the plant perimeter is 0.3 mrem per year (for a 0.2 Ci release). The annual dose

to the individual thyroid at the plant perimeter from the 1975 release of 0.14 Ci is 0.56 mrem.

At this time, not enough is known about the long-term behavior of iodine-129 in the environment to make estimates of lifetime dose commitment. However, because of limited residence time in the thyroid (half-life 138 days), dilution with natural stable ^{127}I, and downward migration out of root zones with rainwater infiltration, residual effects to the surrounding population from the small releases of ^{129}I are believed to be much smaller than the estimated doses during the year of release. The theoretical cumulative annual thyroid doses from release of ^{129}I to the atmosphere from SRP from 1954 through 1975 are calculated to be:

Individual at plant boundary	17 mrem
Average individual in 100 km radius	3.4 mrem
100 km population	2242 man (thyroid)-rem

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TABLE G-1

MAN-REM CALCULATIONS FOR 1975 ATMOSPHERIC RELEASES BY RADIAL INCREMENT

DST KM	WHOLE BODY GAMMA	TOTAL SKIN DOSE	TOTAL BODY DOSE	CRITICAL ORGAN: BONE	LUNG	THYROID	KIDNEY	LIVER	G I TRACT
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	8.0547E-01	6.1563E 00	4.0791E 00	4.0791E 00	4.0812E 00	7.5371E 00	4.0791E 00	4.0791E 00	4.0791E 00
25	1.4092E 00	1.1469E 01	7.5811E 00	7.5811E 00	7.5847E 00	1.3929E 01	7.5811E 00	7.5811E 00	7.5811E 00
30	2.3419E 00	2.1087E 01	1.3889E 01	1.3889E 01	1.3895E 01	2.5291E 01	1.3889E 01	1.3889E 01	1.3889E 01
35	3.2187E 00	3.1520E 01	2.0711E 01	2.0711E 01	2.0719E 01	3.7309E 01	2.0711E 01	2.0711E 01	2.0711E 01
40	4.4632E 00	4.8280E 01	3.1646E 01	3.1646E 01	3.1658E 01	5.6149E 01	3.1646E 01	3.1646E 01	3.1646E 01
45	6.2782E 00	7.6685E 01	5.0123E 01	5.0124E 01	5.0141E 01	8.7404E 01	5.0123E 01	5.0123E 01	5.0123E 01
50	7.4879E 00	9.8160E 01	6.4070E 01	6.4070E 01	6.4092E 01	1.1056E 02	6.4070E 01	6.4070E 01	6.4070E 01
55	7.9973E 00	1.0829E 02	7.0638E 01	7.0638E 01	7.0662E 01	1.2130E 02	7.0638E 01	7.0638E 01	7.0638E 01
60	8.3606E 00	1.1637E 02	7.5871E 01	7.5871E 01	7.5896E 01	1.2975E 02	7.5871E 01	7.5871E 01	7.5871E 01
65	8.5892E 00	1.2183E 02	7.9409E 01	7.9409E 01	7.9434E 01	1.3538E 02	7.9409E 01	7.9409E 01	7.9409E 01
70	8.8587E 00	1.2901E 02	8.4052E 01	8.4053E 01	8.4079E 01	1.4262E 02	8.4052E 01	8.4052E 01	8.4052E 01
75	9.0583E 00	1.3497E 02	8.7907E 01	8.7907E 01	8.7934E 01	1.4852E 02	8.7907E 01	8.7907E 01	8.7907E 01
80	9.3167E 00	1.4336E 02	9.3322E 01	9.3323E 01	9.3351E 01	1.5672E 02	9.3322E 01	9.3322E 01	9.3322E 01
85	9.4859E 00	1.4944E 02	9.7250E 01	9.7251E 01	9.7279E 01	1.6257E 02	9.7250E 01	9.7250E 01	9.7250E 01
90	9.6969E 00	1.5807E 02	1.0281E 02	1.0281E 02	1.0284E 02	1.7067E 02	1.0281E 02	1.0281E 02	1.0281E 02
95	9.8633E 00	1.6558E 02	1.0766E 02	1.0766E 02	1.0769E 02	1.7762E 02	1.0766E 02	1.0766E 02	1.0766E 02
100	1.0112E 01*	1.7737E 02	1.1526E 02	1.1527E 02	1.1530E 02	1.8850E 02	1.1526E 02	1.1526E 02	1.1526E 02

* 1.0112E 01 means 1.0112×10^1 or 10.112.

TABLE G-2

MAN-REM CALCULATIONS FOR 1975 ATMOSPHERIC RELEASES BY ISOTOPE

	POP DOSE	INDIVIDUAL WHOLE BODY DOSE, MILLIREM				AVERAGE ORGAN DOSE, PLANT PERIMETER, MILLIREM					
		PLANT PERIMETER		80 KM	100 KM						
	MAN-REM	AVE	MAX	AVE	AVE	BONE	LUNG	THYROID	KIDNEY	LIVER	G I TRACT
H3	9.603E 01	4.945E-01	6.696E-01	1.049E-01	8.327E-02	4.945E-01	4.945E-01	4.945E-01	4.945E-01	4.945E-01	4.945E-01
C14	8.968E 00	4.629E-02	6.267E-02	9.816E-03	7.793E-03	4.629E-02	4.629E-02	4.629E-02	4.629E-02	4.629E-02	4.629E-02
AR41	9.233E 00	1.197E-01	1.837E-01	4.799E-03	2.482E-03	1.197E-01	1.197E-01	1.197E-01	1.197E-01	1.197E-01	1.197E-01
KR85M	1.568E-02	1.447E-04	2.137E-04	1.143E-05	7.159E-06	1.447E-04	1.447E-04	1.447E-04	1.447E-04	1.447E-04	1.447E-04
KR85	4.158E-01	1.840E-03	2.559E-03	4.921E-04	3.974E-04	1.840E-03	1.840E-03	1.840E-03	1.840E-03	1.840E-03	1.840E-03
KR87	1.184E-04	1.583E-06	2.445E-06	6.329E-08	2.855E-08	1.583E-06	1.583E-06	1.583E-06	1.583E-06	1.583E-06	1.583E-06
KR88RB	3.400E-01	3.629E-03	5.455E-03	2.163E-04	1.245E-04	3.629E-03	3.629E-03	3.629E-03	3.629E-03	3.629E-03	3.629E-03
XE131M	4.885E-04	2.898E-06	4.110E-06	4.917E-07	3.788E-07	2.898E-06	2.898E-06	2.898E-06	2.898E-06	2.898E-06	2.898E-06
XE133	4.419E-02	2.692E-04	3.822E-04	4.372E-05	3.334E-05	2.692E-04	2.692E-04	2.692E-04	2.692E-04	2.692E-04	2.692E-04
XE135	6.361E-02	4.926E-04	7.132E-04	5.344E-05	3.654E-05	4.926E-04	4.926E-04	4.926E-04	4.926E-04	4.926E-04	4.926E-04
I-129	1.157E-01	8.956E-04	1.276E-03	9.621E-05	6.393E-05	8.956E-04	8.956E-04	5.607E-01	8.956E-04	8.956E-04	8.956E-04
I-131	2.657E-03	2.063E-05	2.940E-05	2.205E-06	1.465E-06	2.063E-05	2.063E-05	6.976E-03	2.063E-05	2.063E-05	2.063E-05
CO60	2.773E-07	2.708E-09	3.614E-09	1.839E-10	1.204E-10	2.708E-09	2.708E-09	2.708E-09	2.708E-09	2.708E-09	4.576E-09
SR8990	1.333E-06	1.302E-08	1.737E-08	8.840E-10	5.787E-10	5.107E-06	1.302E-08	1.302E-08	1.302E-08	1.302E-08	1.302E-08
NB95	4.590E-06	4.482E-08	5.982E-08	3.044E-09	1.993E-09	4.482E-08	6.561E-07	4.482E-08	4.482E-08	4.482E-08	4.482E-08
ZR95	9.736E-06	9.508E-08	1.269E-07	6.457E-09	4.227E-09	9.508E-08	1.204E-06	9.508E-08	9.508E-08	9.508E-08	9.508E-08
RU103	5.849E-08	5.712E-10	7.623E-10	3.879E-11	2.539E-11	5.712E-10	5.456E-08	5.712E-10	5.712E-10	5.712E-10	5.712E-10
RU106	4.503E-06	4.398E-08	5.869E-08	2.987E-09	1.955E-09	4.398E-08	1.701E-05	4.398E-08	4.398E-08	4.398E-08	4.398E-08
CS134	8.693E-07	8.489E-09	1.133E-08	5.765E-10	3.774E-10	8.489E-09	5.150E-08	8.489E-09	8.489E-09	8.489E-09	8.489E-09
CS137	2.878E-06	2.811E-08	3.751E-08	1.909E-09	1.249E-09	2.811E-08	2.211E-07	2.811E-08	2.811E-08	2.811E-08	2.811E-08
CE141	1.947E-08	1.902E-10	2.538E-10	1.291E-11	8.453E-12	1.902E-10	4.786E-09	1.902E-10	1.902E-10	1.902E-10	1.902E-10
CE144	4.358E-05	4.256E-07	5.680E-07	2.890E-08	1.892E-08	4.256E-07	6.764E-06	4.256E-07	4.256E-07	4.256E-07	4.256E-07
U235/8	2.234E-04	2.181E-06	2.911E-06	1.481E-07	9.696E-08	2.181E-06	8.496E-05	2.181E-06	2.181E-06	2.181E-06	2.181E-06
PU238	1.507E-02	1.471E-04	1.964E-04	9.993E-06	6.541E-06	1.471E-04	3.056E-04	1.471E-04	1.471E-04	1.471E-04	1.471E-04
PU239	4.822E-03	4.709E-05	6.284E-05	3.198E-06	2.093E-06	4.709E-05	8.535E-05	4.709E-05	4.709E-05	4.709E-05	4.709E-05
TOTALS	1.153E 02	6.680E-01	9.269E 01	1.204E-01	9.422E-02	6.680E-01	6.683E-01	1.235E 00	6.680E-01	6.680E-01	6.680E-01

TABLE G-3

BEAUFORT-JASPER WATER AUTHORITY
WATER TREATMENT PLANT

Water Treatment Capacity: 50,000,000 gal/day

Communities or Population Groups Served

- Parris Island Marine Corps Recruit Depot
- U. S. Naval Hospital, Beaufort, S. C.
- Marine Corps Air Station, Beaufort, S. C.
- Laurel Bay - Federal Housing Project
- Beaufort, S. C.
- Port Royal, S. C.
- Chelsea and Chechessee Water Co.

Number of Consumers based on 1970 Census: 50,000

Source of Information:

Beaufort-Jasper Water Authority
Box 275
Beaufort, S. C. 29902

TABLE G-4

CHEROKEE HILL WATER TREATMENT PLANT
PORT WENTWORTH, GA.

Water Treatment Capacity: 45,000,000 gal/day

Customers (Primarily Industrial)	Amount Used, gal/mo
Continental Can Corp. (paper plant)	2.7×10^{8}
Union Camp (paper plant)	4×10^{8}
American Cyanimide	1.9×10^{8}
Kaiser Agricultural Chemical Co.	4×10^{7}
Savannah Electric Co.	3.2×10^{6}
American Oil Co.	3×10^{6}
Georgia Port Authority[a]	2.2×10^{6}
Coca Cola Bottling Co.[b]	1.3×10^{6}
Royal Crown Cola Bottling Co.[b]	3.2×10^{5}
Atlantic Creosoting Co.	1.25×10^{6}
Savannah Sugar Refinery	2.4×10^{7}
Continental Roofing Co.	6.8×10^{5}
Johns Mansville Co.	6.7×10^{5}
Chevron Oil Co.	2×10^{5}
Koppers Co.	4.7×10^{5}
Hubson Battery Mfg. Co.	1×10^{5}
St. Regis Paper Co.	8.6×10^{3}
Allied Chem. Co. - Indust. Chem. Div.	5.1×10^{3}
Estimated Number of Customers	
Industrial Workers	1×10^{3}
Seamen (effective man-year users)	2×10^{3} [a]
Beverages (effective man-year users)	1.7×10^{4} [b]
Total	2×10^{4}

Source of Information:

Cherokee Water Treatment Plant
Port Wentworth, Georgia

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a. Provides fresh water to incoming ships to Savannah Harbor. Assumes 1% of water delivered is consumed by crewmen.

b. Assumes 10% of water delivered is used for preparing bottled beverages.

TABLE G-5

DOSE CONVERSION FACTORS (D_c) FOR ATMOSPHERIC RELEASE VECTORS[a]

	Vectors								
	01[b]	02	03	04	05	05[c]	06	06[c]	07
	External	External	External	External	Internal				
Nuclide	Cloud Gamma Body	Submersion Beta Skin	Surface Deposition Gamma Body	Surface Deposition Beta Skin	Inhalation Organ	Inhalation Organ	Inhalation Body	Inhalation Body	Deposition Surface Water Organ
^{3}H		0	0	0	0	0	3×10^{8}	3.2×10^{8}	
^{14}C		0	0	0		0	2.3×10^{8}[e]	0	0
^{41}Ar		3.8×10^{8}	0	0	0	0	0	0	0
^{60}Co		-	5.0×10^{7}		3.0×10^{7} (LLI)	-	4.3×10^{7}	7.6×10^{7}	
^{83m}Kr		0	0	0	0	0	0	0	0
^{85m}Kr		1.8×10^{8}	0	0	0	0	0	0	0
^{85}Kr		1.9×10^{8}	0	0	0	0	0	0	0
^{87}Kr		1.1×10^{7}	0	0	0	0	0	0	0
$^{88}KrRb$		2.1×10^{7}	0	0	0	0	0	0	0
^{89}Sr					2.7×10^{8} (bone)	-	7.9×10^{8}	-	
^{90}Sr			6.0×10^{8}		1.8×10^{10} (bone)	-	4.6×10^{7}	d	
^{95}Zr					1.4×10^{8} (lung)	-	1.2×10^{8}	2.1×10^{8}	
^{95}Nb					4.5×10^{8} (lung)	-	3.3×10^{7}	5.7×10^{7}	
^{103}Ru			6.6×10^{9}		5.3×10^{8} (lung)	-	5.6×10^{8}	9.8×10^{8}	
^{106}Ru			1.6×10^{9}		8.1×10^{8} (lung)	-	2.1×10^{7}	3.6×10^{7}	
^{129}I					2.0×10^{10} (thyroid)[e]	2.9×10^{10} (thyroid)	3.2×10^{10}	3.4×10^{10}	
^{131}I		1.6×10^{8}	3.1×10^{9}		1.1×10^{10} (thyroid)	1.6×10^{10} (thyroid)	1.9×10^{7}	2.0×10^{7}	
^{133}I		0	0	0	2.9×10^{8} (thyroid)	0	4.2×10^{8}	0	0
^{131m}Xe		0	0	0	0	0	0	0	0
^{133m}Xe		0	0	0	0	0	0	0	0
^{133}Xe		9.1×10^{5}	0	0	0	0	0	0	0
^{135m}Xe		0	0	0	0	0	0	0	0
^{135}Xe		2.6×10^{8}	0	0	0	0	0	7.0×10^{8}	0
^{138}Xe		7.6×10^{8}							
^{134}Cs					1.3×10^{8} (lung)	-	7.5×10^{8}	7.0×10^{8}	
^{137}Cs			1.3×10^{8}		3.1×10^{8} (lung)	-	4.3×10^{8}	4.1×10^{8}	
^{141}Ce					2.9×10^{8} (lung)	-	1.2×10^{7}	2.1×10^{7}	
^{144}Ce			2.3×10^{9}		7.0×10^{8} (lung)	-	4.7×10^{8}	8.2×10^{8}	
^{147}Pm		0	0	0	1.4×10^{8} (bone)	0	5.0×10^{7}		
^{232}Th					4.3×10^{12} (lung)	-	1.8×10^{12}	d	
^{231}Pa					2.6×10^{8} (lung)	-	1.7×10^{7}	2.9×10^{7}	
^{233}U					3.8×10^{11} (lung)	-	9.5×10^{8}	d	
nat U			0		3.3×10^{11} (lung)	-	8.2×10^{8}	d	
^{234}U					3.5×10^{11} (lung)	-	8.8×10^{8}	d	
^{235}U					3.6×10^{11} (lung)	-	9.0×10^{8}	d	
^{238}U					3.2×10^{10} (kidney)	-	8.2×10^{8}	d	
^{238}Pu		6.5×10^{9}			1.4×10^{12} (lung)[f]	-	1.3×10^{12}	d	
^{239}Pu			0		1.3×10^{12} (lung)[g]	-	1.6×10^{12}	d	
^{240}Pu					6.5×10^{12} (bone)	-	1.6×10^{12}	d	
^{241}Pu					9.4×10^{11} (bone)		1.9×10^{10}		
^{242}Pu		0	0	0	[illegible] (bone)	0	[illegible]		
^{241}Am					2.0×10^{13} (bone)	-	1.2×10^{12}	d	
^{243}Am			0		4.0×10^{11} (liver)	-	2.5×10^{10}	d	
^{244}Cm					4.8×10^{11} (lung)	-	5.8×10^{11}	d	
^{252}Cf					1.6×10^{12} (bone)	-	3.8×10^{11}	d	

a. Dose conversion factors are in units of rem per Ci-yr/m³.

b. Vector 01 calculated as integral part of the atmospheric dispersion program.

c. Infant

d. Nuclides with long effective half-lives not applicable to infants because of rapid changes in organ and body size during early years of growth.

e. Dose conversion factor applies to all ingestion and inhalation pathways.

f. Insoluble form. Soluble form factor is 5.3×10^{12} (bone).

g. Insoluble form. Soluble factor is 6.5×10^{12} (bone).

TABLE G-5 (CONTINUED)

Nuclide	Vectors 08 Internal Deposition Surface Water Body	09 Internal Deposition Vegetable Crops Organ	10 Internal Deposition Vegetable Crops Body	11 Internal Deposition Meat Products Organ	12 Internal Deposition Meat Products Body	13 Internal Deposition Milk Organ	13' Internal Deposition Milk Organ	14 Internal Deposition Milk Body	14' Internal Deposition Milk Body
^{3}H						0	0	[illegible] × 10[illegible]	1.2 × 10[illegible]
^{14}C									
^{41}Ar	0	0	0	0	0	0	0	0	0
^{60}Co									
^{83m}Kr	0	0	0	0	0	0	0	0	0
^{85m}Kr	0	0	0	0	0	0	0	0	0
^{85}Kr	0	0	0	0	0	0	0	0	
^{87}Kr	0	0	0	0	0	0	0	0	
$^{88}KrRb$	0	0	0	0	0	0	0		0
^{89}Sr									
^{90}Sr									
^{95}Zr									
^{95}Nb									
^{103}Ru									
^{106}Ru									
^{129}I									
^{131}I									
^{133}I									
						2.8 × 10[illegible] (thyroid)	2.9 × 10[illegible] (thyroid)	8.4 × 10[illegible]	[illegible] × 10[illegible]
^{131m}Xe	0	0	0	0	0	0	0	0	0
^{133m}Xe	0	0	0	0	0	0	0	0	0
^{133}Xe	0	0	0	0	0	0	0	0	0
^{135m}Xe	0	0	0	0	0	0			
^{135}Xe	0	0	0	0	0	0			
^{138}Xe									
^{134}Cs									
^{137}Cs									
^{141}Ce									
^{144}Ce									
^{147}Pm									
^{232}Th									
^{231}Pa									
^{233}U									
^{nat}U									
^{235}U									
^{236}U									
^{238}U									
^{238}Pu									
^{239}Pu									
^{240}Pu									
^{241}Pu									
^{242}Pu									
^{241}Am									
^{242}Cm									
^{244}Cm									
^{252}Cf									

' Infant

TABLE G-6

DOSE CONVERSION FACTORS (D_c) FOR LIQUID VECTORS[a]

Nuclide	21 Internal River Water Consumption Organ	22 Internal River Water Consumption Body
^{3}H	0	8.9×10^{1}
^{24}Na	5.2×10^{4} (LLI)	7.4×10^{2}
^{32}P	8.5×10^{4} (bone)	3.2×10^{3}
^{33}P	3.8×10^{4} (LLI)	-
^{35}S	4.5×10^{3} (testes)	1.1×10^{3}
^{51}Cr	5.5×10^{2} (LLI)	1.5
^{54}Mn	7.3×10^{3} (LLI)	1.3×10^{2}
^{59}Fe	1.6×10^{4} (LLI)	1.6×10^{3}
^{58}Co	9.3×10^{3} (LLI)	7.0×10^{2}
^{60}Co	2.5×10^{4} (LLI)	2.0×10^{3}
^{65}Zn	7.0×10^{3} (prostate)	2.8×10^{3}
^{69}Zn	6.5×10^{3} (liver)	-
^{89}Sr	9.2×10^{3} (bone)	2.7×10^{2}
^{90}Sr	6.6×10^{5} (bone)	1.6×10^{3}
^{91}Y	3.3×10^{4} (LLI)	1.6
$^{95}ZrNb$	1.3×10^{4} (LLI)	2.9
^{95}Nb	8.9×10^{3} (LLI)	7.8×10^{-1}
^{99}Mo	4.5×10^{3} (kidney)	3.4×10^{2}
^{103}Ru	7.8×10^{3} (LLI)	3.7×10^{1}
^{106}Ru	7.3×10^{4} (LLI)	1.4×10^{2}
^{124}Sb	3.7×10^{4} (LLI)	5.2×10^{2}
^{125}Sb	7.3×10^{3} (LLI)	2.1×10^{2}
^{129}I	4.5×10^{6} (thyroid)	5.6×10^{3}
^{131}I	8.4×10^{5} (thyroid)	1.5×10^{3}
^{134}Cs	0	4.5×10^{4}
^{137}Cs	0	2.7×10^{4}
$^{140}BaLa$	6.1×10^{4} (LLI)	5.6×10^{2}
^{140}La	3.6×10^{4} (LLI)	2.9×10^{-1}
^{141}Ce	9.4×10^{3} (LLI)	2.9×10^{-1}
^{144}Ce	7.3×10^{4} (LLI)	1.1×10^{1}
^{147}Pm	3.9×10^{3} (LLI)	1.2
^{233}U	2.7×10^{4} (LLI)	2.3×10^{2}
^{nat}U	2.5×10^{4} (LLI)	2.0×10^{2}
^{235}U	2.9×10^{4} (LLI)	2.1×10^{2}
^{234}U	2.5×10^{4} (LLI)	2.2×10^{2}
^{238}U	2.4×10^{4} (LLI)	2.0×10^{2}
^{239}Np	6.7×10^{3} (LLI)	3.1×10^{-2}
^{238}Pu	3.8×10^{5} (bone)	9.5×10^{3}
^{239}Pu	4.7×10^{5} (bone)	1.1×10^{4}
^{240}Pu	4.6×10^{5} (bone)	1.1×10^{4}
^{241}Am	2.2×10^{3} (kidney)	2.9×10^{4}
^{242}Cm	3.4×10^{4} (LLI)	5.9×10^{2}
^{244}Cm	2.4×10^{3} (bone)	1.4×10^{4}
^{252}Cf	1.2×10^{5} (LLI)	2.3×10^{3}

a. Dose conversion factors are in units of rem per Ci-yr/m^3

TABLE G-7

K FACTORS

Vector	Intake Rate/Day	K
Inhalation - adult	2×10^{7} cc	3.7×10^{11}
Inhalation - infant	3×10^{6} cc	5.55×10^{10}
Water - adult	1200 ml	2.22×10^{7}
Milk - infant	1000 ml	1.85×10^{7}
Food - adult	1000 g	1.85×10^{7}
Fish - adult	32.4 g (1/2 lb/wk)	6.0×10^{5}

TABLE G-8

K FACTORS FOR G.I. TRACT

Intake Mode	Intake Rate/Day	K
Inhalation - adult	2×10^{7} cc	1.9×10^{11}
Inhalation - infant	3×10^{6} cc	2.9×10^{10}
Water	1200 ml	1.1×10^{7}
Food	1000 g	9.3×10^{6}
Fish	32.4 g	3.1×10^{5}

TABLE G-9

G.I. TRACT CONSTANTS

Portion of G.I. Tract	t, days	τ, days	m, g
Stomach (S)	0	4.17×10^{-2}	250
Small Intestine (SI)	4.17×10^{-2}	1.7×10^{-1}	1100
Upper Large Intestine (ULI)	2.08×10^{-1}	3.33×10^{-1}	135
Lower Large Intestine (LLI)	5.42×10^{-1}	7.5×10^{-1}	150

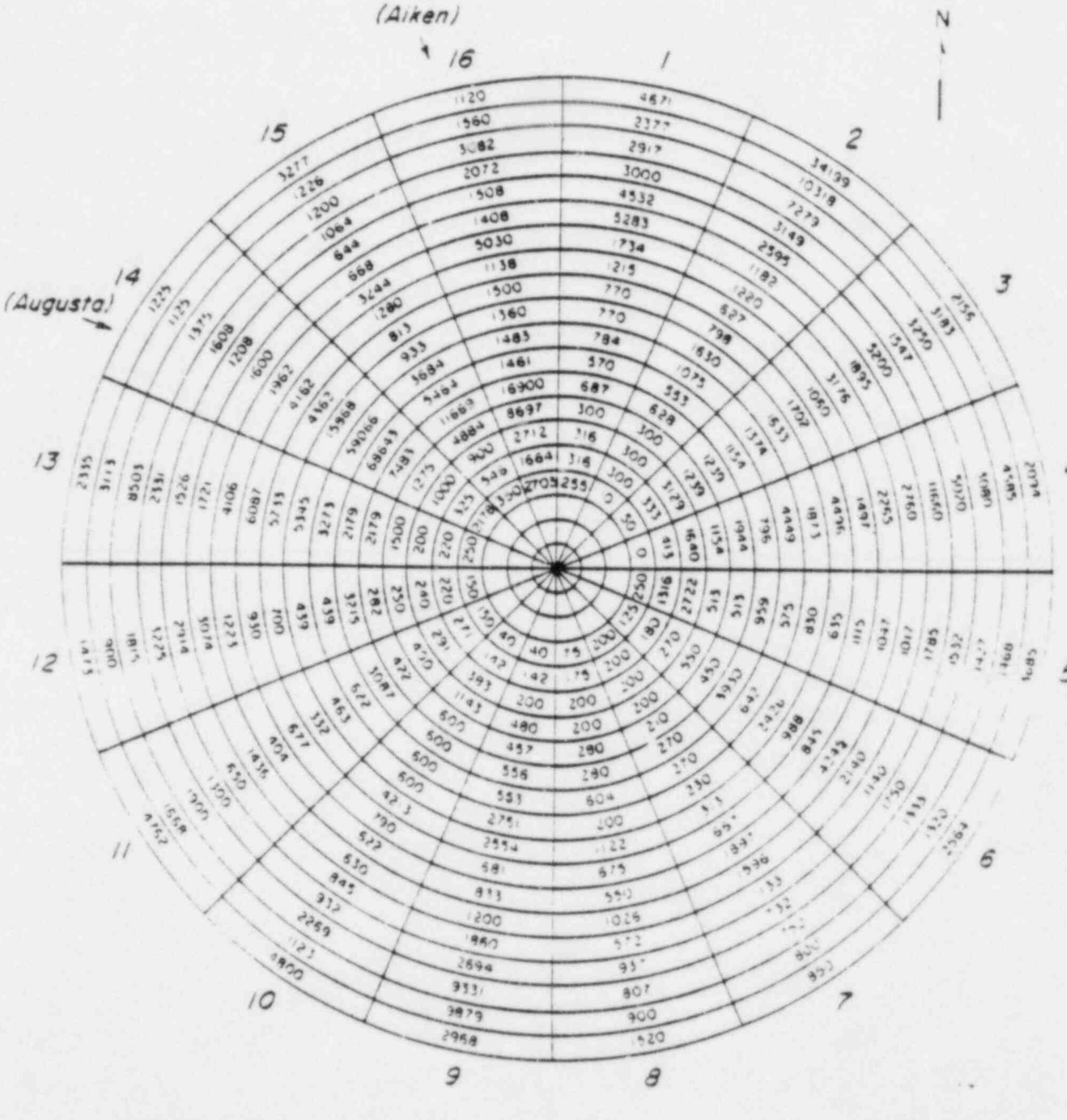

FIGURE G-1. Distribution of Population in Region Surrounding the Savannah River Plant
1970 Census
(Radial increments = 5 km)

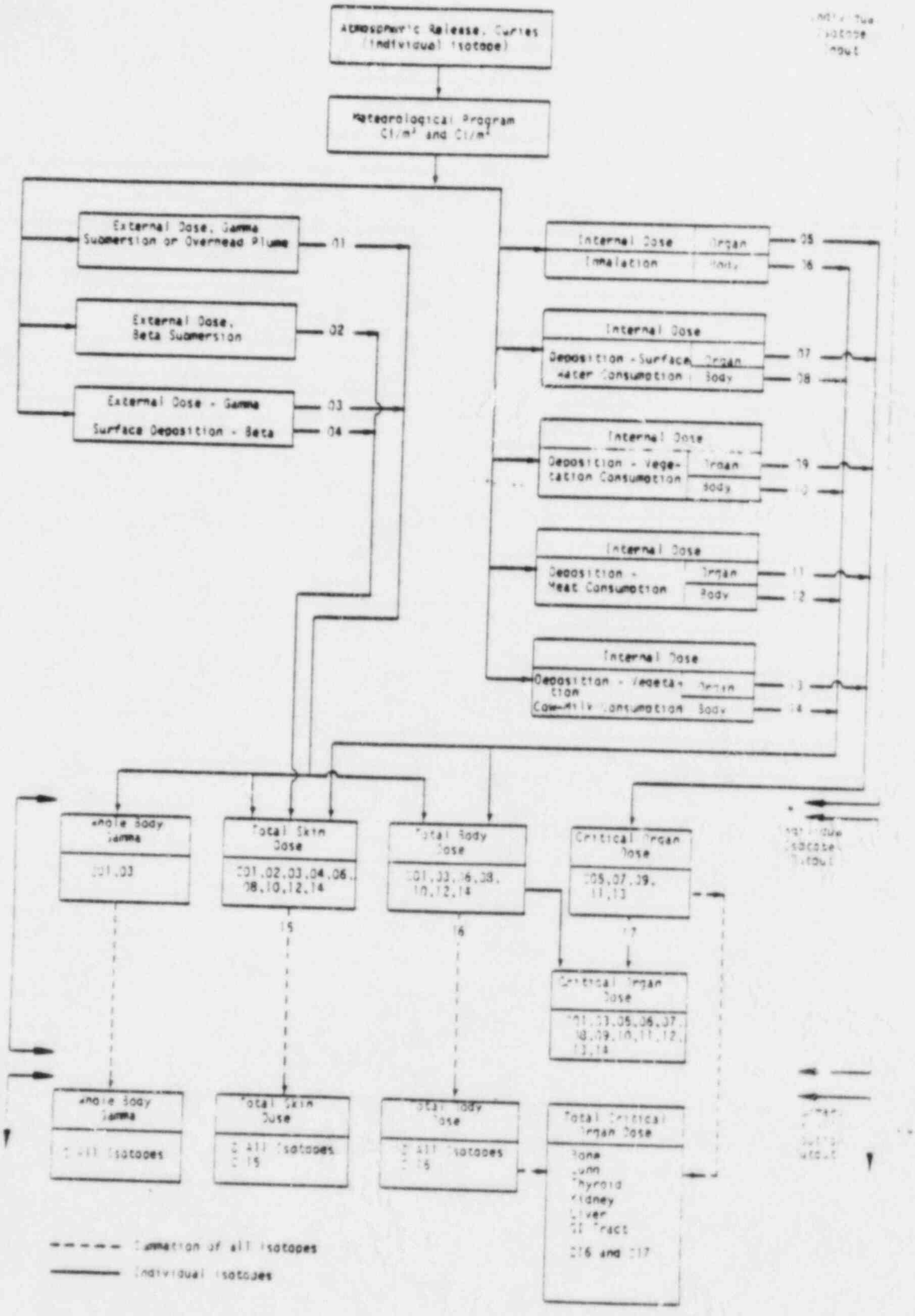

FIGURE G-2. Atmospheric Release Model

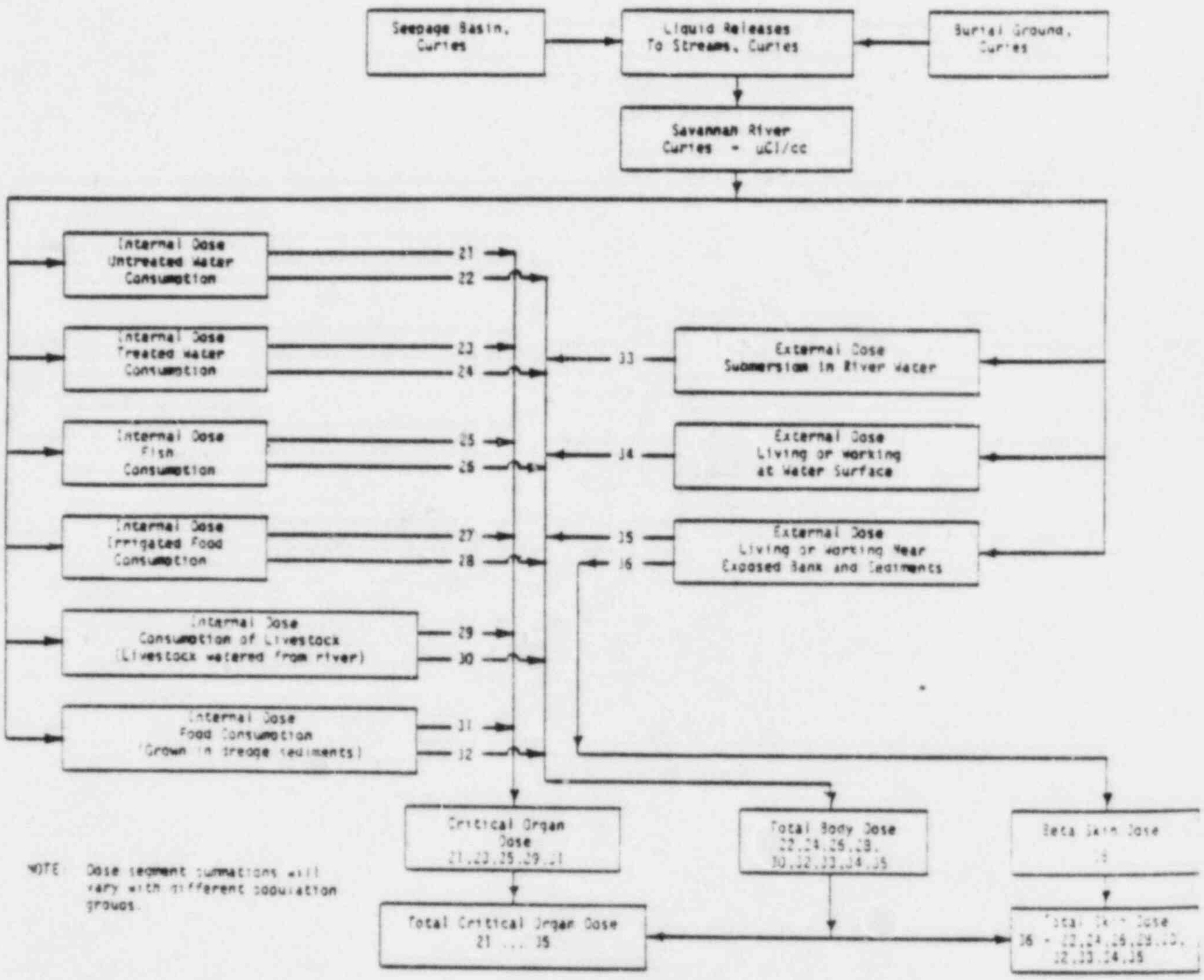

FIGURE G-3. Liquid Release Model

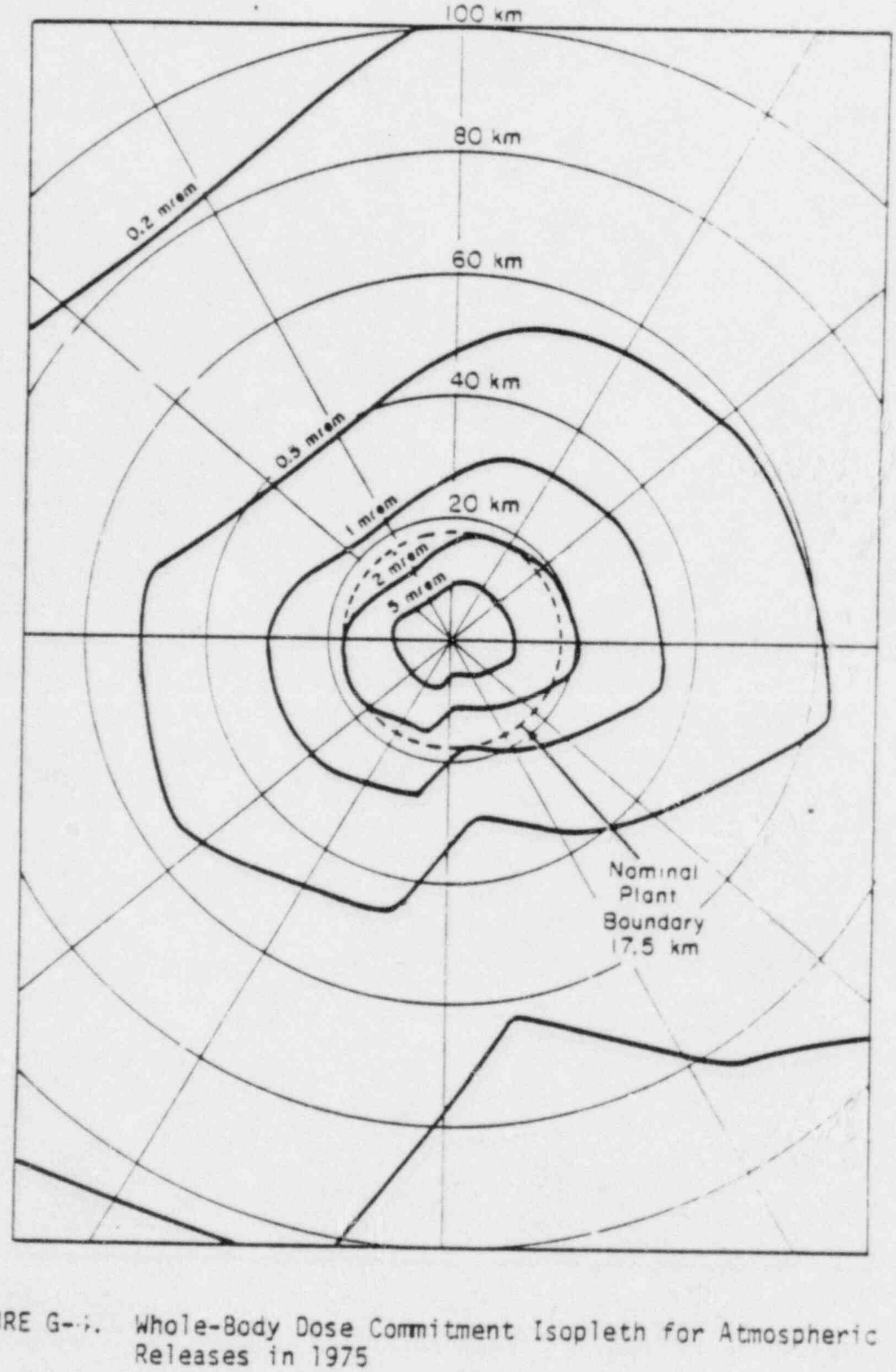

FIGURE G-;. Whole-Body Dose Commitment Isopleth for Atmospheric Releases in 1975

DPST-81-643

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

October 10, 1981

TO: E. L. ALBENESIUS

FROM: J. W. FENIMORE JWF

ANNUAL SUMMARY OF BURIAL GROUND GRID WELL ASSAYS - 1980

During 1980, 1180 assays were performed on samples of ground water collected from the grid of 67 ground water monitoring wells in the original 76 acre SRP burial ground (643-G). Location of the wells is shown in Figure 1 and results are summarized in Table 1.

A plot of data over the past seven years, Figure 2, shows that average concentrations have remained approximately constant and at very low levels. The average alpha concentration, for instance, over the seven year period is a little less than 1/6th the drinking water concentration guide given in the ERDA Manual, chapter 0524. Beta-gamma average concentration is about 1/78th the guide. Tritium is the only radionuclide which has exceeded drinking water levels.

The bulk of leached tritium in groundwater within the fenced burial grund is in three areas. An area in the west section is shown by wells A3, A5, C3, C5, C7, E3 and I7; a middle area is shown by wells C23, G13 and G21; and an area in the east section shown by wells G32 and G34. Average tritium concentration in the burial ground groundwater is about 23 times the drinking water guide. However, after migrating down the flow path to the

outcrop, groundwater emerges from the ground at only about 4 times the guide and is shortly reduced by dilution in the stream to less than drinking water levels.

Tritium Flow Path Repair

The outcrop into a surface effluent stream of ground water containing low concentrations of tritium from low-level waste disposed of by burial was repaired. Erosion of the effluent stream bed by 25 years of Plant cooling water discharges and storm runoff had deepened the stream bed and shortened by about 50% the subsurface flow path from the burial ground. Tritium contaminated waste, typically solidified Li-Al masses in stainless steel crucibles from which most of the tritium had been extracted thermally, exchanges its residual tritium with infiltrating rainwater. This water slowly percolates to the water table and moves with the ground water to outcrop zones or springs down the water table gradient. The erosion of the effluent channel had advanced the natural outcrop zone toward the burial ground by about 1000 ft, causing premature release of tritium contaminated water to the surface stream for the past several years. Even though small in total quantity repair of the eroded effluent and restoration of the natural flow path was undertaken as consistent with the Plant's objective of reducing radioactive releases to the environment to levels as low as reasonably achievable.

The repair work proceeded in two stages: in the first stage, completed in May 1980, an engineered channel 2100-ft long and 30-ft wide was constructed parallel to the eroded effluent bed (Figure 3). The base of the new channel is hardened with graded rock to inhibit erosion and preclude return of the original problem. The isolated old effluent channel was repaired in the second stages in two steps: the upper 900 ft whose bed base was still higher than the water table was simply filled with sandy clay from the contiguous ground surface. Greater care was taken with the lower 1000 ft. Stream banks were widened and the bed base, enlarged to six feet, was excavated to several feet below the eroded surface. Selected clay of low permeability, was laid into the base of the excavation in successive increments one ft in thickness. After each addition, the clay was compacted to 85% of maximum density with a vibratory compactor. The final two feet of the excavation was completed with top soil, which was graded and planted with grass seed for erosion control. Repair was completed at the end of November 1980.

The effect of the repair is expected to restore ten to twenty years to the subsurface flow path of tritium contaminated water

from the burial ground. This added distance in addition to flattening the gradient of the water table over most of the distance to the burial ground is expected to virtually stop the seepage of tritiated water in the near term and to reduce the equilibrium seepage rate of tritium contaminated water to perhaps 25% of its present level one to two decades in the future. Measurements of water table changes and annual definition of the subsurface tritiated water plume by analysis of deep soil cores are planned over the next few years to quantify the effect.

Inventory

A detailed estimate of the quantity of tritium in burial ground groundwater was attempted for the first time in 1979.* This estimate used the measured area and thickness of the tritium plume plus an estimate of average sediment porosity to calculate the volume of water in the plume. The volume was then multiplied by the observed average concentration to determine the quantity in the plume. Using this method and average yearly concentrations obvserved since 1974 produces results shown in Table 2 below.

TABLE 2. Yearly Estimates of T in Burial Groundwater

	Average Conc., μCi/l	Quantity in Plume, Ci
1974	31.6	13,300
1975	94.0	39,600
1976	58.0	24,400
1977	59.0	24,800
1978	90.4	38,000
1979	65.8	27,700
1980	90.0	37,900

It is probable that the plume expands and contracts in response to varying quantities of feed received from buried wastes. Considering such flucuations and observed flucuations in concentrations plus the lack of increasing or decreasing long term tends it is likely that the quantity of tritium in burial ground groundwater at any particular time will remain in the range of 10,000 to 40,000 Ci.

Such detailed estimates for alpha and non-volatile beta-gamma emitters is not possible because of lack of knowledge of the 3 dimensional space occupied by such emitters. However, the conservative estimate of 2 mCi alpha and 16 mCi beta-gamma given in DPST-80-266 is probably much above the actual quantities present and is safe to use for environmental impact estimates.

Expansion of Monitoring Grid to 643-7G

During the year a portion of 643-7G was completed and 26 ground water monitoring wells on 200 foot centers were installed in this area. The wells were installed and all but 7 were developed by years end. Results for this system will be reported in the 1981 annual report of burial ground results.

*DPST-80-266 "Annual Summary of Burial Ground Grid Well Assays-1979"

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NUMERICAL MODELING OF GROUND-WATER FLOW AT THE SAVANNAH RIVER PLANT

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Publication Date: August 1983

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ABSTRACT

The Savannah River Plant is a Department of Energy facility operated primarily to produce nuclear materials for national defense. Solid low-level radioactive waste generated during plant operations is buried in trenches in specific areas designated for this purpose. A three-dimensional finite-difference numerical model has been developed to study the ground-water flow system in the saturated zone underlying these waste burial areas. A steady-state flow model has been calibrated and indicates that the average horizontal hydraulic conductivity of the underlying water-bearing formations is 1.8 meters per day (5.9 feet per day). Given the hydraulic gradients in the area, flow velocities in the range of 10 to 22 meters per year (30 to 70 ft per year) were calculated and are generally supported by aquifer pumping and tracer tests.

NUMERICAL MODELING OF GROUND-WATER FLOW AT THE SAVANNAH RIVER PLANT

INTRODUCTION

The Savannah River Plant is a Department of Energy facility located on the coastal plain of South Carolina about 32 km (20 miles) southeast of the Fall Line (Figure 1). The plant primarily produces nuclear materials for the national defense. Solid low-level radioactive waste generated during plant operations is buried in trenches located in specific areas of the plant designated for this purpose. These waste burial grounds cover an area of 8.1×10^5 m^2 (8.7×10^6 ft^2) (Figure 2) and have been receiving waste since plant startup in 1953. Burial trenches are excavated to a depth of 6 meters (20 ft) with the trench bottom at least 3 meters (10 ft) above the mean water table. Emplaced waste is covered with at least 1.2 meters (4 ft) of compacted backfill.

Studies of the fate of radionuclides buried with the wastes began in 1956 and continue to the present. These studies have focused on the hydrogeology of the area because circulating ground water provides the principal mechanism of leaching and migration of radionuclides buried with waste. Studies have included water-table shape, injection-detection ground-water velocity tracer tests, point dilution ground-water velocity tracer tests, and soil moisture studies including tracing movement in the unsaturated region above the water table where wastes are buried.

These studies have shown that ground water in the interstream region between Upper Three Runs Creek and Four Mile Creek (where the burial ground is located) flows partially to Upper Three Runs Creek and partly to Four Mile Creek. Most of the burial ground lies in the Four Mile Creek drainage basin. In general, water moves slowly away from the ground-water divide and then at an accelerating rate down the gradient to outcrop at the springs, swamps, and beds of the two streams.[1] Rain falling on the burial ground seeps down through the unsaturated zone to enter the saturated zone at the water table and then moves horizontally and vertically along a curvilinear path to outcrop in the springs, swamp, and creeks. Consideration of sediment characteristics (grain size and shape, grading, packing), water-table gradients, and horizontal and vertical head distribution followed by tracer studies led to the following flow rate estimates: unsaturated zone, 7 ft/yr;[2,3] horizontal rate near the water table divide (flat gradient), 3 to 7 ft/year; halfway between the divide and outcrop where

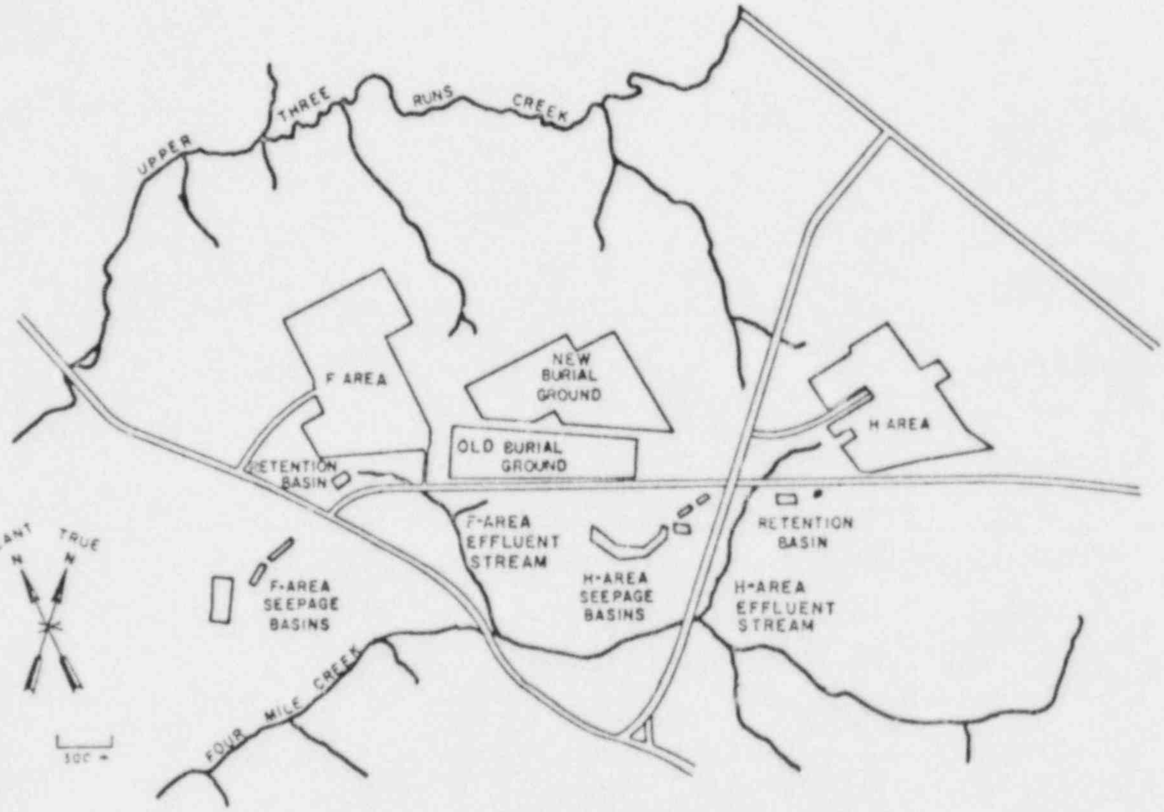

FIGURE 2. Map of Burial Ground Area.

gradients are steeper, 30 to 70 ft/year; and near the outcrop under steepest gradients, up to 475 ft/year.[4]

These estimates appeared adequate for travel time projections in dose-to-man modeling and related environmental analysis for many years but in 1978, small quantities of leached tritium from the burial ground outcropped in a shorter time than expected into a drainage ditch that had become deeply eroded by continuous flow of cooling water discharged from the F-fuel separations areas. This erosion had shortened the flow path of subsurface water from the burial ground to the outcrop by about 900 feet. In 1980, a new engineered drainage channel was constructed, and the eroded ditch was repaired, restoring the flow path to its original distance of 1700 feet. A program of well drilling and analysis of soil cores was undertaken to provide a detailed understanding of the hydrology and water flow rates in this 1700-ft zone. At the same time, it became apparent that a way to extrapolate known information into areas where no wells were located was highly desirable. The aim was to prepare a numerical model such that coordinates of points in areas not yet drilled could be entered and estimates of flow velocities at the points would be generated. Work described in this report was therefore undertaken in an effort to generalize and extend known information throughout the original burial ground area in the form of a numerical model.

Solute transport in the ground is primarily by convective movement of ground water. Predicting the transport rate of a solute in the saturated zone depends on the distribution coefficient of the solute with the matrix as well as the flow velocity throughout the system. Calculating the velocity requires knowing the hydraulic head, the effective porosity, and the hydraulic conductivity. The hydraulic head was measured for many years in wells constructed in the study area, and the effective porosity is estimated from laboratory tests on undisturbed subsurface samples. The hydraulic conductivity, however, is more difficult to determine. Aquifer tests conducted in and around the study area provide hydraulic conductivity values for portions of the subsurface. However, the relatively low transmissive capability of the shallow coastal plain sediments limits the extent of the influence of such tests. Therefore, their results may not be widely applicable.

As discussed above, the purpose of this modeling study was to develop a numerical model of the ground-water flow system underlying the study area, providing an approximation of the known ground-water velocity field. This was accomplished by inputting initial estimates of the hydraulic characteristics of the subsurface material into a finite-difference model of ground-water flow and reproducing observed water level distributions. The result of the calibration was a hydraulic conductivity distribution which, when coupled with the hydraulic head gradients and the effective porosity, estimated

the ground-water velocity field underlying the area. These velocities compared reasonably well with the results of field tests.

SITE CHARACTERISTICS

The Savannah River Plant occupies about 770 square kilometers (300 square miles) of the Atlantic Coastal Plain. The underlying materials are largely unconsolidated and semiconsolidated sands, clays, sandy clays, and clayey sands.[5] A generalized geologic profile across the plantsite is shown in Figure 3. The uppermost sediments belong to the Hawthorn Formation of Miocene age and the Barnwell Formation of upper Eocene age (for the purposes of this study the Hawthorn Formation is combined with the Barnwell Formation due to the similarity in lithologic characteristics). The Barnwell Formation consists largely of red fine to coarse clayey sand and sandy clay with a thickness of about 30 meters (100 ft). The formation dips to the southeast at about 2 meters per kilometer (10 ft per mile) and contains the water table beneath the burial grounds at a depth of 12 to 18 meters (40 to 60 feet) below land surface. All trenches excavated to receive waste are located in the Barnwell Formation. Hydraulic conductivities are low, with pumping tests giving results on the order of 0.07 to 0.3 meters per day (mpd) [0.23 to 1.0 ft per day (fpd)].[7]

Immediately underlying the Barnwell Formation is an areally extensive kaolinitic[6] clay layer with a thickness of 1 to 3 meters (3 to 10 ft). This clay layer, locally called the Tan Clay, to some degree retards the downward flow of water. This is manifested by wells screened above the layer exhibiting water levels one to two meters (3 to 6 ft) higher than wells screened below the layer.

Underlying the Tan Clay is the Eocene McBean Formation, which dips to the southeast at about two meters per kilometer (10 ft per mile). This formation consists of an upper part of tan clayey sand and a lower part of tan to white calcareous clayey sand. The entire formation is about 21 meters (70 ft) thick. As evidenced by pumping test results, the McBean Formation has hydraulic characteristics similar to the Barnwell Formation. Underlying the McBean Formation is an areally-extensive gray to green clay layer (locally called the Green Clay) with a thickness of about 2 meters (6 ft). There is a hydraulic head difference of up to 24 meters (79 ft) vertically across this clay layer, suggesting that it is relatively impermeable.

Underlying this clay layer are about 235 meters (770 ft) of Eocene to upper Cretaceous age sands and clays resting on crystalline bedrock. The lower part of these sediments, the Tuscaloosa Formation, is a major water supply aquifer.

The burial grounds are located on a topographic ridge which slopes to Upper Three Runs Creek to the north and to Four Mile Creek to the south (Figure 2). The terrain on the ridge is generally flat to slightly rolling. A few small streams, mostly intermittent, drain the general area. Two streams which have a measurable flow in at least part of their courses during most of the year are designated "F-Area Effluent Stream" and "H-Area Effluent Stream" in Figure 2. These streams receive surface runoff from the two Separations Areas. Precipitation is distributed approximately uniformly over the area and amounts to about 1.2 meters (47 inches) per year.

The water table (Figure 4) conforms to a subdued expression of the topography, forming a ground-water ridge that discharges laterally toward the bounding streams to the north and south. The area outlined in Figure 4 is the region modeled in this study and focuses on the flow system beneath the old burial ground. For this study area, the ground-water system is bounded on its north side by the ground-water divide separating flow between the northern and southern discharge areas. The eastern hydrologic boundary for the water table aquifer is a small stream and swamp, while the western hydrologic boundary is the no-flow condition imposed by flow approximately normal to Four Mile Creek and its adjoining swamp. The southern hydrologic boundary is Four Mile Creek. The ground-water flow beneath the old burial ground is contained within these hydrologic boundaries, which direct lateral flow toward Four Mile Creek.

The clay layers in the subsurface retard the downward movement of ground water, thereby causing vertical head gradients across these clays. Most notable of these are the Tan Clay and the Green Clay discussed above. Because of the presence of the Tan Clay, the potentiometric surface in the upper part of the McBean Formation stands lower than the water table by about 1.5 meters (5 ft). Smaller declines in hydraulic head are observed within each water-bearing formation due to intercalated clay lenses. The large head decline downward across the Green Clay attests to its relatively low permeability; therefore, the Green Clay was considered to be the lower boundary of the burial ground flow system.

Figure 5 shows schematically the geologic cross section of materials underlying the general area of the burial grounds to a depth of approximately 55 meters (180 ft). The cross section shown runs approximately north to south from the old burial ground toward Four Mile Creek. Also shown are water levels in wells screened in various portions of the subsurface, illustrating the presence of vertical head gradients.

Recharge to the water table is by downward percolation of infiltrating precipitation. This amounts to about 0.4 meters

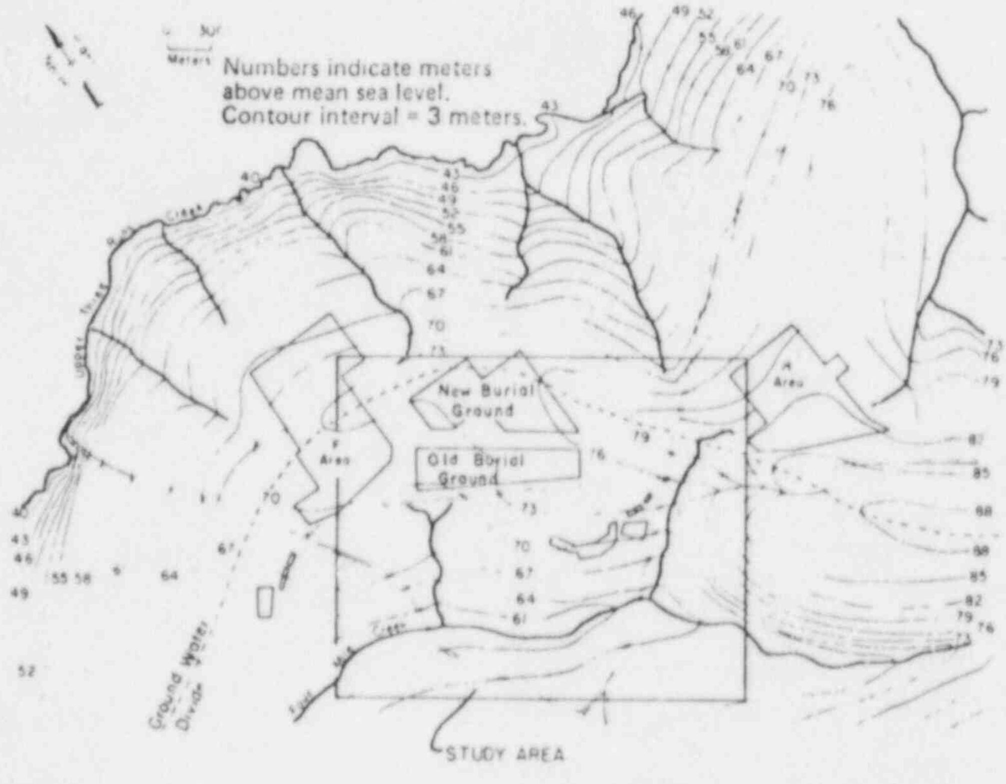

FIGURE 4. Average Elevation of the Water Table in the Burial Ground

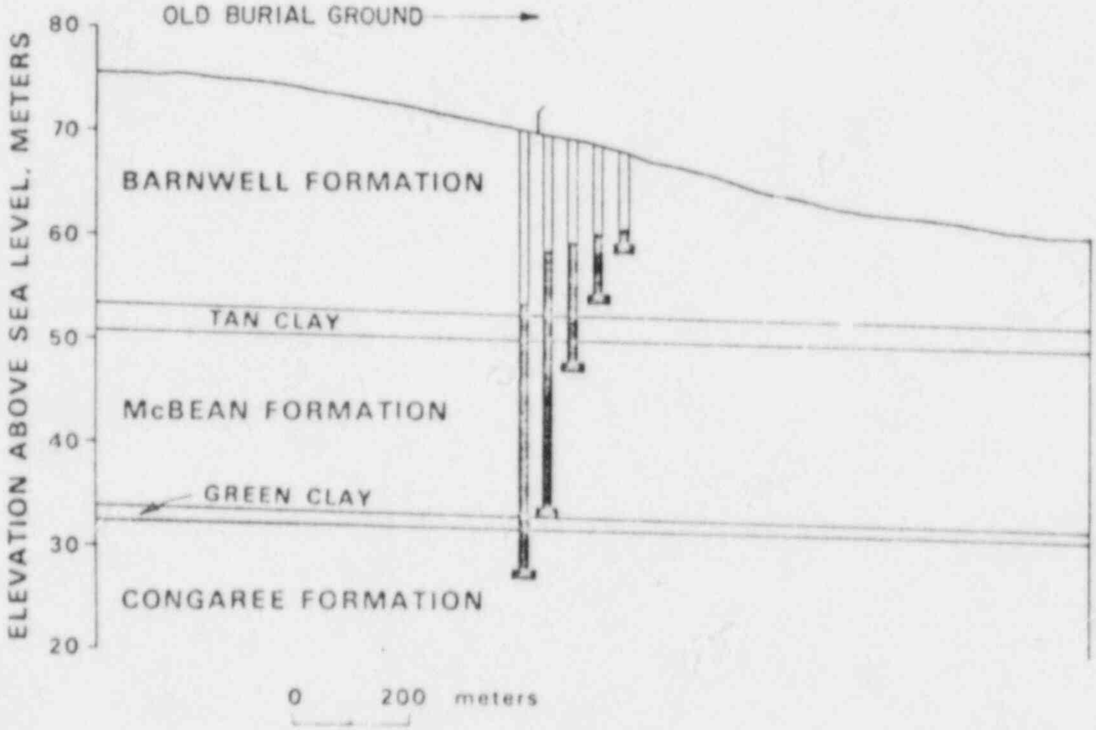

FIGURE 5. Stratigraphy Underlying the Burial Ground

(15 inches) per year. Recharge to the McBean Formation beneath the study area is entirely by leakage through the Tan Clay from the overlying Barnwell Formation.

COMPUTER SIMULATION OF THE GROUND-WATER SYSTEM

The major purpose of this modeling effort was to generate the steady-state velocities and directions of flow of ground water underlying part of the burial grounds. Ground-water velocity is determined by using Darcy's Law and by accounting for the effective porosity of the porous media:

$$u = \frac{k_x}{n_e} h_x$$

where

u = flow velocity in the x-direction (L/T),

k = hydraulic conductivity in the x-direction (L/T),

n_e = effective porosity (dimensionless), and

h_x = hydraulic head gradient in the x-direction (L/L).

Analogous definitions may be written for v (the velocity in the y-direction) and for w (the velocity in the z-direction).

In order to define the flow directions and rates in space, the effective porosity, the head gradient, and the hydraulic conductivity must be known throughout the system. The effective porosity has been measured in soil cores to be on the order of 0.25; this value is applied to the entire porous media. The hydraulic head has been measured for the water table and the upper part of the McBean Formation for a number of years. The heads vary due to climatic factors such as rainfall and evaporation. Because a steady-state solution for the velocity distribution was sought, the water levels measured in each monitoring well were averaged over the entire available period of record. The resulting averaged water table distribution and upper McBean Formation potentiometric surface were taken as being representative of steady-state conditions. Water level maps were made and are shown in Figures 6 and 7.

The final term needed for the velocity calculation is the hydraulic conductivity distribution. The subsurface materials underlying the burial grounds were deposited in a variety of sedimentary environments, including nearshore and estuarine. As a result, the hydraulic conductivities vary considerably due to the

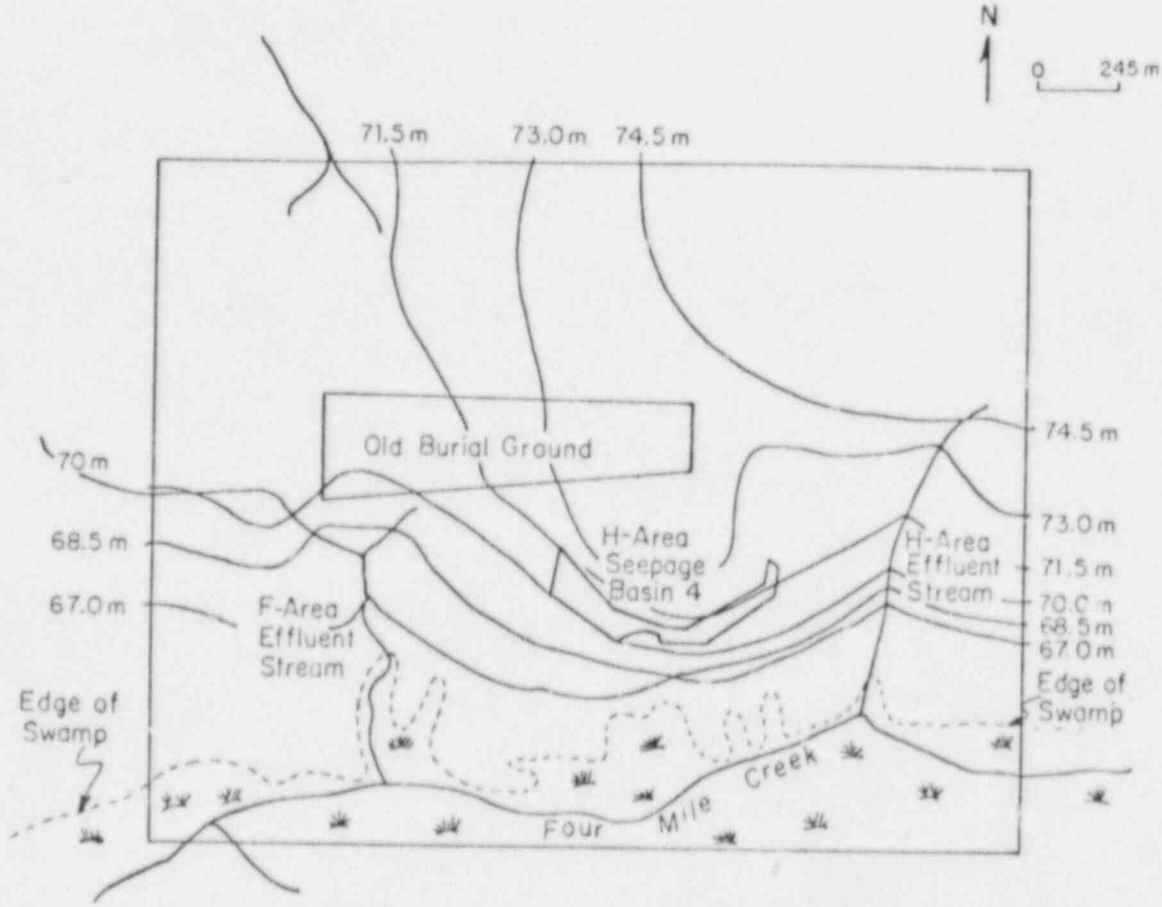

FIGURE 6. Elevation Contours on the Average Water Table in the Immediate Vicinity of the Old Burial Ground

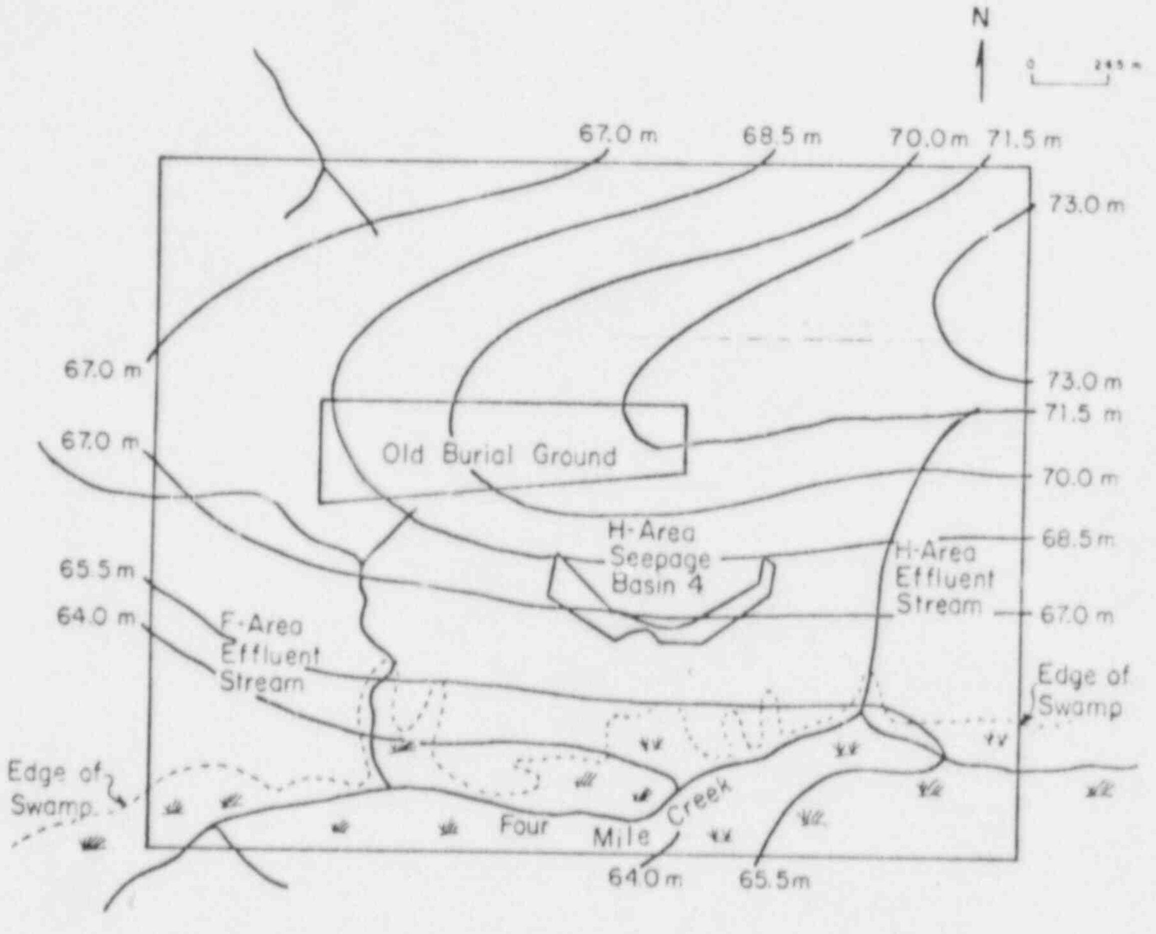

FIGURE 7. Elevation Contours on the Average Piezometric Surface of the Upper Part of the McBean Formation in the Immediate Vicinity of the Old Burial Ground

presence of interlayered sands, sandy clays, clayey sands, and clays. Pumping tests have provided some scattered values of the hydraulic conductivity for limited portions of the subsurface material. These were used as initial inputs to the flow model. Laboratory hydraulic conductivity tests have indicated the ratio of horizontal to vertical conductivity to be approximately 2:1.

The numerical computer code to be used had to provide several capabilities: (1) The first and most important was that it had to be three-dimensional. The existence of a head gradient downward across the Tan Clay indicated a vertical component of flow that had to be considered. Tracer tests supported this observation. (2) It had to have a capability for calculating the components of the ground-water flow velocity or be easily modified to do so. (3) This also required that the code be well-documented to simplify modifications. (4) Finally, the code had to be valid and accepted as usable. The code that was selected and had all of the qualities was that of Trescott.[8] This code uses the finite-difference method to solve the hydraulic head distribution in time and space in three dimensions.

A separate computer program was written to calculate the components of the ground-water flow velocity. The hydraulic head computer code calculated the steady-state head in each specified grid block. These values were used as input to the program VELOCITY, along with values for the hydraulic conductivity and the effective porosity of each grid block. The Trescott code has an option to simulate confining layers by incorporating their vertical hydraulic conductivity values into those of the overlying and underlying layers; this option was used to simulate the Tan Clay. The VELOCITY program then calculated the ground-water velocity at grid block intersections. At each point the x-, y-, and z- components of flow were specified as u, v, and w, respectively.

Figure 8 shows the finite-difference grid and the boundaries used in the model. The study area was divided into a 21 x 21 rectangular grid arrangement for the horizontal dimensions. The grid block dimensions in the x-direction varied from 61 meters (200 ft) in the primary area of interest to 244 meter (800 ft) at the boundaries; in the y-direction the block dimension varied from 61 to 183 meters (200 to 600 ft). The total horizontal area modeled is approximately 6 square kilometers (2.3 square miles). The refined 61 meter x 61 meter (200 ft x 200 ft) grid is used south of the west end of the old burial ground because ground water flowing out from under the old burial ground moves through this region. The increase in block sizes is limited to a ratio of 1:1.5 or less.

The hydrologic boundaries for the study area were specified as shown in Figure 8. The north boundary is a no-flow boundary due to the presence of the water table divide: flow is parallel to this

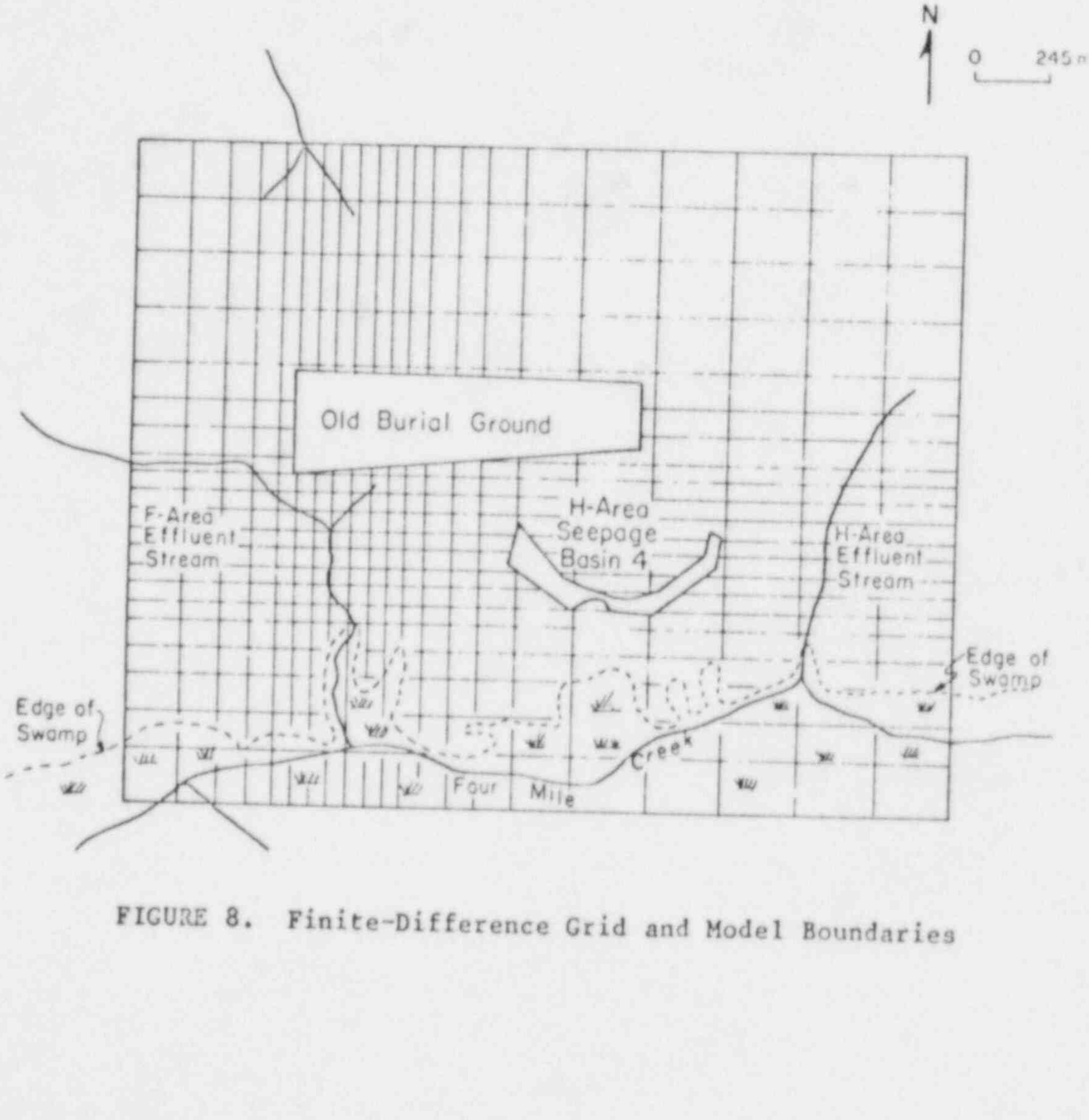

FIGURE 8. Finite-Difference Grid and Model Boundaries

boundary. The Trescott code automatically specified zero transmissivity to the outermost columns and rows. Where the divide did not exactly correspond to this boundary, grid blocks were assigned zero transmissivity to account for the divide's irregular disposition. The south boundary consisted of constant head nodes to simulate Four Mile Creek and its bordering swamp. The west boundary consisted of: (1) no-flow conditions in the lower half of the study area to account for flow essentially normal to Four Mile Creek (Figure 6), and (2) constant head nodes in the upper half to account for flow downgradient across the boundary. The east boundary is primarily constant head nodes to simulate the H-Area Effluent Stream that bounds flow on this side. Ground water discharges along the lower course of the F-Area Effluent Stream and along Four Mile Creek; for the purposes of this model these streams are simulated by constant head nodes in the model layers in which the streams actually occur. Constant head nodes were also used to simulate the H-Area Seepage Basins, which continuously received water and transmitted it to the water table.

The model consisted of six layers in the vertical direction, with three layers each assigned to the Barnwell and to the McBean formations. Each layer is assigned a thickness of unity because transmissivities were entered into the model and, therefore, accounted for the variation in layer thickness. For use in calculating transmissivities, these layers had thicknesses equivalent to from 4.6 to 9.1 meters (15 to 30 ft) (Figure 9). The Tan Clay is located between layers 3 and 4; however, the effects of its vertical hydraulic conductivity were incorporated into the overlying and underlying layers. The code automatically assigns no-flow conditions to the lowermost boundary; this situation is used to represent the relatively impermeable Green Clay, assumed to be the bottom of the modeled flow system. Figure 9 illustrates the vertical finite-difference grid.

Recharge was specified as 0.4 meters (15 inches) over the entire model area and assigned to all nodes in which the water table was located. Pumping tests conducted at several locations in the Barnwell and the McBean formations resulted in hydraulic conductivity values that could be used as initial input values. There was considerable overlap in the data from the two formations; also, the geologic materials are for the most part very similar. Therefore, the same conductivity values were assigned to both the Barnwell and to the McBean formations. These were multiplied by the layer thickness to produce a transmissivity for each grid block for model input. Because this was to be a steady-state simulation, the storage was maintained as zero at all times throughout the model.

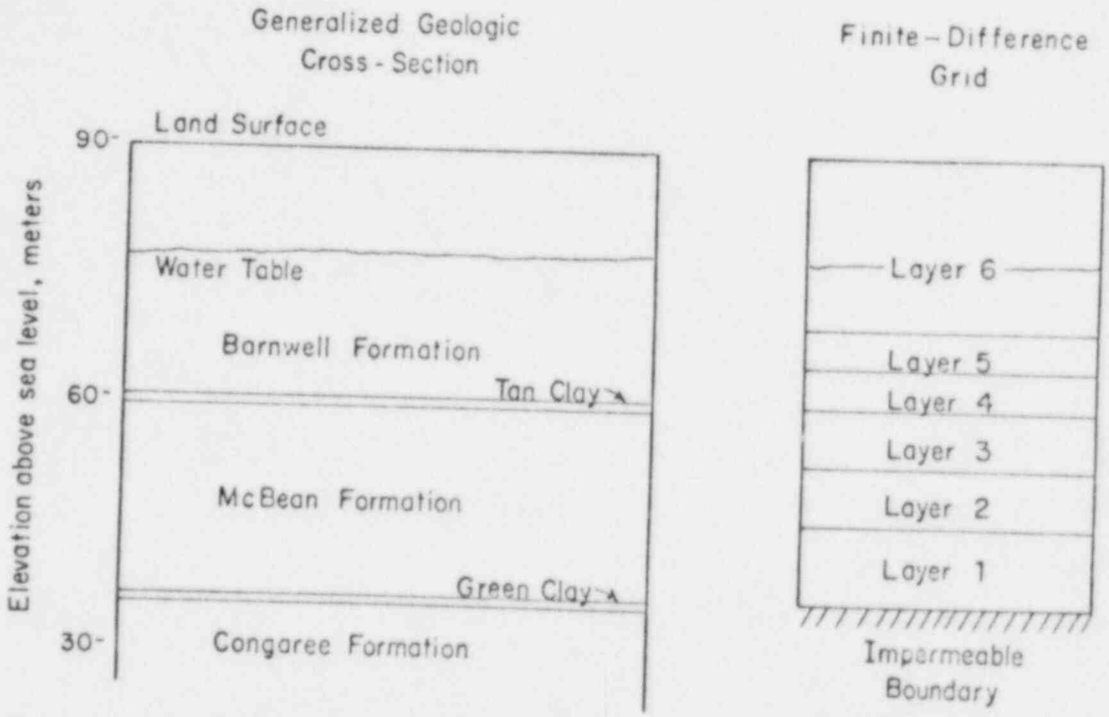

FIGURE 9. Generalized Geologic Cross Section and Vertical Finite-Difference Grid

CALIBRATION OF THE MODEL

The purpose of the modeling effort was to develop a representation of the spatial ground-water velocity distribution of the study area. Because the steady-state hydraulic head distribution was already well-defined, the head model was needed to determined the hydraulic conductivities controlling the rates of flow. The intention was to run the head model with different combinations of hydraulic conductivity to determine which combination most nearly reproduced the observed hydraulic head distribution.

Median hydraulic conductivity values obtained from the pumping tests were used as initial input. A vertical-to-horizontal anisotropy of 1:2 was used throughout the model. In order to simplify the calibration effort, only two parameters were varied in order to reproduce the observed head distributions: the horizontal conductivity of the Barnwell and McBean formations (at all times equal to each other) and the vertical conductivity of the Tan Clay. These were varied in a systematic way, and the resulting steady-state head distribution was compared to the initial input.

In order to easily evaluate the effects of varying these input parameters, subroutine STEP of the Trescott code was modified slightly. The steady-state heads calculated by the code for a small portion of the study area were compared to the initial input, the deviations from the initial input for each block were squared, and the squares were summed. This provided a "sum-of-the-squares" measure of the deviations of the calculated heads from the observed heads. The area of the model for which this was done for the water table included all blocks in the old burial ground and in the area south of the old burial ground, between the F-Area Effluent Stream and the H-Area Seepage Basins. These areas had the greatest density of control points for water levels and, therefore, gave the best approximation of the steady-state water table distribution. A similar approach was used for the upper McBean Formation potentiometric head.

The horizontal conductivity of the Barnwell and McBean formations was expected to be within the range from 0.53 mpd to 5.3 mpd (1.7 fpd to 17 fpd). A sequence of simulation runs was made using several conductivity values within these ranges. A number of values for the horizontal conductivity of the Barnwell and McBean formations was run with one value for the vertical conductivity of the Tan Clay, and the sums of the squares of the deviations and the system mass balances were noted. The Tan Clay vertical conductivity was changed, and the entire sequence was run again. This was done systemmatically until the full range of conductivities had been covered, an effort which involved 40 computer runs. Each run used about 1 minute of central processing unit time and 400,000 bytes of core storage.

Figure 10 shows the comparison of the observed and calculated steady-state water table. The major area of interest in this modeling effort lies south of the burial ground and between the F-Area Effluent Stream and H-Area Seepage Basin 4. Deviation between calculated and observed heads in this area is on the order of 0.5 meters (1.6 ft) or less. Figure 11 shows the computer-generated potentiometric surface for the upper part of the McBean Formation. The head distribution is reasonable since it has a ground-water divide approximately coincident with the topography and exhibits lateral flow toward the bounding streams - Upper Three Runs Creek and Four Mile Creek. The control points represent wells in the McBean Formation with enough historical water level data to provide approximate steady-state measurements. The calculated heads generally deviate from the measured heads by 1 meter (3 ft) or less.

RESULTS AND CONCLUSIONS

From the calibration process a combination of hydraulic conductivities was found. These conductivities gave a minimum sum of the squares of the deviations for both the water table and the potentiometric surface of the upper part of the McBean Formation. In addition, the system mass imbalance was less than 2%. The horizontal conductivity of the Barnwell Formation and of the McBean Formation was estimated to be 1.8 mpd (5.9 fpd), and the vertical conductivity of the Tan Clay was estimated to be 1.6×10^{-3} mpd (5.3×10^{-3} fpd). The horizontal conductivity value is approximately one order of magnitude greater than the median of values measured by pumping tests. This may be accounted for by the wide variation in conductivity expected in these subsurface materials. Most pumping test results are from sites to the east of the study area, where conductivities may be different. For the purpose of a first-approximation study, only a single conductivity was intended to be applied to the geologic formations. A more sophisticated study would spatially vary the conductivity values, which would then presumably have more correspondence to the pumping test results. Also, deviation by the subsurface material from any of the assumptions of the pumping test conditions, which would be expected, would cause some error in the test results.

Using the steady-state head distribution, the hydraulic conductivities determined from the calibration, and an effective porosity of 0.25, the ground-water flow velocities throughout the system were calculated. Calculated flow rates vary from about 9 meters per year (30 feet per year) (fpy) along the ground-water divide to about 62 meters per year (205 fpy) near Four Mile Creek. Ground water, therefore, passes slowly beneath the burial ground in a westerly direction. Near the west end of the burial ground the flow turns south to parallel the F-Area Effluent Stream. As

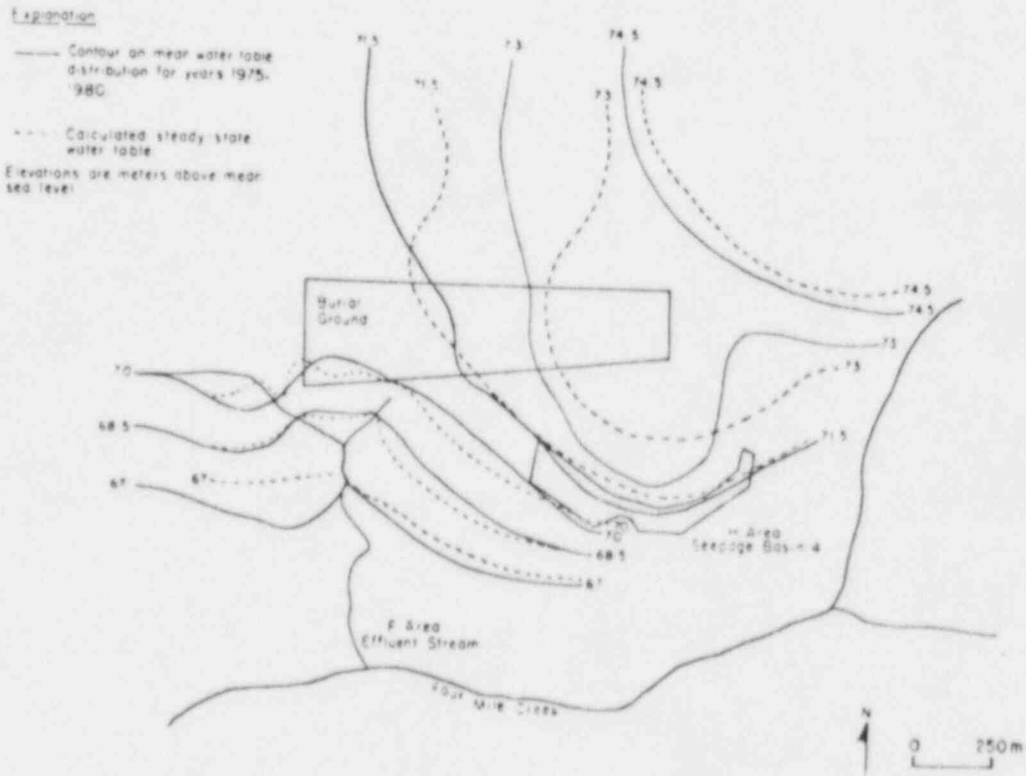

FIGURE 10. Comparison of Observed and Calculated Steady-State Water Table

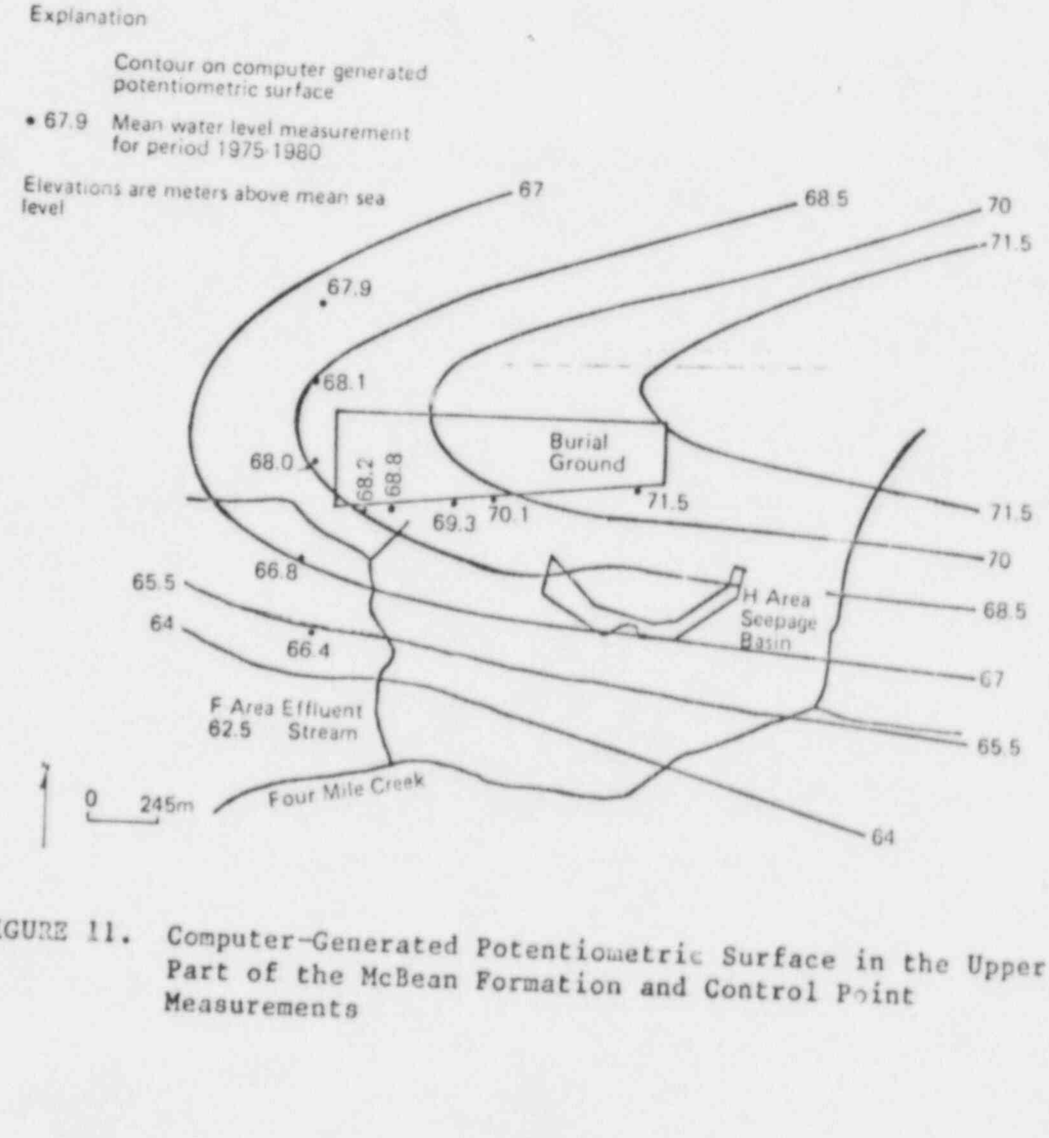

FIGURE 11. Computer-Generated Potentiometric Surface in the Upper Part of the McBean Formation and Control Point Measurements

recharge adds mass to the ground-water system, the flow rate gradually increases as ground water approaches the discharge area.

A few measurements of flow velocity have been made using the point dilution method in wells in the western portion of the study area, near the F-Area Effluent Stream. Results from these tests ranged from about 11 meters per year (36 fpy) to about 22 meters per year (72 fpy). However, a value of 0.33 for the effective porosity was used in calculating the point dilution test velocities, rather than the 0.25 used in the model. Using a porosity of 0.33 in the flow model would produce velocities on the order of 7 meters per year (24 fpy) to 47 meters per year (154 fpy). Thus, the ground-water flow rates calculated by the model are in general agreement with those determined by the point dilution method.

Ground water passing beneath the old burial ground moves down the hydraulic gradient toward Four Mile Creek. A swamp borders the creek along its northern side; therefore, ground water will outcrop along the edge of this swamp. Ground water converges on the F-Area Effluent Stream and outcrops into the stream about 315 meters (1033 ft) upstream from Four Mile Creek. The flow path from the edge of the old burial ground to the ground-water outcrop is about 530 meters (1740 ft). The flow velocity gradually increases toward the outcrop. Assuming a flow rate of 22 meters per year (73 fpy) in the first half of this flow path and a flow rate of 55 meters per year (180 fpy) in the second half, ground water passing the boundary of the old burial ground will outcrop in the F-Area Effluent Stream after about 17 years.

Rates and times generated by the model can be compared with experience. Average ground-water velocity throughout the burial ground region varies with the water table gradient at the rate of 0.13 ft/day/1% gradient. Applying these rates to the observed ground-water gradients produces transit times for the east, middle, and southwest flow paths beneath the old burial ground as shown in Figure 12. The figure shows the average estimated time for tritiated water to move from the head of the flow path to the outcrop.

The vertical conductivity of the Tan Clay was estimated to be 1.6×10^{-3} mpd (5.3×10^{-3} fpd). A head gradient of about 1.5 meters (5 ft) per 2 meters (6.6 ft) of clay thickness exists across the layer. Using an effective porosity of 0.25, a velocity of about 1.8 meters per year (5.9 fpy) across the Tan Clay can be calculated. This velocity allows water to move across the Tan Clay in about 1 year. Therefore, although the Tan Clay is a barrier to vertical flow and, therefore, supports a head gradient, it still permits water passage.

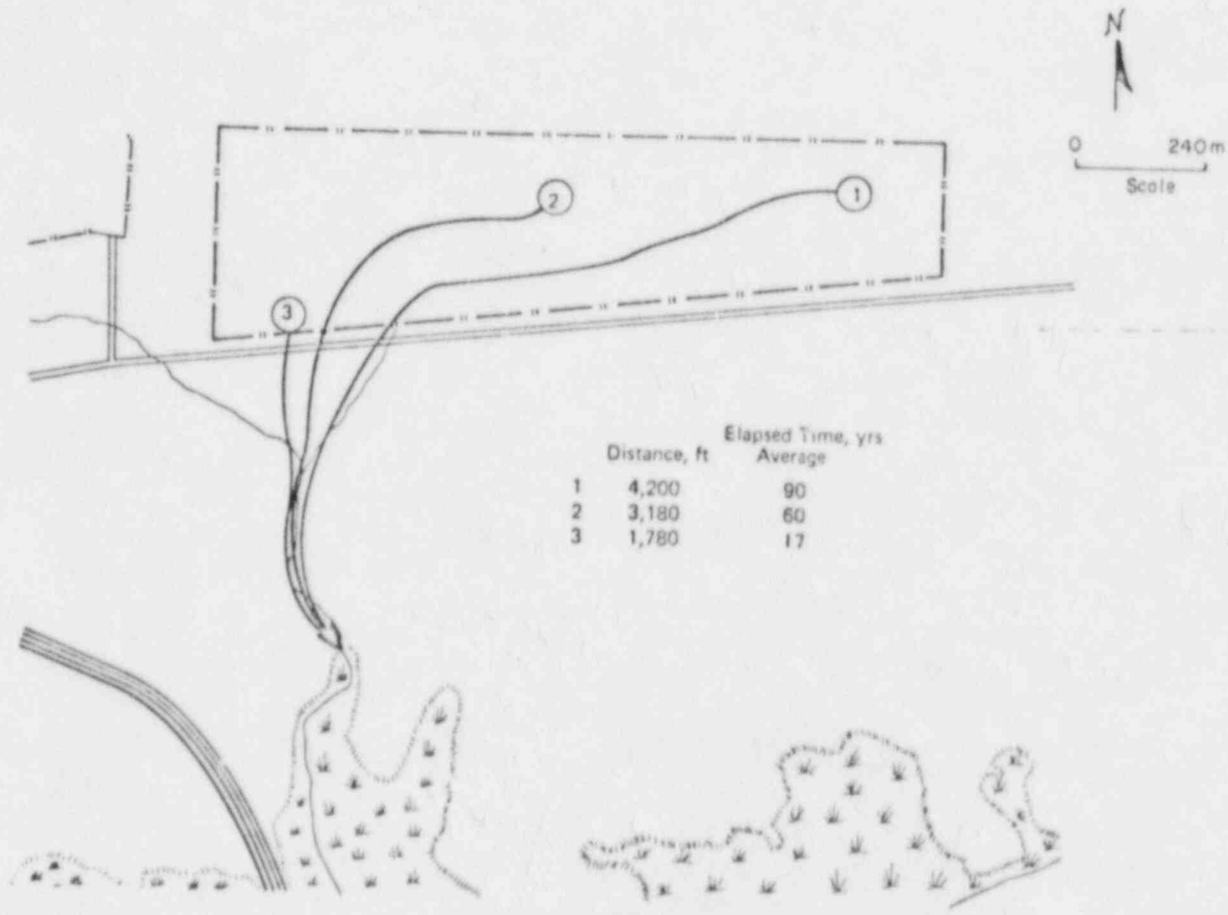

FIGURE 12. Time Required for Water (and Tritium) to Travel 643G Flow Paths

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DuPont

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September 29, 1976

Mr. N. Stetson, Manager
Savannah River Operations Office
U. S. Energy Research and
Development Administration
Aiken, South Carolina 29801

Dear Mr. Stetson:

As requested in your teletype of September 17, 1976 to J. D. Ellett, we have prepared comments on the technical matters mentioned in the suit by NRDC et al against ERDA concerning the construction of additional waste storage tanks. In accordance with the direction of our attorneys in connection with the preparation of the defense of this law suit, we are submitting the information in the attachment.

The Introduction of the complaint contains broad allegations that are generally repeated with more specificity in later sections. We have replied primarily to these latter sections to minimize repetition. Some of the technical issues are common to Savannah River and Hanford, and the replies of both sites may require coordination. These particular paragraphs are noted in the attachment.

The draft environmental statement on waste management operations at the Savannah River Plant (ERDA-1537) addresses in detail most of the technical matters in the suit. When issued, ERDA-1537 could serve as an important document in responding to the suit. In addition, the "Integrated Radioactive Waste Management Plan for the Savannah River Plant" (SRO-TWM-76-1) provides extensive descriptions of the engineering and safety features of the waste tanks and the plans for long-term management of high-level waste.

Sincerely yours,

C. H. Ice

C. H. Ice, Director

WCR:msg
Attach.

COMMENTS ON TECHNICAL ISSUES IN NRDC SUIT

16.* The storage of high-level radioactive waste in the tanks funded for FY 1976 and FY 1977 will not result in undue risk to the public from release of radioactive materials to the environment. All relevant and proven technology currently available is incorporated in the design of the new tanks to ensure high-integrity containment over their service life. Although the tanks will have safety features beyond those included in the design of the tanks built earlier at the Savannah River Plant, there is no undue risk to the public from present storage of waste. The radiation dose in 1975 to the population within 50 miles of SRP from storage of high-level waste was 3 man-rem (0.004 percent of the dose from natural radioactivity). This radiation exposure was not caused by leakage or accidental dispersal of radioactivity, but by normal processing of the high-level waste.

31b & 51. Project 76-8-a will provide six waste tanks, two evaporators, and additional waste tank farm facilities (pumps, concentrate transfer systems, etc.) The six new waste tanks will have a total capacity of 7.8 million gallons.

32b. Project 77-13-d will provide four waste tanks, a waste maintenance facility and a variety of tank farm improvements. The additional tanks will have a total storage capacity of 5.2 million gallons of waste.

36. Strontium-90 (half life of 28.9 years) has been assigned to the Medium-Toxicity (Upper Sub-Group A) category of radionuclides by the International Atomic Energy Agency. (Basic Toxicity Classification of Radionuclides, IAEA Technical Report Series 15, 1963).

37. Cesium-137 (half life of 30.1 years) has been assigned to the Medium-Toxicity (Upper Sub-Group A) category of radionuclides by the International Atomic Energy Agency. (Basic Toxicity Classification of Radionuclides, IAEA Technical Report Series 15, 1963).

52. The term "soft steel" may be misleading. The generic name applied to the steels used to fabricate SRP high-level waste tanks is "carbon steel". More precisely, the steels can be specified in terms of ASTM Standard designations. The tensile strengths of carbon steels used in SRP waste tanks (all are pressure-vessel quality steels) are similar to tensile strengths of austenitic stainless steels used in the waste storage tanks at the Idaho National Engineering Laboratory in INEL tanks as shown below.

ASTM Designation Carbon Steels	Tensile Strength, lbs. per sq. in. Range or Minimum
A 285-Grade B	50,000 - 70,000
A 516-70	70,000 - 90,000
A 537-Class 1 (normalized)	70,000 - 90,000

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* Comments are numbered to correspond with the numeration of the paragraphs in the complaint.

ASTM Designation Carbon Steels	Tensile Strength, lbs. per sq. in Range or Minimum
Austenitic Stainless Steels	
A 479* Types 304L and 316L	70,000
Type 348	75,000

* Current ASTM Standard for stainless steel plates for pressure vessels.

Selection of steel for waste tank construction has been studied extensively at the Savannah River Plant. Both carbon steels and austenitic stainless steels have been considered in recent years for tank fabrication. Based on technical and economic reasons carbon steel was selected as the material of construction for SRP tanks (see Items 68 and 69).

The steel used in the early SRP tanks was A 285-Grade B, and the fabricated tanks were not stress-relieved. These are the only tanks that have experienced nitrate stress corrosion cracking. Waste tanks constructed at SRP since 1967 were made of A 516-70 and were stress-relieved after erection. The steel for tanks funded in FY 1974 and FY 1975 is A 516-70 in the normalized condition. Normalizing is a heat treatment (analogous to annealing) that refines the grain size and improves the toughness of the steel plates. A 537-Class 1 steel is specified for the FY 1976 and 1977 tanks. This steel is supplied only in the normalized condition, and the chemical composition is very similar to A 516-70, except that the specifications on impurities are tighter to ensure more uniform properties among multiple batches of steel.

54. Eight of the sixteen original SRP waste tanks have experienced some leakage from the primary tank to the annular space inside the secondary container. All these eight tanks were built prior to 1960 of A 285 Grade B steel and not stress relieved after fabrication (see Item 52). The leaks occur through small hairline cracks, usually adjacent to welds. The rate of leakage was very slow (<0.05 gal/min) except from Tank 16. In that tank minor leakage was detected in November 1959 from the primary tank to the annular space inside the secondary container (steel pan) and concrete vault. Subsequently, during September of 1960, a large number of very small leaks resulted in a leak rate reaching a maximum of about 4 gal/min. The level of waste in the annular space exceeded the 5-foot height of the steel pan for an estimated period of six hours while a transfer jet was being installed in the annulus to remove the leaked waste. Some waste overflowed into the space between the concrete vault and the steel pan. Leakage from the primary tank was stopped by reducing the liquid level inside the tank below the major leak sites.

A maximum of 700 gallons of alkaline waste rose above the top of the 5-foot-high steel pan liner of Tank 16. Intensive investigation and monitoring over the intervening years confirm that most of the 700 gallons was contained in the concrete vault and the quantity of waste leakage into the soil was limited to a few tens of gallons of waste containing about 7 Ci of radioactivity per gallon (primarily ^{137}Cs). Because the tank bottom is below the surface of the near-surface water table, the radioactivity that reached the soil also immediately reached the ground water. The soil contains clay with a significant ion exchange capacity, and consequently during the ensuing period the radioactivity has moved only a few additional feet. The limited migration has been confirmed by extensive sampling and testing with encased wells. The radioactivity level in the ground water 15 feet from the edge of the concrete pad under Tank 16 is about 10 times the normal background of 5 to 15 pCi/l (the Concentration Guide for ^{137}Cs in drinking water is 2×10^4 pCi/l) and between 2×10^{-4} and 4×10^{-4} Ci of radioactivity is estimated to have moved beyond this point. Continued use of Tank 16 was restricted to a reduced volume (below the worst cracks) until it was removed from liquid storage service in early 1972. Further details on leakage from Tank 16 are given in DP-1358.

To prevent possible future accumulation of liquid waste in the annular space, jets of 75 gal/min capacity are installed in the annular space of each high-level waste tank so that liquid waste may be rapidly returned to the storage tank. All tank annuli are purged with air to dehumidify the space and evaporate any leakage to dry, immobile salt.

56. SRP has demonstrated the capability to safely remove sludges and salt cake from SRP waste tanks. Salt cake in SRP tanks can be redissolved in water, and transfer of the resultant solution from one tank to another is a routine SRP operation. Sludge was first resuspended and pumped from a waste tank in 1966 by slurrying with water. Sludge has been also slurried from several other waste tanks since then. In addition, a more cost-effective technique for slurrying the sludge with supernate is being developed and a demonstration with actual waste is planned. Chemical techniques are being developed for final cleaning of retired waste tanks and a demonstration in a cracked waste tank is being planned.

Salt and sludge can also be removed safely from leaking waste tanks. As indicated in response to Item 54, leaks from SRP waste tanks have resulted from small hairline cracks in the primary tank. These small cracks would not interfere with salt or sludge removal. Should complete failure of the primary tank occur, the secondary tank will serve to contain the tank contents during salt or sludge removal.

A process is being developed for solidifying and packaging of SRP waste for long-term storage. The waste will be converted to a solid form that is highly resistant to dispersion to the environment. The

development program is described in the document, "Integrated Radioactive Waste Management Plan for the Savannah River Plant" (SRO-TWM-76-1). No technical obstacles have been identified that would prevent solidification and packaging of SRP high-level waste for long-term storage

58,59,76. Although WASH-1528 (issued in April 1973) indicated that the waste may remain in SRP tanks through 1999, Savannah River is now planning to remove high-level waste from the tanks at an earlier date. Schedules for several of the options for long-term management of SRP waste show waste solidification to begin in 1987. During the solidification period, waste tanks will be emptied on a scheduled basis to limit high-level waste storage in tanks funded in FY 1976, FY 1977 or in future years to a period of less than 20 years. Other waste management options are also available to meet the schedule of removing the high-level waste from these tanks within 20 years. If a long-term repository is not available to receive the waste, the solidified encapsulated waste could be temporarily and retrievably stored in an environmentally safe facility until the long-term storage facility is completed.

60. SRP waste tanks do not have domes. The Savannah River Plant Type III waste tank design, developed in 1966, and continually refined since then, includes a steel-reinforced concrete center column 6 feet in diameter that supports the 4-foot-thick reinforced concrete roof slab. The flat 1/2-inch-thick steel roof plates of the tank are pinned to the concrete roof slab to ensure the highest possible structural integrity. Collapse of the roof slab of SRP tanks has a very low probability of occurrence.

61.+ Salt cake is no more corrosive than the liquid high-level waste. This has been demonstrated through experience with waste tanks at SRP in which salt cake has been stored since 1960. Literature survey and laboratory studies substantiate this experience. Stress corrosion cracking can be caused by either strong NO_3^- or strong OH^- concentrations. Cracking by either anion is inhibited by the presence of small amounts of the other one. NO_2^- also acts as an inhibiting agent. In the case of the waste tanks which are known to have cracked due to stress corrosion, the cause was a high concentration of NO_3^- and relatively low concentrations of OH^- and NO_2^- in fresh waste. As the waste solutions age, radiolytic decomposition of the NO_3^- occurs, converting it to NO_2^- and rendering the waste solution less aggressive. During cyrstallization of waste, the interstitial liquor becomes more concentrated in OH^- as the NO_3^- and NO_2^- crystallize in the salt receiver tank. Samples of the "terminal liquor" have been analyzed to contain 9M OH^-, 2M NO_3^-, and 1M NO_2^-. Laboratory studies indicate that this liquid (with its high OH^- concentration) is stabilized by the NO_3^- and NO_2^- concentration and should not cause stress cracking of the waste tanks.

+ Reply may require coordination with Hanford.

Salt cake has a higher density than liquid waste. The amount of salt stored in a tank is limited so that its weight does not exceed the design specification of the tank.

62. Meltdown of SRP tanks resulting from a loss of coolant is incredible. The waste tanks are equipped with cooling coils in multiple headers to remove radiolytic heat. A failure of one or more coil headers will not affect the operation of other coils. Twice as many coils as are necessary to cool the waste are installed as a contingency against multiple failure. In addition three other safety provisions have been included in the tank design. These are 1) forced air cooling of the external surfaces of the primary tank, 2) access ports in the tank roof to allow insertion of supplementary cooling coil bundles, and 3) the condenser in the tank ventilation system which returns condensate to the tank. If all of the backup cooling systems were entirely lost for a tank containing the maximum heat content waste, four to ten days would be required before the contents of the waste would reach boiling. During this time the waste could be transferred to a tank with adequate cooling.

63-64. There has been no evidence of stress corrosion cracking on the bottom of SRP tanks. Bottoms of new tanks are specified to be flat within 3 inches with no more than a 0.33-inch-per-foot slope on any distortion. Out-of-flatness experience for all recent primary tank bottoms has been less than half the specified maximum.

65.+ a. Generalized corrosion is minimal in SRP waste tanks. Wall thickness measurements on ten tanks, and measurements of the bottom plate thickness on two tanks have shown no wall thinning due to general corrosion. Test coupons exposed in synthetic and actual waste solution showed pitting-type corrosion to be insignificant (rates of less than 2.5×10^{-3} cm/year). Examination of one of the cracked tanks showed that the stress-corrosion cracks originated on the internal surfaces and that corrosion on the external surface of the steel was minor. Based on these measurements corrosion is insignificant. The thickness of the steel, as determined from working stresses in the tank walls, is considered to be adequate.

b. As indicated in item 52, the carbon steel specification for waste tanks at SRP was changed when stress corrosion cracking was detected. Fabrication techniques were also revised to minimize stress corrosion by a stress relieving heat treatment of the fabricated primary vessel. The steel specifications have been revised further so that the plates are supplied in the normalized condition.

c. Cathodic protection for SRP waste tanks was considered in 1971 and 1972. A consulting firm concluded that cathodic protection was feasible contingent on the results of additional studies to

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1) determine effects of cathodic protection on tanks containing salt

2) develop anode material and design for a workable system

3) develop anode supports and seals

These additional studies relate to the engineering and maintenance considerations of ensuring proper electrical potential and current distribution.

Other problems were identified by SRP. These included

1) differences in electrical conductivity of waste supernate, salt cake, and sludge would prevent uniform distribution of current flow over the inner surface of a tank,

2) the integrity of the electrical insulation between the system anodes and the tank could not be ensured over a period of years,

3) stray electrical currents that might develop could actually accelerate localized corrosion in tanks.

The benefits of cathodic protection for waste tanks was judged by SRP to be small in comparison to the uncertainties and problems of installing such a system. As a result of the advances in tank construction - improved materials and construction technique (stress relief of finished tanks) - and better understanding and definition of the characteristics of SRP waste that caused corrosion problems in waste tanks, development of the information necessary to implement cathodic protection was not judged to be necessary. Reliance was continued on use of the more resistant steels and improved tank designs for long-term protection.

d. As indicated in Items 63-64, design, construction and testing specifications for these waste tanks are developed through extensive analysis by specialists and consultants. These specifications are revised as necessary to ensure that SRP tanks incorporate all relevant and proven technology to ensure tank dependability.

66. a. The long-shafted pumps that can be used to remove liquid waste, redissolve salt, or slurry sludge from SRP waste tanks are designed to fit into any tank riser larger than two feet. The SRP Type III waste tanks contain numerous access risers larger than this two-foot diameter. Pumping of all these waste products has been demonstrated in existing SRP waste tanks as described in items 56, 67 and 73.

b. Internal tank cooling coils are a standard part of waste tank design for removing radioactive decay heat from high-heat waste tanks at SRP.

67[+], 75.[+] SRP tanks funded for FY 1976 and FY 1977 incorporate in their design and construction all relevant and proven technology currently available to ensure tank integrity over many decades, although they are scheduled to be used for storage of high-level waste for less than 20 years. Tanks and associated equipment are designed with a large factor of safety. They will not be subjected to all the adverse conditions allowed for and should be serviceable for a much longer period than their design life. In the very unlikely event that a tank deteriorates to a point of questionable adequacy before its planned retirement, waste will be transferred from it to another tank (see item 56).

68[+], 69.[+] The life expectancy of waste storage tanks made either of stainless steel or carbon steel depends on operational and environmental factors and ability to control those factors. Carbon steel and stainless steel suitable for waste tank construction have similar strengths (see item 52). Austenitic stainless steel of the type used for waste storage is susceptible under specific conditions to the same forms of corrosion that can damage carbon steels. Austenitic stainless steels are susceptible to stress corrosion cracking by chlorides and by caustic; fluoride ions are also known to have caused cracking. Pitting and/or intergranular corrosion (especially in weld heat-affected zones) can occur due to chlorides, fluorides, nitrates, chromates, and other ionic chemical species. Therefore, the specific chemical nature of waste being stored and changes that occur for any reason during storage must be known and must be amenable to adjustment so that conditions corrosive to the steels are avoided. We have a high level of confidence in the longevity of the new carbon steel tank. A similar level of confidence could be obtained for stainless steel tanks only after extensive tests with SRP waste.

INEL is able to maintain tank temperatures at about 35°C because of the low levels of radioactivity in its wastes compared to SRP. This 35°C temperature prevents attack by fluorides that are present. An extraordinarily large cooling capacity would be required to maintain SRP high-level tanks at this low temperature.

Storage of SRP wastes as acid solutions in stainless steel tanks has been evaluated as an alternative to the present neutralized waste system. Safety, technical and economic considerations were included in these evaluations. Acidic waste from SRP processing would involve storing of solids; the amount of solids might be as high as 0.1% (by weight) of the fuel processed. It was concluded that storage of liquid waste in either mode was probably feasible. The risk of either system could be reduced to negligible levels by adequate design and engineered safeguards. The stress corrosion cracking observed previously in carbon steel tanks would not have occurred had they been stress relived and protected by hydroxide and nitrite ion which are stress corrosion inhibitors. Although either system would provide adequate safety, the neutralized wastes possess certain inherent safety advantages for SRP; namely, the inclusion of the majority of radionuclides in an insoluble and relatively immobile sludge phase and negligible mobility of neutralized

+ Reply may require coordination with Hanford.

waste in SRP soil due to soil pluggage by hydroxide ion. Since there were no safety advantages for the stainless steel tanks at SRP, the decision between the two systems was made in favor of continued use of carbon steel tanks.

71. The Savannah River Plant waste tanks funded for FY 1976 and FY 1977 are adequately and properly designed to meet their objective of safe, short-term storage of waste. They will effectively contain the waste, and therefore, their use will not impose a risk to the public from the release of radionuclides. Design of the tanks represents the combined efforts of competent engineers, designers, and consultants. The tank fabricator is selected from among only the most capable industrial tank fabricators in the United States. (see also items 65 b, 67 and 75).

72. In the event that waste leaked from the tanks into the ground, it would not enter the Tuscaloosa aquifer. The near-surface ground water at the tank farms is isolated from the deeper Tuscaloosa aquifer. The near-surface ground water in the vicinity of the tanks is entirely contained on the site. The large Tuscaloosa aquifer is 300 feet deeper than the near-surface ground water, separated by several nearly impermeable clay barriers, and is at a higher artesian pressure than the ground water exposed to the waste tanks. Thus, flow of contaminated ground water could not reach the Tuscaloosa aquifer. Radionuclides that enter the near-surface ground water would decay to permissible levels before reaching the nearest creek because of low ground water velocity and ion exchange characteristics of the soil (see item 54).

73.+ There is neither intention nor need to remove waste from SRP tanks by direct contact or mechanical mining methods; aqueous dissolution and hydraulic slurrying techniques have been demonstrated as discussed in items 56 and 67. Worker exposure to radiation is minimized by adequate shielding, and will be maintained well within permissible guidelines. Access openings (risers) through the tank tops are provided to allow installation of waste removal equipment when needed. Installation of much of this equipment, particularly the submerged slurrying pumps, before it is to be used is impractical because of potential plugging and other deterioration incurred during the time while the tanks are serving their intended function of safe waste storage. However, each SRP tank in liquid waste service is provided with the facilities required for prompt removal of the tank liquid should this become necessary for either routine or emergency reasons.

74.+ Seismic analyses are an integral part of SRP waste tank design. Consultants recognized for their competence in earthquake phenomenon participated in the design of Type III waste tanks. Analyses have shown that the Type III waste tank, with a 4-foot-thick steel-reinforced concrete roof and a 6-foot diameter steel-reinforced

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+ Reply may require coordination with Hanford.

concrete center column, will maintain functional integrity in an earthquake producing ground acceleration of 0.2 g. This design criterion is 4 times the acceleration estimated to have occurred at the SRP site in the 1886 earthquake at Charleston, South Carolina.

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DPST-83-829
Vol. I

TECHNICAL SUMMARY OF GROUNDWATER QUALITY PROTECTION PROGRAM AT SAVANNAH RIVER PLANT

VOLUME I - SITE GEOHYDROLOGY, AND SOLID AND HAZARDOUS WASTES

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1.0 EXECUTIVE SUMMARY

The program for protecting the quality of groundwater underlying the Savannah River Plant (SRP) is described in this technical summary report. The report is divided into two volumes. Volume I contains a discussion of the general site geohydrology and of both active and inactive sites used for disposal of solid and hazardous wastes. Volume II includes a discussion of radioactive waste disposal. Most information contained in these two volumes is current as of December 1983.

The groundwater quality protection program has several elements which, taken collectively, are designed to achieve three major goals. These goals are to evaluate the impact on groundwater quality as a result of SRP operations, to restore or protect groundwater quality by taking corrective action as necessary, and to ensure disposal of waste materials in accordance with regulatory guidelines.

The Savannah River Plant is located in the Upper Atlantic Coastal Plain, about 20 miles southeast of the Fall Line, which separates the Piedmont and Coastal Plain provinces. The Savannah River Plant is on the Aiken Plateau, a comparatively flat surface that slopes southeastward but is dissected by several tributaries to the Savannah River. This surface is underlain by about 1000 feet of unconsolidated sands, clayey sands, and sandy clays, which in turn are underlain by dense crystalline metamorphic rock or consolidated red mudstone. The geologic terminology in southwestern South Carolina has been undergoing change since 1978. Until this terminology stabilizes, the following stratigraphic names in ascending order are used for groundwater discussions in this report (the numbers in parentheses represent average thickness):

- Tuscaloosa Formation - consisting of a basal confining bed (~40 ft), a basal aquifer (~300 ft), a middle confining bed (~40 ft), an upper aquifer (~150 ft), and an upper confining bed (~60 ft).

- Ellenton Formation - partly constituting an aquifer and partly a regional confining bed (~60 ft).

- Congaree Formation - partly constituting an aquifer (~120 ft).

- McBean Formation - made up of a lower unit of calcareous sand and an upper unit of clayey sand (~80 ft), and separated from the Congaree by a "Green Clay" confining bed.

- Barnwell Formation - composed of a coarse clayey sand and compact sandy clay (~100 ft) and generally separated from the McBean by a "Tan Clay" semi-confining bed.

- Hawthorn Formation and Surficial Formations - usually unsaturated sediments that are not regionally important as aquifers.

The two aquifers in the Tuscaloosa Formation are used separately and in combination to obtain yields of greater than 1000 gallons per minute to properly designed and constructed wells. The Congaree Formation also contains sands that yield a few hundred gallons per minute in many locations. Apart from these two aquifers, most of the rest of the Coastal Plain sediments transmit water on a regional scale, but do not yield water to wells in sufficient quantity to be classified as primary aquifers. A few dug wells and some low yield drilled wells exist in the Barnwell and McBean Formations; thus, these formations could marginally be classified as aquifers. The confining beds retard the interchange of water between formations, but do not totally prevent it.

The direction of groundwater movement is governed largely by the depth of incision of the creeks that dissect the Aiken Plateau. Small creek valleys govern the groundwater flow directions in the shallow sediments, the valleys of major tributaries to the Savannah River govern the flow direction in the sediments of intermediate depth, and the flow in the deep sediments is governed by the valley of the Savannah River itself. Groundwater in the Tuscaloosa aquifer flows toward the Savannah River, and that in the Congaree flows toward Upper Three Runs Creek or the Savannah River depending on its location. In several locations, dissection by creek valleys, particularly of the Barnwell, McBean, and Congaree Formations create groundwater subunits or islands, such that groundwater in one subunit of a particular formation is confined to that subunit and cannot pass to another subunit by lateral flow in that formation.

In the northwestern part of SRP, groundwater head decreases with depth, providing the potential for recharge from the surface to penetrate to the deeper formations. However, in the vicinity of the valleys of Upper Three Runs Creek and the Savannah River, the water levels in the Congaree Formation are drawn down by natural discharge to a greater extent than those in the Tuscaloosa Formation. Thus, there is a head reversal at the Congaree Formation and the vertical groundwater gradients below this formation are upward.

Water levels in the Tuscaloosa Formation fluctuate with rainfall; however, in the past five years, water levels have fallen to a degree that cannot be totally correlated with rainfall. Pumpage for irrigation in Allendale and Barnwell Counties has increased greatly during this period. In addition, the pumpage at the Savannah River Plant has also increased during this period. The head reversal at the Congaree Formation near the central part of the plant has not disappeared due to the falling water levels, but it has decreased.

Some 153 individual waste sites used for the disposal of a variety of hazardous, solid, and radioactive materials have been identified within the boundaries of SRP. The waste sites are located in over 100 separate areas around the plant and the majority can be categorized in general groupings of basins, pits, and piles. Of the 153 separate waste sites, some 118 contain only nonradioactive waste materials, and 20 have been used as disposal sites for only radioactive wastes. The nonradioactive wastes may be comprised of materials classified as solid, hazardous (as defined by state and federal regulatory agencies), or a combination of both. Fifteen sites have been used as disposal locations for both nonradioactive and radioactive wastes, referred to as mixed wastes when the nonradioactive component contains hazardous substances.

Process effluents from the fuel and target fabrication area (M Area) have been discharged to a settling basin since 1958. Metal-degreasing solvents (volatile chlorinated hydrocarbons) have seeped into the ground from the settling basin and from leaks along the process sewer line and entered the shallow groundwater system. The plume of chlorocarbons in the groundwater is being mapped through an extensive exploratory well drilling program. Remedial measures for removing the contaminated groundwater and separating the organics are being developed. An effluent treatment facility is planned to allow discontinued use of the basin by March 1985.

The CMP pits were operated from 1971 to 1979 as a disposal site for chemicals, metals, and pesticides. Volatile organics have been detected in the groundwater in the vicinity of the pits. Plans are being made for removal of the buried waste, as well as any highly contaminated soil, from the pits. The groundwater is being monitored and additional exploratory wells for further investigation are being installed.

The old TNX seepage basin operated from 1958 to 1980 to receive wastes from pilot scale experiments. The basin was then filled with soil and clay capped. Uranium settled out in the bottom of the basin and mercury has been found in the groundwater in the vicinity of the basin. A comprehensive program for defining the spatial extent of contamination at the basin is underway. Additional closure action may be required. A new TNX seepage basin has been in operation since 1980. A project to control the pH of process wastewater released to the new basin is being developed. An effluent treatment facility is planned for this new basin, and subsequent to operation of the treatment facility the basin will be closed.

The separations area seepage basins which have been operational since 1955 receive mainly condensate from various evaporators in the chemical separations facilities and waste management operations. Chemical constituents in the wastewater have seeped into the groundwater beneath the basins. Plumes of nitrates and mercury have been mapped and are moving in the groundwater and

outcropping in small concentrations into surface streams. A program to refine the spatial extent of hazardous and radioactive contaminants in the vicinity of the seepage basins is planned. Development of treatment facilities for removing chromium, mercury, and other chemicals to allow discharge to surface streams is under way.

The Savannah River Laboratory seepage basins received discharges from laboratory sinks from 1954 to 1982. Certain metals, inorganic ions, and volatile organics have been detected in groundwater from monitoring wells around the basins. A program to define the spatial extent of contamination in the soils and groundwater beneath the basins has been initiated. A final closure plan for the basins will be developed after the contamination has been defined.

General waste materials including metal shavings, wood, bricks, concrete, drums, tires, etc, were discarded at the Silverton Road waste site from unknown sources up to 1974. The wastes were covered by bulldozing. Very low levels of volatile organics have been detected in the shallow groundwater in the vicinity of the site. Exploratory wells have been installed to further define migration of organic solvents in the groundwater. The installation of a clay cap over the waste site to reduce percolation of water through the scrap materials is being considered as a possible closure action.

A burial ground for solid radioactive waste has been in operation since 1953. The burial site is divided into sections for accommodating various levels and types of radioactivity in waste materials. Mercury in polyethylene bottles and degraded solvent containing traces of metals which have been collected in storage tanks both have been buried at the site. No evidence of mercury migration has been observed. There are no known leaks from the solvent storage tanks. Monitoring of groundwater for nonradioactive materials at the burial ground is continuing. Groundwater monitoring in the burial ground for radioactive isotopes is discussed in Volume II.

A basin at the L-Reactor site for receiving oil and chemicals from equipment cleaning was operated from 1961 to 1977. Monitoring of groundwater in the vicinity of the basin indicates that waste chemicals and oils have not migrated to the water table. Groundwater monitoring is continuing.

Coal pile runoff containment basins are located at seven different sites throughout SRP. Acid from oxidation of sulfur materials in the coal is washed by rain into the runoff basins. Monitoring of the groundwater at the seven basins shows concentrations of some heavy metals above background levels. Groundwater monitoring is continuing.

The metallurgical laboratory basin has received waste effluent from 723-A metallurgical laboratory since 1956. A wide range of chemicals have been discharged to the basin. Monitoring wells have been installed to determine the groundwater quality at the basin. Water quality sample results are not yet available.

The Ford Building seepage basin was constructed in 1964 and has been used since then for disposal of liquids from heat exchanger testing. The installation of monitoring wells has been completed and analyses will be available in 1984.

The Road A chemical basin near K Area was used until 1973 for disposal of chemical substances for which there are no inventory records. Monitoring wells have been installed but analyses of groundwater quality are not yet available. Further action depends on results of water quality analyses.

Waste oil products have been discharged to three basins at SRP. None of these basins is still in use. Installation of monitoring wells at all basins has been completed. These wells will be monitored to determine any environmental impact.

Hydroflouric acid was spilled onto the ground west of the Central Shops Area sometime prior to 1970. The spill area was isolated and has not received additional waste material. Groundwater monitoring wells have been installed and will be analyzed for water quality.

Burning pits were used to dispose of ignitable waste from 1951 to 1973 at fifteen locations. Each pit was then filled with rubble (paper, lumber, cans, barrels, etc.) and covered with a layer of soil. Monitoring wells have been installed at all burning/rubble pits and further action depends on groundwater quality analyses.

Basins located in the major production areas have been used to receive sulfuric acid and sodium hydroxide solutions from regeneration of ion exchange units. Neutralization systems installed in 1982 eliminated the need for these acid/caustic basins so they all were removed from service but remain open. Installation of monitoring wells at all basins has been completed to determine groundwater quality. Further action depends on water quality analyses.

A metals burning pit was used to incinerate reactive metals from 1952 to 1974. Groundwater monitoring wells have been installed at the pit. Any additional action will be defined after evaluation of groundwater quality analyses.

Four pits have been used to receive asbestos material, and all but one have been closed. There are no groundwater monitoring wells at these asbestos pits and none are planned. Asbestos is basically insoluble and should pose no threat to groundwater quality.

Ten ash basins and five ash piles have been used for disposal of coal ash from powerhouse operations. Monitoring wells have been installed at the K-Area ash basin to provide information on groundwater quality. Monitoring wells at the other ash basins/piles are not planned. There are no plans to discontinue the use of ash basins/piles.

A sanitary landfill opened in 1973 is operated for disposal of burnable wastes plus aerosol cans, food waste, and asbestos in bags. Fifteen monitoring wells have been installed at the landfill site to collect groundwater quality data.

The remaining quantities of solid and hazardous wastes are categorized into 17 groupings. These waste sites are of lesser significance and are not expected to pose any threat to groundwater quality.

As discussed in Volume II, radioactive wastes have been managed through a program of storage and controlled release to the environment. The fate of radioactive wastes at the 35 individual waste sites is discussed under 7 general groupings. The waste site categories which have received radioactive wastes are the separations area seepage basins, Savannah River Laboratory seepage basins, radioactive waste burial grounds, reactor seepage basins, L-Area oil and chemical basin, Ford Building seepage basin, and separations area retention basins.

A ranking technique has been used to evaluate the hazardous and solid waste sites. Over 40 different attributes related to the waste type and physical characteristics of each site were evaluated. A priority listing has been developed for two general classifications of waste sites: those with groundwater monitoring and those without groundwater monitoring. The major conclusions are:

- The M-Area settling basin has the highest priority for attention to groundwater quality protection
- The old TNX seepage basin ranked second on such a priority listing for waste sites.
- Many waste sites without groundwater monitoring require the installation of wells for collecting water quality data or collection of water quality data from recently installed wells to establish the basis for further action.

2.0 INTRODUCTION

The policy governing production operations at the Savannah River Plant has always been to protect the environment, and the safety and health of the public and operating personnel. Pursuant to this policy is a program for protecting the quality of groundwater underlying the Savannah River Plant (SRP). The major goals of the groundwater protection program are to evaluate the impact on groundwater quality as a result of SRP operations, to take corrective measures as required to restore or protect groundwater quality, and to ensure disposal of waste materials in accordance with current regulatory guidelines. The specific program elements for accomplishing these goals are listed below.

- Identify and prioritize waste sites according to the order in which they warrant consideration.
- Gather geohydrologic data to define groundwater conditions and stratigraphy.
- Collect groundwater quality data and identify sites with potential or known environmental impact.
- Develop remedial action strategies as required based on evaluation of groundwater monitoring results and projected environmental impact of waste substances in the ground.
- Implement remedial action as required to restore or protect groundwater quality.
- Review current waste disposal practices for potential impact on groundwater resources.
- Reduce discharge of waste materials to the environment through process modifications and improved technologies.

This report contains a summary description of these elements which comprise the groundwater quality protection program.

The Savannah River Plant is a major installation of the Department of Energy for producing nuclear materials for national defense. Hazardous, solid, and radioactive wastes are generated as byproducts of production operations. The fate and impact of hazardous and solid wastes are discussed in Volume I of this report. The control of radioactive wastes at SRP is discussed in an environmental impact statement (ERDA-1537) and a supplement document (DOE/EIS-0062) which assess environmental effects associated with radioactive waste management operations at the site. An updated discussion on disposal of radioactive wastes is included in Volume II of this report.

Waste disposal practices have changed at SRP, as they have throughout the United States, in the past thirty years. Wastes generated at SRP have always been discarded in accordance with accepted practices at the time. As substances were identified as toxic in nature or classified as hazardous, the procedures for disposal of these materials were changed. The use of many chemicals was discontinued after such reclassification. Several locations at SRP have been used as waste disposal sites for a variety of materials. Many of these facilities were closed as changes were made in the acceptable methods of disposal. Groundwater monitoring activities were initiated at some of the waste sites, both active and inactive, to assess potential impacts on groundwater quality. Additional monitoring wells were installed in response to the hazardous waste regulations promulgated by the South Carolina Department of Health and Environmental Control.

This report is intended to summarize the program for protecting the quality of groundwater at SRP. Information is current as of December 1983. Supplemental documentation will be issued to provide more details as the program proceeds and additional information is obtained.

3.0 CHARACTERIZATION OF SITE GEOLOGY AND HYDROLOGY

3.1 REGIONAL GEOLOGY AND PHYSIOGRAPHY

The Savannah River Plant (SRP) is located in the Upper Atlantic Coastal Plain, about 20 miles southeast of the Fall Line, which separates the Piedmont and Coastal Plain provinces (Figure 3-1). The Coastal Plain is underlain by a wedge of seaward-dipping unconsolidated and semiconsolidated sediments which increase in thickness from zero at the Fall Line to greater than 3,100 ft near the coast of South Carolina.[1] This sedimentary wedge, which ranges in age from Late Cretaceous (~100 million years) to Holocene, continues to the seaward edge of the Continental Shelf.

The Atlantic Coastal Plain extends from Massachusetts to Florida where it merges with the Gulf Coastal Plain, which extends westward to Texas. The topographic surface of the Coastal Plain slopes gently seaward as do the geologic units underlying this surface.

The Savannah River Plant lies on the Aiken Plateau as defined by Cooke.[2] The Aiken Plateau is bounded by the Savannah and Congaree Rivers (Figure 3-1), and slopes from an elevation of 650 ft at the Fall Line to an elevation of about 250 ft. The surface of the Aiken Plateau is highly dissected and is characterized by broad interfluvial areas with narrow steep-sided valleys. Relief is locally as much as 300 ft.[3] The Plateau is generally well drained although small poorly drained depressions occur.

The Savannah and Congaree Rivers are the largest in the region. The Savannah River forms the boundary between South Carolina and Georgia. The river has a flood plain 4 to 5 miles wide downstream from Augusta and a stream gradient of about one foot per mile opposite the SRP.

Between the Savannah and the Congaree Rivers are the North and South Forks of the Edisto River and the Salkehatchie River. Both of these rivers originate on the Coastal Plain and flow southeastward into the Atlantic Ocean. These rivers do not incise their valleys as deeply into the sediments as do the Savannah and Congaree Rivers.

On the Aiken Plateau there are several southwest flowing tributaries to the Savannah River. From the Fall Line these are Horse Creek, Hollow Creek, Upper Three Runs Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek (Figure 3-2).

These creeks, which flow southwestward to join the Savannah River, commonly have asymmetrical valleys with the northwest side being of gentle topographic slope and the southeast side being steeper. It is inferred that the asymmetrical shape is caused by the fact that the course of the creeks is generally parallel to the strike of the Coastal Plain formations and the northwest side approximates a dip slope. Thus, the topography takes the form of a series of mild cuestas.

The sediments of the Atlantic Coastal Plain in South Carolina are stratified gravel, sand, clay, and limestone which dip-gently seaward; although, there are local variations in dip and thickness due to locally variable depositional regimes. The base of the Coastal Plain sediments lies on the weathered surface of the crystalline metamorphic rock that dips at about 36 ft per mile from the Fall Line. Imbedded in basins in the crystalline metamorphic rock is at least one sedimentary basin of Triassic age. The basin is comprised of sedimentary rocks that are buff to maroon in color and contain poorly-sorted sands and clays. The erosional surface on the crystalline metamorphic rock is continuous across the Triassic basin and has a very low relief.

The structural setting of the Atlantic Coastal Plain is a monoclinal dip of ~9 to 36 ft per mile to the southeast with some local variations. The Triassic basins beneath the Coastal Plain were created by tensional rifting and erosion from fault block mountains and deposition into fault block valleys, much as is occurring today in the Basin and Range province of Utah and Nevada.

During the deposition of the Coastal Plain sediments there was no large-scale faulting due either to tension or compression. However, recent detailed examination has shown some small-scale thrust faulting (on the order of 100 ft displacement) near the Fall Line (Belair Fault). Other compressional faults have been indicated by geophysical methods in the subsurface beneath the Lower Coastal Plain and the Continental Shelf.[4,5] Drilling at SRP[6] has revealed that interpretation of reflection seismic records is sometimes misleading due to lensing of reflective layers in the Coastal Plain sediments.

In February 1982 the U.S. Geological Survey released an Open File Report (82-156) that suggested that there was a fault affecting a substantial thickness of the Coastal Plain sediments (700 ft of displacement at the base of the Coastal Plain sediments decreasing to 40 ft in the Eocene sediments). This postulated fault was also invoked to explain certain spatial head relationships in the Coastal Plain sediments although the authors admitted that the more conventional interpretation was possible. Subsequent detailed work by Georgia Power Co. indicated that a fault of this magnitude does

not exist and that the more conventional interpretation of the head relationships is satisfactory. Neither geophysical nor hydrologic work at SRP has indicated the existence of a fault of this magnitude.

3.2 REGIONAL HYDROLOGY

Water moves through the ground from areas of high potential energy (usually measured by the combined elevation and pressure heads) to areas of lower energy. In general, on the Atlantic Coastal Plain, this involves moving seaward from the higher areas of the Aiken Plateau toward the Continental Shelf. Because most sedimentary units become finer grained toward the coast this movement becomes exceedingly slow. Of major significance is the modification from this general southeastward movement caused by the incision of the Savannah and Congaree Rivers. Water in the regions of these rivers is diverted toward the hydraulic-energy low caused by discharge to the surface in these river valleys. SRP is totally on the Savannah River side of the groundwater divide that occurs between these two rivers. Thus, in most of the discussions to follow, directions of flow will be determined by the relationship of the groundwater to the Savannah River Valley.

The depth of dissection by the southwestward flowing tributaries has a significant influence on the direction of flow in most hydrostratigraphic units. In general, the direction of flow in the shallow groundwater is most affected by small tributaries, deeper groundwater by major tributaries, and deepest groundwater only by the Savannah River itself. It is not unusual to have the deepest groundwater moving at right angles or even in the opposite direction to the shallow groundwater at a particular location.

The depth to the water table (the beginning of the saturated zone, below which all pores are filled with water and above which pores are partially filled with air) ranges from zero to about 125 ft below the surface. The depth to the water table is dependant on the horizontal and vertical hydraulic conductivity as well as the topography. In some places where interbedded clays are common, they tend to impede the vertical movement of water in the saturated zone and a shallow water table exists. In other places where these clays are not present, the water table may be very deep. The water table in general is a subdued replica of the land surface; however, it generally slopes more gently than the land surface. Thus, deeper water tables commonly exist near the cuesta face of the asymmetrical tributary creek valleys, i.e., the southeast side of the valleys; whereas shallower water tables exist on the northwest side.

As used in this report, the SRP vicinity extends only to those distances that could have a cause-effect relationship to groundwater at SRP. This distance ranges from about 40 miles from the center of the plant in a northerly direction to about 20 miles in a southeasterly direction. Even though the geologic names used for some of the water-bearing units at SRP extend to great distances, the hydrologic relationships do not. Thus, the hydrologic region is much more restricted than the geologic region.

The Coastal Plain sediments constitute a multilayer hydrologic system in which there are retarding beds and beds that transmit water more readily. Hydraulic properties vary for each of the hydrostratigraphic units, depending on their lithology. Groundwater flow paths and flow velocities for each of these units are governed by the hydraulic properties, by the geometry of the particular unit, and by the distribution of recharge and discharge in the area.

Because of the sandy nature of the sediments and the comparatively short residence time of groundwater (centuries), the water in the Coastal Plain sediments is low in dissolved solids. Most of the waters have a low pH (about 5.5) and are generally corrosive to metal surfaces.

3.3 TERMINOLOGY

In order to discuss the geology and hydrology of the region and of the Savannah River Plant specifically, it is necessary to designate parts of the geologic column with names. Historically, the criteria for designating geologic units with names is well established, but in practical application, this topic is sometimes confusing. Ideally, each geologic unit should have a set of physical and visually observable characteristics that distinguish it from other units in the area. When a geologic unit has such a set of characteristics and is thick enough and extensive enough to be shown on the usual scale of geologic mapping, it is called a "formation" and receives a formal name. These names are designated and accepted through publication in the open refereed literature according to certain rules.

One of the characteristics of rocks that is useful in separating them into units is the contained fossils, which are indicators of the age of the sediments. Age determination from fossils is a highly interpretive science, and different classes of fossils may not always provide the same interpreted age. In South Carolina, certain parts of the geologic column consist of rocks with similar physical characteristics, and attempts have been made to divide the

geologic column on the basis of age determinations. Historically, this has led to great confusion in terminology even though great progress has been made since 1978 and is continuing.

In addition to terminology based on lithostratigraphy (rock strata) and biostratigraphy (fossil strata), it is common under certain circumstances to use terminology derived from hydrostratigraphy (strata designated by the rock's hydrologic characteristics). It is not necessary that the terminology for all three of these stratigraphies coincide.

Where there is confusing terminology, units are sometimes designated not by formal names but by letters. The difficulty with this method is that the characteristics of the lettered units are usually strange to the reader, and their relationship to the more commonly used names is not apparent. The purpose of terminology is to convey meaning not to satisfy some assumed "correct" usage.

The terminology for the hydrostratigraphic units used in this report (Table 3-1) is modified from that used by Siple.[3] Table 3-1 describes the lithology and water-bearing characteristics of these units. These terms, as modified, have been found to be very useful in numerous studies of groundwater at SRP. Figure 3-3 is a cross section through SRP from the Fall Line showing the relationship of the units discussed in Table 3-1. Figure 3-4 shows a tentative correlation of these units to stratigraphic terminology being described in current publications.[7,8,9] However, the thrust of much of this current literature is on biostratigraphy and regional correlation of mappable units and not on hydrostratigraphy. Thus, for purposes of this report, the older terminology as modified from Siple[3] is retained. However, it is anticipated that when acceptable lithostratigraphic and hydrostratigraphic units are defined and agreed to by the numerous State and Federal agencies involved, the newer terminology will be used.

3.4 DESCRIPTION OF HYDROSTRATIGRAPHIC UNITS

Three distinct geologic and hydrologic systems exist in the SRP vicinity:

- The Coastal Plain sediments of Cretaceous and Tertiary age where water occurs in porous, unconsolidated to semiconsolidated sands and clays.

- The buried crystalline metamorphic basement rock consisting of chlorite-hornblende schist, hornblende gneiss, and lesser amounts of quartzites, where water occurs in small fractures.

- A buried Triassic basin consisting mostly of red consolidated mudstone with some poorly sorted sandstones, where water occurs in the intergranular space but is very restricted in movement by the extremely low permeability.

Figure 3-5 shows the depth and thickness of the hydrostratigraphic units at SRP and the water levels associated with each unit near the center of SRP (at the chemical separations areas also referred to as F and H Areas) as measured in 1972.

3.4.1 Crystalline Metamorphic Rock

Near the center of SRP the crystalline metamorphic rock is buried beneath about 930 ft of unconsolidated-to-semiconsolidated Coastal Plain sediments.[10] The surface of the rock dips to the southeast at about 36 ft per mile, and the rock crops out at the Fall Line about 20 miles northwest of SRP.[3]

Water injection and removal tests on packed-off sections of rock indicate that there are two types of fractures in the crystalline rock.[11] The first type consists of minute fractures that pervade the entire rock mass but transmit water extremely slowly. Rock that contains only this type of fracture is called "virtually impermeable rock." The other type of fracture is restricted to definite zones that are vertically restricted but laterally correlatable and have larger openings that transmit water faster. Rock that includes this type of fracture is called "hydraulically transmissive rock."

Representative values of the hydraulic conductivity are 3×10^{-4} gpd/ft^2 for virtually impermeable rock and 0.8 gpd/ft^2 for hydraulically transmissive rock.[12] Analysis of a two-well tracer test with tritium indicated a fracture porosity of 0.08% in a hydraulically transmissive fracture zone.[13] Laboratory analyses of rock cores indicated an average intergranular porosity of 0.13%.

Immediately overlying the crystalline rock is a layer of clay (saprolite), which is the residual product of weathering of the crystalline rock.

The combined saprolite and basal Tuscaloosa clay (Figure 3-5) at the top of the metamorphic rock form an effective seal that separates water in the Coastal Plain sediments from water in the crystalline metamorphic rock.

Except for testing programs, there is no pumpage from the metamorphic rock until the Fall Line is approached. From there westward in the Piedmont province, the metamorphic rock provides water for domestic use.

Because of the prolific aquifers in the Coastal Plain above, it is unlikely that the hydrologic regime of the metamorphic rock will change in this area.

Table 3.2 shows a typical chemical analysis of water from the crystalline metamorphic rock. The water has a total dissolved solids content of about 6,000 mg/L, which is largely calcium (500 mg/L), sodium (1,300 mg/L), sulfate (2,500 mg/L), and chloride (1,100 mg/L).

3.4.2 Triassic Sedimentary Rock

A basin of mudstone (the Dunbarton basin), formed in the Triassic Period, is buried within the metamorphic rock beneath about 1200 ft of Coastal Plain sediments (Figure 3-3). The northwest boundary of the basin has been well defined by seismic traverses and by a well that penetrated 1,600 ft of Triassic rock and then passed into the crystalline metamorphic rock below.[14] The southeast margin is not as well defined because there is no well similarly placed to the one that defines the northwest margin.

The upper surface of the Triassic rock is beveled by the same erosional cycle that created a peneplain on the crystalline rock surface. This surface is now tilted about 36 ft per mile,[3] but after correcting for this dip, the surface is extremely flat and featureless.

The depth to the bottom of the Dunbarton basin is not known from well penetration except along the northwest border. A well near the center of the basin was drilled to a depth of 4,200 ft and did not penetrate crystalline rock.

The Triassic sediments consist of poorly sorted, consolidated gravel, sand, silt, and clay. The coarser material is found near the northwest margin where fanglomerates are abundant. Nearer the center, sand, silt, and clay predominate; however, the sorting is always extremely poor,[14] which causes an extremely low primary permeability in the Triassic rocks. The lithology of the clasts in the sedimentary rock indicate that they were derived from the crystalline metamorphic rock to the northwest of the Dunbarton basin. Many of the sands are arkosic, showing rapid deposition.

Triassic sedimentary rock is typically red, like most of the East Coast Triassic rocks. There are, however, a few buff to pinkish sands. In the red mudstone beds, there are occasional layers or patches of green caused by local reducing conditions.

Groundwater occurs in the primary porosity of the Triassic clastic rock. However, the hydraulic conductivity is extremely low, and water movement is almost nonexistent.

The hydraulic conductivity of the Triassic sedimentary rock as determined from field tests[15] ranged from 10^{-4} to 10^{-7} gpd/ft^2. The average total porosity was 8.0% for sandstones and 3.3% for mudstones. The average effective porosity was 7.0% for sandstones and 0.53% for mudstones.

No water is pumped from the Dunbarton basin, nor is there likely to be in the future because of the poor water quality and the low permeability of the rocks.

Table 3-2 lists some chemical analyses of water samples from the Triassic rock in the Dunbarton basin. Samples from the deeper wells near the center of the basin had total dissolved solids contents (almost entirely sodium chloride) of 12,000 and 18,000 mg/L.

3.4.3 Tuscaloosa Formation

3.4.3.1 Hydrostratigraphy

The Tuscaloosa Formation consists primarily of fluvial and estuarine deposits of cross-bedded sand and gravel with lenses of silt and clay. It rests directly on saprolite, a residual clay weathered from the crystalline metamorphic rock. The Tuscaloosa is overlain conformably by the Ellenton Formation, but near the Fall Line, where the Ellenton is absent, it is overlain unconformably by sediments of Tertiary and Quaternary age.[3] The Tuscaloosa crops out in a belt that extends from Western Tennessee to North Carolina. In South Carolina, this belt is from 10 to 30 miles wide. The thickness of the Tuscaloosa ranges from zero at the Fall Line to about 600 ft beneath SRP (Figure 3-3). The thickness remains fairly constant in the SRP area.

In this region, the Tuscaloosa consists of light gray to white, tan, and buff colored cross-bedded quartzitic to arkosic coarse sand and gravel, with lenses of white, pink, red, brown, and purple silt and clay.[3] Ferruginous sandstone concretions, siderite nodules, and lenses of kaolin 2 to 40 ft thick are present in the Tuscaloosa. The chief minerals in the sediments are quartz, feldspar, and mica, which were derived from weathering of the igneous and metamorphic rocks of the Piedmont province to the northwest.

In areas of the South Carolina Coastal Plain within about 25 miles of the Fall Line, sand beds in the Tuscaloosa Formation form one of the major supplies of groundwater. Industrial wells in this aquifer commonly yield more than 1,000 gpm of good quality water.

The Tuscaloosa Formation is the thickest (600 ft) of the Coastal Plain formations in this area (Figures 3-3 and 3-5). Near the center of the SRP site, the units of the Tuscaloosa Formation from top to bottom (Figure 3-5) are: (1) a unit of clay, sandy clay, or clayey sand about 60 ft thick; (2) an aquifer unit of well-sorted medium to coarse sand about 150 ft thick; (3) a unit, about 40 ft thick, in which one or more clay lenses occur; (4) an aquifer unit of well-sorted medium-to-coarse sand about 300 ft thick; and (5) a basal unit of sandy clay about 40 ft thick. The two aquifer units (2 and 4) combined are about 450 ft thick and are used singly and together to supply water-production wells at SRP. For many purposes, they are treated as one aquifer; however, they are hydraulically separated at SRP, except near wells that take water from both units.

3.4.3.2 Hydrologic Characteristics

Field tests of the transmissivity of the Tuscaloosa Formation were made when the original wells were drilled during the construction of SRP.[3] A representative value of transmissivity is listed in Table 3-3 for each area at SRP shown on Figure 3-6.[16] The average of these 11 transmissivity values is 118,000 gpd/ft; the median is 110,000 gpd/ft.

Storage coefficients were determined for seven regions of the Tuscaloosa Formation;[3] the average value is 4.5×10^{-4}. Effective porosities were assumed to be 20% and 30%, which seem reasonable, for calculating the water velocity.[3]

A piezometric map for the Tuscaloosa Formation is shown in Figure 3-7. Continuous hydrographs on selected wells (Figure 3-8) show that there has been no progressive decline in water level as a result of plant pumpage. Thus, the piezometric map was still representative up to 1973.

The locations of SRP and the outcrop area of the Tuscaloosa Formation are shown in Figure 3-7. Where the outcrop area is high in elevation, such as on the Aiken Plateau in the northeast sector, water recharged to the Tuscaloosa Formation exceeds the water discharged to local streams, and this excess water moves southeastward through the aquifer. Where the outcrop area is low in elevation, such as along the Savannah River Valley in the northwest sector, water discharges from the formation. Thus, the pattern of flow is arcuate.

Recently (1982) two independent piezometric maps of the Tuscaloosa aquifer have been published. The first of these (Figure 3-9) was prepared by Faye and Prowell[17] based on data from 1945 to 1981. The general piezometric pattern presented on this

map is the same as that presented by Siple,[3] and the map shows an arcuate flow pattern toward a sink along the Savannah River. Another piezometric map of the Tuscaloosa Formation (Figure 3-10) was prepared in a study for Georgia Power Co.[18] using only data from May to June 1982. This map also shows a groundwater sink along the Savannah River. All of these maps indicate that groundwater in the Tuscaloosa Formation does not cross from South Carolina into Georgia or from Georgia into South Carolina.

Even though the term Tuscaloosa Formation has been used for geologic deposits from North Carolina to Louisiana, and it is a prolific aquifer in parts of North Carolina, South Carolina, and Georgia, the water in the formation that passes beneath SRP recharges and discharges from the formation only in Aiken, Barnwell, and Allendale Counties of South Carolina. In general, the three piezometric maps referenced above do not distinguish between wells in upper and lower aquifers of the Tuscaloosa Formation; yet it is known at SRP that wells screened near the base of the lower Tuscaloosa that are away from centers of pumpage have a higher water level than those in the upper part of the Tuscaloosa. Figure 3-11 is a piezometric map of the Tuscaloosa aquifer on SRP only. Water level data from wells screened only at the bottom of the aquifer were not used. Although the data for this map is sparce, flow in the Tuscaloosa toward the Savannah River is confirmed but a curved flow pattern is not.

The relationship of water levels in the Tuscaloosa Formation to those in overlying formations at H Area in 1972 is shown in Figure 3-5. The head in the Tuscaloosa is 5 to 6 feet above those in the Congaree; however, these particular Tuscaloosa observation wells are within the influence of the cone of depression caused by the continuous pumpage from nearby wells in H Area. A single water-level measurement in 1952, before pumping began, indicates a water level of 192 feet above sea level in H Area.

In addition to showing more detailed stratigraphy at SRP, Figure 3-5 also shows that the water head in the Coastal Plain formations in the vicinity of H Area generally decreases with increasing depth down to the Congaree Formation. This trend indicates some downward movement of water in addition to its horizontal movement. The Congaree Formation crops out in the more deeply incised stream valleys on the plant site, and the water head in this aquifer is controlled in part by the elevation of these onplant streams. The water heads in the Tuscaloosa and Ellenton Formations are higher than that in the Congaree Formation (Figure 3-5), showing that the Tuscaloosa and Ellenton Formations at SRP are separated from the Congaree Formation by a confining layer. Figure 3-12 shows the vertical head relationships near the southern boundary of the plant where the water level in the Tuscaloosa Formation is also higher than in the Congaree.

Figure 3-12 also shows that the water level in the deep Tuscaloosa aquifer is higher than that in the shallower Tuscaloosa aquifer by about 28 ft.

This difference means that care must be exercised in constructing a Tuscaloosa piezometric map. Each aquifer must be mapped separately. Figure 3-11 is a map of the Upper Aquifer of the Tuscaloosa Formation. The water levels in P5A and P7A (both screened in the Lower Aquifer of the Tuscaloosa Formation) are not shown, because they are 25 and 10 ft higher, respectively, than those of the Upper Aquifer at those locations.

Figure 3-13 shows the vertical head relationships near M Area where the Tuscaloosa water level is below that of the Congaree. At this location there is a continuous decline of head with depth indicating that this is a recharge area for the Tuscaloosa, similar to much of the area on the Aiken Plateau northwest of SRP.

In the outcrop area of the Tuscaloosa Formation, hydraulic gradients are steep (0.003 ft/ft) and groundwater velocities are correspondingly high. Downdip where the Tuscaloosa is overlain by a significant thickness of other Coastal Plain sediments, the gradients are gentler (0.0007 ft/ft) and the velocities are lower. Siple[3] calculated the horizontal velocity of water of 180 ft/yr using the following hydraulic constants: hydraulic conductivity of 1000 gpd/ft^2, a gradient of 4 ft/mile (0.0007 ft/ft), and an effective porosity of 20%.

Water is naturally discharged from the Tuscaloosa where the outcrop area is low in elevation, as in the Savannah River and Horse Creek valleys. In these regions, the base flow of streams is supported by discharge from the Tuscaloosa.

As shown in Figure 3-8, 22 years of pumping about 10 ft^3/sec (4500 gpd) at the Savannah River Plant caused no progressive decline in water levels in the Tuscaloosa Formation. The Tuscaloosa is a prolific aquifer in this region, and development for industrial or irrigational use can be expected in the future. Water development is discussed in Section 4.

3.4.3.3 Water Quality

Water from the Tuscaloosa Formation is low in dissolved solids (Table 3-4). Specific analyses of water from the Tuscaloosa are given in Table 3-5. Locations of the sampled wells are shown in Figure 3-14. Because the water is soft and acidic, it has a tendency to corrode most metal surfaces.[3] This is especially true where the water contains appreciable amounts of dissolved oxygen and carbon dioxide. The dissolved oxygen content of water from the

Tuscaloosa Formation around the separations areas is very low,[19] and the sulfate content is about 13 mg/L. The dissolved oxygen content is inversely related to the sulfate content of the water. In the northwest part of SRP nearer the outcrop area, water in the Tuscaloosa is near saturation with dissolved oxygen while the sulfate content is very low.

3.4.4 Ellenton Formation

3.4.4.1 Hydrostratigraphy

The Ellenton Formation overlies the Tuscaloosa Formation and consists of dark lignitic clay with coarse sand units. It is thought to be Late Cretaceous or Paleocene in age and is unconformably overlain by the Congaree Formation (of the Eocene Epoch). The known Ellenton sediments are entirely within the subsurface; they range in thickness from zero near the northwest boundary of SRP to about 100 ft southeast of SRP.[3] Just inside the northwest boundary of SRP, however, the thickness of the Ellenton is about 40 ft as shown on a diagram by Siple[3] and by recent coring in this area by SRP.

The Ellenton Formation was described and named by Siple from subsurface studies on the Savannah River Plant.[3] The formation was not correlated out of this area, but Siple speculated that it might be equivalent to the Black Creek Formation of Late Cretaceous age or the Black Mingo Formation of Paleocene or early Eocene age.

The lignitic clay is dark gray to black, sandy, and micaceous. It is interbedded with medium quartz sand. The clay contains pyrite and gypsum. The upper part of the formation is characterized by gray silty-to-sandy clay with which gypsum is associated. The lower part consists generally of medium-to-coarse clayey quartz sand, which is very coarse and gravelly in some areas.[3]

In many places in the vicinity of SRP, there is a thick clay at the top of the Tuscaloosa (Figure 3-5) which apparently separates the aquifers of the Ellenton and the Tuscaloosa. However, this clay contains lenses of sand that may connect the two aquifers. Although the Tuscaloosa Formation can be differentiated from the Ellenton Formation, the permeable or waterbearing zones within the two formations are not completely separated by an intervening confining bed.[3] Since groundwater is free to move from one formation into the other where they are hydraulically connected, the permeable zones in the Tuscaloosa and Ellenton Formations are considered to constitute a single aquifer over a large part of the area. The water levels shown in Figure 3-5 indicate that this is probably the case.

3.4.4.2 Hydrologic Characteristics

Some of the sand lenses in the Ellenton may be as permeable as sands in the Tuscaloosa, but they are not as thick as the Tuscaloosa sands, and are therefore not developed by wells as commonly as those of the Tuscaloosa.

Pumping tests to determine hydraulic constants are rare in the Ellenton Formation. In general, Siple did not distinguish between the Ellenton and the Tuscaloosa Formations in reporting the results of pumping tests.

Figure 3-5 shows the relationship of the water level in the Ellenton to water levels in the formations above and below. The water level in the Ellenton is above that in the Tuscaloosa in Figure 3-5 because these Tuscaloosa wells are all within the cone of depression of the continuous pumping in H Area. These Tuscaloosa observation wells are probably more responsive to the hydraulic effects of this local pumping than is the Ellenton well.

No piezometric map exclusively of the Ellenton Formation exists. Thus, little is known about the lateral flow path of water within the formation. Because it is apparently hydraulically connected to the Tuscaloosa Formation, its flow pattern is probably similar.

The hydraulic heads shown on Figure 3-5 indicate that there is not a direct hydraulic connection between the Ellenton and the overlying Congaree Formation. Although the clays that separate the Ellenton and the Congaree are not thick, they are apparently extensive and continuous enough to impede the hydraulic connection. A pisolitic clay at the base of the Congaree appears to be extensive and may constitute the principal confining bed that separates the Congaree and the deeper hydrologic system.[3] The upper part of the Ellenton is a sandy clay, which may also function as a confining bed between the Ellenton and the Congaree.

The poor hydraulic connection of the Ellenton with the Congaree and the apparent good connection with the Tuscaloosa can be explained on the basis of the sedimentary environments of these formations. The Tuscaloosa was deposited under nonmarine conditions, and therefore the sands and clays might be discontinuous. The Ellenton was deposited under both nonmarine and estuarine conditions. However, the Congaree was deposited under marine conditions, which would be conducive to deposition of extensive continuous layers of clay and layers of sand.

Because the Ellenton is entirely a subsurface formation, there is no natural discharge to the surface. Water passing through the Ellenton is principally recharged by and discharged to the Tuscaloosa Formation.

Although few wells pump exclusively from the Ellenton Formation, some wells that are screened in the Tuscaloosa are also screened in the Ellenton. Thus it is difficult to estimate the quantity pumped from the Ellenton alone.

The course of future well development in the Ellenton will parallel the development of the Tuscaloosa Formation.

3.4.4.3 Water Quality

A summary of chemical analyses of water from the Ellenton Formation is given in Table 3-4. Its dissolved solids content is somewhat higher than that of water from the Tuscaloosa, but it is still very low.

3.4.5 Congaree Formation

3.4.5.1 Hydrostratigraphy

The Congaree Formation was included in the McBean Formation by Cooke,[2] and this usage was followed by the U.S. Army Corps of Engineers during the original foundation studies for the construction of the Savannah River Plant.[20] The lower part of the original McBean was raised to formational status and called the Congaree Formation and the Warley Hill Marl by Cooke and MacNeil.[21] In discussing geology and groundwater at SRP, Siple used the term "McBean" both to include all deposits of Claiborne age and to include only the upper part of these deposits. In much of the area studied by Siple, the two formations could not be distinguished either where exposed or in well logs.[20]

Subsequent investigations at SRP have shown that for hydrologic studies, it is desirable to distinguish the McBean Formation (as used in the restricted sense) from the Congaree Formation, because in the central part of SRP the water level in the Congaree is about 80 ft lower than that in the McBean (restricted sense), and the Congaree is more permeable.[20] These two hydrostratigraphic units are separated by a clay layer informally called the "Green Clay" in studies at SRP. This clay occupies the same stratigraphic position as the Warley Hill Marl of Cooke and MacNeil.[21]

In discussing the geohydrology, the term McBean Formation will be used only in the restricted sense. The term "deposits of Claiborne age" will be used to refer to the broad sense in which the term "McBean Formation" was previously used.[2]

The deposits of Claiborne age strike about N 60°E and dip about 8 to 9 ft per mile toward the south or southeast.[3] Their

thickness ranges from zero near the Fall Line to about 250 ft in southeastern Allendale County.

In the central part of SRP, the Claiborne deposits are about 200 ft thick (Figure 3-5), of which about 120 ft is Congaree Formation. The Congaree Formation has a relatively high hydraulic conductivity and forms a relatively high-yielding aquifer, second only to the Tuscaloosa Formation in this area.

In the central SRP area, the Congaree Formation consists of gray, green, and tan sand with some layers of gray, green, or tan clay.[20] In the northwest SRP area, it consists primarily of tan clayey sand. It is slightly glauconitic in some places, slightly calcareous in others. In some locations in Calhoun County, SC, it consists of well to poorly sorted sand, fuller's earth, brittle siltstone, and light gray to green shale, alternating with thin-bedded fine-grained sandstone. Elsewhere in Lexington and Calhoun Counties, it includes tan, white, and reddish-brown cross-bedded sand very similar to that in the McBean Formation.[3]

Although subdivision of the Claiborne Group may be warranted in the SRP area and in other parts of South Carolina and Georgia, such subdivision appears less warranted toward the Fall Line because the shoreward facies of each unit grades into a comparatively thin zone, and the ability to distinguish them becomes uncertain. That this is so is confirmed by drilling in the northwestern part of SRP (M Area), where the "Green Clay" is thin and discontinuous and the sediments of both McBean and Congaree are very similar in appearance.

A pisolitic clay zone at the base of the Claiborne deposits is the base of the Congaree Formation.[3] If this characteristic clay is correlative with a similar pisolitic clay zone at the base of the Claiborne deposits on the Gulf Coast, then it is likely that the clay is continuous within the SRP area. This may be the effective confining bed that hydrologically separates the aquifer in the Congaree Formation from that of the Ellenton Formation.

The "Green Clay" layer at the top of the Congaree Formation appears to be continuous in the central SRP area. In the northwest SRP area, i.e., updip, it becomes discontinuous. This clay is hydrologically significant because it supports a large head differential between water in the McBean Formation above and water in the Congaree Formation below. In the northwest SRP area where the clay is discontinuous, the head differential is not as large. To the south it appears that the green clay thickens to about 60 ft to become what is referred to in Georgia as the Blue Bluff Marl of the Lisbon Formation (Figure 3-4). It is encountered at the Vogtle Nuclear Power Station in Georgia, in wells in the southern part of SRP, and offsite to the south. However, intermediate wells to confirm the tentative correlation of the "Green Clay" with the Blue

Bluff Marl do not exist. The "Green Clay" is herein considered to be part of the Congaree Formation even though there is no faunal support for this assignment. This clay consists of gray-to-green, dense, occasionally indurated clay.[20] The indurated nature of the clay is commonly caused by dense compaction and siliceous cement. Calcareous cement is usually absent from this indurated zone. Farther south calareous cement may be more common.

The sand beds of the Congaree Formation constitute an aquifer in this region that is second only to the Tuscaloosa aquifer in productivity. Maximum yields of 660 gpm with 50 ft of drawdown have been reported from wells in Claiborne deposits on SRP.[3] Much of the water produced by high-yielding wells reported to be pumping from the McBean Formation (in the broad sense, i.e., Claiborne deposits) probably comes from the Congaree Formation. Another well in these deposits yielded only 175 gpm with 50 ft of drawdown. Wells in the municipal well field at Barnwell, SC, have yielded as much as 400 gpm with 40 ft of drawdown. However, in other areas such as northwestern SRP (M Area), the yield may be as low as 30 gpm with 30 ft of drawdown.

3.4.5.2 Hydrologic Characteristics

Table 3-6 lists hydraulic constants for the Claiborne deposits. Two of the tests, which were located near the central part of SRP, indicated a hydraulic conductivity of nearly 1000 gpd/ft^2, whereas one of the values (for the test near M Area) is 50 times less than this. The median value for 10 slug tests (decay of an instantaneous head change) in sandy zones of the Congaree Formation in the separations areas of SRP[22] was 44 gpd/ft^2. The median of two water-level recovery tests was 37 gpd/ft^2. Values for the median hydraulic conductivities for the Tertiary hydrostratigraphic units in the separations areas determined from aquifer tests are shown in Table 3-7. The results of pumping tests, recovery tests, and slug tests on Tertiary units in the separations areas are shown in Figure 3-15.

Laboratory tests by the U.S. Army Corps of Engineers indicated a median value of 43% for the total porosity of the upper part of the Congaree Formation. However, this porosity should not be used to calculate the groundwater velocity in this formation. The effective porosity should be used for this calculation. It is estimated that an effective porosity of 20% is reasonable. A pumping test in northwestern SRP gave a value of 14%.

Figure 3-5 shows the water level in the Congaree Formation and its relationship to that in the hydrostratigraphic units above and

below. These data are for one location in the separations areas where water level differences are probably at their maximum. Near the discharge areas of creek valleys, water levels of the several Tertiary aquifers converge (Figure 3-16).

The fluctuation of water levels in the Congaree Formation and their relationship to those in other hydrostratigraphic units are shown in Figure 3-17.

The spatial variation of water levels in the Congaree Formation in the separations areas is shown in Figure 3-18. This piezometric map indicates a northwestward movement of water across the separations areas. This direction of movement is governed by the discharge of the water in the Congaree Formation to Upper Three Runs Creek, where the "Green Clay" is breached. Because Four Mile Creek does not breach the "Green Clay," the piezometric map is unaffected by its valley. This map has adequate water level control. Figure 3-19 shows a regional piezometric map for the Congaree even though the control is not as good.

As shown in Figure 3-19 the water levels in the Congaree Formation are significantly drawn down by the groundwater discharge to the Savannah River and to Upper Three Runs Creek. Two regional piezometric maps of the Congaree have been recently published (1982), but neither reflects the significant drawdown due to the incision of the formation by Upper Three Runs Creek. The first by Faye and Prowell[17] is shown in Figure 3-20. The second prepared by Georgia Power Co.[18] is shown in Figure 3-21.

The vertical head relationships of the Congaree to the units above and below are shown in Figures 3-5, 3-16, and 3-17. These figures show that the head in the Congaree Formation in the separations areas is the lowest of any hydrostratigraphic unit in the Coastal Plain system. This is brought about by two factors: (1) the low permeability of the "Green Clay" through which recharge must take place, and (2) the high hydraulic conductivity of the Congaree sands below the "Green Clay," which enhances lateral movement and discharge to the deeper creek valleys. Upward recharge of water to the Congaree from the Ellenton-Tuscaloosa systems is also impeded by clay layers at the base of the Congaree and at the top of the Ellenton.

The lateral hydraulic gradient, I, in the Congaree Formation (Figure 3-18) ranges from about 0.003 to 0.005 ft/ft. Using a hydraulic conductivity, K, of 4.9 ft/day (Table 3-7) and an effective porosity, ε, of 20%, the flow velocity would be

$$V = \frac{IK}{\varepsilon} = \frac{365 \text{ days/yr} \times 0.005 \text{ ft/ft} \times 4.9 \text{ ft/day}}{0.20} = 44 \text{ ft/yr}$$

The natural discharge areas for the Congaree Formation at SRP are the swamps and marshes along Upper Three Runs Creek and along the Savannah River Valley. Although springs do occur, most of the discharge occurs along the valley bottoms in swamps, making it difficult to measure.

On a regional basis, the dissecting creeks divide the groundwater in the Congaree Formation into discrete subunits. Depending on the depth of dissection, groundwater is confined to its own subunit. Thus, even though the hydraulic characteristics of the formation may be similar throughout the area, each subunit has its own recharge area and its own discharge area. If dissection is through most of the formation thickness, then no water would move from one subunit to another.

Figure 3-19 is a potentiometric map of the Congaree Formation on SRP and shows the dominant influence of Upper Three Runs Creek and the Savannah River.

The Congaree Formation provides water to SRP (tens to hundreds of gallons per minute) and to the rural population around SRP. In the M-Area vicinity the Congaree Formation is clayey sand rather than sand as it is farther downdip. Thus well yields in this area are not nearly as high as in the downdip areas. Compare the value of 18 gpd/ft^2 hydraulic conductivity near M Area as shown in Table 3-6 to the value of ~1000 gpd/ft^2 obtained from pumping tests near C Area and P Area. The number of users will probably increase as the region develops; but most users that require thousands of gallons per minute will develop it from the Tuscaloosa Formation. Thus, the total quantity pumped from the Congaree Formation will probably increase more slowly than the total quantity pumped from the Tuscaloosa Formation.

3.4.5.3 Water Quality

Ranges and medians of chemical analyses of water from deposits of Eocene age are given in Table 3-4 as reported by Siple.[3] These analyses are grouped into those from Eocene limestone, which would be primarily for water from the McBean Formation but might include some analyses of water from the Congaree Formation, and those of water from Eocene sand, which would include the Barnwell, McBean, and Congaree Formations.

The analyses of water from the Eocene sands is similar to those from the Tuscaloosa Formation, which is also predominantly sand. The water is low in dissolved solids (about 20 ppm) and is acidic (pH about 5.5). In comparison, the water from the Eocene limestone is much higher in dissolved solids (about 100 ppm) and is nearly neutral (pH about 7). Most of the increase in dissolved

solids is due to increases in calcium and bicarbonate ions, as would be expected from sediments high in calcium carbonate.

Two analyses of water from sands in the Congaree Formation are shown in Table 3-5. The analyses are similar to those reported for Eocene limestone by Siple, including a high calcium and bicarbonate content. These zones in the Congaree Formation probably contained some calcareous cement, giving rise to the ionic content of this water.

3.4.6 McBean Formation

3.4.6.1 Hydrostratigraphy

As previously discussed, the term McBean was orginally used to designate all deposits of Claiborne age in this area, but it is now used to designate only the upper part of these sediments. Even though this distinction was originally made on a stratigraphic basis, the distinction is even more significant on a hydrologic basis. Hydraulic head differences between the McBean and Congaree Formations are large in many places, and the Congaree is about ten times more permeable.

The McBean Formation may be divided into two subunits, an upper unit consisting of tan clayey sands and occasionally red sand,[20] and a lower unit consisting of light tan-to-white calcareous clayey sand. This lower unit is locally referred to as the "calcareous zone"; in some places, it contains void spaces that result in rod drops or lost circulation during drilling operations.[24] To the northwest these void spaces appear to decrease so that no calcareous zone exists in the northwest part of SRP (M Area). However, to the southeast the lime content of the zone increases as do void spaces. Southeast of SRP the zone becomes limestone with only small amounts of sand, and its water yielding potential increases.

The McBean Formation is considered to be the shoreward facies of the Santee limestone, which occurs to the southeast.[3] In the SRP area, the calcareous zone may represent a tongue of the Santee limestone. Toward the Fall Line to the northwest of SRP, it becomes more difficult to distinguish the several Eocene formations, and Siple maps the Eocene deposits undifferentiated. In the northwest SRP area (M Area), the calcareous zone is replaced by a clayey sand unit.

Groundwater occurs in both the upper sandy unit and in the calcareous zone, but neither are prolific aquifers in the central part of SRP. Farther to the southeast, where the calcareous content, as well as the number and size of the voids in the calcareous zone increase, well yields are moderate.

As with the Congaree Formation, creeks in the region dissect the McBean Formation, and divide the hydrogeologic unit into separated subunits, each having its own recharge and discharge area. Because the McBean is a shallower formation than the Congaree, smaller creeks with less deeply incised valleys make these divisions. The subunits of the McBean are therefore smaller than those of the Congaree. In the separations areas, the only stream that cuts into the Congaree is Upper Three Runs Creek, whereas the McBean is incised by Upper Three Runs Creek, several of its larger tributaries, and Four Mile Creek. Thus, groundwater that enters the McBean Formation in the separations areas cannot migrate to other subunits of the McBean.

3.4.6.2 Hydrologic Characteristics

The median hydraulic conductivity of the upper sand of the McBean Formation is 3.2 gpd/ft^2 and that of the calcareous zone is about half that of the upper sand (Table 3-7). Figure 3-15 shows the median and range of hydraulic conductivity as measured in the field by slug tests, recovery tests, and drawdown tests.

Figure 3-22 shows the range and median of laboratory measurements of hydraulic conductivity.

As with the Congaree Formation, determinations of total porosity of the McBean Formation were made, but these are not useful for calculating groundwater velocity. For this purpose, an effective porosity value of 20% is used.

Fluid losses in the calcareous zone during drilling operations make it appear very permeable. However, pumping tests on the calcareous zone indicate a low hydraulic conductivity (Table 3-7 and Figure 3-15). The observation and pumping wells used in these tests were developed using surge block and water jet techniques. Response tests also indicated good connections of the fluid in the wells to the fluid in the formation. Apparently zones of higher permeability do not connect over large distances, and the regional permeability of the calcareous zone is lower than it appears from drilling experience.

Water levels in both the upper sand unit and in the calcareous zone are shown in Figures 3-5 and 3-17. These data, based on wells in the recharge area, indicate a difference of about 2 ft in hydraulic head between the top of the McBean Formation and its base. This indicates a better hydraulic connection between the sandy unit of the McBean and the calcareous zone than between the McBean and the Congaree Formation below or the Barnwell Formation above.

Figure 3-23 shows the piezometric surface of the upper part of the McBean Formation in the separations areas. This map indicates lateral flow in the upper part of the McBean Formation toward Upper Three Runs Creek to the north and toward Four Mile Creek to the south. Because of the hydraulic connection between the upper sandy

zone and the calcareous zone, Figure 3-23 can probably be used to determine the approximate flow path of water in the calcareous zone also.

As previously described, the "Green Clay" impedes downward movement of water from the McBean to the Congaree Formation in the central part of SRP, thereby contributing to a hydraulic head differential of about 80 ft (Figure 3-5).

In the Barnwell Formation just above the McBean Formation, a "Tan Clay" impedes vertical movement of water from the Barnwell Formation into the McBean. This "Tan Clay" is not as continuous as the "Green Clay", and it has a higher hydraulic conductivity. The McBean Formation is less permeable than the Congaree and therefore does not conduct water laterally as quickly; thus, the head differential between the Barnwell and the McBean Formations is only about 12 ft (Figure 3-5) as opposed to the 80 ft differential between the McBean and Congaree.

The hydraulic conductivity of the upper sand unit of the McBean is 3.2 gpd/ft^2 (Table 3-7) in the central part of SRP. Using this value together with an effective porosity of 20% and a hydraulic gradient of 0.017 ft/ft (Figure 3-23), the average horizontal velocity is calculated to be:

$$V = \frac{IK}{\varepsilon} = \frac{365 \text{ days/yr} \times 0.017 \text{ ft/ft} \times 0.4 \text{ ft/day}}{0.20} = 12.4 \text{ ft/yr}$$

Assuming the same gradient as for the Upper McBean, the regional groundwater velocity in the calcareous zone is calculated to be:

$$V = \frac{IK}{\varepsilon} = \frac{365 \text{ days/yr} \times 0.017 \text{ ft/ft} \times 0.23 \text{ ft/day}}{0.20} = 7.1 \text{ ft/yr}$$

The natural discharge areas of the McBean Formation in the separations areas are along the banks of Upper Three Runs Creek and its major tributaries and in the valley floor and along the banks of Four Mile Creek.

In the northwest part of SRP (M Area) the average hydraulic conductivity of the McBean and Congaree Formations together, as determined from a pumping test, is 2.5 ft/day with a hydraulic gradient of 0.003 ft/ft and an effective porosity of 0.14. The average velocity is thus about 20 ft/yr.

Water from the McBean Formation is not used for industrial or municipal purposes. Larger wells producing from the Claiborne deposits probably derive most of their water from the Congaree. The McBean is, however, sufficiently permeable in some places to supply water for domestic use.

Because the McBean Formation is not used for large supplies of water, it is not anticipated that there will be much future change in the hydrologic regime of this formation. The head differential between the McBean and Congaree is about 80 ft at

present, and even if the Congaree were subjected to additional drawdown, it is unlikely that there would be much effect on the McBean hydrology.

Dissection of the McBean by local creeks also divides the formation into subunits whose hydrologic regime is unaffected by adjacent subunits. Thus, increased development in one of the subunits would have little effect on the regional hydrology of this formation.

3.4.6.3 Water Quality

Samples of water from Eocene sand and Eocene limestone probably include some water from both the upper sand and the calcareous subunits of the McBean Formation. The median and range of chemical analyses are listed in Table 3-4. The water from both subunits is low in dissolved solids, with the water from the upper sand subunit having the much lower content of dissolved solids. The differences in the chemical characteristics of water from the two subunits of the McBean are readily apparent in Table 3-5. Well HC3D in the upper sandy unit has a total dissolved solids content of 14 ppm, with all constituents being very low. The other three wells are screened in the calcareous zone and have a dissolved solids content of more than 50 ppm, with higher calcium and bicarbonate contents. The pH of the water from the calcareous zone is near 7, while that of water from the upper sandy zone is generally less than 5.

3.4.7 Barnwell Formation

3.4.7.1 Hydrostratigraphy

The Barnwell Formation is reported to be Jackson (uppermost Eocene) in age.[3] It directly overlies the McBean Formation and is exposed over a considerable area in the uplands of Aiken and Barnwell Counties. The formation thickens to the southeast from zero in the northeastern part of Aiken County to about 90 ft at the southeastern boundary of Barnwell County. The Barnwell Formation is overlain by the Hawthorn Formation, from which it is usually difficult to distinguish. In the separations areas, these two units together are usually about 100 ft thick.

The Barnwell Formation consists mainly of deep red fine-to-coarse clayey sand and compact sandy clay. Other parts of the formation contain beds of mottled-gray or greenish-gray sandy clay and layers of ferruginous sandstone that range in thickness from 1 inch to 3 feet. Although fossils at some places indicate a marine origin, material identified as Barnwell may have been

deposited in other places as alluvium during Pliocene to Pleistocene time.[3] Beds of limestone occur in the Barnwell Formation in Georgia, but none have been recognized in South Carolina.

These factors indicate that a considerable part of the Barnwell Formation was deposited as an arenaceous limestone in a near-shore or estuarine environment. Some evidence of the remnant calcareous nature of the formation is indicated by the comparatively high proportion of calcium carbonate found in groundwater circulating in this unit.[3]

In the separations areas, the Barnwell Formation appears divisible into three parts:

- The lowest unit "Tan Clay" commonly consists of two thin clay layers separated by a sandy zone. The entire unit is about 10 to 15 ft thick and is semicontinuous over the area.
- Above the "Tan Clay" is a silty sand unit, 0 to 40 ft thick.
- Above the silty sand is a unit of clayey sand, 0 to 100 ft thick, that may include beds of silty clay or lenses of silty sand. This sand is slightly less permeable than the underlying silty sand.

Because of the large amount of clay and silt mixed with the sands, the Barnwell Formation does not generally yield water to wells. However, an occasional lens of sand may be relatively free of clay and can provide adequate quantities of water for domestic use.

3.4.7.2 Hydrologic Characteristics

Laboratory measurements of hydraulic conductivities of many undisturbed Barnwell samples, as well as results of point-dilution tracer tests, are shown in Figure 3-22. The median conductivity was 1.0 gpd/ft^2 for the clayey sand unit (Table 3-7 and Figure 3-15). Although no pumping tests were made on the silty sand unit (Table 3-7), a pumping test in a sand lens within this unit indicated a hydraulic conductivity of 7.4 gpd/ft^2.

The relationship of water levels in different zones within the Barnwell, as well as the relationship of these levels to those in the formations below, are shown in Figures 3-5 and 3-16. The variations of water levels in the Barnwell over a period of five years are shown in Figure 3-17. This figure also indicates that the amplitude of water level fluctuation is greater in the Barnwell than in the formations below.

The water table is commonly within the Barnwell Formation, although in the creek valleys it successively occupies positions in the lower formations (Figure 3-16). A map of the elevation of the water table is shown in Figure 3-24. The surface drainage and topography strongly influence the flow path at any point. Even small tributaries to the larger creeks cause depressions in the water table, diverting groundwater flow towards them.

Figures 3-5 and 3-16 show a hydraulic gradient within the Barnwell Formation in a downward direction. Although the "Tan Clay" impedes the downward movement of water, the McBean Formation is recharged by water that passes through this hydrostratigraphic unit.

Using an overall average gradient for the water table of 0.018 ft/ft, a hydraulic conductivity for the clayey sand unit of 1.0 gpd/ft^2 (Table 3-7), and an effective porosity of 20%, the velocity through Barnwell material is calculated to be

$$V = \frac{IK}{\epsilon} = \frac{365 \text{ days/yr} \times 0.018 \text{ ft/ft} \times 0.13 \text{ ft/day}}{0.20} = 4.3 \text{ ft/yr}$$

If a sand lens with a hydraulic conductivity of 7.4 gpd/ft^2 (Table 3-7) existed for the entire flow path, the velocity would be 32 ft/yr. A series of tracer dilution tests and tracer injection detection tests yielded velocities ranging from 2.3 to 69 ft/yr.[25]

Natural discharge from the water table, which is predominantly in the Barnwell Formation, is to the creeks and their tributaries on SRP. The areas of perennial creek drainage are shown by the solid lines representing creeks in Figure 3-24.

The Barnwell Formation supplies water for domestic purposes in some places in the region, but it is not used by industry or municipalities. Total pumpage has not been estimated, but it would be small.

The future hydrologic regime of the Barnwell Formation will probably not change much.

3.4.7.3 Water Quality

Five analyses of water from the Barnwell Formation in the separations areas are given in Table 3-5. The dissolved solids content is low, and the calcium and bicarbonate ions are not as high as in the McBean and Congaree Formations. The pH of water from the Barnwell Formation is as low as that of water from other formations in the area.

3.4.8 Hawthorn Formation

3.4.8.1 Hydrostratigraphy

The Hawthorn Formation crops out over a very large area of the Atlantic Coastal Plain and is perhaps the most extensive surficial deposit of Tertiary age in this region.[3] It is bounded on top and bottom by erosional unconformities, and is present at the surface in the higher areas of Aiken County. It ranges in thickness from zero in northwestern Aiken County to about 80 ft near the Barnwell-Allendale County line.

Typical Hawthorn Formation is fine, sandy, phosphatic marl or soft limestone and brittle shale resembling silicified fuller's earth. Updip, however, in the vicinity of Aiken and Barnwell Counties, it is characterized by tan, reddish-purple, and gray sandy, dense clay that contains coarse gravel, limonitic nodules, and disseminated flecks of kaolinitic material.

The fine-grain materials within the Hawthorn Formation, consisting of compact silt and clay, are incapable of yielding water and are therefore not suitable for wells.[3] The Hawthorn Formation is above the water table throughout much of the SRP area. However, where low permeability beds are overlain by more permeable beds, perched water bodies may occur.

3.4.8.2 Hydrologic Characteristics

Because the Hawthorn Formation in the SRP area is usually unsaturated, no pumping tests have been performed. There is no piezometric map of the Hawthorn Formation in this area. Flow paths are predominantly vertical, with only short horizontal flow paths.

Occasional perched water bodies may have fluctuating water levels that cannot be correlated with other water levels in the area.

Within the Hawthorn there are numerous clastic dikes that criss-cross the clayey sand of the formation. These dikes are generally filled with greenish-gray silty-to-sandy clay. The dike wall, 0.2 to 1.0 inch thick, is generally indurated and consists of an iron oxide-cemented quartz sand.[3] Thus, the dike filling is generally finer grained than the surrounding sediments.

The origin of the dikes is uncertain. Possible explanations include (1) shrinkage resulting from weathering, (2) seismic activity, and (3) relief of compressional stresses by upward movement of plastic material.[3]

3.4.8.3 Water Quality

No water samples from the unsaturated zone have been analyzed.

3.4.9 Surficial Formations

3.4.9.1 Tertiary Alluvium

Alluvial deposits of late Tertiary age occur irregularly and discontinuously on the interstream divides or plateaus. They are composed of coarse gravel and poorly sorted sand and were tentatively classified by Siple as Pliocene in age. Their thickness ranges from 5 to 20 ft. Generally these deposits are considerably above the water table and are therefore unimportant as a source of groundwater for wells. Nevertheless, they are fairly permeable, and are capable of storing and transmitting water. Their presence therefore enhances recharge to underlying formations.

3.4.9.2 Terrace Deposits

Cooke recognized seven marine terraces of Pleistocene age on the Atlantic Coastal Plain of South Carolina.[2] He indicated that the four highest terraces are present in the Savannah River Valley. These features are not universally recognizable and have therefore been the subject of discussion. The deposits that may be associated with these terraces are not more than a few tens of feet thick. Because of their near-surface location, they are not important as sources of well water.

3.4.9.3 Holocene Alluvium

Alluvium of Holocene age occurs in the tributary and main channels of the Savannah River. These deposits, which are generally cross-bedded and heterogeneous in composition, range in thickness from 5 to 30 ft.[3] The poorly sorted sand, clay, and gravel have little potential for groundwater development except along the larger streams where infiltration galleries might be possible.

3.5 HYDROLOGIC INTERRELATIONSHIPS AT SRP

Although a number of hydrologic interrelationships between the various hydrogeologic units at SRP have been discussed in the previous section (3.4) describing the hydrostratigraphic units, the purpose of this section is to summarize and amplify these relationships.

Precipitation at SRP averages about 48 inches per year with a maximum of 73.47 inches in 1964 and a minimum of 28.82 inches in 1954. Table 3-8 shows the monthly precipitation at SRP near the administration area since 1952. Although there may be both spatial and temporal variations in the fraction of this precipitation that recharges the groundwater, the overall average is about 30% or 15 inches per year. This average will vary due to slight variations in the hydraulic conductivity of the shallow layers of sediment, the proportion of the rainfall that falls in the nongrowing season, and the antecedent wet or dry conditions.

This water moves vertically through the unsaturated zone at a rate of about 3 to 7 ft/yr as determined by tracer tests in the central part of SRP to recharge the water table which is commonly in the Barnwell Formation.[26] This rate may also vary spatially and temporally. Upon reaching the water table, the water travels a path that has both vertical and horizontal components. The magnitude of these two components depends on the vertical and horizontal components of the hydraulic conductivity. Clay layers of low hydraulic conductivity tend to impede vertical flow and enhance horizontal flow. If the horizontal hydraulic conductivity is low, water will tend to "pile up" above the clay, and the water table will be high. On the other hand, if the hydraulic conductivity is high, the water will be conducted more quickly away from the recharge area, and the water table will be low.

Figure 3-5 shows the head relationship of the various hydrostratigraphic units in H Area, and Figure 3-16 shows how these relationships change toward Upper Three Runs Creek. The water table is high in H Area because the "Tan Clay" inhibits the downward movement of water and the low horizontal hydraulic conductivity of the Barnwell Formation does not permit rapid removal of the water in a horizontal direction. The hydraulic head builds up in the Barnwell Formation sufficiently to drive the water through the material of low hydraulic conductivity; some going vertically through the "Tan Clay" and some moving laterally to the nearby tributary streams. Although there are temporal variations in the elevation of the water table, there is an overall equilibrium of the water table that is dependent on the respective components of hydraulic conductivity and the geometry of the system.

Water that enters the McBean Formation also follows a path that has both vertical and horizontal components. The water recharging this formation through the "Tan Clay" is the nominal surface recharge (15 inches/yr) minus the amount of water that is removed from the Barnwell by lateral flow. The discharge points for the McBean Formation are more distant from their respective groundwater divides than those of the Barnwell Formation.

The "Green Clay" has a lower hydraulic conductivity than the material above; as a result, recharge to the Congaree through this clay is less than the recharge to the McBean. In addition, the Congaree has a higher hydraulic conductivity than the material above and as a result lateral flow is enhanced making the water levels in the Congaree much lower than those above, as shown in Figures 3-5 and 3-16. The discharge areas for the Congaree are the valleys of the Savannah River and Upper Three Runs Creek. Even though these discharge areas are more distant from H Area than the discharge areas for the Barnwell and McBean Formations, the hydraulic conductivity is sufficiently high so that the natural discharge from the Congaree makes its water level much lower than the formations above.

Tuscaloosa Formation water levels in H Area are above those in the Congaree (Figure 3-5) showing that in this area, the Tuscaloosa is not naturally recharged from the Congaree. Water in the Tuscaloosa passing beneath H Area is recharged through the Tertiary sediments to the north of SRP (Figure 3-7). Water is discharged from the Tuscaloosa upward into the overlying sediments in the Savannah River Valley. This relationship is shown on Figure 3-25 which is a hydrologic section through H Area approximately perpendicular to the Savannah River. This diagram shows that in the Savannah River Valley and Upper Three Runs Creek Valley, the head in the Tuscaloosa is consistently above that of the Congaree. Water levels in the Tuscaloosa in the Savannah River Valley are commonly above land surface and wells in these areas flow naturally. It also shows that water from either formation does not naturally flow from South Carolina to Georgia or vice versa. Figure 3-12 shows the vertical head relationships between the Congaree, shallow Tuscaloosa, and deep Tuscaloosa in the southern part of SRP. The head relationship between the Congaree water level and higher Tuscaloosa water level is the same here as in H Area but the head difference is greater. This area is greatly influenced by the drawing down of the head in the Congaree due to the nearness of the Savannah River Valley.

The head relationships in the northwest part of SRP (M Area) are quite different as shown on Figure 3-13. In this updip area the "Green Clay" is very discontinuous and is not as thick as it is farther downdip. The "Tan Clay" has disappeared entirely. Thus, there is little impedance to downward vertical flow within the Tertiary sediments. Thus, the water levels are farther below the land surface than in H Area. Another very important factor is that the geologic character of the Congaree Formation in M Area is different than in H Area; the geologic material is not as well sorted and its hydraulic conductivity is decreased. As a result, the lateral flow of water in the Congaree is insufficient to draw its water level down below that of the Tuscaloosa in M Area. Thus, a downward gradient exists from the Congaree to the Tuscaloosa.

Closer to the Savannah River, the discharge from the Congaree draws its water level down below that of the Tuscaloosa (Figure 3-26).

The Congaree and Tuscaloosa Formations are separated in M Area even though this area is near the updip termination of the Ellenton Formation as shown in Figure 3-3. In places, the Ellenton consists of 60 ft of sandy clay of low hydraulic conductivity, but it appears not to be this thick continuously. Thus there may be discontinuous recharge from the Congaree to the Tuscaloosa through the Ellenton in this area.

An indication of the location of areas where there is a head reversal between the Congaree and the Tuscaloosa and areas where there is not, may be obtained by constructing a map showing the difference between the Tuscaloosa piezometric map (Figure 3-11) and the Congaree piezometric map (Figure 3-19). This head difference map (Figure 3-27) shows that the head in the Tuscaloosa is higher than the head in the Congaree in a broad area within about 10 km of the Savannah River and Upper Three Runs Creek. The head in the Congaree is higher in an area around M Area and in the Par Pond vicinity. It must be emphasized that this map is constructed by subtracting two piezometric maps for which control is somewhat sparce. Thus it should not be used to predict detailed head relationships but only to indicate directions of expected vertical gradient in general areas.

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TABLE 3-1

Hydrostratigraphic Units Underlying Savannah River Plant*

Formation	Geologic Age	Outcrop	Description	Water Yield	Thickness, ft
Alluvium	Recent Epoch	River and creek bottoms	Fine to coarse sand, silt, and clay	Very little	0 to 30
Terrace Deposits	Pleistocene Epoch	In flood plains and terraces of stream valleys	Tan to gray sand, clay, silt, and gravel on higher terraces	Moderate to none	0 to 30
Alluvium	Pliocene Epoch	Surface of Aiken Plateau	Gravel and sandy clay	Little or none	0 to 20
Hawthorn	Miocene Epoch	Large part of ground surface	Tan, red, and purple sandy clay with numerous clastic dikes	Little or none	0 to 80
Barnwell	Eocene Epoch	Large part of ground surface near streams	Red, brown, yellow, and buff, fine to course sand and sandy clay	Limited but sufficient for domestic use	0 to 90
McBean Congaree	Eocene Epoch	In banks of larger streams	Yellow-brown to green, fine to coarse, glauconite quartz sand, intercalated with green, red, yellow, and tan clay, sandy marl, and lenses of siliceous limestone	Moderate to large.	100 to 250
Ellenton	Upper Cretaceous Epoch	None on plant	Dark gray to black sandy lignitic micaceous clay containing disseminate crystalline gypsum and coarse quartz sand	Moderate to large; higher sulfate and iron than water from other formations	5 to 100
Tuscaloosa	Upper Cretaceous Epoch	None on plant except the extreme upper part of Upper Three Runs Creek Valley	Tan, buff, red, and white; crossbedded, micaceous quartzitic and arkosic sand and gravel imbedded with red, brown, and purple clay and white kaolin	Large, up to 2000 gpm; soft, low in total solids	~600
Newark Series "Red Beds"	Triassic Period	None on plant	Dark-brown and brick-red sandstone, siltstone, and claystone containing gray calcareous patches. Fanglomerates near border.	Very little	>3,000
Basement rocks of the Slate Belt and Charlotte Group	Precambrian and Paleozoic Eras	None on plant	Hornblende gneiss, chlorite-hornblende schist, lesser amounts of quartzite. Covered by saprolite layer derived from basement rock	Very little	Many thousands

* Modified from Siple (Reference 3).

TABLE 3-2

Chemical Analyses of Water from Metamorphic and Triassic Rock at SRP

Formation	Boring No.	Chemical Constituents (mg/L)									Total Dissolved Solids (mg/L)
		SiO_2	Fe	Ca	Mg	Na	K	HCO_3	SO_4	Cl	
Crystalline Rock	DRB8	7.6	0.03	467	15	1,200	16	18	2,590	900	5,660
Triassic	DRB9	1.0	0.00	518	83	1,120	30	72	420	2,620	5,950
Crystalline Rock	DRB9	6.1	0.09	46!	38	1,440	11	29	2,460	1,260	5,990
Triassic	P12R	-	0.05	22	7.6	262	9.3	157	<1	330	800
Triassic	DRB11	-	<1	3,845	8.5	2,710	22.1	~1	~1	11,600	18,500
Triassic	DRB10	3.5	0.04	1,990	53	2,100	44	85	110	6,720	11,900
Coastal Plain	54P (well)	12	0.18	5.0	0.9	1.2	1.0	10.5	14.1	1.4	38

TABLE 3-3

Transmissivity of the Tuscaloosa Formation

Location*	Transmissivity[16] (gal/day/ft)
Savannah River Plant Area Designation	
A	100,000
C	115,000
F	200,000
H	200,000
K	110,000
L	70,000
P	50,000
R	90,000
Aiken	100,000
Williston	120,000
Barnwell Nuclear Fuel Plant	143,000
Average	118,000
Median	110,000

* Location of SRP Areas are shown on Figure 3-6.

TABLE 3-4

pH and Composition of Water from Four Major Sources in the Vicinity of SRP*

Source of Water	Number of Analyses	Range and Median	pH	Chemical Constituents (mg/L) Fe	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	CO_3^{2-}	SO_4^{2-}	Cl^-	F^-	NO_3^-	Total Dissolved Solids**	Hardness†
Tuscaloosa Formation	13	Maximum	6.9	0.77	1.4	0.9	6.7	17	4.8	4.0	0.1	8.8	28	7
		Minimum	4.4	0.00	0.3	0.0	0.9	0	0.5	0.8	0.00	0.0	14	2
		Median	5.4	0.16	0.9	0.5	2.1	3	1.4	2.2	0.0	0.6	19	5
Ellenton Formation	16	Maximum	6.8	4.1	8.7	1.3	4.2	23	27	6.0	0.2	0.9	54	30
		Minimum	4.4	0.10	3.9	0.4	1.5	4	7.4	1.5	0.0	0.0	36	10
		Median	5.9	1.1	6.4	1.0	2.7	12	11	2.1	0.1	0.0	41	19
Eocene Limestone	15	Maximum	7.6	1.0	47	9.4	19	17.1	14	4.5	0.5	6.2	192	132
		Minimum	6.8	0.00	17	0.3	0.4	55	0.8	0.4	0.0	0.0	75	50
		Median	7.1	0.25	27	2.0	1.7	94	4.3	2.8	0.1	0.2	95	72
Eocene Sand	9	Maximum	6.1	1.84	8.7	4.2	2.4	17	9.3	4.0	0.3	2.3	29	15
		Minimum	4.2	0.04	0.5	0.3	0.4	1	0.8	1.5	0.00	0	20	4
		Median	5.5	0.16	1.5	0.7	2.1	5.5	1.9	2.7	0.1	1.3	21	8

* From Siple (Reference 3)

** Residue after evaporation at 180°C in mg/L

† As $CaCO_3$

TABLE 3-5

Analyses of Groundwater from Tertiary and Cretaceous Formations at SRP

	Source of Water			Properties			Chemical Constituents (mg/L)														
Date Sampled	Well Number	Screen Depth (ft)	Formation	Temp (°C)*	pH*	Specific Conductance (Micromhos)	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	Fe	Si	Al	Mn	HCO_3^-	Cl^-	SO_4^{-2}	NO_3^-	PO_4^{-3}	F^-	TDS
12/16/66	HC1E	43 to 48	Barnwell Upper Zone	21.7	5.8	48	3.3	0.3	1.6	TR	.52	6.8	TR	0.02	12	6.0	1.0	3.8	0.0	0.0	34
10/25/77	HC2F	74 to 79	Barnwell	23.0	5.04	NM	0.42	0.05	0.10	3.96	<0.2	3.9	<1	<0.02	NM	3.7	0.25	5.8	.32	.01	20
8/1/74	HC3F	55 to 60	Barnwell	NM	5.2	15	1.7	0.43	0.25	2.9	<0.1	2.9	NM	NM	4.0	3.3	1.0	0.78	NM	NM	15
10/18/77	HC6B	85 to 90	Barnwell	22.0	6.30	NM	3.72	0.03	1.91	2.20	<0.2	4.6	<1	<0.03	18.3	1.5	0.62	5.1	.01	0.01	30
7/25/74	HC3E	93 to 98	Barnwell	NM	5.7	18	5.4	0.25	0.54	2.5	<0.1	4.6	NM	NM	16.3	3.0	1.8	<0.0001	NM	NM	26
7/23/74	HC3D	121 to 126	McBean	NM	4.8	11	0.8	0.37	0.22	1.7	<0.1	5.5	NM	NM	2.1	3.0	1.0	<0.0001	NM	NM	14
4/28/65	HC2H	134 to 144	McBean CZ	23.2	7.1	103	11	0.4	3.0	TR	0.02	12	0.1	0.00	45	4.1	5.8	0.2	0.78	0.1	66
11/23/77	HC6A	139 to 144	McBean CZ	21.2	6.93	NM	13.8	0.02	0.64	2.57	<0.2	5.4	<1	<0.02	49.3	2.3	0.62	0.05	0.01	0.01	51
2/21/72	905-72G	110 to 160	McBean CZ	NM	7.0	NM	7.0	9.2	0.90	12.5	0.012	0.60	NM	0.05	27.5	1.6	10.2	0.11	0.18	NM	56
7/19/74	HC3A	230 to 235	Congaree	NM	6.4	130	28	0.54	0.55	1.5	<0.1	9.4	NM	NM	72	2.8	2.2	0.001	NM	NM	81
1/19/78	FC2A	231 to 235	Congaree	19.6	6.15	NM	11.1	0.07	0.94	1.45	<0.2	10.7	<1	<0.03	42.7	3.92	10.5	0.05	0.12	0.01	61
2/21/72	905-31A	440 to 536	Tuscaloosa	NM	5.5	17	0.11	1.7	NM	1.75	0.01	0.56	NM	<0.05	5.4	0.8	2.3	0.02	5.06	NM	10
2/29/72	905-41D	335 to 490	Tuscaloosa	NM	6.6	NM	1.4	3.5	4.3	11.0	<0.05	0.6	NM	<0.05	9.9	0.59	15.0	0.26	3.3	NM	42
2/21/72	905-43H	660 to 850	Tuscaloosa	NM	4.3	54	0.82	1.52	1.15	1.82	0.14	0.9	NM	0.05	0.97	0.60	11.3	0.09	—	NM	22
2/21/72	905-67U	615 to 725	Tuscaloosa	NM	5.15	19	0.22	1.5	0.43	1.6	0.05	0.44	NM	0.05	0.97	0.71	3.5	—	—	NM	10

* Measured at well head.

NM = Not measured.
TR = Trace.
CZ = Calcareous zone.

TABLE 3-6

Summary of Pumping Test Data on the McBean and Congaree Formations

Pumping Well	Observation Well	Date of Test	SRP Process Area	Pumping Rate (gpm)	Aquifer Thickness (feet)	Trans-missivity (gal/day/ft)	Permeability (gal/day/ft^2)	(ft/day)	Storage Coefficient
10 TCA	9 TCA	4-16-51	Near C	480	60	59,000	980	131	0.0002*
14 TSC	14 TC	4-20-51	CS	175	50	7,200	140	19	------*
26 CY	26 CY	10-18-51	Near P	410	105	100,000	950	127	------*
MPTW-1	MSB-11C	6-21-82	Near M	30	60	1,100	18	2.4	0.14

* First three tests from Siple (Reference 3).

TABLE 3-7

Median Hydraulic Conductivities of Tertiary Hydrostratigraphic Units as Determined by Pumping Tests

Formation	Conductivity (m/day)*	(ft/day)	(gal/day/ft^2)
Barnwell Sand Lens	0.3	1.0	7.5
Barnwell Clayey Sand	0.04	.13	1.0
Barnwell Silty Sand	-	-	-
Upper McBean	0.13	.43	3.2
Lower McBean	0.07	.23	1.72
Congaree	1.5	4.9	36.7

---

* From Marine and Root (Reference 23).

TABLE 3-8

SRP Precipitation by Month and Year, 1952 Thru 1983
(Inches/Period, 77?-12A)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Departure From Avg.
1952	2.07	3.23	6.55	3.12	5.56	5.67	2.82	5.98	3.34	1.36	2.86	3.99	46.55	-1.55
1953	2.69	5.48	3.83	2.96	4.42	5.38	3.63	3.61	8.53	0.11	1.04	7.51	49.19	1.09
1954	1.26	1.64	2.95	2.50	2.89	2.91	2.03	4.10	1.43	1.29	2.94	2.88	28.82	-19.28
1955	4.75	2.62	2.21	5.57	4.53	3.31	3.94	5.07	3.42	1.32	2.93	0.46	40.13	-7.97
1956	1.67	7.94	4.84	3.21	3.07	2.34	4.34	3.18	4.56	1.83	0.93	2.05	39.96	-8.14
1957	2.05	1.58	4.29	2.75	8.02	4.17	3.51	2.41	5.04	6.12	6.46	2.24	48.64	0.54
1958	4.01	4.38	4.96	3.63	2.07	2.50	5.32	2.76	1.12	0.96	0.21	4.42	38.34	-9.76
1959	3.54	6.06	6.44	2.03	3.81	4.06	5.80	2.93	8.71	10.86	1.97	3.54	59.75	11.65
1960	6.91	5.81	5.76	5.07	1.96	3.66	5.27	2.81	4.84	0.97	0.83	2.93	46.82	-1.28
1961	3.59	5.76	7.23	8.20	3.88	3.01	3.09	7.15	1.00	0.07	1.83	6.60	51.41	3.31
1962	4.64	5.14	6.52	4.03	3.50	4.41	2.56	3.43	5.55	2.27	3.50	2.20	47.75	-0.35
1963	5.96	3.64	3.34	3.70	2.98	8.42	3.18	1.04	5.37	0.00	3.68	4.47	45.78	-2.32
1964	7.79	6.00	5.79	5.94	3.62	4.50	10.42	12.34	5.68	6.13	0.88	4.38	73.47	25.37
1965	2.00	6.39	8.47	2.43	1.33	5.04	8.04	1.94	2.83	2.59	2.17	1.41	44.84	-3.26
1966	7.18	5.96	4.43	2.53	5.51	4.66	4.11	5.23	3.64	1.25	1.05	3.40	48.95	0.85
1967	3.66	3.80	5.68	2.82	5.01	3.74	7.52	7.32	1.70	0.64	2.51	3.13	47.53	-0.57
1968	3.98	0.94	1.49	2.12	3.46	6.20	2.88	4.27	2.24	3.00	3.39	2.73	37.70	-10.40
1969	2.00	2.46	3.38	4.09	3.02	3.95	2.71	5.42	4.56	1.16	0.40	4.19	37.34	-10.76
1970	2.79	2.69	7.36	1.38	4.16	3.46	4.85	3.79	1.71	5.01	1.68	4.92	43.80	-4.30
1971	5.11	4.16	8.68	2.92	2.98	5.92	10.53	8.76	3.80	5.95	2.31	2.89	64.01	15.91
1972	8.91	4.42	2.82	0.57	4.72	6.57	2.64	6.05	1.47	1.20	3.56	5.23	48.16	0.06
1973	5.36	5.26	6.38	4.58	3.50	10.89	6.04	3.81	3.71	1.22	0.31	4.64	55.70	7.60
1974	2.58	7.03	2.87	2.93	4.15	2.79	4.08	6.27	3.22	0.08	2.19	3.83	42.02	-6.08
1975	4.98	6.64	5.91	4.42	5.15	3.84	8.55	3.83	5.18	1.74	3.41	2.03	55.68	7.58
1976	4.18	1.08	3.83	2.50	10.90	4.35	1.95	1.64	5.48	4.92	4.19	5.08	50.10	2.00
1977	3.72	1.62	6.86	1.27	1.79	2.47	3.42	7.30	5.50	4.27	1.63	3.86	43.71	-4.39
1978	10.02	1.32	3.07	3.53	3.64	3.43	4.12	5.11	4.06	0.06	3.54	1.88	43.78	-4.32
1979	3.59	7.74	3.09	6.49	8.94	1.54	7.85	2.12	6.13	1.35	3.95	2.17	54.96	6.86
1980	5.12	3.48	10.96	1.69	3.49	2.99	0.90	2.03	5.86	2.14	2.50	1.91	43.07	-5.03
1981	0.89	5.02	4.72	2.07	6.90	4.29	3.97	5.79	0.54	2.81	1.00	9.55	47.55	-0.55
1982	3.94	4.45	2.50	5.68	2.72	4.27	11.48	5.00	4.62	3.87	2.40	4.83	55.76	7.66
1983	3.77	7.21	6.77	5.77	1.67	6.57	4.85	6.32	3.56	1.92	5.38	4.15	57.94	9.84
Sum	134.71	140.95	164.18	114.50	133.35	141.31	157.40	148.81	128.40	78.47	77.63	119.50	1539.20	
Avg.	4.21	4.40	5.13	3.58	4.17	4.42	4.92	4.65	4.01	2.45	2.43	3.73	48.10	
Max.	10.02	7.94	10.96	8.20	10.90	10.89	11.48	12.34	8.71	10.86	6.46	9.55	73.47	
Year	1978	1956	1980	1961	1976	1973	1982	1964	1959	1959	1957	1981	1964	
Min.	0.89	0.94	1.49	0.57	1.33	1.54	0.90	1.04	0.54	0.00	0.21	0.46	28.82	
Year	1981	1968	1972	1965	1979	1980	1963	1963	1981	1963	1958	1955	1954	

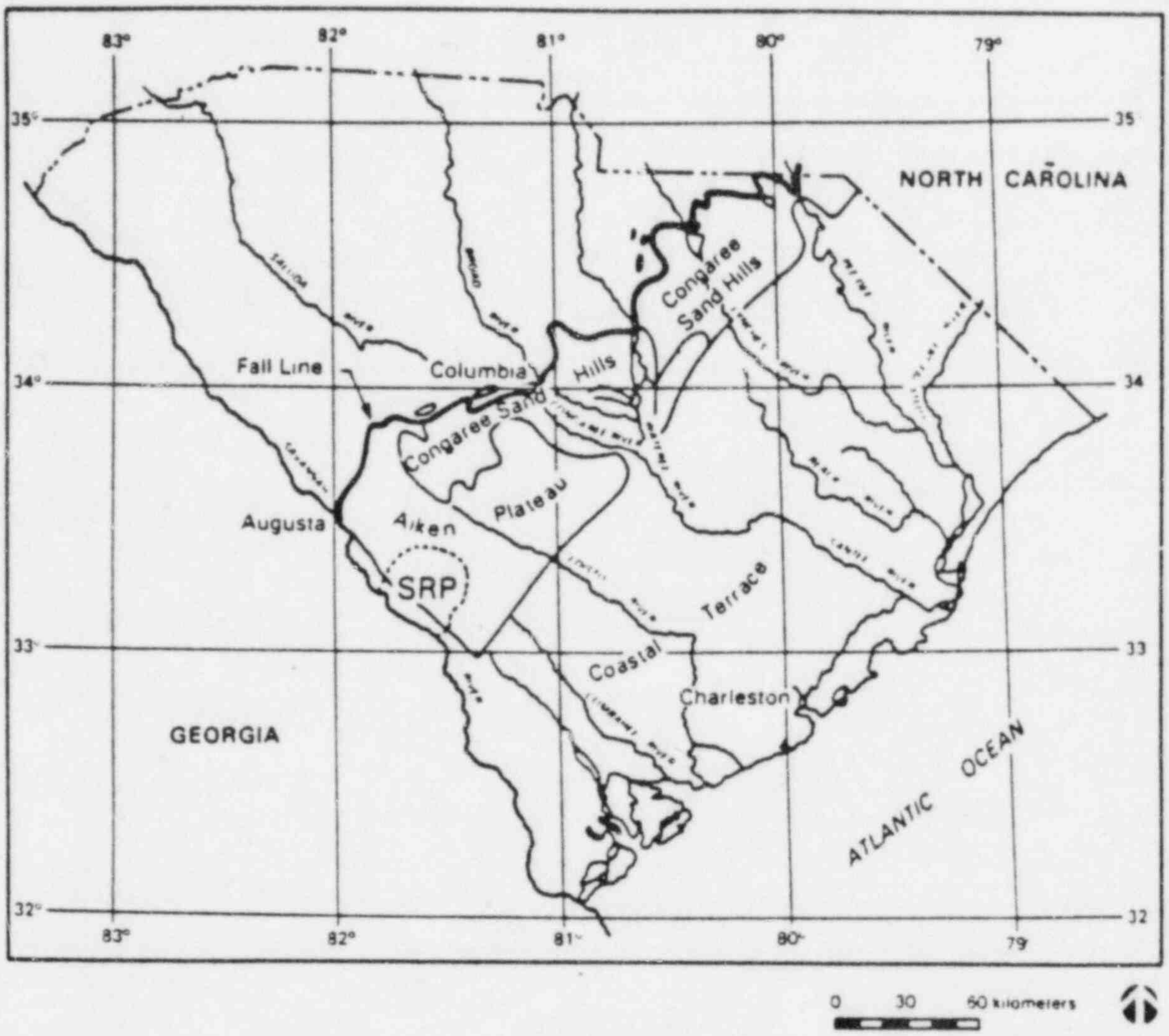

FIGURE 3-1. Physiography of the Savannah River Region

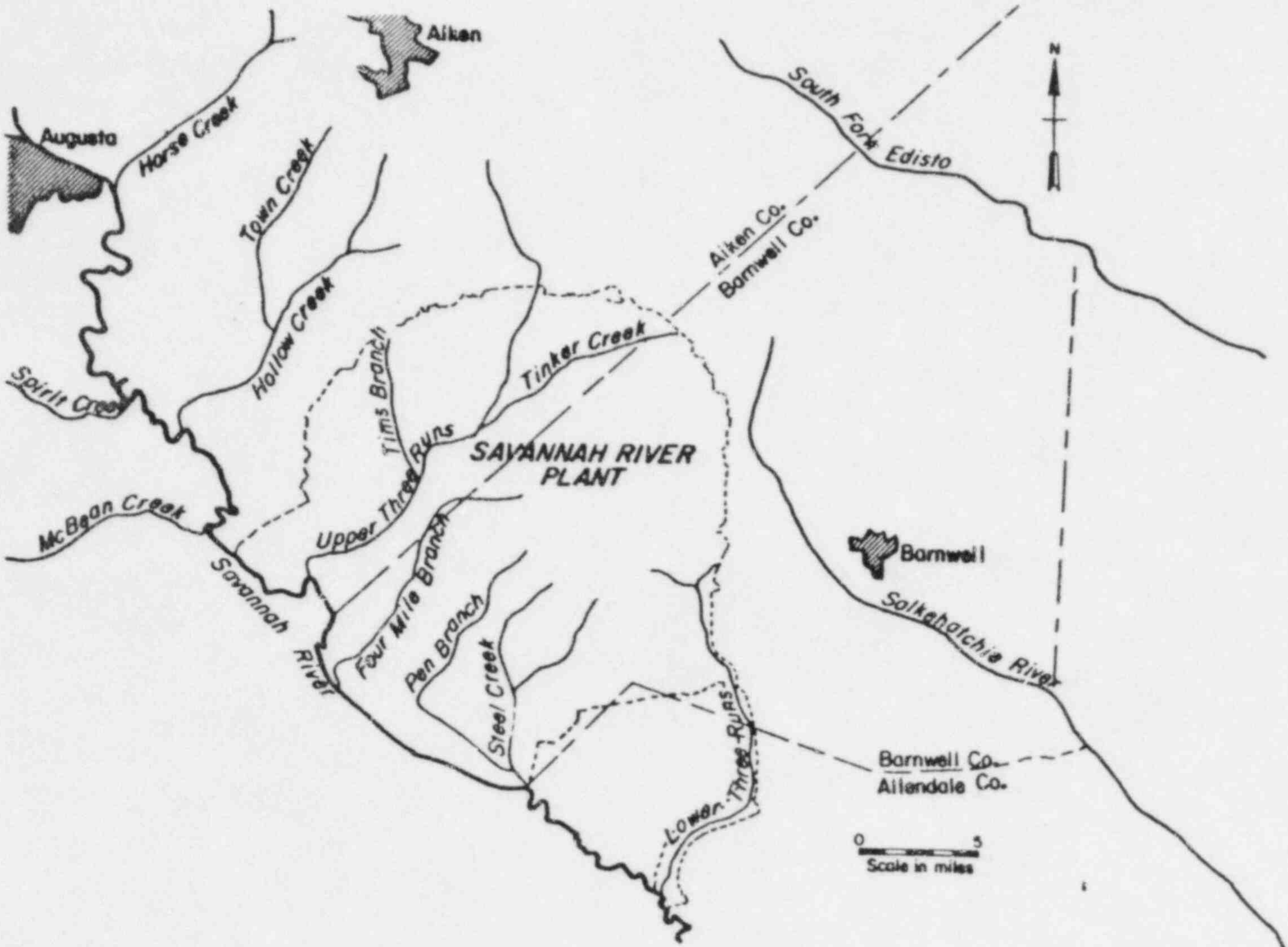

FIGURE 3-2. Surface Hydrologic Features in the Vicinity of the Savannah River Plant

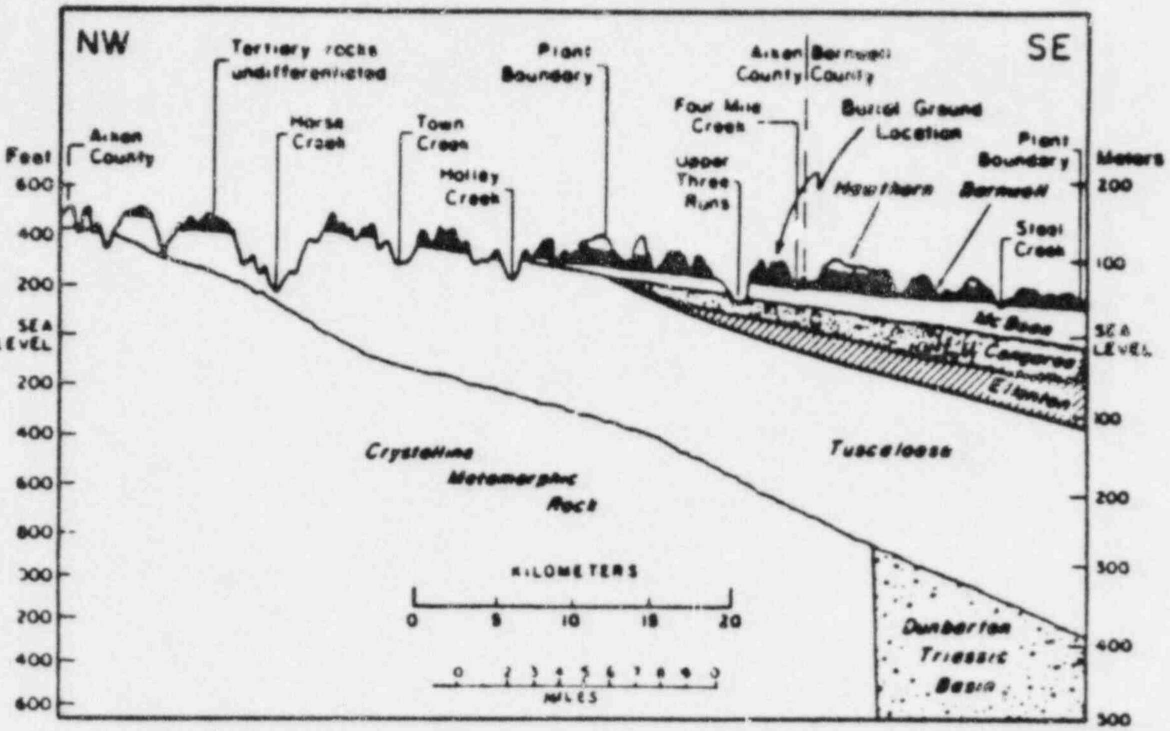

FIGURE 3-3. Generalized NW to SE Geologic Profile Across the Savannah River Plant

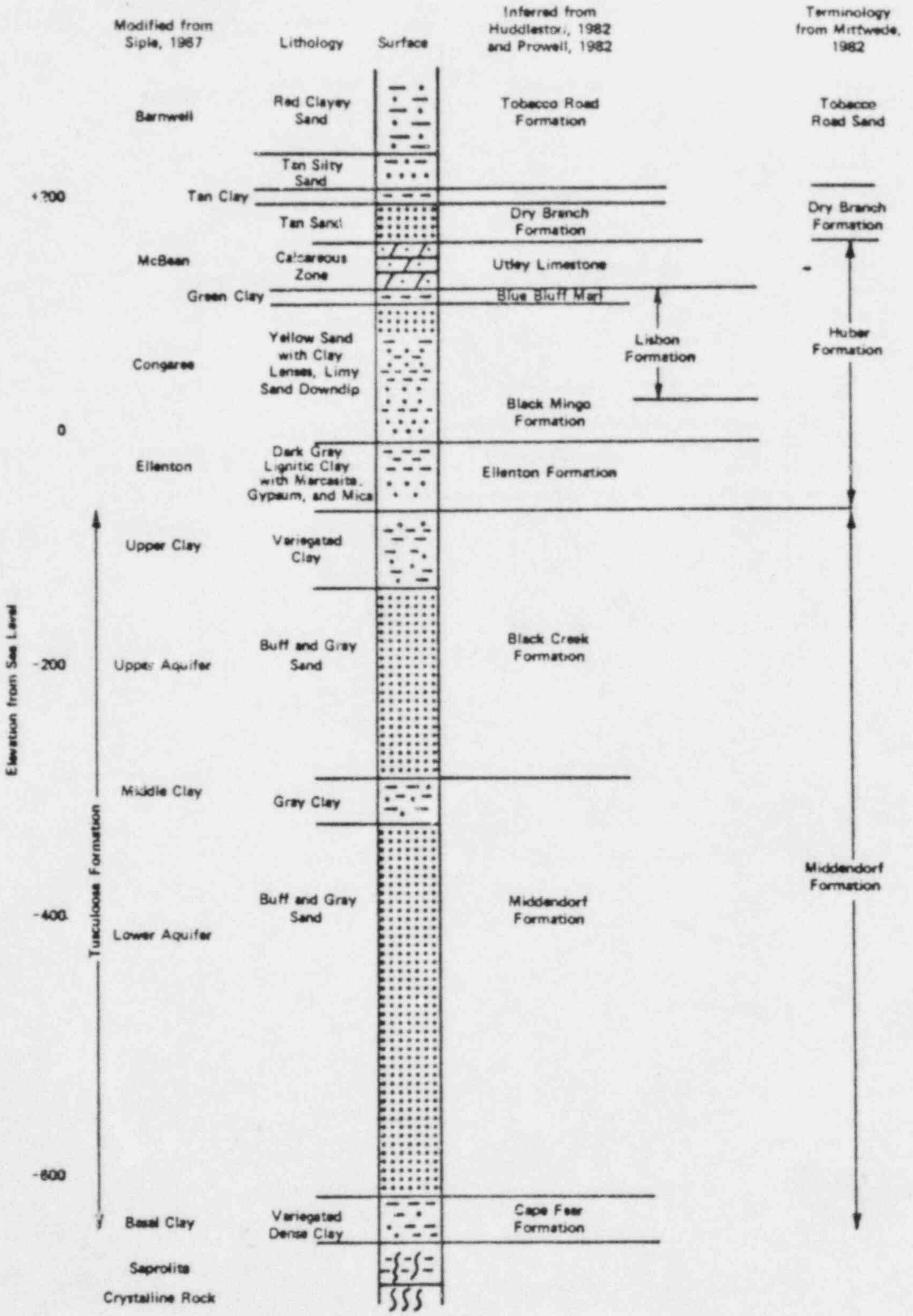

FIGURE 3-4. Tentative Correlation of Stratigraphic Terminology of the Southwestern South Carolina Coastal Plain

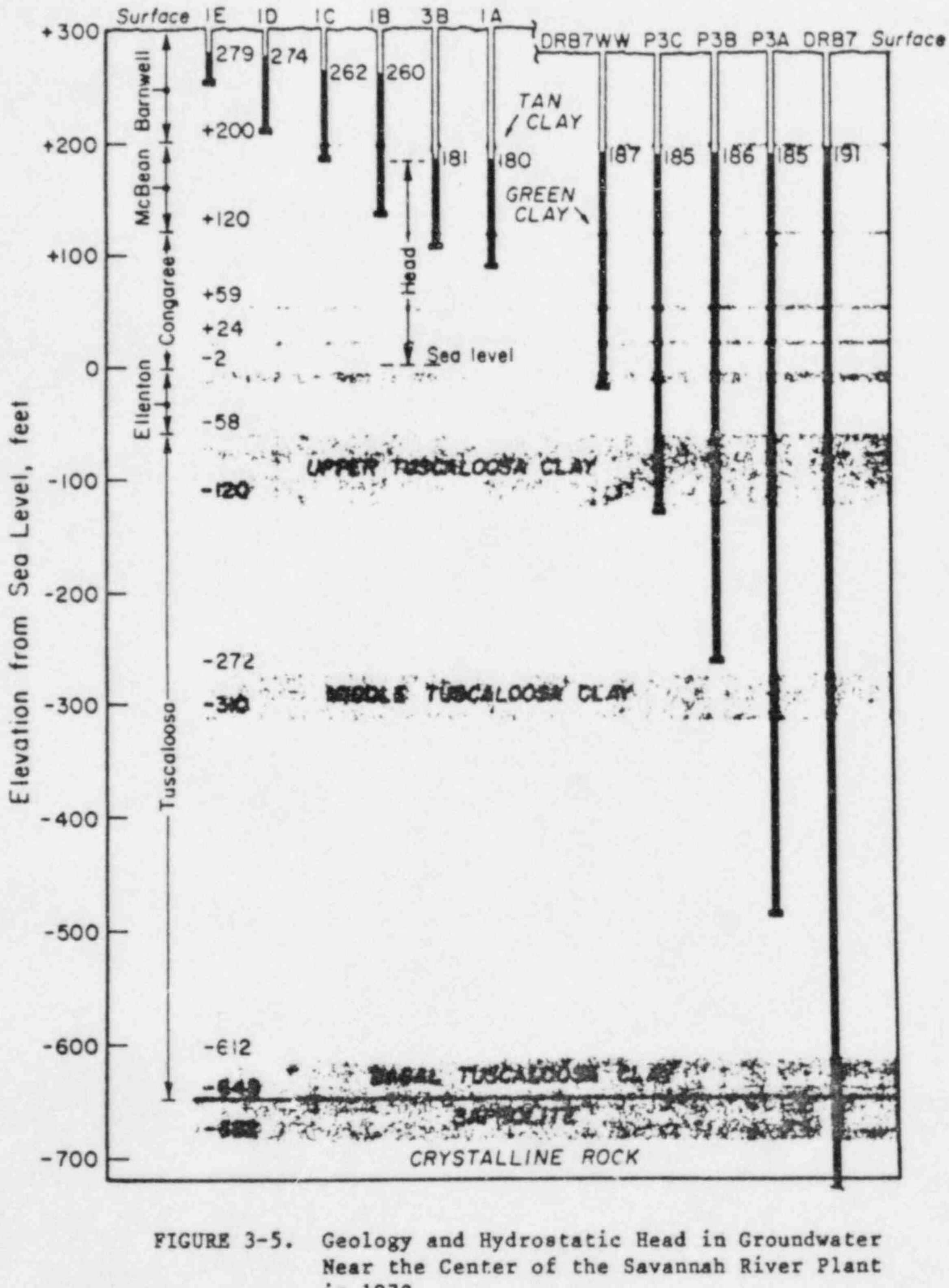

FIGURE 3-5. Geology and Hydrostatic Head in Groundwater Near the Center of the Savannah River Plant in 1972

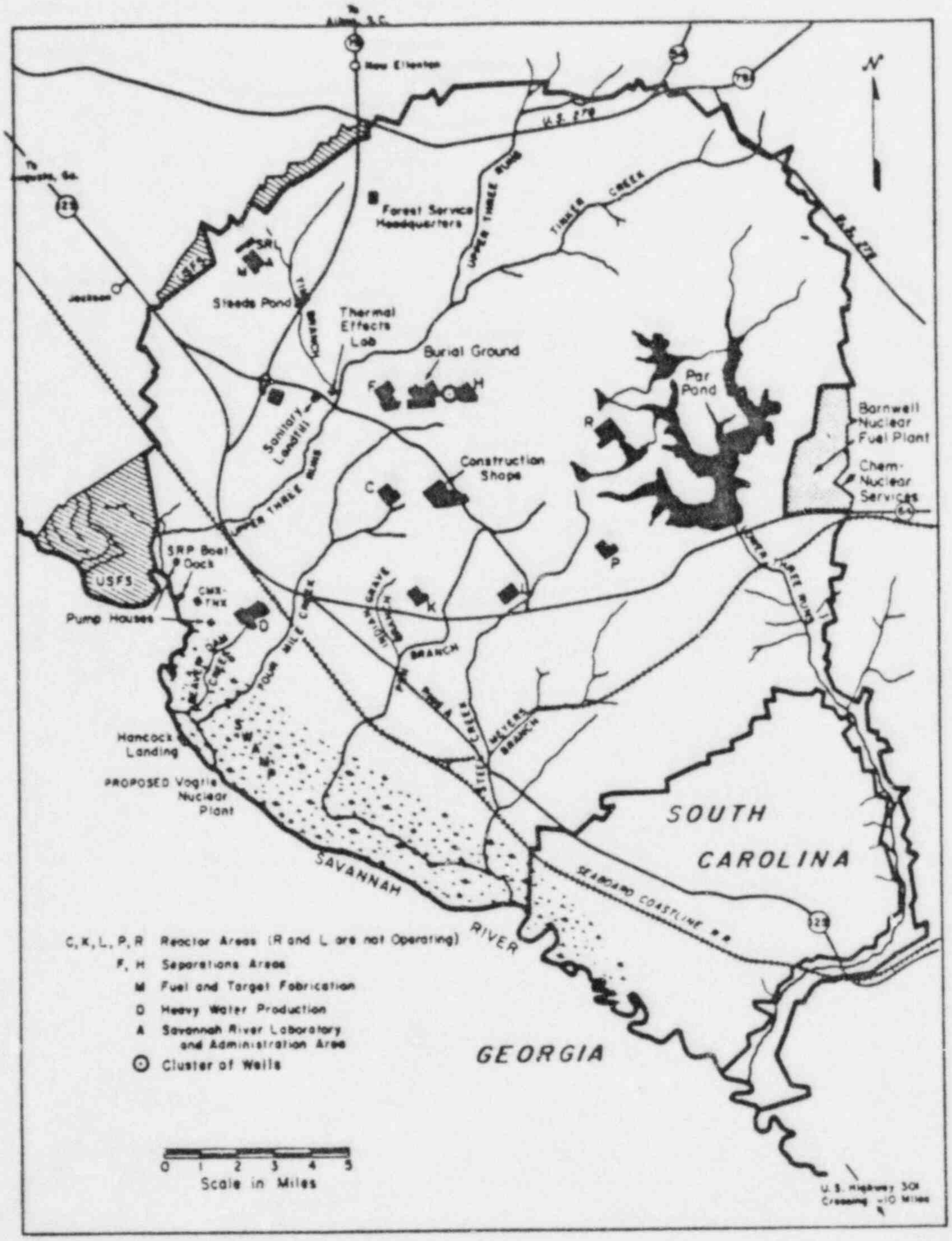

FIGURE 3-6. Areas for Which the Transmissivity of the Tuscaloosa Formation is Given on Table 3-3 and the Location of the Cluster of Wells Shown on Figure 3-5.

FIGURE 3-7. Piezometric Surface and Outcrop Area of the Tuscaloosa Formation Reproduced from Siple[3]

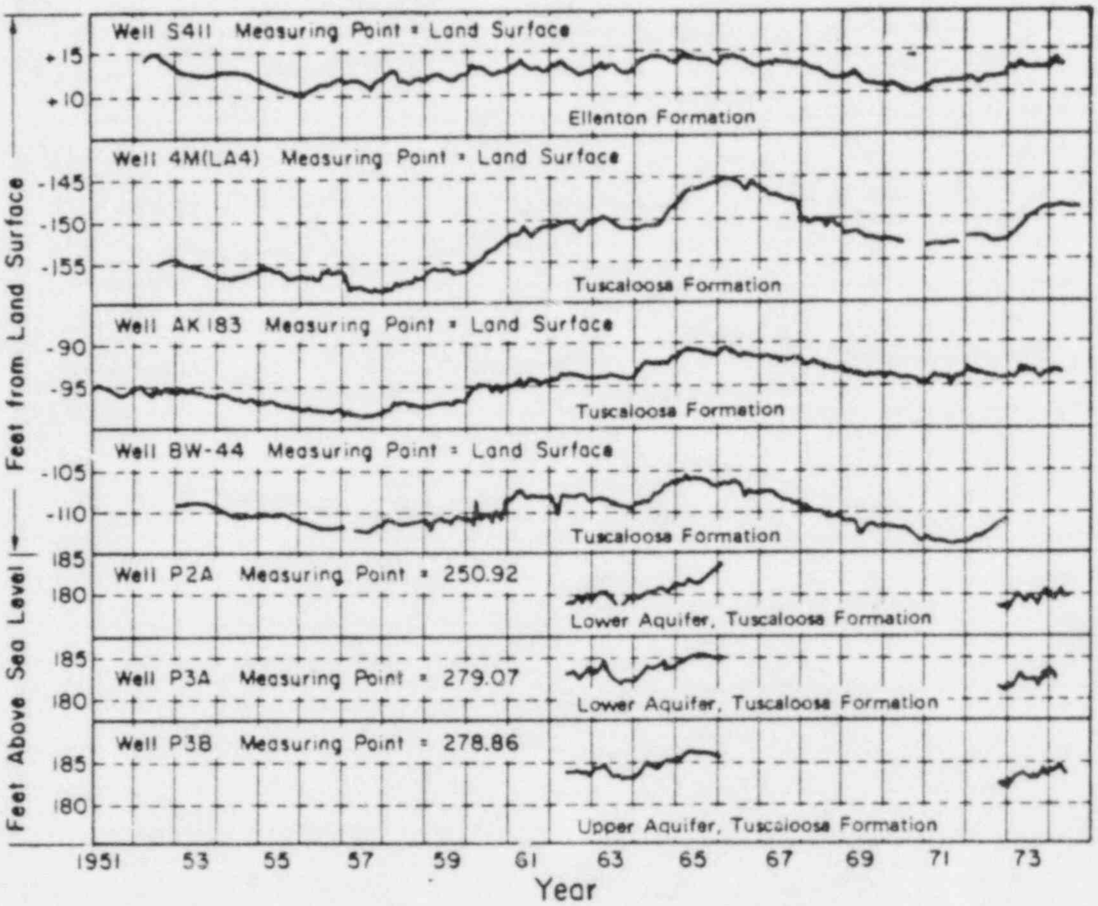

FIGURE 3-8. Long-Term Hydrographs of Water Levels in the Tuscaloosa and Ellenton Formations

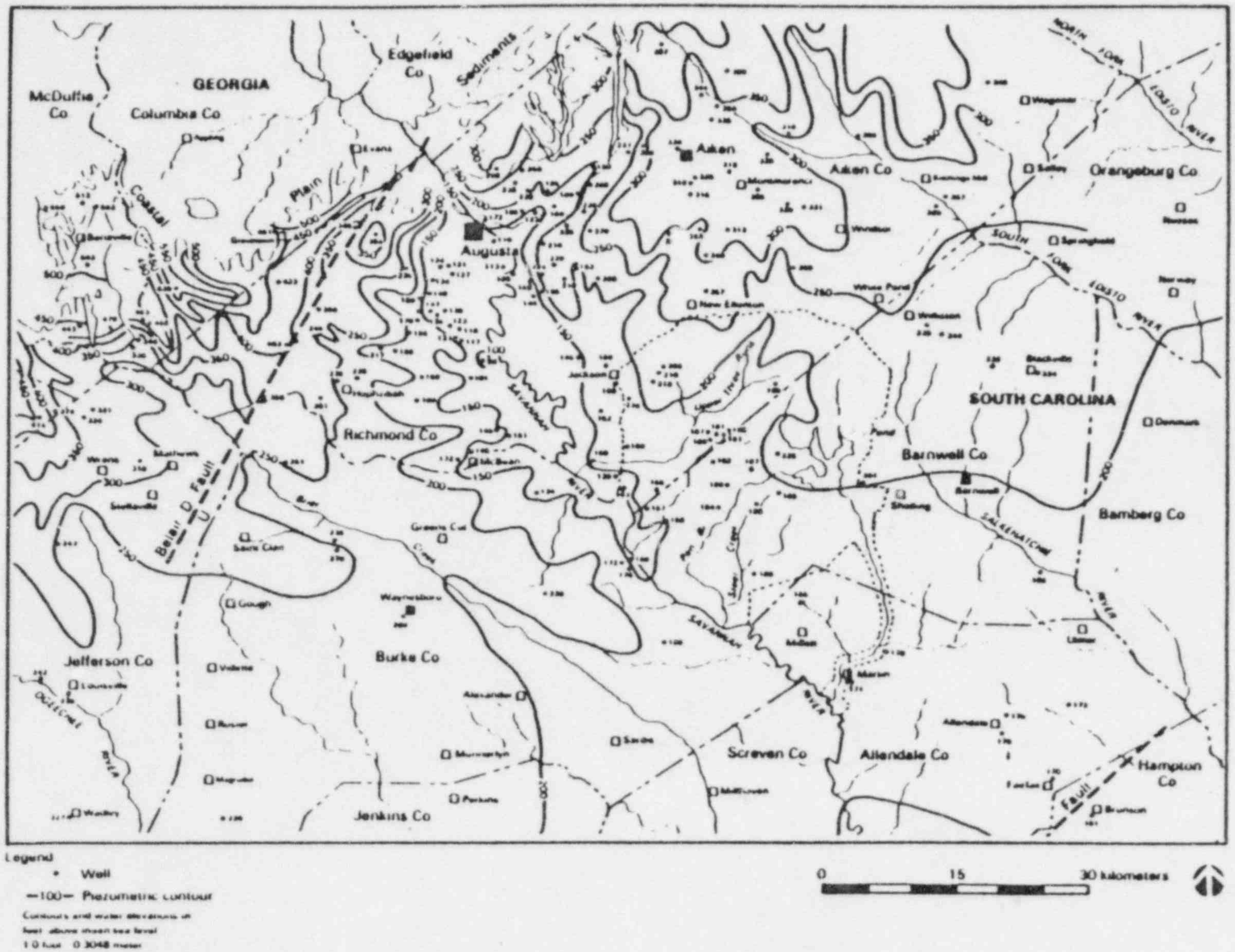

FIGURE 3-9. Piezometric Surface of the Tuscaloosa Formation Reproduced from Faye and Prowell[17]

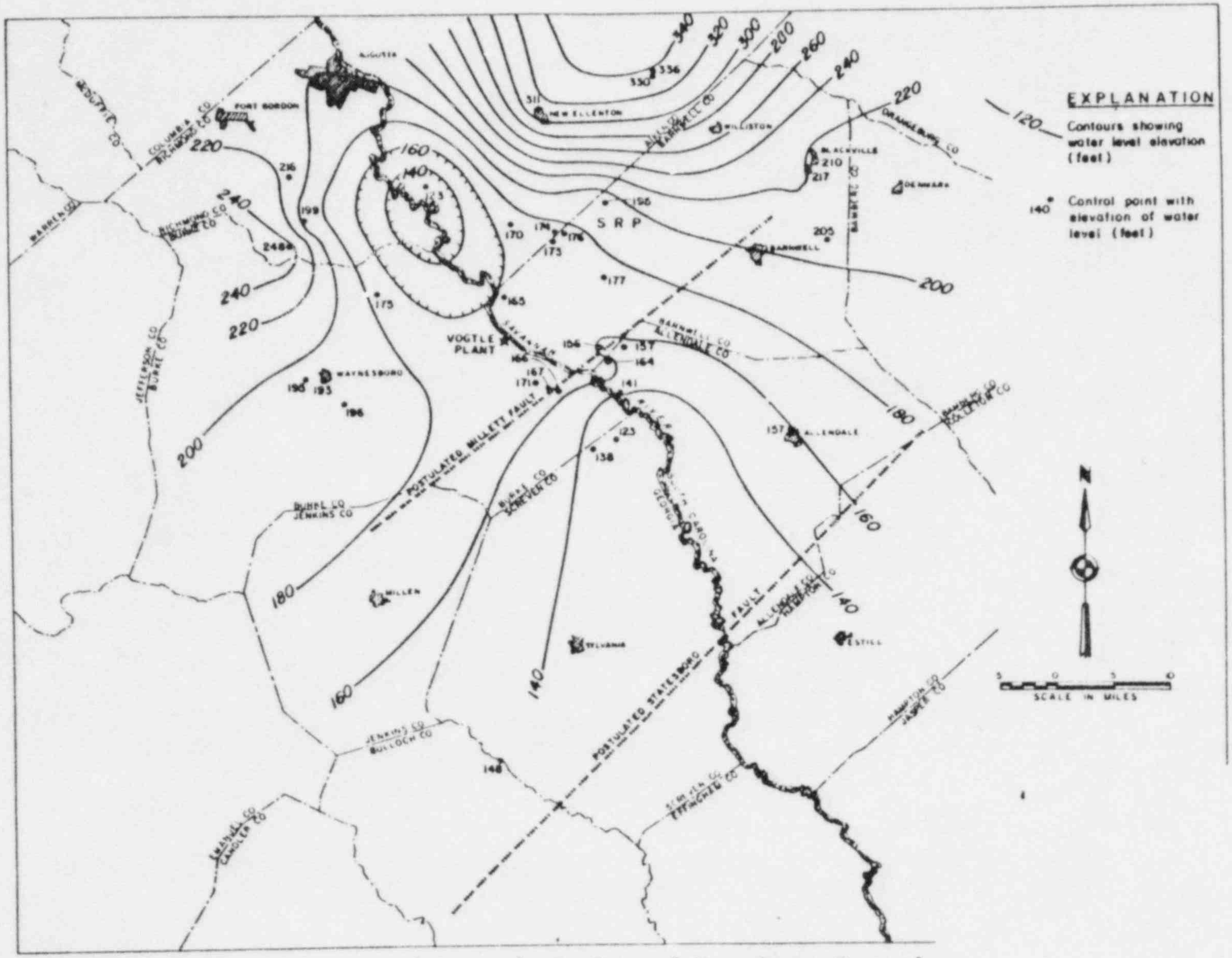

FIGURE 3-10. Piezometric Surface of Tuscaloosa Formation Reproduced from Georgia Power Company[18]

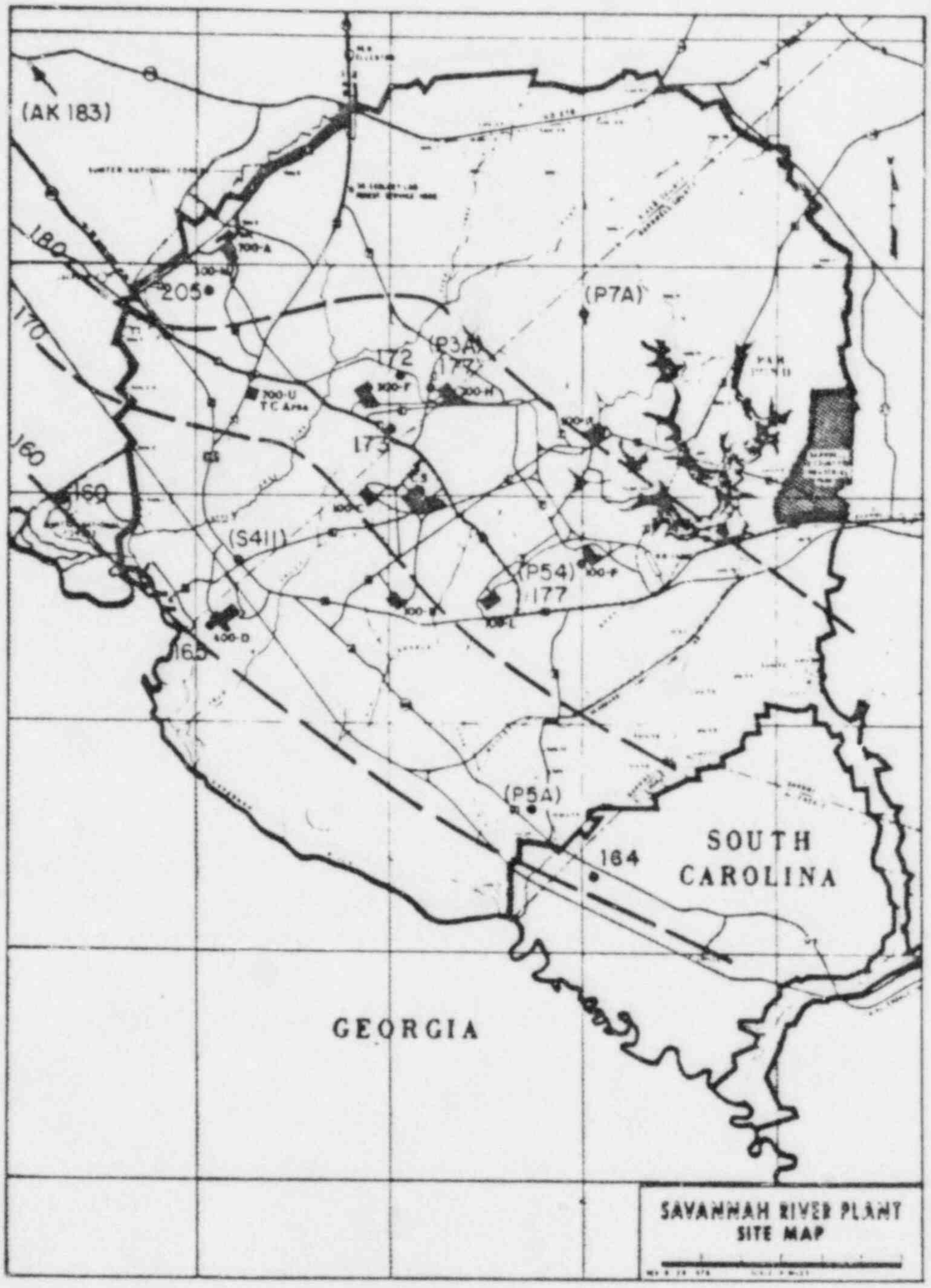

FIGURE 3-11. Piezometric Surface of Tuscaloosa Formation at SRP (May 11, 1982) and Locations of Tuscaloosa Wells (Parentheses) for Which Hydrographs are Given in Figure 4-3. (Contours and Water Levels in Feet Above Mean Sea Level.)

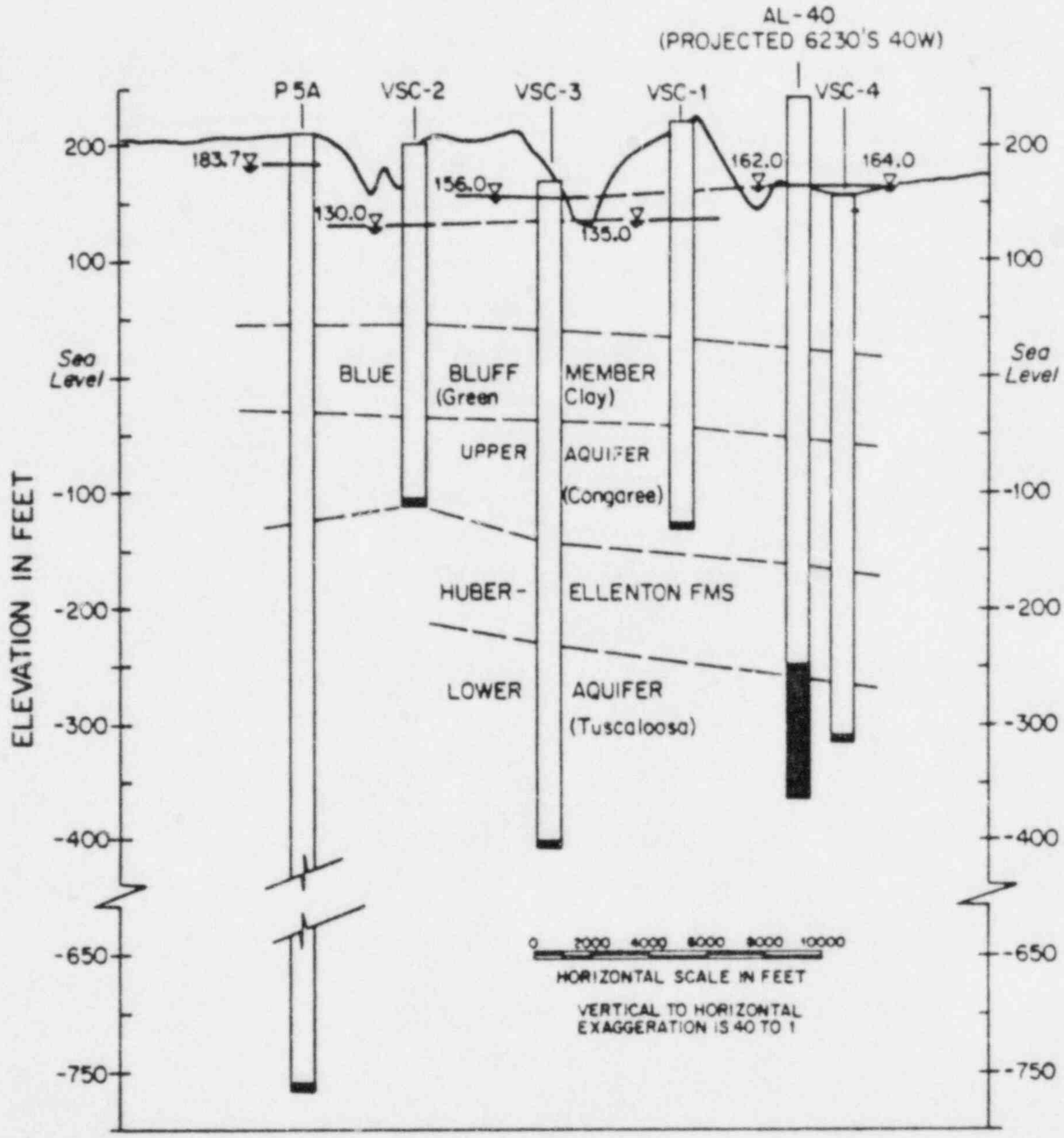

FIGURE 3-12. Comparison of Water Levels in the Congaree Formation to Those in the Tuscaloosa Formation in the Southern Part of SRP

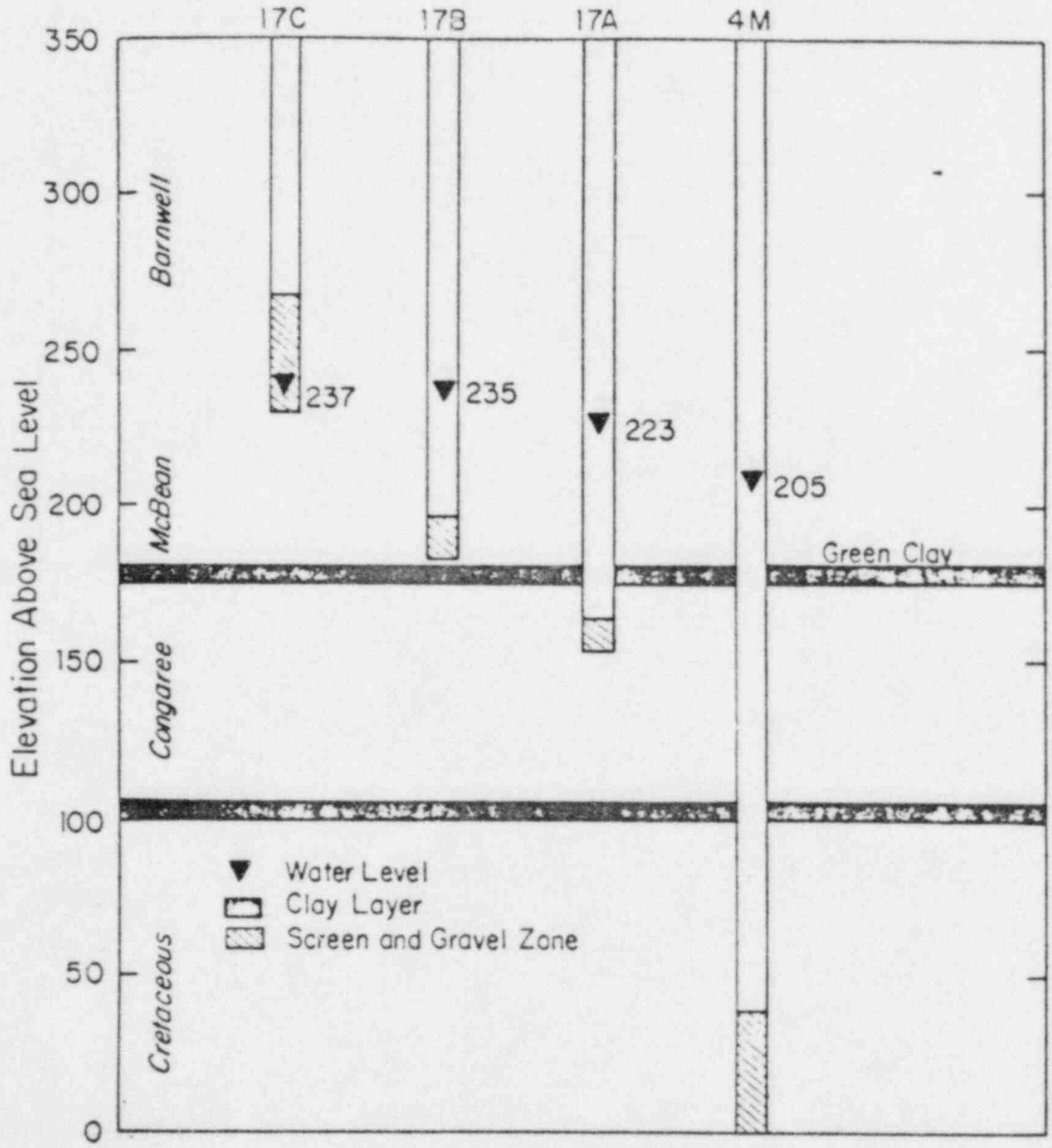

FIGURE 3-13. Vertical Head Relationships Near M Area

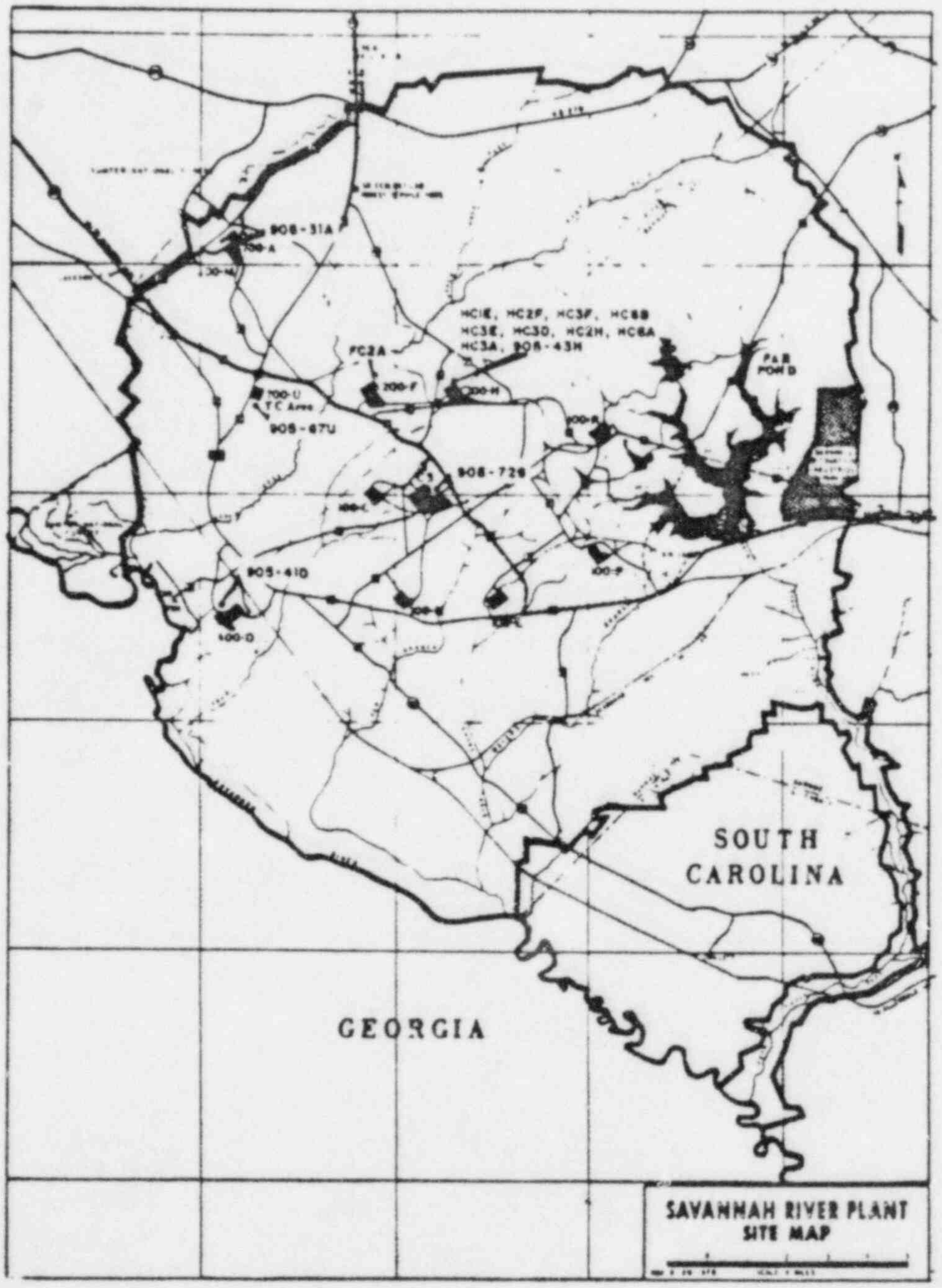

FIGURE 3-14. Locations of Wells Sampled for Chemical Analyses of Groundwater

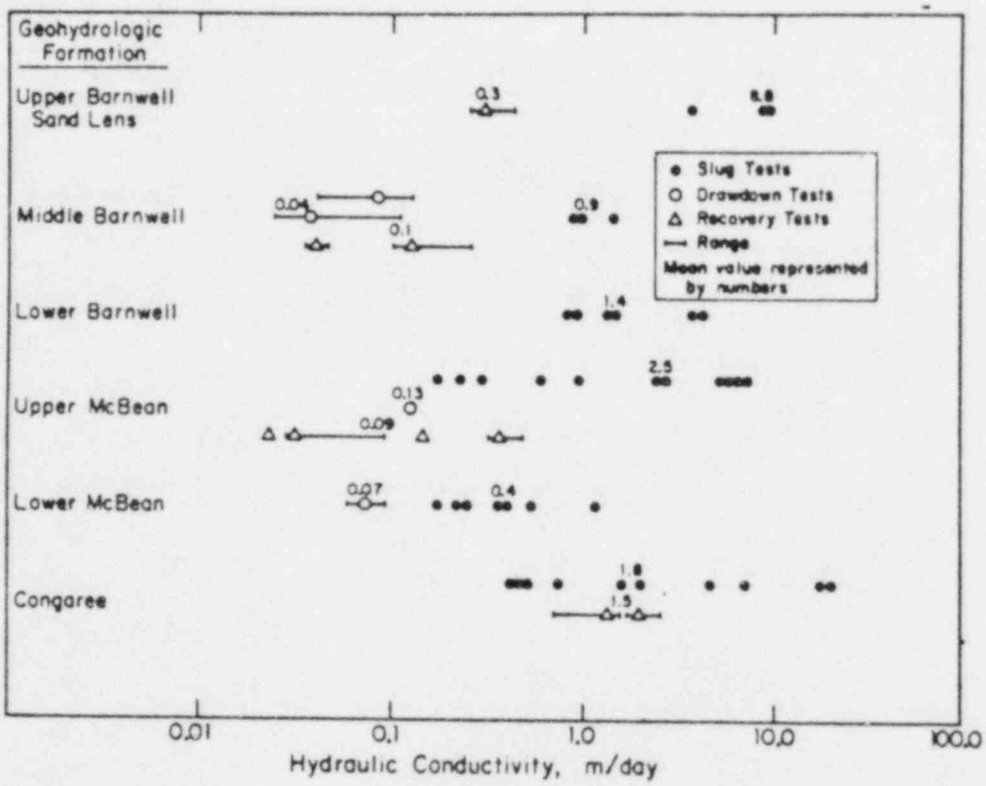

FIGURE 3-15. Hydraulic Conductivity Values from Selected Hydrostratigraphic Units Near the Center of SRP

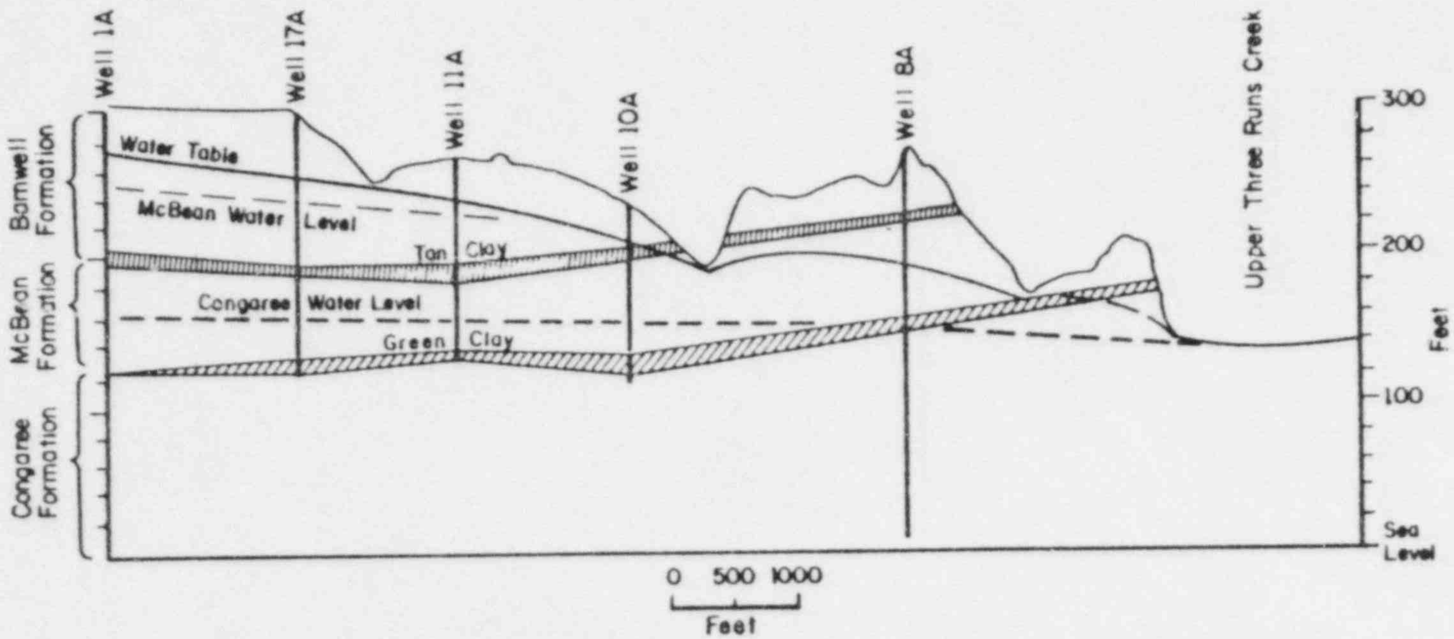

FIGURE 3-16. Geohydrologic Section in Central Part of SRP

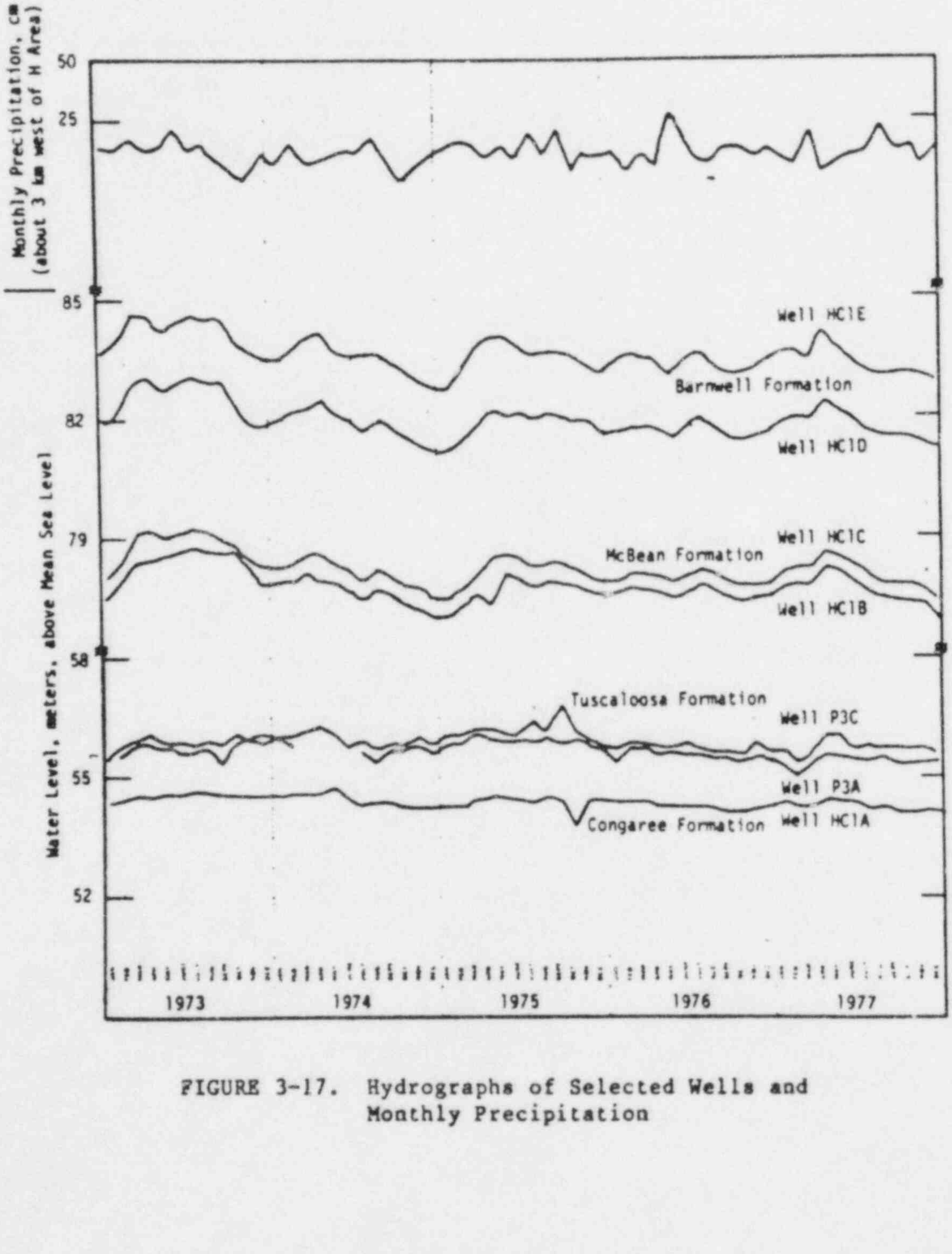

FIGURE 3-17. Hydrographs of Selected Wells and Monthly Precipitation

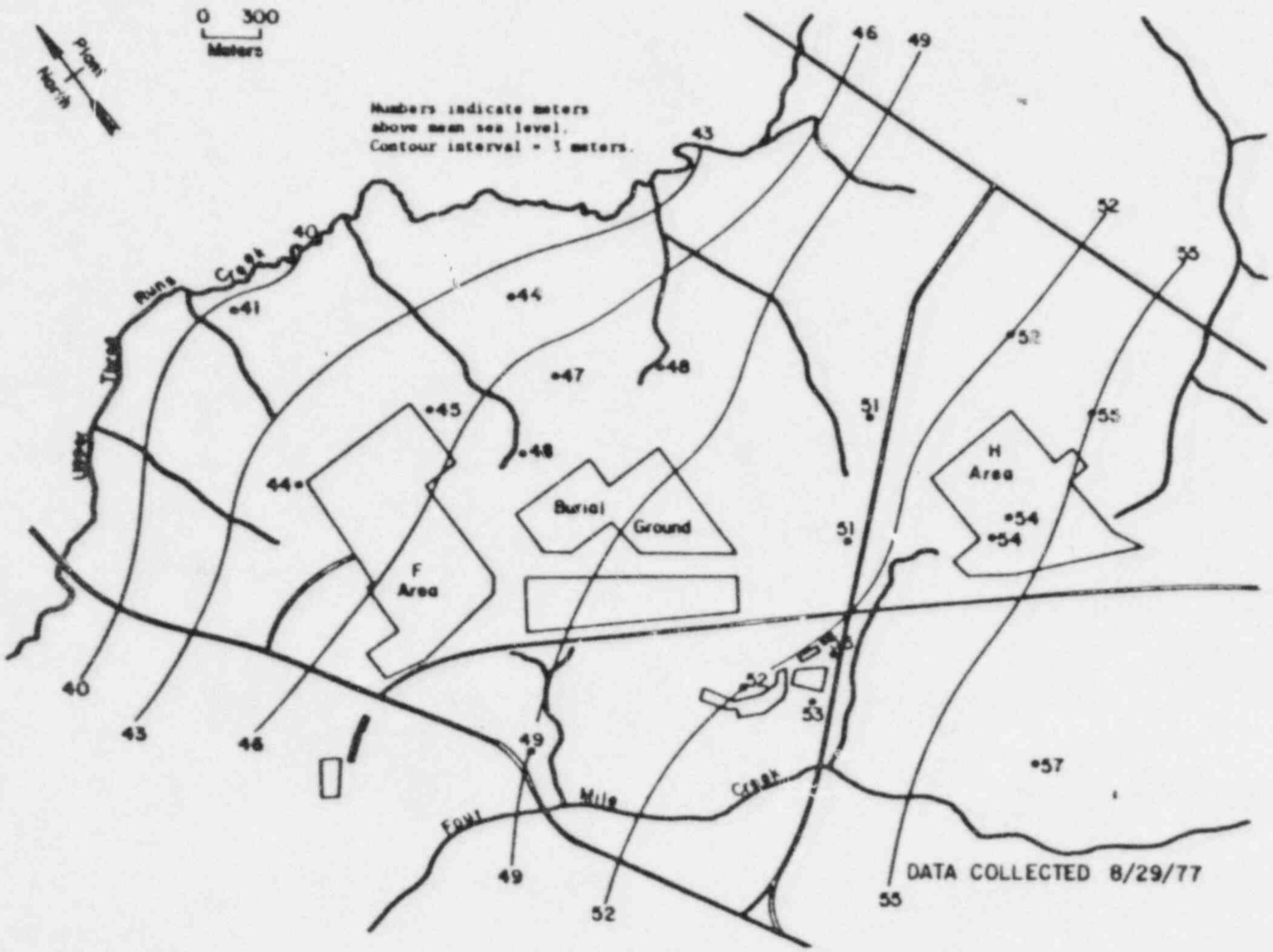

FIGURE 3-18. Piezometric Map of the Upper Part of the Congaree Formation in the Separations Areas at SRP

FIGURE 3-19. Piezometric Map of the Congaree Formation (May 11, 1982) at SRP. (Contours and Water Levels in Feet Above Mean Sea Level.)

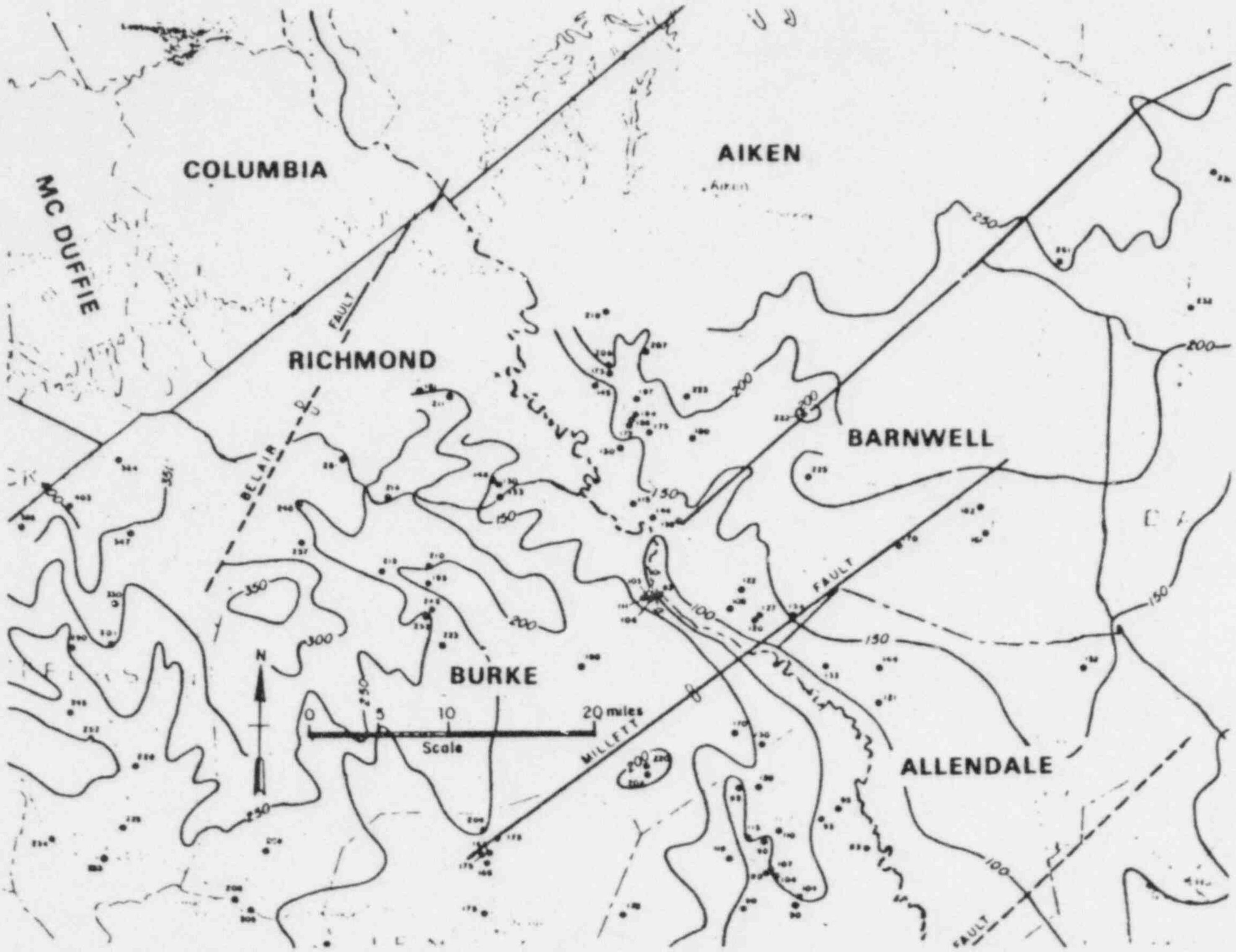

FIGURE 3-20. Piezometric Surface of the Congaree Formation Reproduced from Faye and Prowell[17]

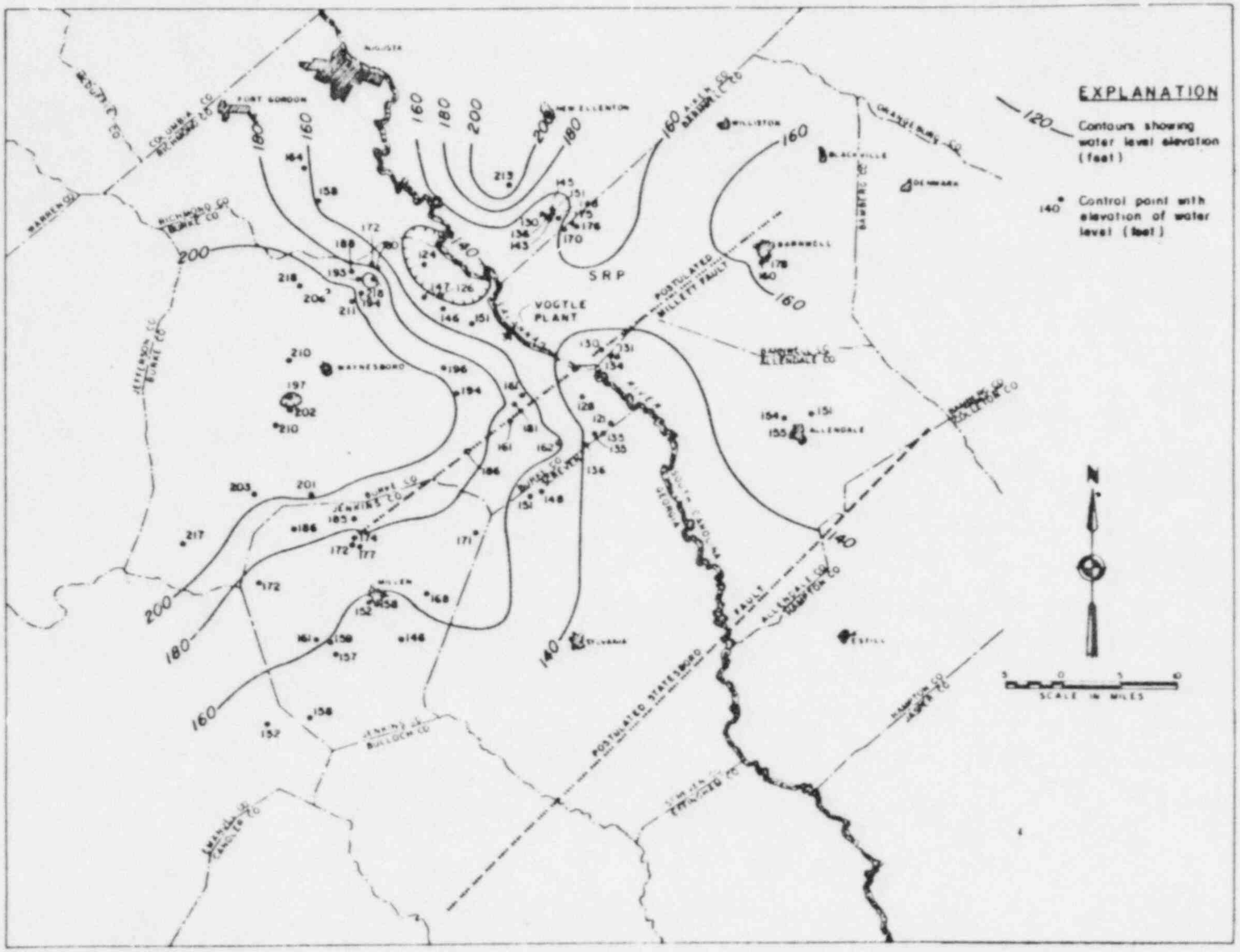

FIGURE 3-21. Piezometric Surface of the Congaree Formation Reproduced from Georgia Power Company[18]

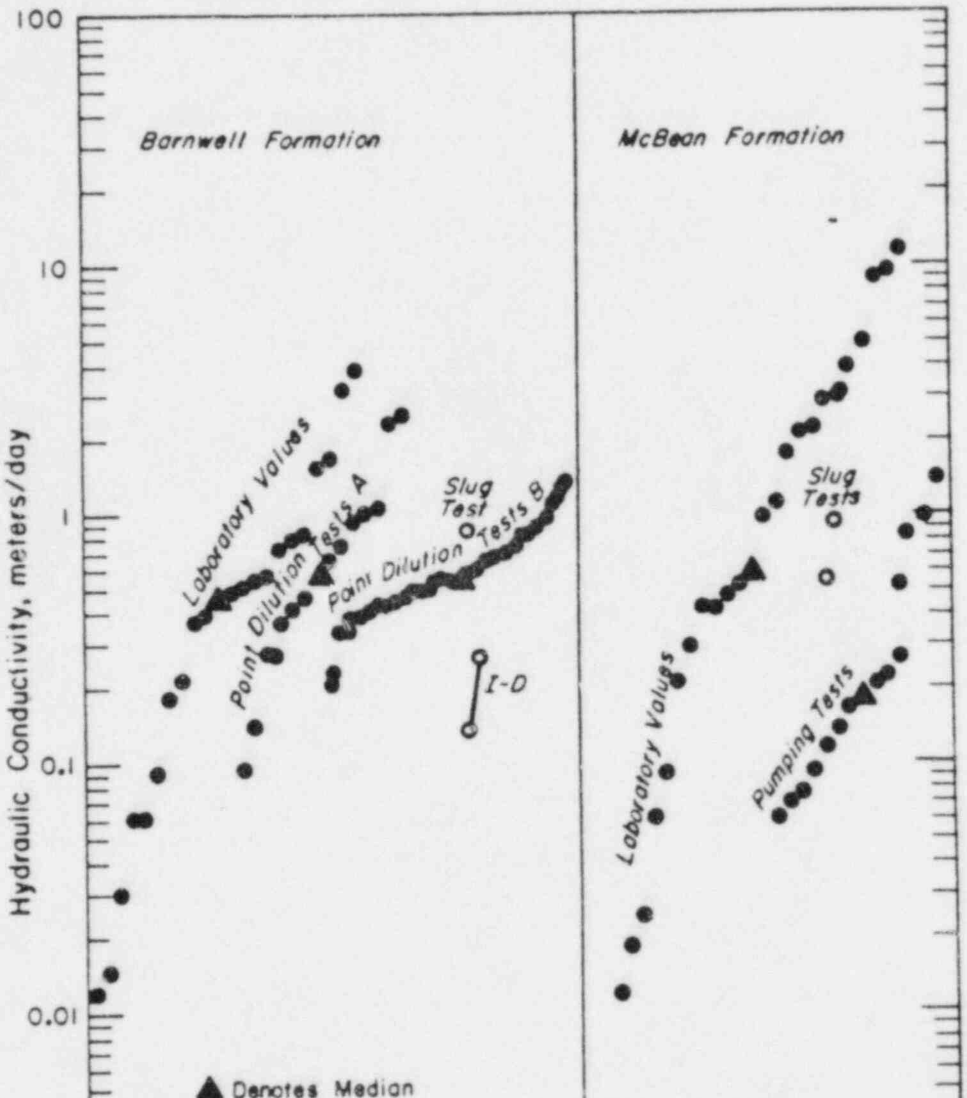

FIGURE 3-22. Horizontal Hydraulic Conductivities of the Barnwell and McBean Formations in the Separations Areas at SRP

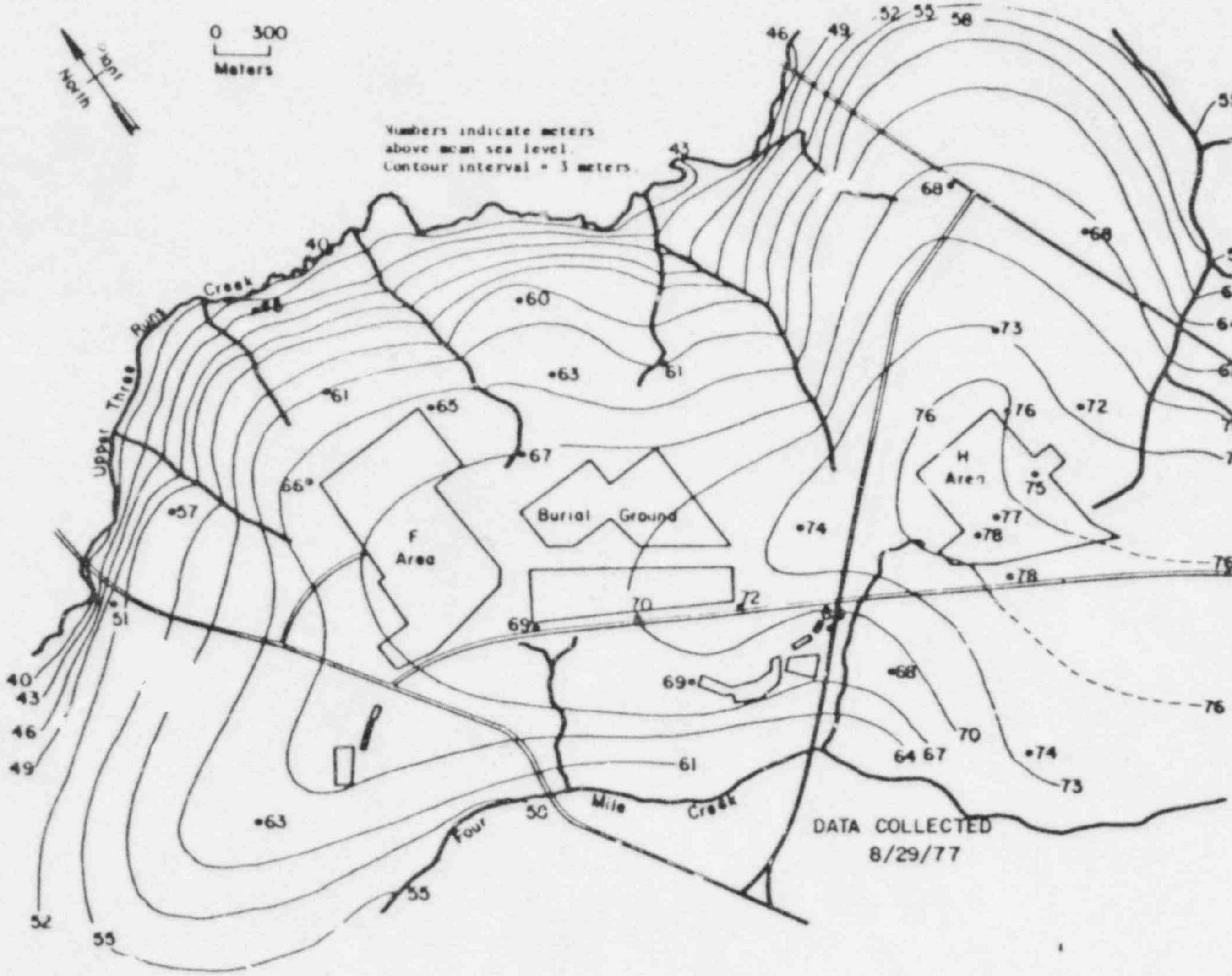

FIGURE 3-23. Piezometric Surface of the Upper Part of the McBean Formation in the Separations Areas at SRP

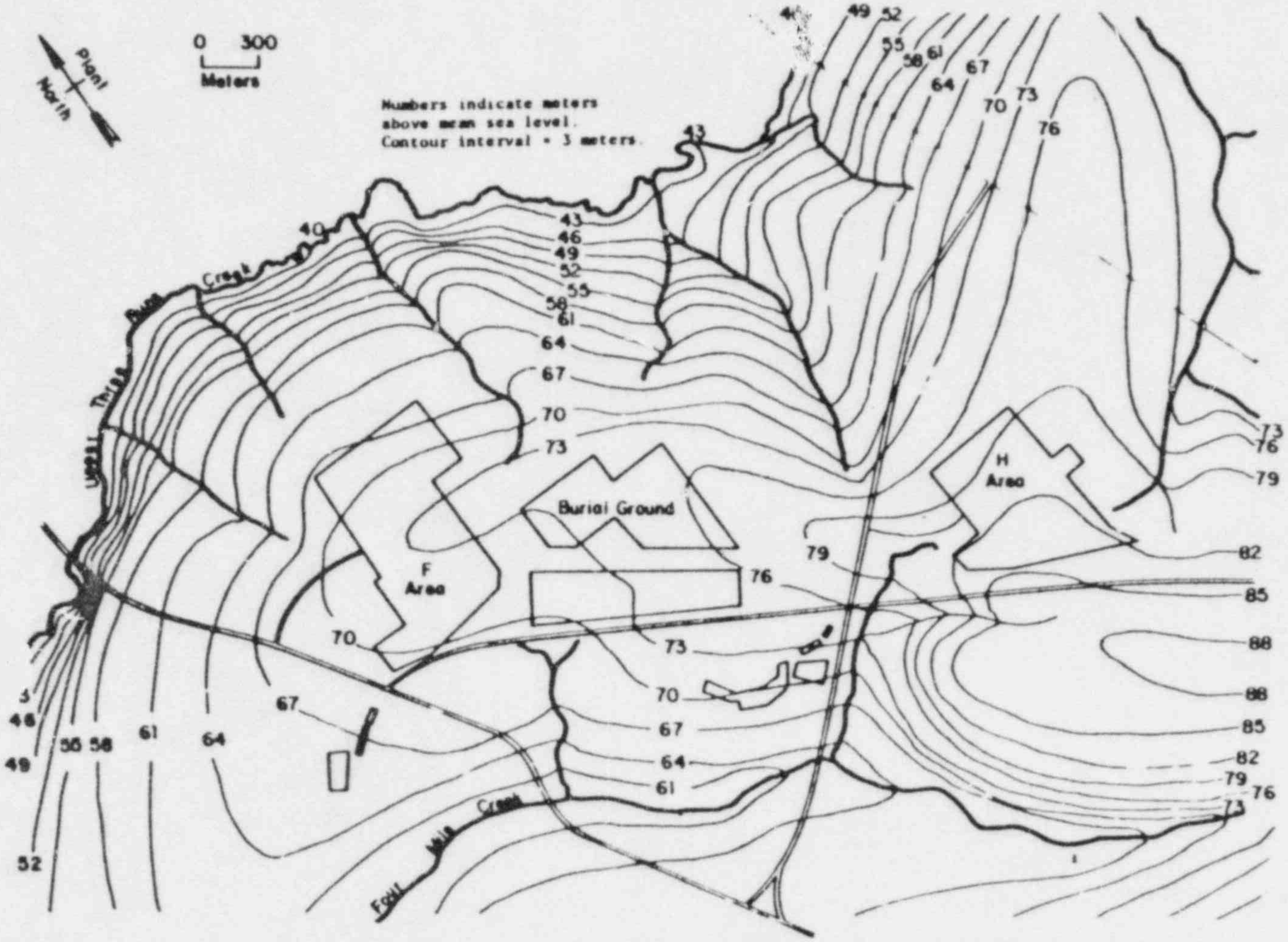

FIGURE 3-24. Average Elevation of the Water Table in the Separations Areas at SRP During 1968

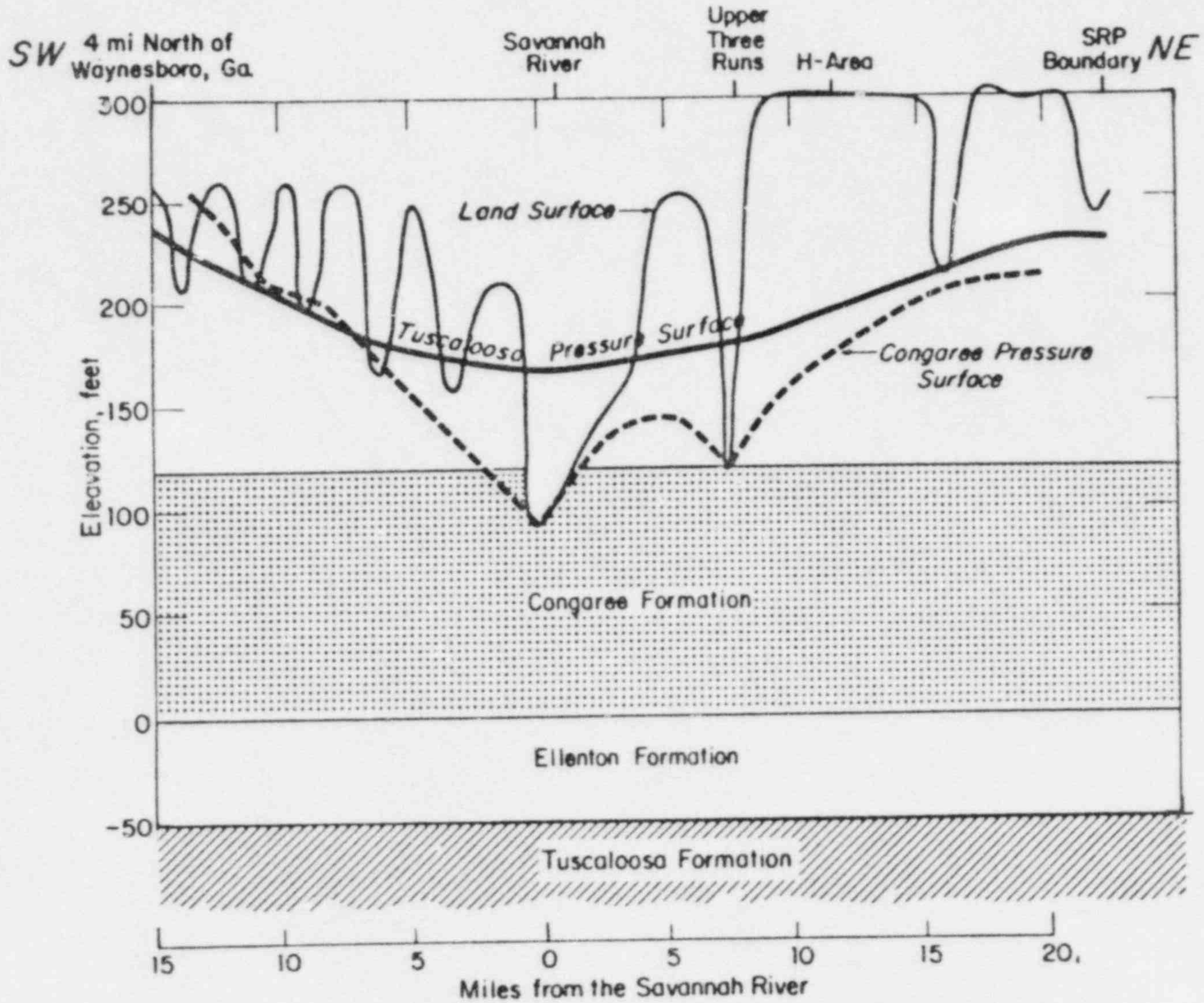

FIGURE 3-25. Hydrologic Section Perpendicular to the Savannah River through H Area[3,17]

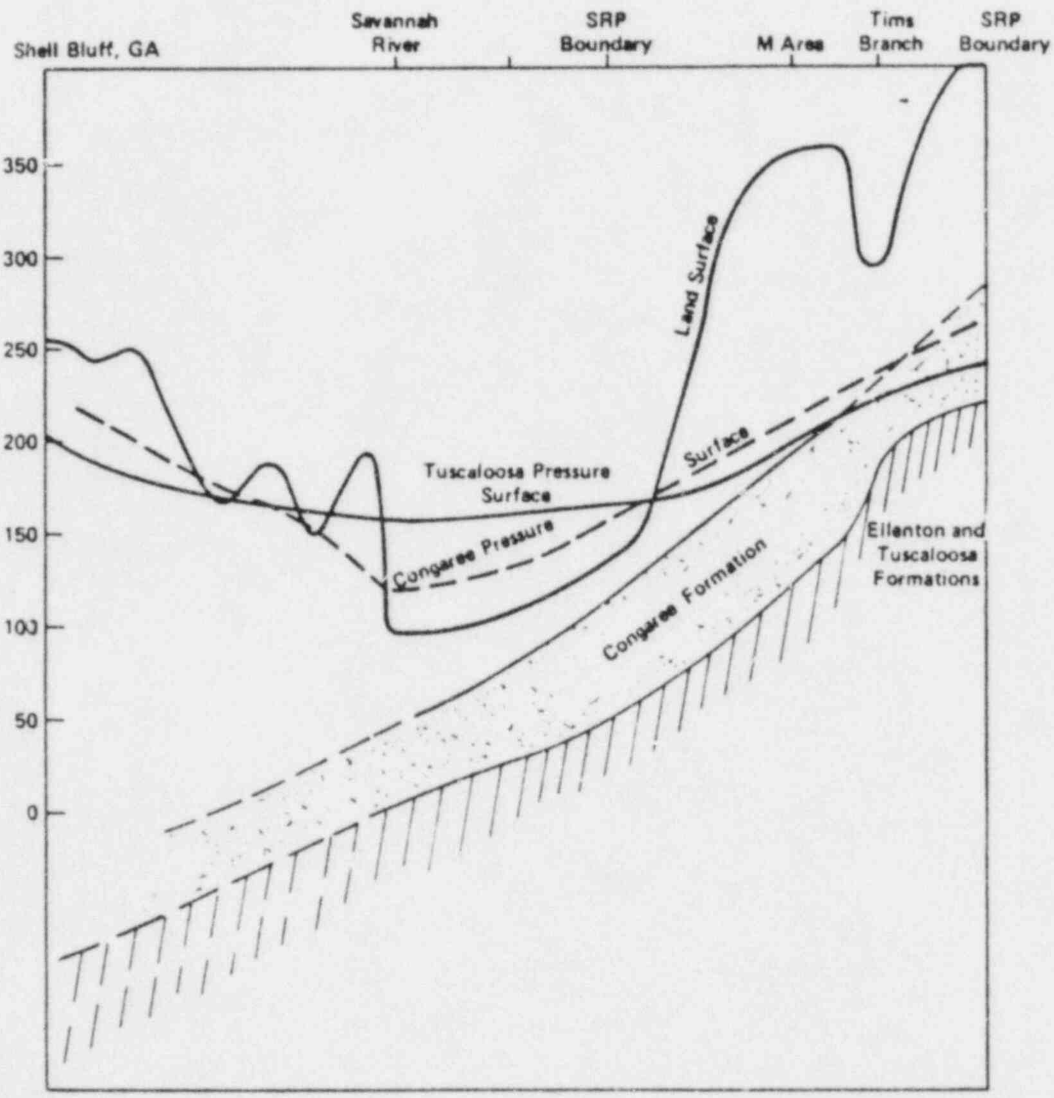

FIGURE 3-26. Hydrologic Section Perpendicular to the Savannah River Through M Area[3,17]

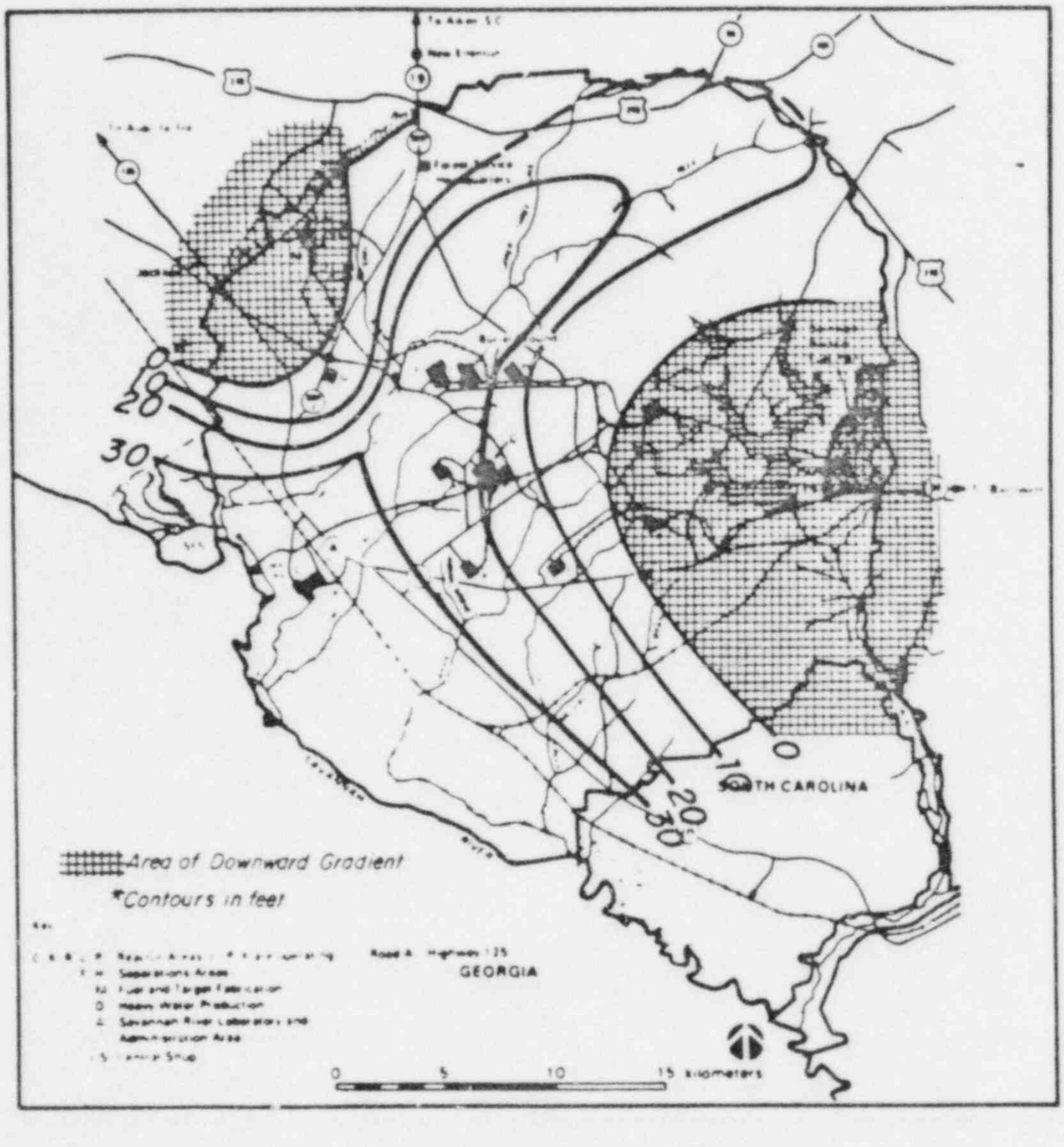

Figure 3-27. Head Difference Between the Tuscaloosa and Congaree Formations at SRP

DPST-83-829

Vol. II

TECHNICAL SUMMARY OF GROUNDWATER QUALITY PROTECTION PROGRAM AT SAVANNAH RIVER PLANT

VOLUME II - RADIOACTIVE WASTE

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CONTENTS

1.0 INTRODUCTION

Groundwater in the public zone in the vicinity of the Savannah River Plant (SRP) is unaffected by operations associated with radioactivity on the SRP site. Factors in protection of the groundwater include the large geographic area of SRP and radioactive waste management procedures practiced at SRP. Shallow groundwater in the limited areas of several of the waste sites is an integral part of the low-level radioactive waste management system. Radioactive seepage basins and the burial grounds for solid radioactive waste rely upon long flowpaths in the shallow groundwater to delay release of radioactivity, primarily tritium, to plant streams. These time delays in the slowly moving groundwater permit a portion of the radioactivity to decay and thus reduce the amount of radioactivity that would otherwise be released.

Operations with radioactive materials at SRP are contained within the 300-square-mile Federal site that provides a large buffer zone from the public. Major radioactive waste management operations are located near the center of the plant site, 6 to 10 miles from the plant boundary. The wide buffer zone not only provides physical security but also assures that concentrations of radioactivity in air and water will be extremely small at the plant boundary. Within these boundaries the plant conducts industrial-scale operations with large quantities of radioactive materials in the national defense interest. This mission must be accomplished while protecting the health and safety of the plant employees and while protecting the environment to the maximum extent possible. Any industrial operation must have some impact upon the environment. With respect to radioactivity, SRP strives to minimize these effects. The wide buffer zone between plant operations and the public is an important consideration for SRP waste management practices.

Volume II of this report presents representative monitoring data for radioactivity in groundwater at SRP. Four major groups of radioactive waste disposal sites and three minor sites are described. Much of the geohydrological and other background information given in Volume I is applicable to these sites and is incorporated by reference. Several of the sites that contain mixed chemical and radioactive wastes are discussed in both Volumes I and II. Bulk unirradiated uranium is considered primarily a chemical waste which is addressed in Volume I, but generally not in Volume II.

The overall effects of radioactive waste disposal on SRP groundwater are summarized in the following section. Then, each of the radioactive waste disposal sites is described in detail.

1.1 EFFECTS OF RADIOACTIVE WASTE DISPOSAL ON GROUNDWATER

Groundwater throughout most of the general plant site is unaffected by radioactive operations, as demonstrated by radioactivity measurements of drinking water throughout the plant.[1] Deep wells to the Tuscaloosa aquifer provide drinking water for numerous areas of the plant. Other wells, in shallow formations, are located at five gate areas at the plant boundary. Monitoring data show that alpha and nonvolatile beta concentrations are essentially the same as detected before plant startup. Tritium concentrations are generally near or less than the sensitivity of the analyses (3×10^{-4} µCi/L). Thus, plant operations have added no detectable amounts of radioactivity to the Tuscaloosa aquifer underlying the plantsite or to shallow aquifers at the plant boundary, as measured by accepted routine monitoring methods.

Several types of radioactive waste are generated by plant operations.[2] High-level liquid waste (HLW) is stored in large, double-walled, steel tanks. Ultimately, the radioactive fraction of this waste will be vitrified in canisters and shipped offsite to a Federal repository for permanent disposal. Solid waste containing more than 10 nCi/g of transuranic (TRU) radionuclides is stored retrievably above ground for future permanent disposal. Neither HLW nor TRU waste produced at SRP has any impact on SRP groundwater. Low-level waste, both liquid and solid, is designated for disposal on the plant site.

As part of low-level radioactive waste operations, small amounts of radioactivity enter the shallow groundwater under specific operating areas of the plantsite. In these areas, the local hydrology involves the uppermost formations, the Barnwell and the McBean. Radioactivity migrates to the groundwater from seepage basins that receive high-volume low-activity liquid waste streams, and from leachates from buried solid radioactive waste. All of the groundwater containing radioactivity eventually outcrops into plant streams. Migration of radioactivity to deep formations is unlikely in most areas because of the clay layers and the hydrologic head reversal, discussed in Volume I. In groundwater, much of the radioactivity decays while enroute to an outcrop. The concentration of radioactivity in plant streams, part of which is due to groundwater outcrops, is far below Concentration Guides at the plant boundary.[1]

Because of its high mobility and abundance, tritium is the most important radionuclide that reaches the water table. Other important radionuclides in the waste, particularly ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu, tend to be adsorbed on the soil column in the groundwater flow paths beneath the seepage basins and the burial grounds. These radionuclides migrate very slowly because of their high soil adherence. Numerous laboratory and field studies on soil/water distribution coefficients (K_d) have been done at SRP

to relate soil adherence with waste migration.[3-5] Thus, the soil column acts as a filter to remove most of the radiostrontium, radiocesium, plutonium, and many other radionuclides from the groundwater. Soil adherence of ^{90}Sr has occasionally been reduced by abnormal chemical conditions such as low pH of groundwater caused by acidification of seepage basins.

Two long-lived, mobile radionuclides, ^{99}Tc and ^{129}I, form stable anionic species that adhere poorly to soil and tend to migrate at the speed of the groundwater. Preliminary data indicate that although both technetium and iodine have been found in groundwater by ultra-sensitive analytical methods,[6] neither is present at concentrations that can be measured by accepted routine monitoring procedures.

Low concentrations of tritium are present in liquid waste streams and burial-ground leachates as HTO, which behaves like water and which cannot be separated practically from large volumes of H_2O. Thus, tritium travels along underground flow paths as part of the groundwater. As discussed above, tritium is the only significant radionuclide to migrate with groundwater. Therefore, the following discussion deals primarily with the behavior of tritium in the SRP waste sites.

The following waste sites are the principal contributors of tritium to shallow groundwater at SRP.

- K-Area Containment Basin: about 10,000 Ci/yr outcrops to a tributary of Pen Branch
- H-Area Seepage Basins: about 7,000 Ci/yr outcrops to Four Mile Creek and tributaries
- F-Area Seepage Basins: about 2,000 Ci/yr outcrops to Four Mile Creek
- Radioactive Burial Grounds: an estimated 200 Ci/yr outcrops to a tributary of Four Mile Creek

With respect to radioactivity, seepage basins at SRP have performed their role satisfactorily for many years. The seepage basins have handled large volumes of liquid waste that contain very low concentrations of tritium and other radionuclides. The concentrations are sufficiently low that these liquid wastes could be discharged directly into plant streams. However, by employing seepage basins to give controlled release through the shallow groundwater flow paths, the amount of radioactivity ultimately released offsite is greatly reduced. Groundwater travel time from F and H seepage basins to the nearest stream ranges from 1 to 9 years, during which the amount of radioactivity is reduced by decay. The groundwater travel time allows up to 40% of the tritium to decay

before outcrop. The fractions that decay are even larger for many of the other radionuclides that migrate much slower than the groundwater. Tritium that outcrops is further diluted in the plant streams and the Savannah River, so that the downstream concentration is well below the DOE concentration guide of 3 µCi/L and the EPA drinking water standard of 0.02 µCi/L.[7]

Seepage basins are a technically acceptable means of handling tritium in low-level radioactive liquids. However, DOE policy is to reduce or eliminate the use of seepage basins, primarily because the non-mobile radionuclides build up in the soil column to create a long-term burden of site control and surveillance.[8] Current practices limit additions to the seepage basins to prevent further buildup. The technology of SRP seepage basins and the results of ongoing environmental monitoring around the basins are described in various public reports.[1,2,9]

The SRP burial grounds for solid radioactive waste contain and control release of radioactivity to the shallow groundwater. The 200 Ci/yr of burial-ground tritium estimated to outcrop into plant streams is less than 1% of the total tritium released to the streams — more than 99% is from seepage basin migration and direct release. The behavior of tritium in the burial grounds has been studied extensively.[2,5,10-12] These studies are continuing.

Properly managed shallow-land burial is a safe, efficient means for disposal of solid radioactive wastes. As practiced at SRP, rainwater that percolates through the burial-ground soil leaches a small fraction of the radioactivity. This small amount of leached radioactivity potentially will enter the shallow groundwater. As with the seepage basins, the soil beneath the burial trenches filters out most of the radionuclides, which then migrate very much slower than groundwater. Leached tritium moves with the groundwater, but the distance to outcrop is considerably longer than for the seepage basins. Travel time for tritium outcrop is 25 to 75 years, or two to six half-lives. Thus, 75% to more than 98% of the tritium will decay before outcrop. Of the 4,000,000 Ci of tritium buried since 1953, less than 40,000 Ci (<1%) has migrated to the shallow groundwater. A 1979 measurement at an outcrop of the flow path foreshortened by erosion (see Section 2.3.5) showed 850 Ci/yr of burial-ground tritium being released to Four Mile Creek. After repairs to lengthen the flow path (discussed in Section 2.3.5), an outcrop of 200 Ci/yr is estimated. This value may increase as the centroid of the tritium plume nears outcrop, but is unlikely ever to exceed 500 Ci/yr. Figure 1.1-1 projects the outcrop of burial-ground tritium to be even lower in future years, from an approximate calculation.

For a small portion of the burial ground north of the water-table divide that drains toward Upper Three Runs Creek, the flow-paths for shallow groundwater are even longer than those toward Four Mile Creek. Tritium from new burials that migrates toward Upper Three Runs Creek will be routinely monitored in the same way as tritium that migrates toward Four Mile Creek.

Waste management practices have been systematically improved since burial operations were started in 1953. Further improvements are expected as a result of recent studies. For example, new burials of tritium-containing waste have improved packaging to reduce leaching. In other studies, a dose-to-man model of releases from the burial ground was developed several years ago.[13] Results of modeling have been valuable in identifying important migration pathways and predicting future effects of radionuclide migration. A key result of dose-to-man calculations is that groundwater pathways are of minor importance in future land-occupation scenarios.

Plans to provide even greater confinement for new burials are under way. Features of this advanced technology being developed at SRP are incineration of combustible waste to reduce volumes, segregation of the higher-activity volume fraction, stabilized waste forms, deeper burial, and clay caps to minimize contact of percolating water with the waste. These measures will provide additional long-term protection of the groundwater.

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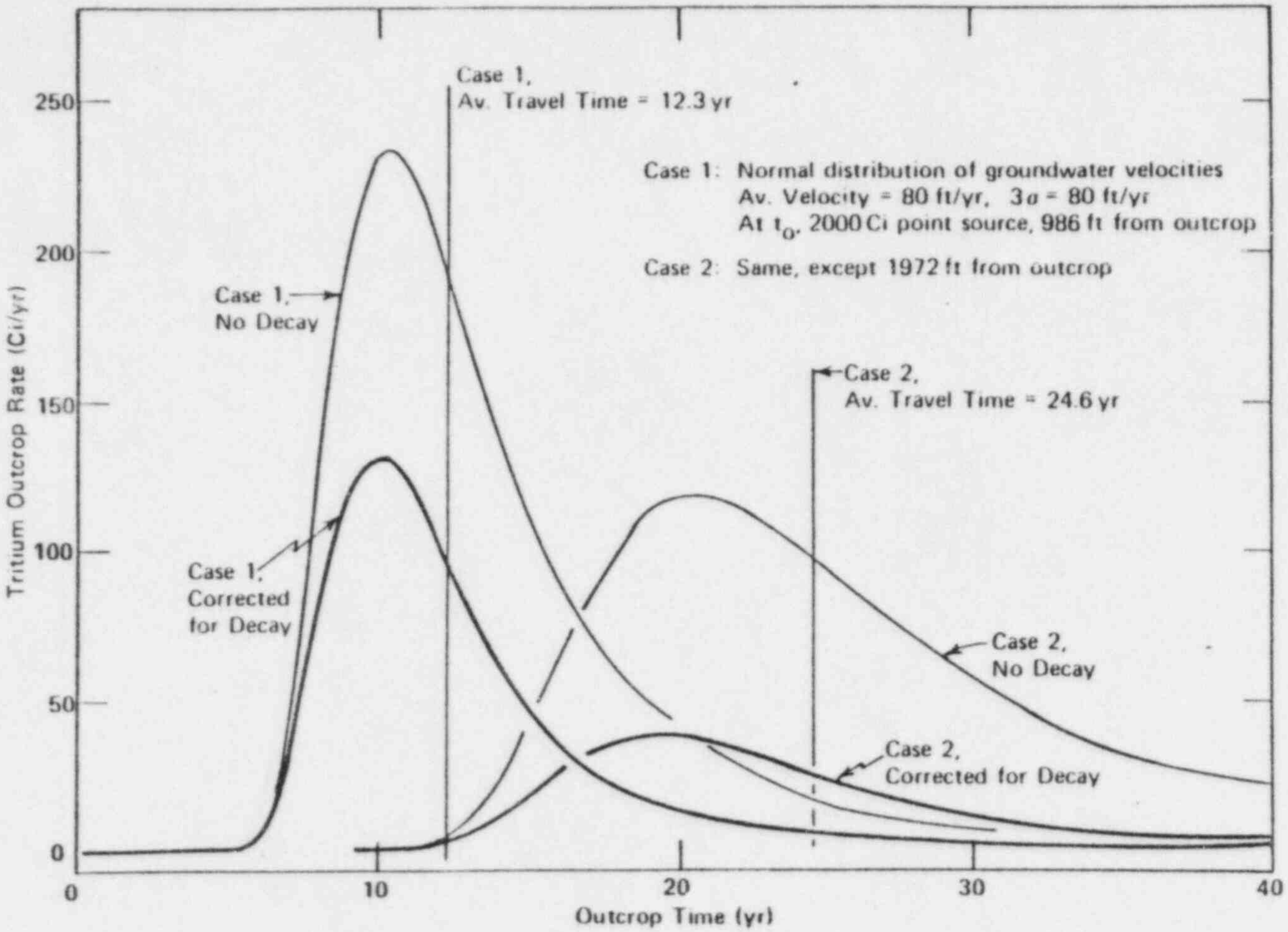

FIGURE 1.1-1. Approximate Calculation of Tritium Outcrop from Burial Ground

2.0 TECHNICAL SUMMARY OF RADIOACTIVE WASTE SITES

Sites for radioactive waste disposal are described in the following sections:

2.1 Separations Area Seepage Basins — 4 basins in F Area and 4 basins in H Area

2.2 Savannah River Laboratory Seepage Basins — 4 basins in A Area

2.3 Radioactive Waste Burial Grounds — a 76-acre plot designated 643-G and a 119-acre plot designated 643-7G, located between F and H Areas

2.4 Reactor Seepage Basins — 4 basins in C Area, 2 basins in K Area, 2 basins in L Area, 4 basins in P Area, and 6 basins in R Area

2.5 L-Area Oil and Chemical Basin — one basin designated 904-83G

2.6 Ford Building Seepage Basin — one basin in CS Area, designated 904-91G

2.7 Separations Area Retention Basins — unlined basins, one in F Area and one in H Area

The sites described in Sections 2.1 through 2.4 are major disposal areas intended for radioactive wastes. Sections 2.5 through 2.7 describe several minor sites where radioactivity is only incidental to the purpose of each site.

2.1 SEPARATIONS AREA SEEPAGE BASINS

2.1.1 Nature of Disposal

History and Inventory

Since 1954, seepage basins have been an important element in the SRP program for managing radioactive waste. Seepage basins are shallow, earthen excavations used to receive wastewater that contains low concentrations of chemicals and radionuclides. The wastewater seeps downward through the sides and floor of a basin to the groundwater. After mixing with the groundwater, it flows slowly in a horizontal direction, eventually to outcrop at a surface stream. During slow travel through the soil, the wastewater will lose some of the contaminants by precipitation, filtration, adsorption, ion exchange, and radioactive decay.

The first SRP seepage basin (Building 904-49G) was constructed north of F Area and used in 1954. However, the seepage rate was inadequate to handle the increasing volumes of wastewater coming from the F-Area separations operation. Three additional basins were constructed south of F Area in 1955. These established size standards for the basins that followed in H Area. By 1964, all of the SRP seepage basins had been constructed and were in use. Table 2.1-1 gives characteristics of the F- and H-Area seepage basin system, and Figure 2.1-1 shows the basins in relation to the SRP chemical separations areas. Table 2.1-2 shows the total amount of radioactive material discharged to the basins from 1954 through 1982. The totals are corrected for decay through 1982.

The basins were installed as an added control step in the release of low-level radioactive liquid wastes to surface streams. However, the basins received other chemicals as well, as discussed in Volume I.

Current Practices

In 1957, trebler proportional samplers were installed in the effluent pipes to each F- and H-Area basin to provide continuous samples of the composite effluent stream. Table 2.1-3 shows current additions of radioactive materials to the basins.

2.1.2 Local Groundwater Conditions

The separations areas, consisting of the area between Upper Three Runs Creek and Four Mile Creek with H Area at one end and F Area at the other, is the most intensely studied area at SRP in terms of geology and groundwater. This is because most of the radioactive waste generated at SRP is in storage in this area.

The area contains the high-level liquid waste storage tanks in both F and H Areas, the low-level radioactive solid waste burial grounds, and the low-level radioactive waste seepage basins. This has also been the area where exploration was conducted from 1961 to 1972 to study the feasibility and safety of storing radioactive waste in the crystalline metamorphic rock beneath the Coastal Plain sediments. Because of all these study programs, much of the information relating to regional groundwater systems described in Volume I was developed in this area.

The general geology of the area is disucssed in Volume I. The water table map for this area is given in Figure 3-24 (Volume I). Piezometric maps for the Tuscaloosa, Congaree, and McBean Formations are given in Figures 3-11, 3-18, and 3-23 (Volume I), respectively. Water is withdrawn from the Tuscaloosa Formation beneath both F and H Areas.

The normal water table at the F-Area basins is 60 to 65 ft below the ground surface, but at H-Area basins is only 15 to 25 ft. The horizontal distance to the outcrop of groundwater in Four Mile Creek paths is 1600 ft at the F-Area basins and 400 to 1400 ft at the H-Area basins. Narrow zones of higher permeability in an otherwise sandy clay environment exist at the H-Area basins. The general geology at the water table at the F-Area basins is sandier than at the H-Area basins. Table 2.1-4 gives some of the seepage parameters for these two basins.

There are two separate and distinct water tables underneath the F-Area seepage basins. One of these is a perched groundwater table 10 to 25 ft below the ground surface. The perched water either seeps through the less permeable underlying strata or flows laterally a maximum of 150 ft before flowing off the edge of the supporting strata, and then vertically to the normal water table that is 60 to 65 ft below the ground surface. The nearest water table outcrop area, which is a line of springs along the edge of Four Mile Creek Swamp, is 1600 ft from the basins.

The geological characteristics of the H-Area basins are different from those of the F-Area basins. The water table is only 15 to 25 ft below the ground surface, and the water table outcrop area is only 400 to 1400 ft from the basins. The soil contains a high percentage of clay and has a relatively low permeability except for certain narrow zones of high permeability.

At H-Area Basin 4, these zones of more rapid flow coincide with discharge into indentations of the seepline along Four Mile Creek. At Basin 1, seepage is into a small swampy area east of Basin 3, which was the head of a branch of Four Mile Creek before H-Area effluent was released into it. Seepage from Basins 2 and 3

does not appear to be influenced by such zones of rapid flow. At certain places between these zones, flow is so slow as to be almost imperceptible.

Permeability of the H-Area basins appears to be quite sensitive to pH changes caused by fluctuation in nitric acid and sodium hydroxide in the waste. The exchange complex of clays is saturated under normal conditions with H^+, Ca^{++}, Fe^{+++}, and other cations. When sodium hydroxide was added in September 1956, the exchange sites became saturated with Na^+, the soil swelled, permeability was sharply reduced, and Basin 1 began overflowing to Basin 2. Such swelling of clay soils due to Na^+ saturation is well known.[1,2]

2.1.3 Groundwater Monitoring Program and Results

History

Seepage basins have been used in the separations areas since 1954 and 1955 to dispose of large volumes of liquids containing nonradioactive chemicals and low levels of radioactivity. These basins and their surroundings have been monitored since startup, and many special studies of environmental effects have been made. Characteristics of movement of materials in the soil and groundwater differ between the two areas because of differences in ion exchange characteristics of the soil and flow velocities of groundwater. In addition the discharge of waste nitric acid and sodium nitrate to the basins influences these characteristics. Wells used in routine monitoring and for special studies are inventoried below.

Well Inventory

Thirteen permanent monitoring wells (Wells F1 through F13 in Figure 2.1-2) were installed around the F-Area basins in the spring of 1956. Wells F1, F5, F6, F7, F10, F12, and F13 were screened in perched water, whereas the others were screened in the normal water table. During the winter of 1956-57, 31 additional uncased temporary wells were drilled. Data from these wells defined the perched water table.

During March 1962, nine additional monitoring wells were drilled. Data from these and the original 13 wells were used to measure the rate of horizontal water movement in the perched zone and the vertical movement in the unsaturated zone between the perched and normal water table.

In 1967, 45 wells were installed in a grid pattern between the F-Area basins and the outcrop zone near Four Mile Creek, as shown in Figure 2.1-3. Twenty wells at different depths in six clusters were also installed to define the vertical pattern of groundwater movement. Sampling zones at the cluster wells in relation to the water table are shown in Figure 2.1-4.

At the H-Area basins, eleven permanent monitoring wells (H1 through H11, Figure 2.1-5) were installed around H-Area basins in 1956. Data from these wells indicated that flow was mainly in a narrow zone of high permeability, and 43 uncased wells were drilled to better define this zone. In 1958, five temporary monitoring wells were installed, of which one was made permanent (H12, Figure 2.1-5). Between 1962 and 1964, 39 permanent monitoring wells were installed (H13 through H51, Figure 2.1-5) between H-Area Basins (3 and 4) and the groundwater outcrop along Four Mile Creek.

In 1967, stream flow gauges and samplers were installed in Four Mile Creek at locations shown in Figure 2.1-6. These locations were selected so that radionuclide contributions from area effluents and seepage basins could be evaluated.

Monitoring Results

Data from these wells indicated that the rate of horizontal water movement in the perched zone at the F-Area basins was 0.7 to 0.9 ft/day, followed by slow movement of ~0.1 ft/day or less in the unsaturated zone between the perched and normal water table.

The influence of the F-Area seepage basins on the area water table is shown in Figure 2.1-7. An irregular-shaped water table mound extends from Basin 3 toward the outcrop zone. Even though three lobes are apparent, the principal zone of movement is down the central lobe. The water table gradient from the top of the mound to the outcrop is 0.5%.

The water table near the H-Area basins (Figure 2.1-8) is not affected as much by basin water seepage as was observed near the F-Area basins. Because most seepage from the basin system is from Basin 4, which was constructed along the topographic contour, basin water enters the water table for a considerable distance along the natural water table contour. Thus, seepage is spread out and has a minimum effect on natural conditions. The water table gradient between Basin 4 and the seep line is 1%.

Data from these studies indicate that water moves from the H-Area basins in relatively narrow zones, particularly toward indented areas of the seep line along Four Mile Creek.

Sampling results show that in the separations areas, approximately 25% of the tritium discharged to seepage basins evaporates to the atmosphere. The remaining tritium moves rapidly to the water table and there moves at the same velocity as the groundwater. In F Area, the average flow rate of tritium from the basins to Four Mile Creek is estimated to be 0.5 ft/day (a travel time of 9 yr to move 1600 ft). Approximately 40% of the tritium decays before emerging in Four Mile Creek. Concentrations at seep line springs range from 40 to 60 µCi/L. Figure 2.1-9 shows horizontal distribution of tritium in groundwater. Concentrations range from maximum in the darkest zone to minimum in the lightest. In H Area, the flow rate of tritium from the seepage basins to Four Mile Creek is estimated to be 1.0 ft/day (a travel time of 3.75 yr to move 1400 ft). Approximately 20% of the tritium decays before emerging in Four Mile Creek. Figure 2.1-10 shows horizontal distribution of tritium at the water table. Narrow zones of high concentration are apparent where seep line indentations extend toward the basins. At the western end of H Basin 4, flow paths are longer, and zonation ceases.

Theoretical considerations of flow through a homogeneous media receiving uniform recharge indicate that a tracer from the basins would dip beneath the water table in traversing a path from source to outcrop. Figure 2.1-11 shows schematically what would occur. The point of view is from the outcrop spring upgradient to the basin. Darker zones indicate higher concentrations. Though F-Area sediments are not ideally homogeneous, the working of this principle is shown by data from the cluster wells. Figure 2.1-12 shows vertical tritium distribution down the F-Area seepage basin main flow path, and the expected distribution is seen. The maximum penetration of tritium is about 50 ft, and throughout most of the distance from the basins to the seep line, the highest concentrations are 10 to 20 ft below the water table. Such a distribution does not occur at the east end of the H basin system because of the nearness of the outcrop. Basin water enters where groundwater already is rising toward the outcrop. At the west end of the basins, however, where flow paths are longer, this type of flow was observed.

Strontium, unlike tritium, does not move at the same velocity as groundwater because of ion exchange characteristics of the soil. Nevertheless, movement does occur, and strontium has been emerging

in Four Mile Creek from the F-Area basin since about 1964, and from the H-Area basin since 1959. The amount entering the creek annually is about 2% of the groundwater strontium inventory in F Area and 0.13% of the inventory in H Area. Under current conditions, F Area is contributing about 10 times as much strontium to creek as H Area because of differing soil retention characteristics. With a groundwater flow rate of 0.5 ft/day in F Area, radioactive decay removes just as much ^{90}Sr as does leaching into Four Mile Creek. In H Area, with a groundwater flow rate of 1 ft/day, radioactive decay currently removes 18 times as much strontium as does leaching into Four Mile Creek. Maximum ^{90}Sr concentrations in groundwater and emergent seep lines ranged from 0.014 µCi/L to 0.34 µCi/L in F Area, and 5.5×10^{-5} µCi/L to 1.[illegible] 10^{-3} µCi/L in H Area.

Cesium is retained well by sediments at SRP, and none has migrated far enough to be detected in groundwater between seepage basins in the separations areas and Four Mile Creek. In 1971, when Basin 3 was temporarily dry in F Area, three soil core samples ranging from 8.5 to 18 ft long were obtained. Although ^{137}Cs was detected throughout the 18-ft sample length, concentrations in the top 9 ft averaged about 3.6 times higher than the bottom 9 ft.

Plutonium is more highly immobilized in SRP soils than cesium. Sampling of F-Area Basin 3 soil in 1971 to a depth of 9.7 ft showed that more than 99% of the plutonium was retained in the top 8 inches of soil, with a maximum concentration of 1.7 nCi/g.

Alpha activity in groundwater between basins and Four Mile Creek in the separations areas is attributed mostly to uranium discharged to the basins, plus a small amount of natural radioactivity. Alpha concentrations in groundwater and seep lines ranged from 1.4×10^{-5} µCi/L to 6.5×10^{-3} µCi/L in F Area, and 7×10^{-7} µCi/L to 7.5×10^{-6} µCi/L in H Area.

Only tritium, ^{90}Sr, and uranium have been routinely detected in groundwater between seepage basins in the separations areas and Four Mile Creek, in concentrations greater than 10 times the natural background. Tables 2.1-5 and 2.1-6 show 1980 results in representative seepage basin wells that are monitored routinely. Gross alpha results are due primarily to uranium, and gross nonvolatile beta results are due primarily to ^{90}Sr. Data on historical trends for tritium and ^{90}Sr discharged to the basins and quantities outcropping are shown in Figures 2.1-13, 2.1-14, 2.1-15, and 2.1-16. In addition, special ultra-low-level analyses for long-lived ^{99}Tc and ^{129}I have been performed on selected samples from the seepage basins.[3] The measurements demonstrate that both ^{99}Tc and ^{129}I are transported freely with the groundwater and outcrop into Four Mile Creek in very low concentrations.

2.1.4 Evaluation o. mpact on Groundwater Quality

The nearest plant boundary to the F-Area seepage basin is about 7 miles to the west, and is about 8 miles from the H-Area basin.

The potential for offsite contamination of groundwater from operation of F- and H-Area seepage basins is negligible. The dissection of the Aiken Plateau by Upper Three Runs Creek and Four Mile Creek creates a groundwater island in the McBean Formation. Water enters the formation on the Aiken Plateau and flows toward one or the other of the two creeks and must exit into the surface water. The valley of Upper Three Runs Creek cuts into the Congaree Formation and creates a groundwater sink that separates water in that formation under the separations areas from the offplant areas to the north and northwest. As shown in the piezometric map (Figure 3-18, Volume I), water from the separations areas could not go "uphill" to the south and southeast. Water in the Tuscaloosa Formation flows toward and exits into the Savannah River (Figure 3-11, Volume I).

The seepage basins were instituted to delay release of low-level radioactive waste water to streams. Thus, the slow movement of groundwater between the basins and Four Mile Creek has been used intentionally for this purpose. As shown in Figure 2.1-12, the depth of ground penetration of this waste water is known, as is the horizontal flow pattern (Figures 2.1-9 and 2.1-10). The vertical flow pattern shows that the highest concentrations of tritium penetrate the McBean Formation but do not enter the "green clay" (Section 3.4.5, Volume I). As both sets of basins are on the slopes of the water table and participate in the horizontal flow toward Four Mile Creek, there is no reason to believe that the flow path will change significantly from the one just described.

The area of the seepage basins along with the rest of the separations areas is where the head in the Tuscaloosa and Ellenton Formations has been historically higher than the head in the Congaree Formation, and thus the potential for contamination of these two formations is low. Because of the position of the seepage basins in a predominantly horizontal flow regime toward Four Mile Creek and the low permeability of the "green clay", the potential for contamination entering the Congaree is low.

Although the cones of depression in the Tuscaloosa from pumping in F Area and in H Area may extend to the areas of the seepage basins, they do not alter the head reversal that occurs in the Congaree Formation in this area. The vertical head distribution shown in Figure 3-5 (Volume I) is between the center of pumpage in H Area and the H-Area seepage basins. Thus, it is known that the

head reversal in the Congaree has been applicable here. To date the head reversal still exists, but is has decreased due to declining water levels in the Tuscaloosa Formation (Figure 4-3, Volume I).

2.1.5 Remedial Action

New processes are being developed to remove radioactivity and hazardous materials from the process effluents presently discharged to the seepage basins. Such processes will be included in the waste treatment facilities that will decontaminate process effluents for direct discharge to Four Mile Creek. The F- and H-Area seepage basins will be retired after the waste treatment facilities are placed in service. Decommissioning plans are incomplete.

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TABLE 2.1-1

Chemical Separations Areas Seepage Basin System Characteristics

Location	Basin No.	Bldg. No.	Used From	Used To	Area (acres)	Volume (gallons)	Remarks
200-F	-	904-49	1954	1955	1.3	-	Northwest of area
	1	904-41	1955	present	0.34	1.0×10^6	
	2	904-42	1955	present	0.69	1.9×10^6	
	3	904-43	1955	present	4.44	1.4×10^7	
200-H	1	904-44	1955	present	0.29	1.0×10^6	
	2	904-45	1955	present	0.79	2.8×10^6	
	3	904-46	1955	1962	3.30	2.3×10^7	
	4	904-56	1962	present	9.30	3.1×10^7	Crescent-shaped

TABLE 2.1-2

Total Quantities of Radionuclides Discharged to Separations Areas Seepage Basins From 1954 Through 1982, Corrected for Decay

	Inventory (Ci)				
Basins	Cs	Tritium*	Sr	Actinides	Other**
200-F	141	269,000	24.6	19.7	18.4
200-H	109		28.7	5.6	10.3

* Total for F and H Areas combined.

** Fission products.

TABLE 2.1-3

Current Radionuclide Additions to Separations Areas Seepage Basins

	1982 Additions (Ci/yr)				
Basins	Cs	Tritium*	Sr	Actinides	Other**
200-F	0.92	13,670	0.100	0.210	17.0
200-H	1.79		0.595	0.026	6.0

* Total for F and H Areas combined.
** Fission products.

TABLE 2.1-4

Seepage Characteristics of F- and H-Area Basins

	F Area	H Area	Units
Mean seepage rate	0.37	0.36	gal/ft^2/day
Distance to outcrop	1600	400-1400	ft
Groundwater flow rate	0.5	1.0	ft/day
Travel time (basin to stream)	9	1-4	yr
Basin evaporation	25%	27%	-

TABLE 2.1-5

Radioactivity in F-Area Seepage Basin Monitoring Wells — 1980

Well No.	Alpha (pCi/L)	Nonvolatile Beta (pCi/L)	Tritium (µCi/L)
1	2600	140000	37
2	19000	7500	23
9	<0.5	12	2
10	440	36000	28
14	41	400	11
15	1	800	2
16	39	820	15
17	1	16	0.07
18	1	40	0.2
19	2	15	0.06
23	1	6*	0.06
24	1	7	0.02
25	7	12	0.3

* Less than nominal lower limit of detection (7 pCi/L).

TABLE 2.1-6

Radioactivity in H-Area Seepage Basin Monitoring Wells — 1980

Well No.	Alpha (pCi/L)	Nonvolatile Beta (pCi/L)	Tritium (μCi/L)
2	4	110	8
4	5	3300	3
6	31	5100	26
7	1	52	0.1
8	<0.5	30	2
9	2	36	2
10	<0.5	15	5
11	<0.5	15	0.05
12	<0.5	55	<6
13	<0.5	7	0.3
14	1	6*	2
15	<0.5	3*	0.05
16	<0.5	3*	0.06
17	1	6*	0.06
18	1	10	0.06
19	1	8	0.9

* Less than nominal lower limit of detection (7 pCi/L).

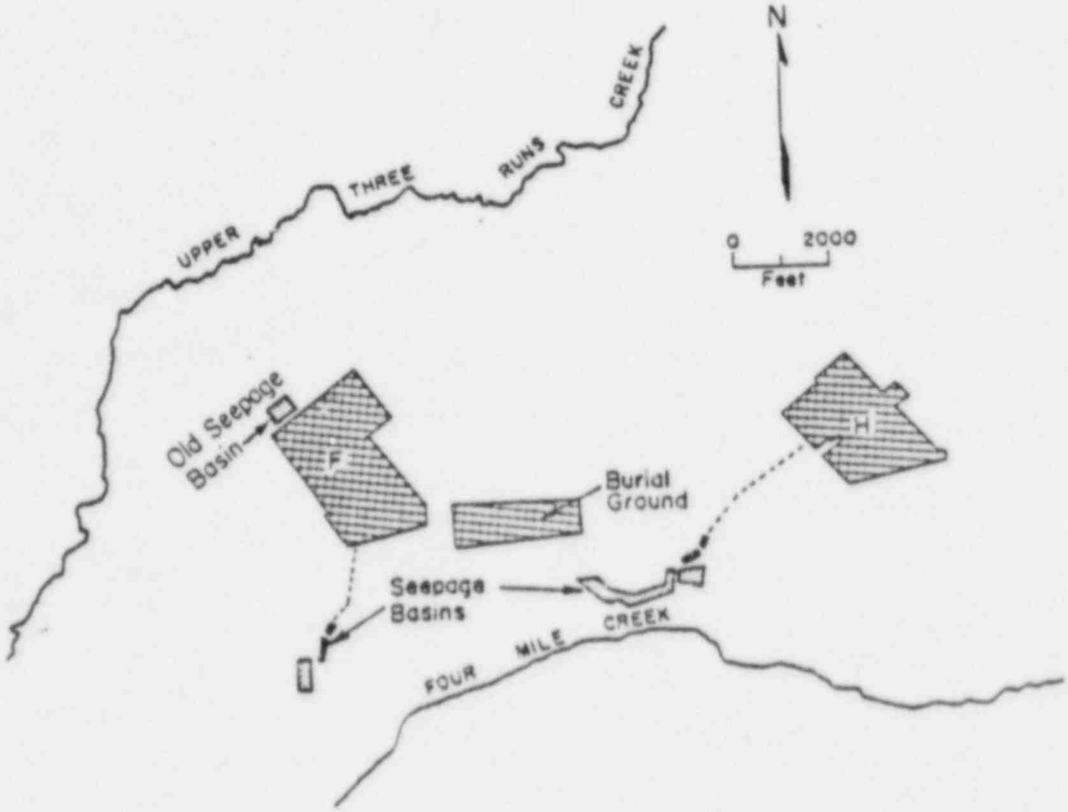

FIGURE 2.1-1. Separations Areas and Seepage Basins

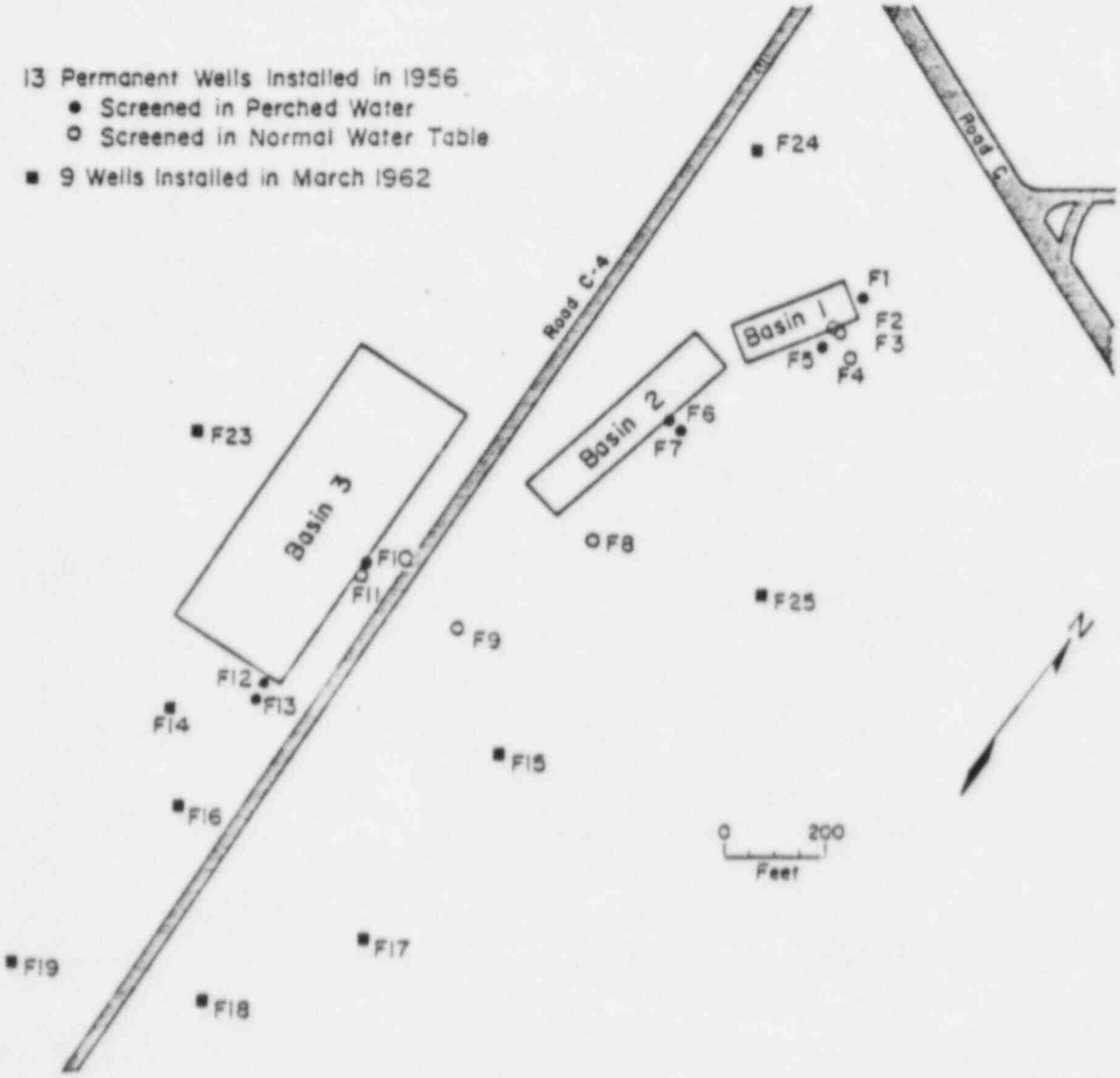

FIGURE 2.1-2. F-Area Seepage Basin Monitoring Wells

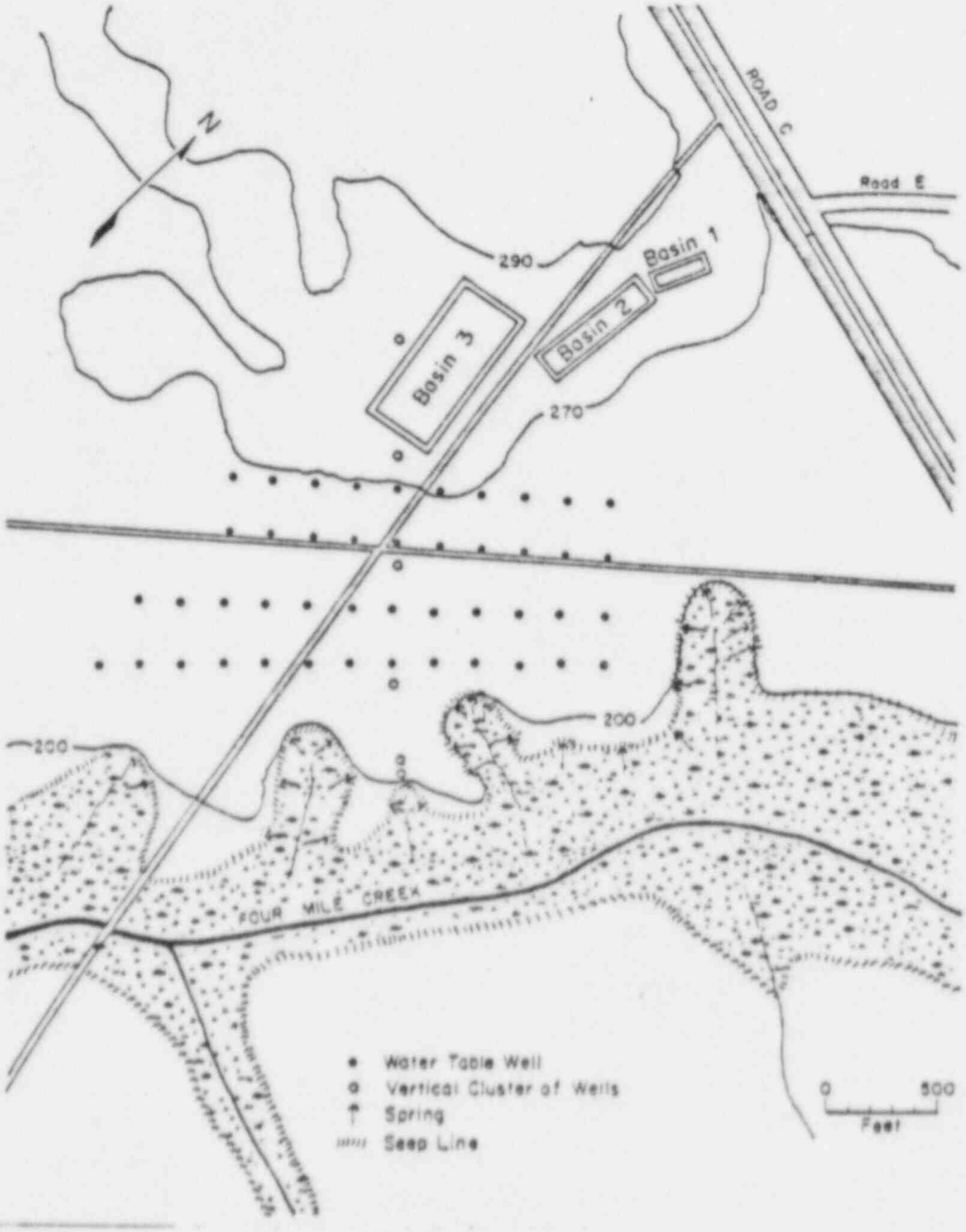

FIGURE 2.1-3. Wells and Seep-Line Springs Used to Determine the Horizontal and Vertical Flow Paths in Groundwater at F-Area Seepage Basins

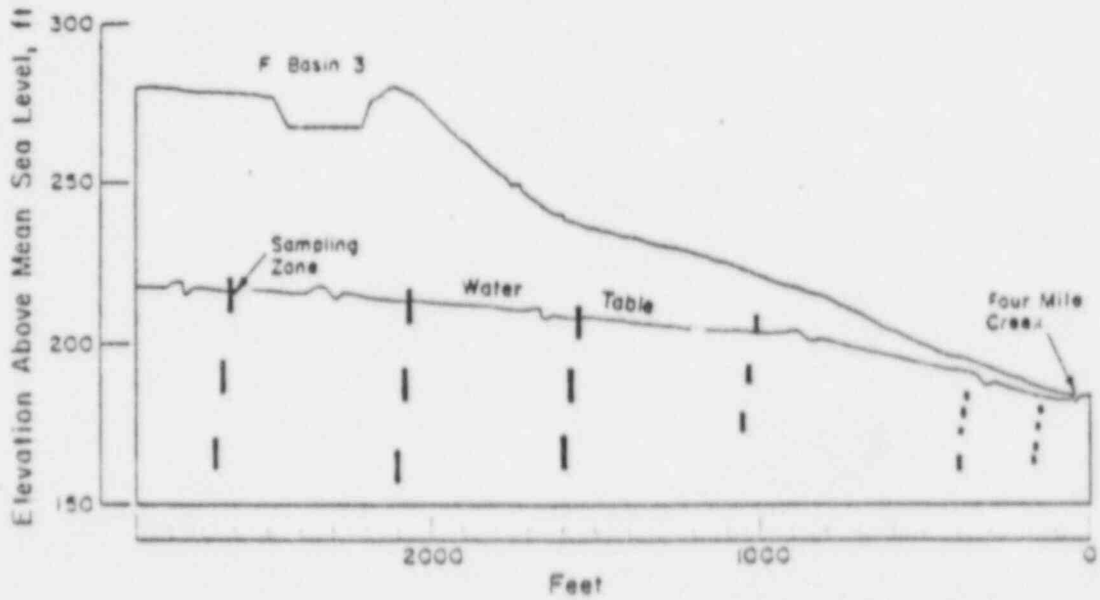

FIGURE 2.1-4. Sampling Zones in F-Area Vertical Cluster Wells

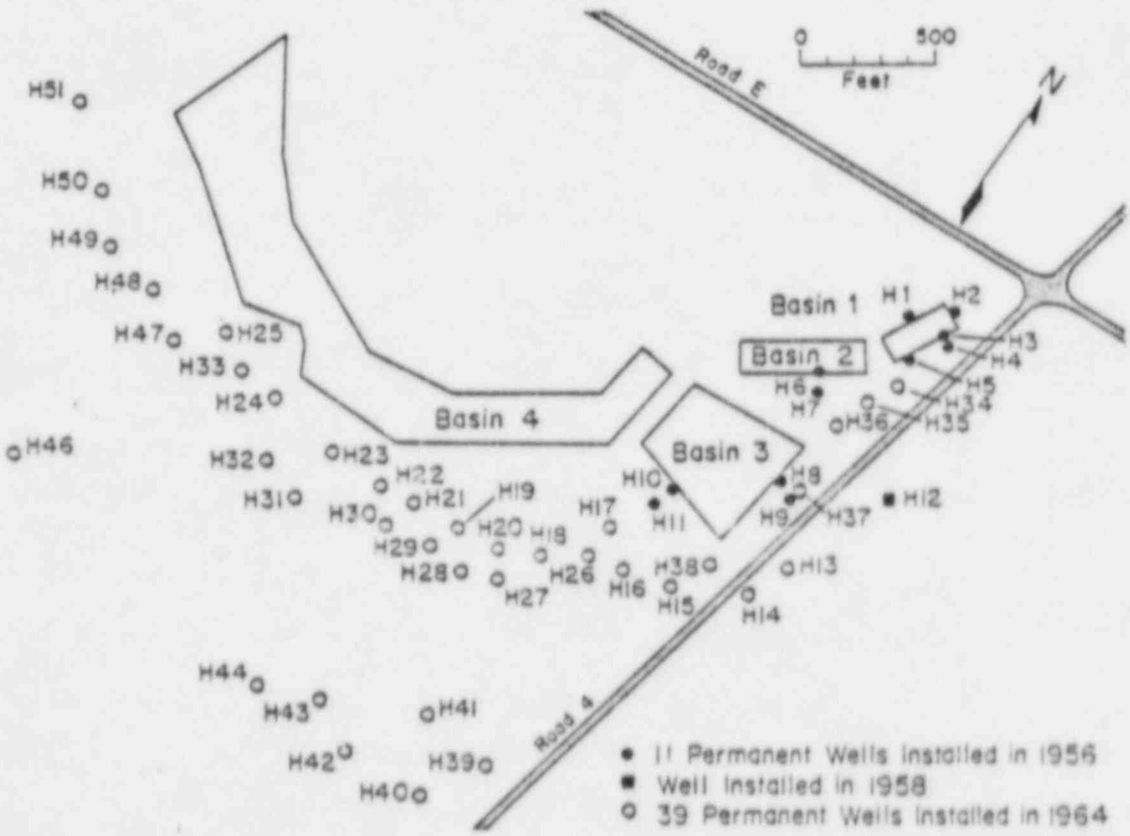

FIGURE 2.1-5. H-Area Seepage Basin Monitoring Wells

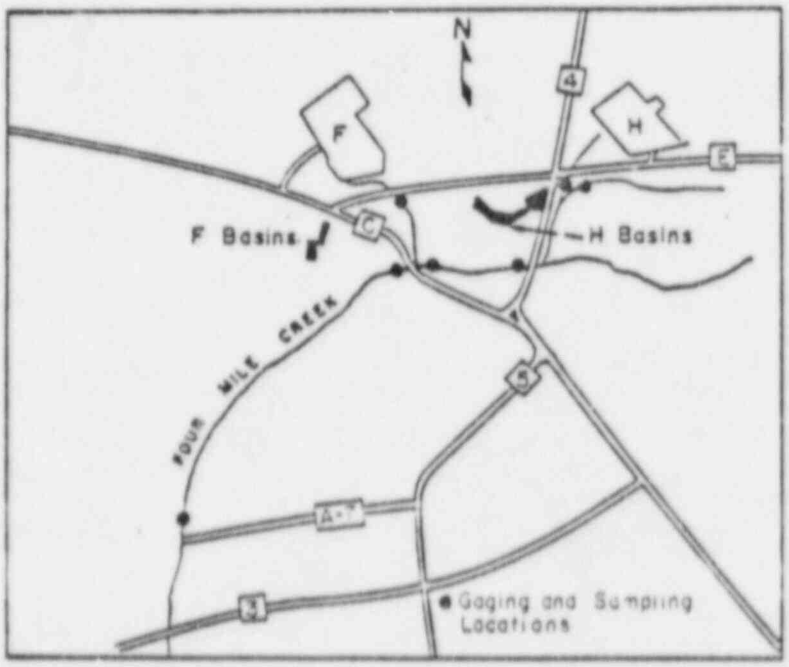

FIGURE 2.1-6. Four Mile Creek Flow Gage and Water Sampling Locations

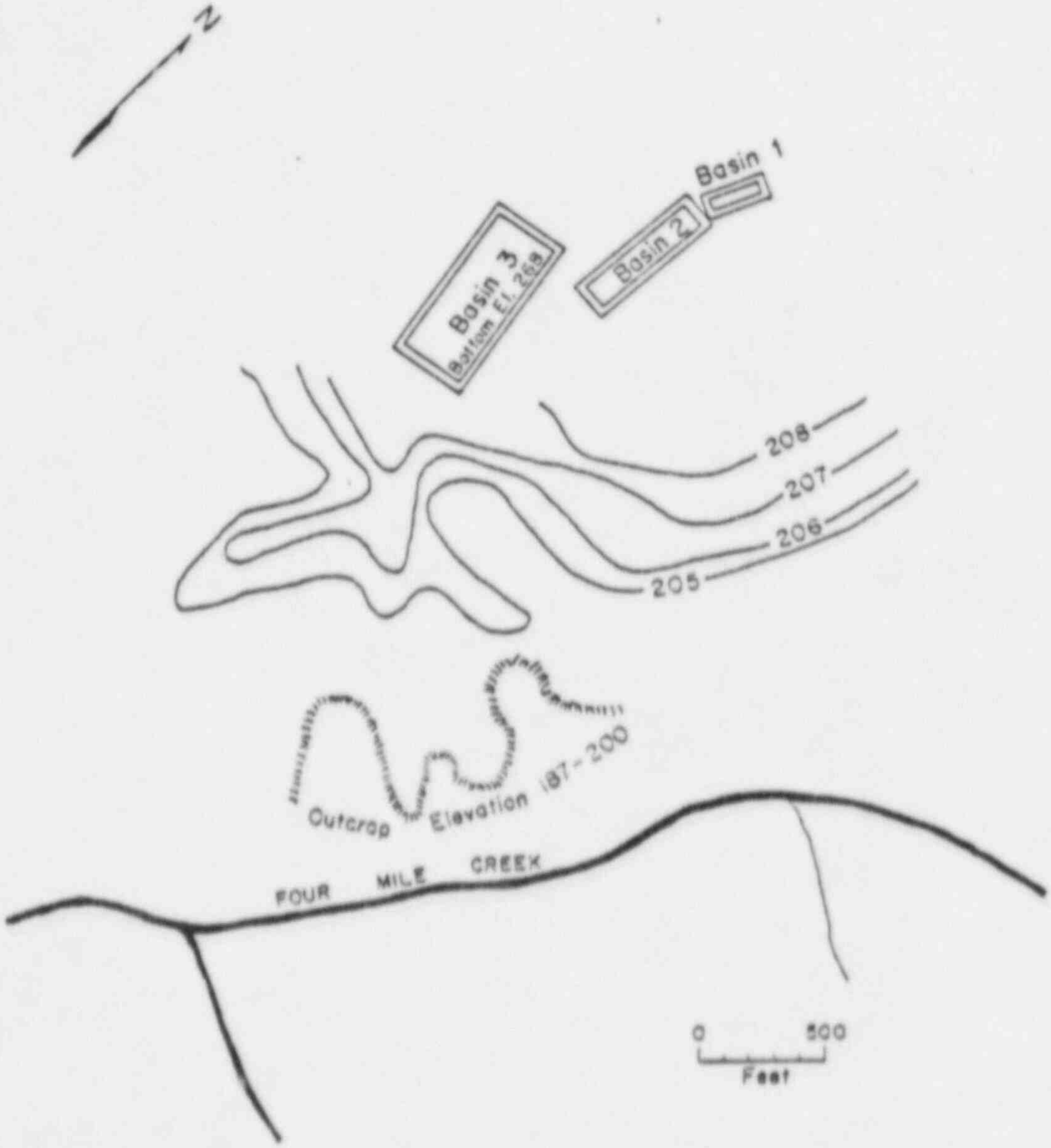

FIGURE 2.1-7. Water Table Elevation Contours at F-Area Seepage Basins

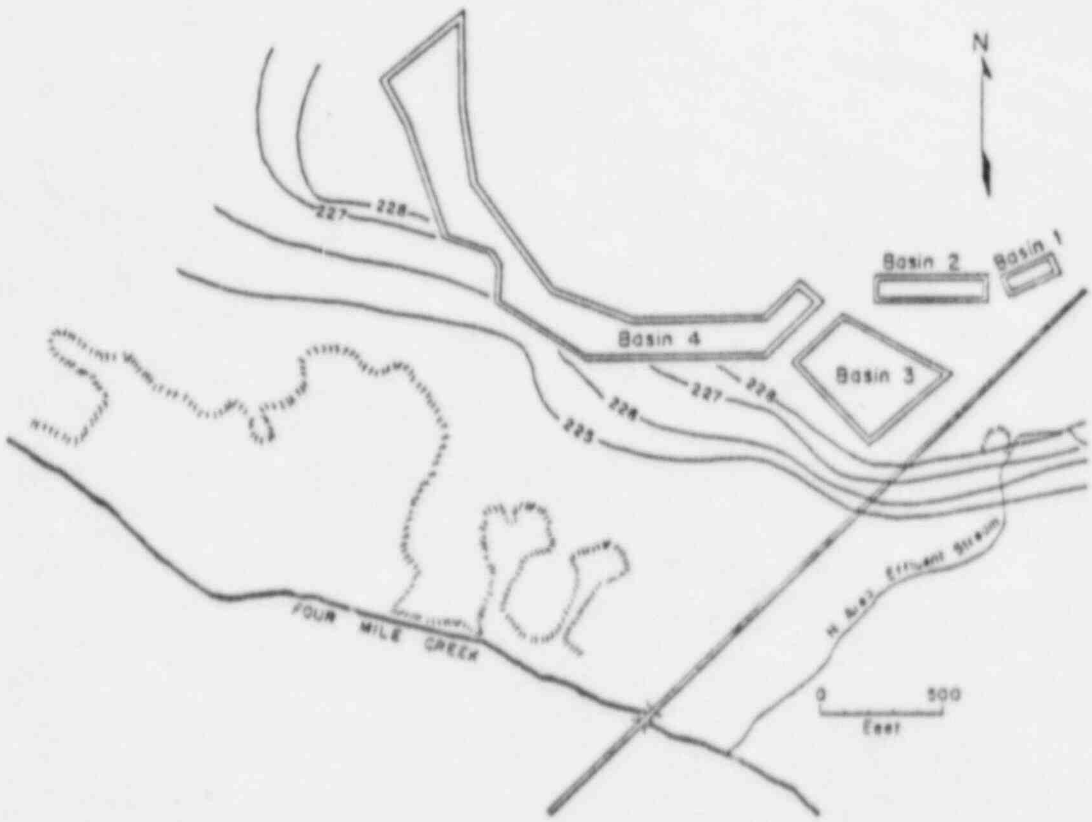

FIGURE 2.1-8. Water Table Elevation Contours at H-Area Seepage Basins

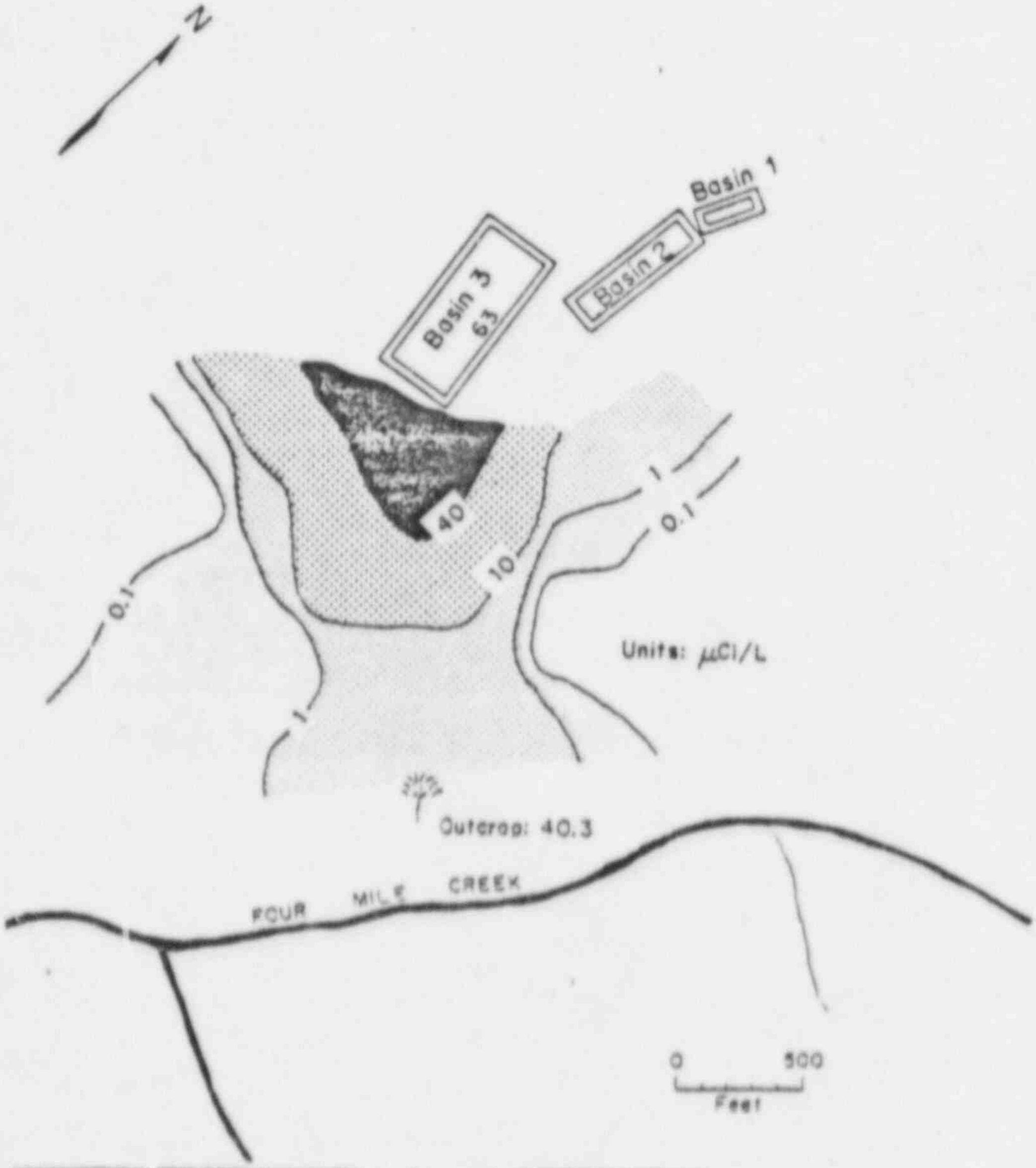

FIGURE 2.1-9. Isoconcentration Contours of Tritium in Groundwater at F-Area Seepage Basins

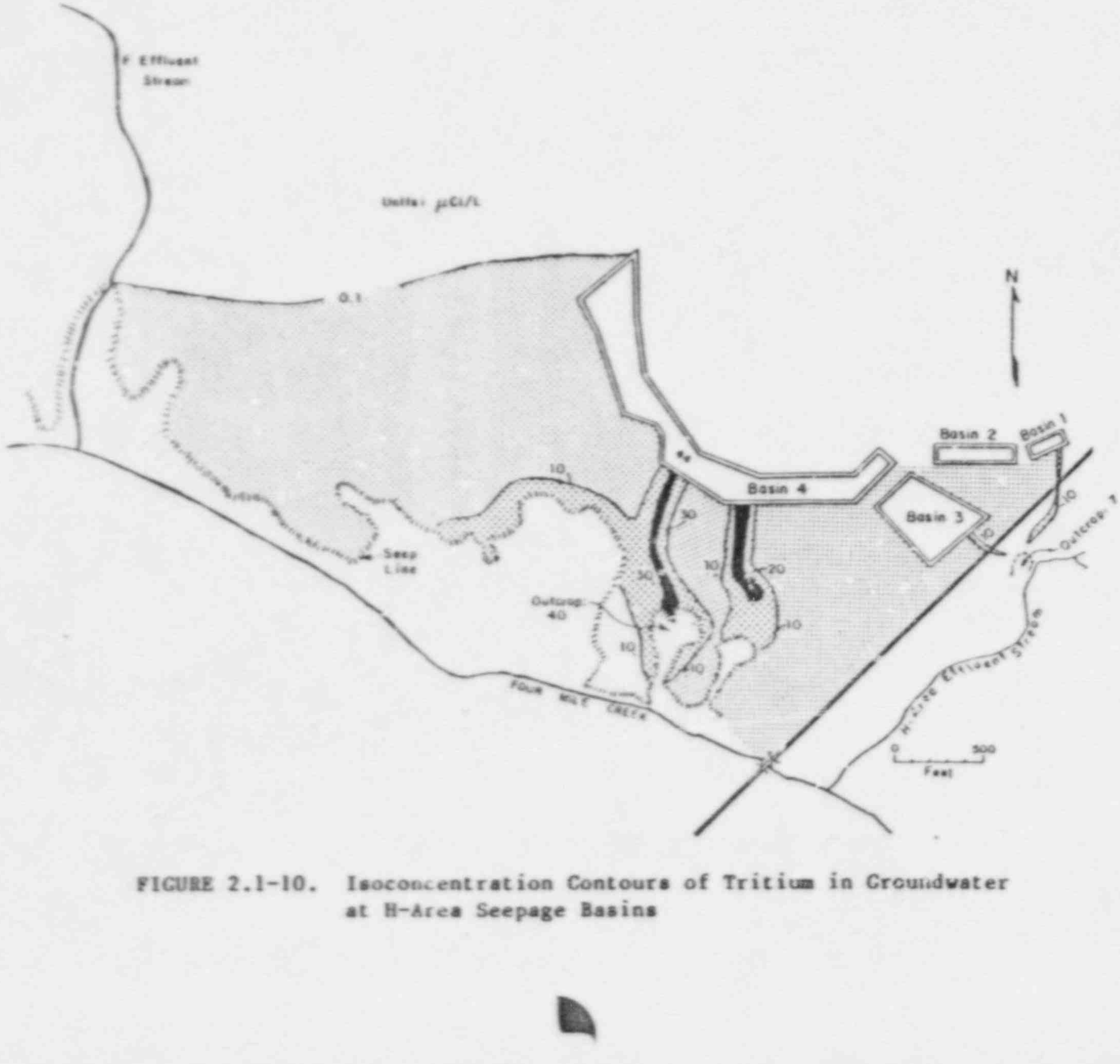

FIGURE 2.1-10. Isoconcentration Contours of Tritium in Groundwater at H-Area Seepage Basins

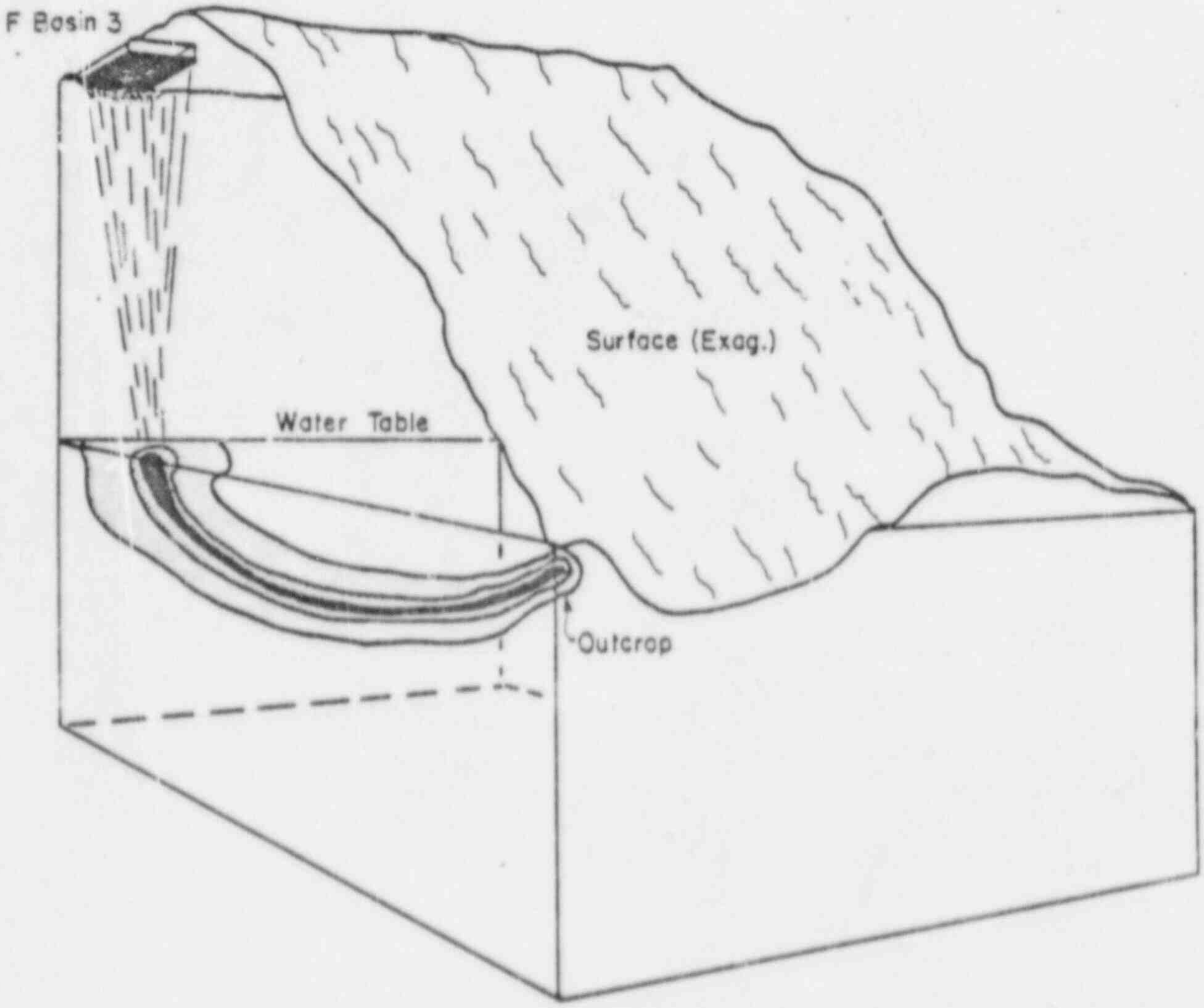

FIGURE 2.1-11. Subsurface Flow Path From F Basin 3

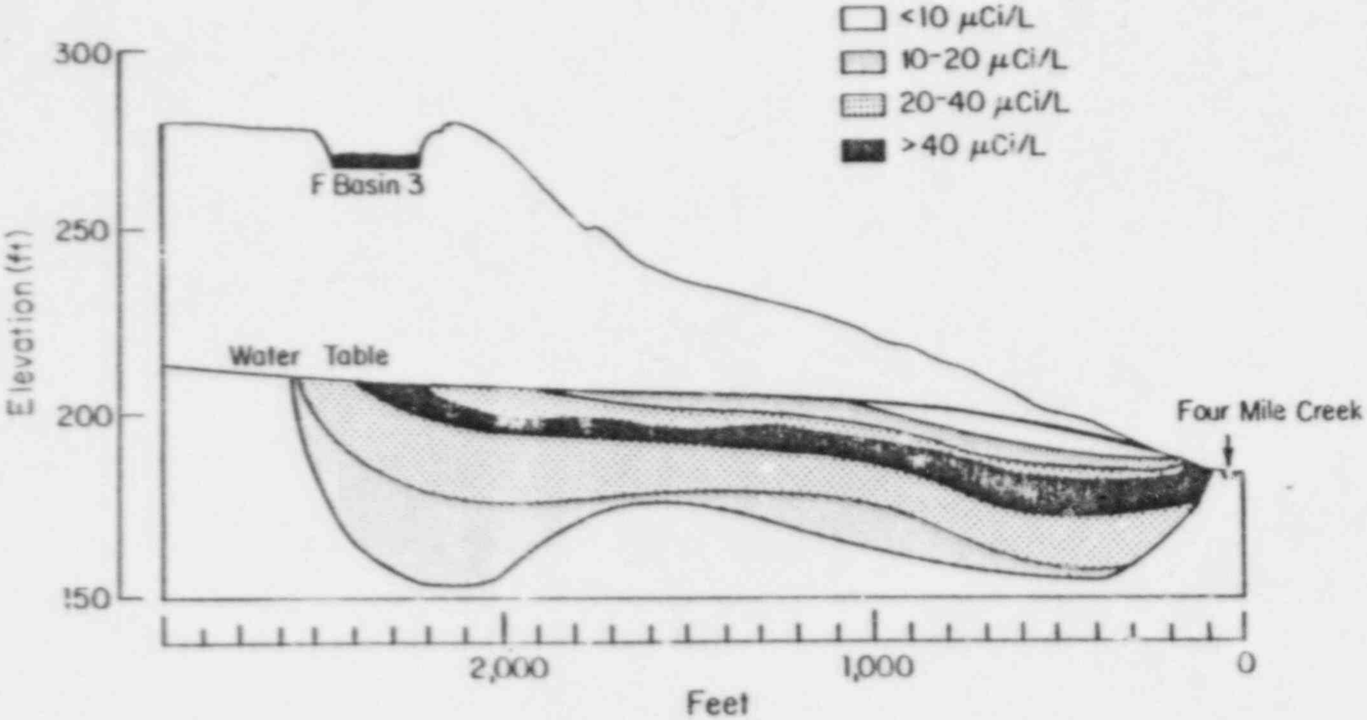

FIGURE 2.1-12. Vertical Distribution of Tritium in Groundwater at F-Area Seepage Basins

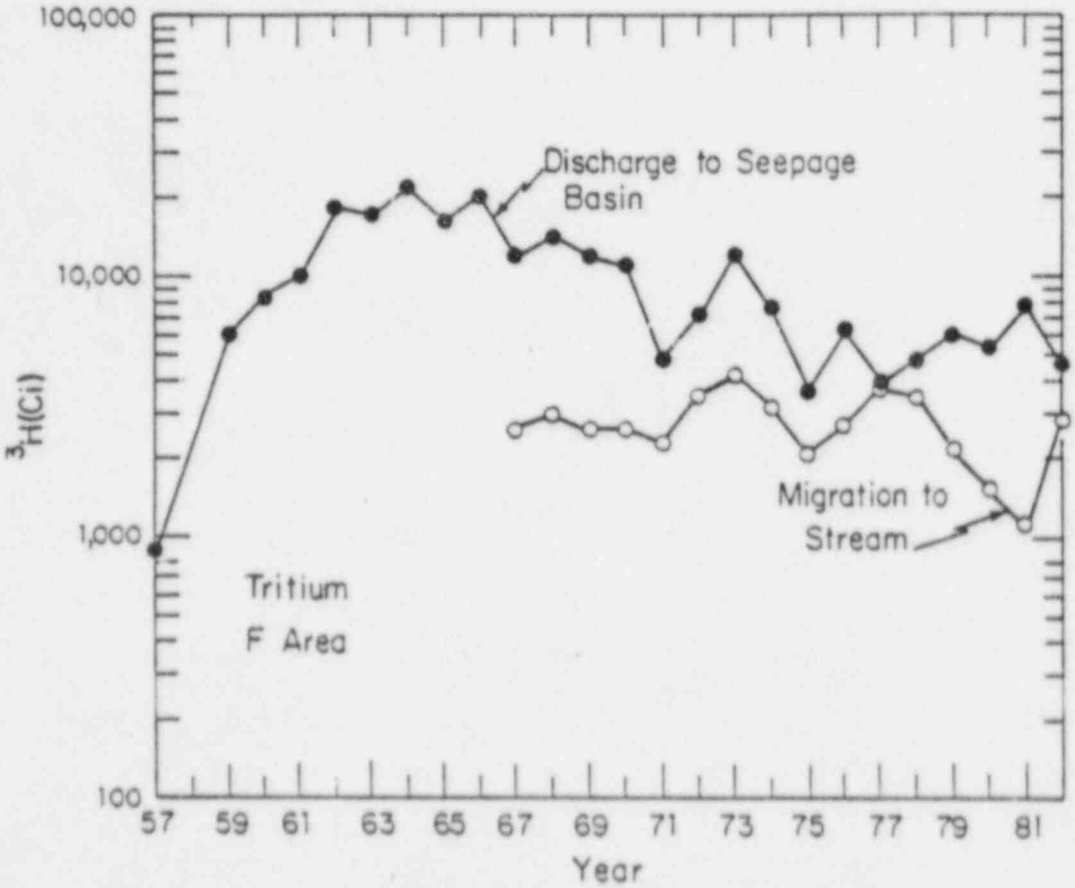

FIGURE 2.1-13. Comparison of Tritium Delivered to Seepage Basins vs. Tritium at Outcrop — F Area

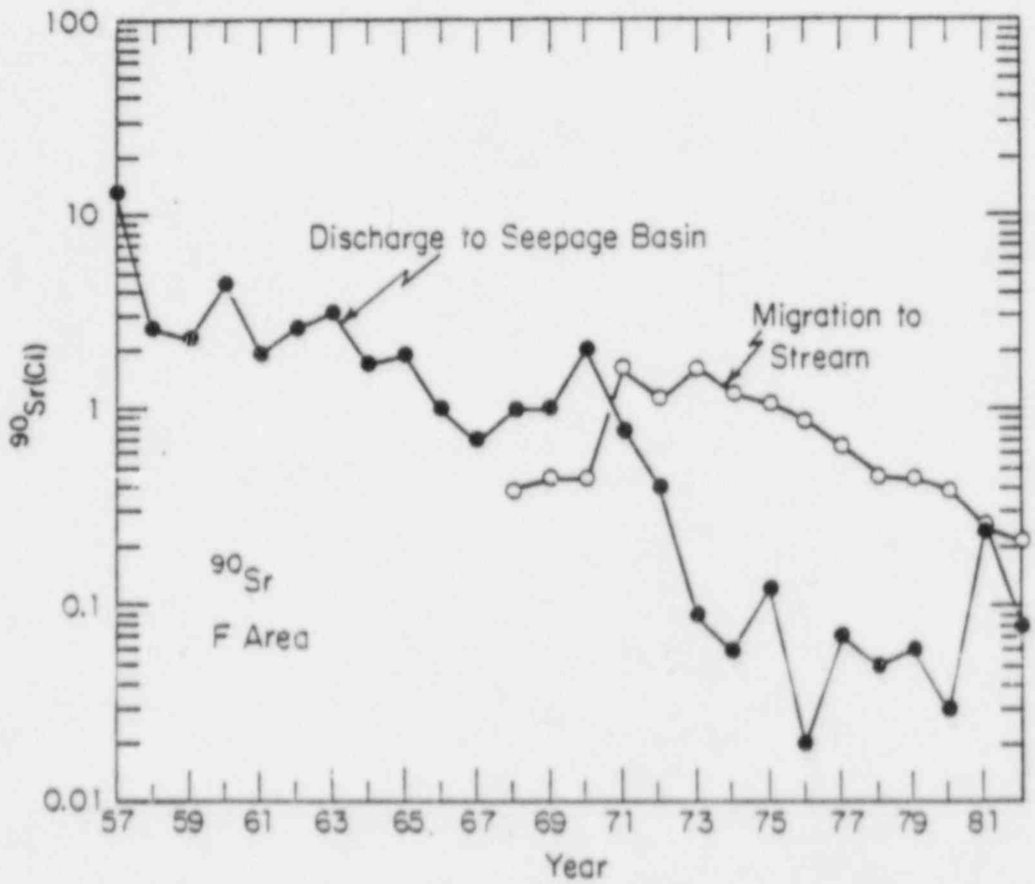

FIGURE 2.1-14. Comparison of ^{90}Sr Delivered to Seepage Basins vs. ^{90}Sr at Outcrop — F Area

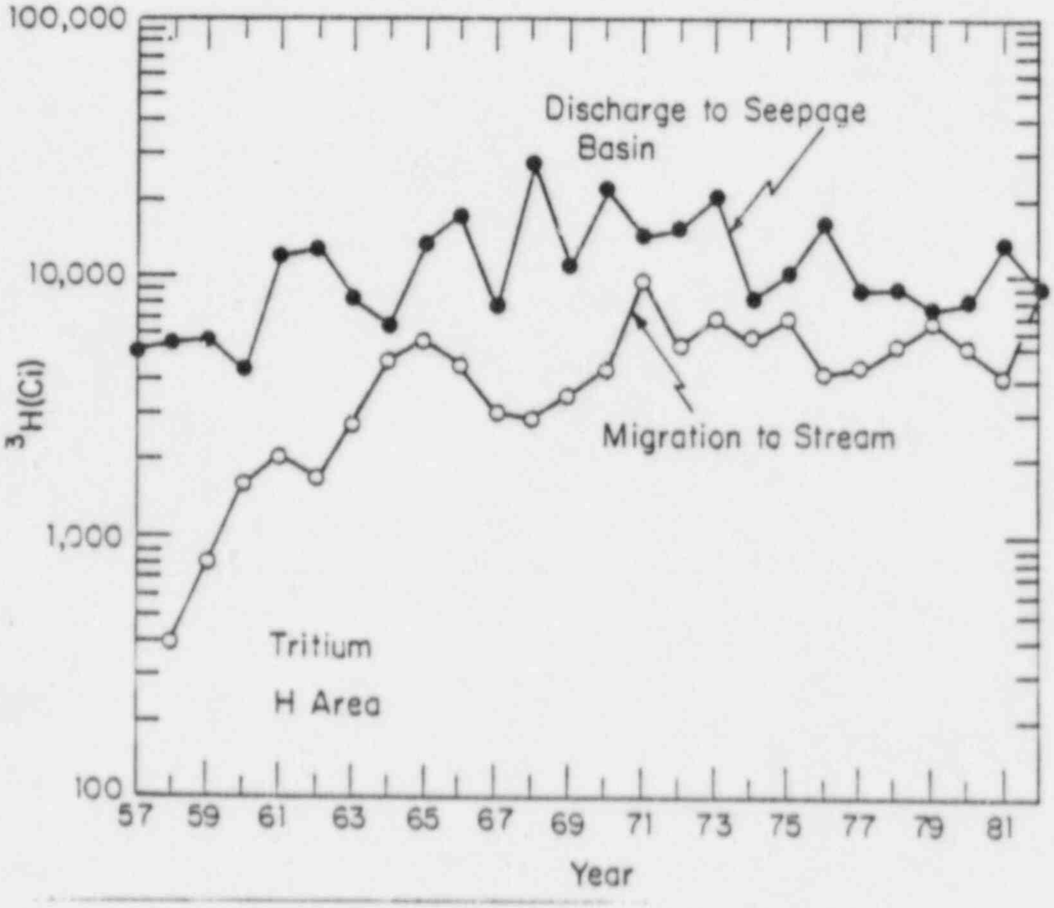

FIGURE 2.1-15. Comparison of Tritium Delivered to Seepage Basins vs. Tritium at Outcrop — H Area

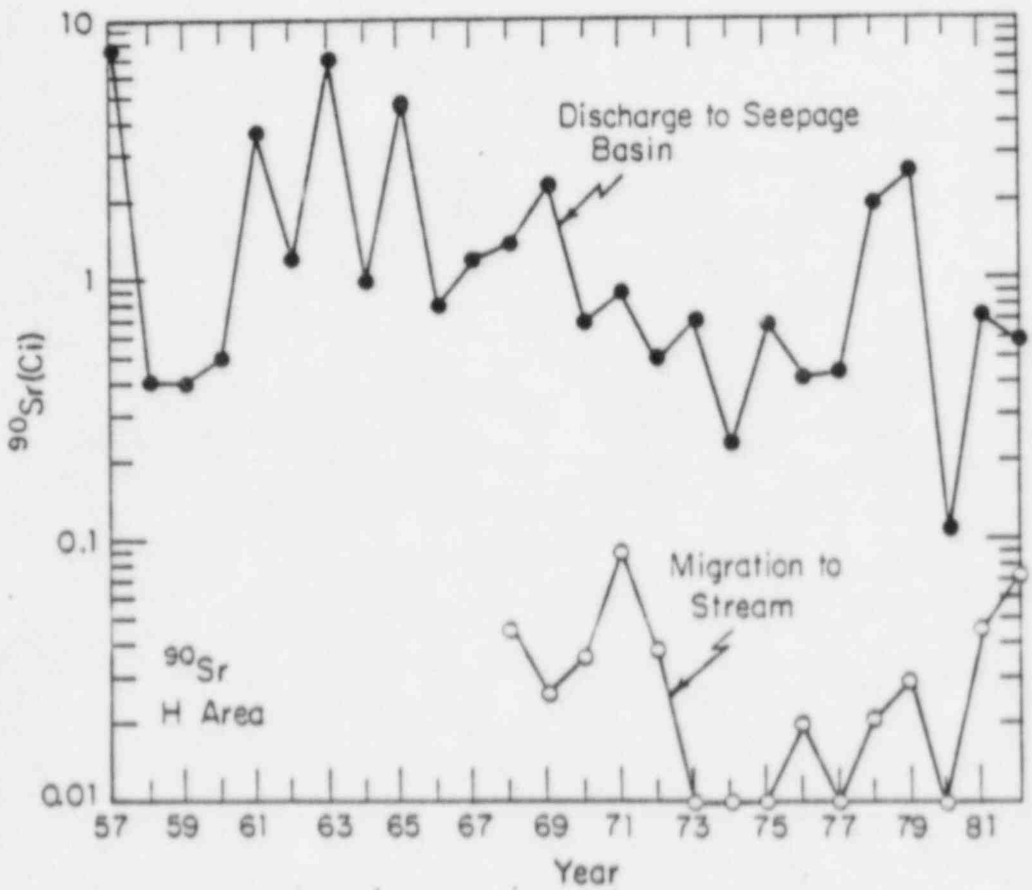

FIGURE 2.1-16. Comparison of ^{90}Sr Delivered to Seepage Basins vs. ^{90}Sr at Outcrop — H Area

2.2 SAVANNAH RIVER LABORATORY SEEPAGE BASINS

Four seepage basins located east of A Area (Figure 2.2-1) have been used by the Savannah River Laboratory for the disposal of low-level liquid wastes, although they are currently out of service.*

2.2.1 Nature of Disposal

When the seepage basins were in use, waste not exceeding 100 d/m/ml alpha and/or 50 d/m/ml beta-gamma was discharged to them from tanks in Building 776-A which received low level waste from Buildings 735-A, 773-A, and 779-A. If the waste exceeded the above limits, it was transferred into a tank trailer and shipped to the Separations Department for final disposition. During the 28-year operating history of the basins, approximately 34 million gallons of water were discharged to the basins, while another one million gallons were transferred to the F-Area evaporators via transfer trailers. A summary of the total discharge of radionuclides to the SRL seepage basins is given in Table 2.2-1.

Recent analysis of surface grab sediment samples collected from the basins showed that ^{90}Sr, ^{60}Co, and ^{137}Cs were relatively low (Table 2.2-2). Of the radionuclides measured, ^{137}Cs had the highest activity with most of it located in the first two basins.

In August 1972, Basin 4 (904-55G) temporarily went dry. Four 12-inch-deep core samples were obtained and divided into 3-inch segments for gamma spectroscopy analysis (Table 2.2-3). The ^{89}Sr and ^{90}Sr contents in the cores were determined chemically. On the basis of the average concentrations of radioactivity, the top 3 inches of sediment contained from 80% to 90% of each of the radionuclides except strontium. ^{89}Sr and ^{90}Sr were distributed uniformly with depth with no indication of reaching background values below 12 inches. The other radionuclides show decreases in activity with increasing depth. The inventories of radionuclides in Basin 4 in the top 12 inches of sediment were estimated using the average concentrations of activity, the surface area of the basin, and a soil density of 1.6 g/cm^3. The calculated inventories were: about 0.46 Ci of ^{137}Cs, 0.41 Ci of ^{106}Ru, 0.05 Ci of ^{141}Ce and ^{144}Ce, 0.04 Ci of ^{60}Co, and 0.01 Ci of ^{89}Sr and ^{90}Sr.

Basin 4 refilled during 1973, then went dry again in 1974, and has remained dry since 1974. Four sediment samples were collected from Basin 4 in 1974. The results of gamma spectroscopy analyses of these cores are given in Table 2.2-4. The highest measured activity was near the surface, with decreasing values with depth.

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* These basins are described more fully in Section 6.5 of Volume I.

The Savannah River Laboratory is now shipping all of its low-level radioactive liquid waste to the general purpose evaporators in Building 211-F. Approximately 40,000 to 50,000 gal/month are transported from SRL in 4,000 gal tank trucks. This rate represents about 1% of the total flow handled in the 211-F evaporators each month. The overheads go directly to the F-Area seepage basins, and the bottoms go to the high-level waste tanks.

2.2.2 Description of Local Groundwater Conditions

The Savannah River Laboratory basins are in the general vicinity of M Area, and the geology and subsurface hydrology are probably similar to that found beneath M-Area.*

2.2.3 Groundwater Monitoring Program and Results

Low-levels of radioactive contamination have been observed in monitoring wells around the Savannah River Laboratory seepage basins. The monitoring program and results are described in Section 6.5.3 of Volume I. Additional analyses for specific radionuclides are required before contamination levels can be compared with drinking water standards.

2.2.4 Evaluation of Impact on Groundwater Quality

Low levels of radionuclides are present at the water table beneath the basins. Although deeper monitoring wells do not exist at this location, there is a potential for deeper penetration of contamination because of the inferred downward gradient.*

2.2.5 Remedial Action

A program is underway to provide the technical basis for final closure of the Savannah River Laboratory seepage basins. The specific tasks include collection of soil samples from the bottom of each basin, determination of chemical and radionuclide inventories in the basins from soil sample analyses, installation of sampling pumps in existing monitoring wells, collection and analysis of groundwater samples, installation of additional exploratory wells, and collection and analysis of groundwater samples from new wells.

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* See Sections 6.5.2 and 6.5.4 in Volume I.

TABLE 2.2-1

Radioactive Releases to the SRL Seepage Basins, 1954 — 1982

Radionuclide	Total (Ci)	Decay Corrected (Ci)
^{3}H	243	124
$^{89,90}Sr$	0.11	0.078
^{137}Cs	0.011	0.010
^{nat}U	0.022	0.022
^{238}Pu	8.9×10^{-3}	8.8×10^{-3}
^{239}Pu	2.9×10^{-3}	2.9×10^{-3}
^{241}Am	7.7×10^{-4}	7.7×10^{-4}
^{244}Cm	5.6×10^{-4}	5.3×10^{-4}
Alpha (unidentified)	4.2	
Beta-Gamma (unidentified)*	10.6	

* Includes ^{60}Co and $^{103,106}Ru$.

TABLE 2.2-2

Measured Radioactivity in the SRL Seepage Basins - October 1982

Locations of Sediment Samples Basin No.	Activity (nCi/g)		
	Sr-90	Cs-137	Co-60
1-Inlet	0.301	37.3	—
1-Center	0.017	28.2	0.210
2-Inlet	0.134	2.92	—
2-Center	0.128	33.1	0.660
3-Inlet	0.021	0.80	—
3-Center	0.037	3.26	0.132
4-Inlet	0.021	0.76	—
4-Center	0.017	0.092	—

TABLE 2.2-3

SRL Seepage Basin 4 Sediment Activity

Radionuclide	Sediment Depth (inches)	Radioactivity at Samples Sites* (nCi/g) 1	2	3	4
^{137}Cs	0 - 3	0.910	0.730	1.450	0.320
	3 - 6	0.057	0.057	0.550	0.113
	6 - 9	0.011	0.004	0.010	0.047
	9 - 12	0.010	0.007	0.001	0.019
$^{103,106}Ru$	0 - 3	0.620	0.480	2.100	0.260
	3 - 6	0.056	0.009	0.106	0.063
	6 - 9	0.010	0.002	0.007	0.019
	9 - 12	0.008	0.009	0.002	0.018
$^{141,144}Ce$	0 - 3	0.110	0.065	0.240	0.037
	3 - 6	0.006	0.016	0.016	0.006
	6 - 9	0.001	0.003	0.004	0.006
	9 - 12	0.004	0.004	0.003	0.003
^{60}Co	0 - 3	0.083	0.036	0.180	0.025
	3 - 6	0.021	0.007	0.014	0.004
	6 - 9	0.002	0.001	0.001	0.004
	9 - 12	0.002	0.002	0.001	0.001
$^{89,90}Sr$	0 - 3	0.004	0.004	0.004	0.001
	3 - 6	0.021	0.007	0.007	0.007
	6 - 9	0.013	0.004	0.004	0.001
	9 - 12	0.012	0.001	0.001	0.002

* Samples taken on August 17, 1972, at 4 locations in Basin 4 with NW corner designated as 1 and going counterclockwise from inlet.

TABLE 2.2-4

SRL Seepage Basin 4 Sediment Activity

Radionuclide	Sediment Depth (inches)	Radioactivity at Sample Sites* (nCi/g) 1	2	3	4
^{137}Cs	0 - 2.5	0.714	0.044	1.100	0.215
	2.5 - 7.5	0.042	0.002	0.207	0.034
	5.0 - 7.5	0.007	0.001	0.036	0.002
	7.5 - 9.5	0.003	0.001	0.004	-
	9.5 - 12.0	0.002	-	0.001	-
^{134}Cs	0 - 2.5	0.037	0.003	0.092	0.016
	2.5 - 5.0	0.003	0.001	0.009	0.001
	5.0 - 7.5	0.001	0.001	0.001	0.001
	7.5 - 9.5	0.001	0.001	0.001	0.001
	9.5 - 12.0	0.001	0.001	0.001	0.001
^{106}Ru	0 - 2.5	Trace	Trace	Trace	Trace
^{60}Co	0 - 2.5	0.050	0.007	0.078	0.020
	2.5 - 5.0	0.002	0.001	0.008	0.001
	5.0 - 7.5	0.001	0.001	0.004	0.001
	7.5 - 9.5	0.001	0.001	0.001	-
	9.5 - 12.0	0.001	-	0.001	-
Alpha	0 - 2.5	0.150	0.140	0.230	0.020
	2.5 - 5.0	0.020	0.002	0.019	0.006
	5.0 - 7.5	0.009	0.002	0.007	0.002
	7.5 - 9.5	0.003	0.002	0.006	-
	9.5 - 12.0	0.002	0.002	0.001	-

* Samples taken in 1974 at 4 locations in Basin 4 with NW corner designated as 1 and going counterclockwise from inlet.

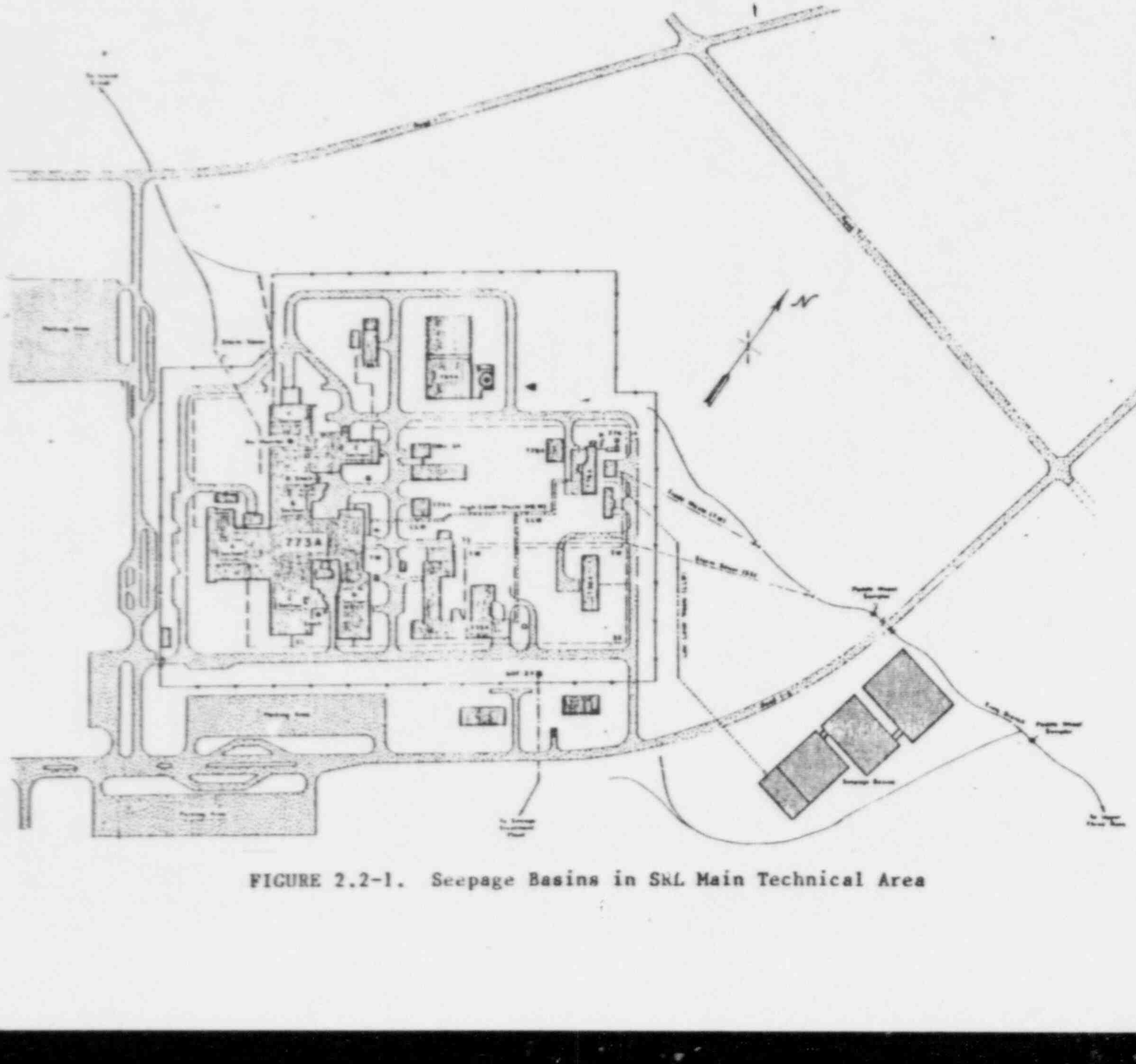

FIGURE 2.2-1. Seepage Basins in SRL Main Technical Area

2.3 RADIOACTIVE WASTE BURIAL GROUNDS

2.3.1 Nature of Disposal

History and Inventory

One centrally located solid radioactive waste storage site is used to store all radioactive solid waste produced at the Savannah River Plant, as well as occasional special shipments from offsite.[1] This storage site occupies 195 acres between the F and H Separations Areas, approximately 6 miles from the nearest plant boundary. The original area was 76 acres designated 643-G, which began to receive waste in 1953 and was filled in 1972. Operations then shifted to a 119-acre site designated 643-7G, contiguous to the original area. The burial grounds are divided into sections for accommodating various levels and types of radioactivity in waste materials: transuranium (TRU) alpha waste, low beta-gamma waste, and intermediate beta-gamma waste (intermediate beta-gamma and low beta-gamma solid radioactive wastes are segregated according to radiation measurement). Examples of the materials in storage include:

- Contaminated equipment — obsolete or failed tanks, pipes, jumpers, and other process equipment from the fuel separations plants.
- Reactor hardware and resins — fuel components and housings not containing irradiated fuel, and spent deionizer resins.
- Spent lithium-aluminum targets — the waste target alloy after tritium has been extracted.
- Oil from gas displacement pumps in the tritium facilities — before burial, oil was placed in drums containing an absorbent material.
- Mercury from gas pumps in tritium facilities — before 1968, radioactively contaminated mercury was buried in one-liter polyethylene bottles.
- Incidental waste from laboratory and production operations — small equipment, spent air filters, clothes, analytical waste, decontamination residues, plastic sheeting, and gloves.
- Occasional shipments from offsite — tritiated waste from Mound Laboratory, ^{238}Pu process waste from Los Alamos Scientific Laboratory and Mound Laboratory, and debris from two U.S. military airplane accidents in foreign countries.

Transuranic waste was buried up to 1965 in plastic bags and cardboard boxes in earthen trenches designated specifically for this waste. Between 1965 and 1974, TRU waste was segregated according to TRU content into two categories. Waste containing less than 0.1 Ci per package was buried unencapsulated in alpha trenches. Waste containing greater than 0.1 Ci per package was buried in retrievable concrete containers 6 ft in diameter and 6.5 ft high. Waste that did not fit into the prefabricated concrete containers was encapsulated in concrete. Transuranium waste from the Savannah River Laboratory was buried in cubical concrete containers. Current practices, described below, were initiated in 1974.

The estimated volume and curie content of solid radioactive waste buried nonretrievably from 1953 through 1982 is shown in Table 2.3-1. This waste is contained in plastic bags and cardboard boxes and is thus subject to leaching if contacted by water-saturated soil. Nuclides in the category "Other Alpha Emitters" are ^{242}Pu, ^{241}Am, ^{243}Am, ^{233}U, enriched U, depleted U, natural U, ^{252}Cf, ^{237}Np, and thorium. Total radionuclides in the groundwater beneath the burial grounds are estimated as 2 mCi of alpha emitters, 16 mCi of beta-gamma emitters, and 28,000 Ci of tritium.

The historical performance of the burial ground may be summarized by containment factors, which are ratios of radioactivity buried to radioactivity that has reached the water table, as estimated from groundwater monitoring. For alpha and beta-gamma emitters the containment factors are quite large, about 10^6 and 10^8, respectively. The tritium containment factor is about 10^2 - about 1% of buried tritium has reached the water table, where it undergoes decay and dilution in a long subsurface flow path.

Current Practices

A paved road to the entrance and many unpaved roads inside the fenced area provide access for trucks, the usual transportation mode for solid waste. Three railroad spurs permit shipments of large pieces of contaminated process equipment from the operating areas. Trenches are excavated 20 ft wide, 20 ft deep, and up to 700 ft long. Waste emplacements are covered with soil to reduce the potential for radiation exposures, fires, and wind-blown contamination. Trenchs that are nearly filled with waste are back-filled with 4 ft or more of soil, to reduce surface radiation to less than 6 mR/hr.

Records are kept of the contents, radiation level, and storage location of each load of waste. Shipments are described and recorded, and permanent computerized records are maintained on duplicate magnetic tapes. The exact location of the burial

trenches is defined by a 100-ft grid system laid out in 1962. The 100-ft grids are further divided into twenty-five 20-ft squares.

In 1974, procedures were modified to reflect new criteria governing retrievable storage of solid transuranic waste. Transuranium wastes contaminated to greater than 10 nCi/g are now stored, protected from contact with water-saturated soil, in containers that can be retrieved intact and free of external contamination for at least twenty years from the time of storage. Combustible and noncombustible wastes are stored in separate containers. Polyethylene-lined galvanized drums are used as the primary container; waste packages containing more than 0.1 Ci are additionally protected by closure in concrete cylinders. Containers are stored on a concrete pad and covered with 4 ft of earth. Canyon equipment and other bulky wastes contaminated with transuranium nuclides to greater than 10 nCi/g and also intensely contaminated with gamma emitters are stored directly in earthen trenches.

Waste contaminated with beta-gamma emitters is separated into two categories for burial: low beta-gamma and intermediate beta-gamma. Low beta-gamma waste is defined as waste measuring less than 50 mR/hr at 3 inches from an unshielded package and less than 50 mR/hr at 10 ft from the truck load. This waste is buried in low beta-gamma waste trenches. Scrap unirradiated uranium is also classified as low beta-gamma waste, but it is buried in separate trenches. Irradiated reactor fuel housing components, tritium waste (classified as intermediate beta-gamma waste because of induced activity associated with the Li-Al melts), and miscellaneous waste in cardboard boxes are segregated and buried in separate trenches.

Degraded solvent is stored in eight bitumastic-coated, mild steel tanks of 25,000 gal capacity, which were installed in 1975. Each tank has a sump which is monitored weekly for leaks by measuring the liquid level. The expected rate of waste solvent generation is about 5,000 gal per year. A study is underway to develop means to dispose of the waste solvent.

Figure 2.3-1 shows zones within the burial ground containing transuranic alpha waste, low level waste, intermediate level waste, and solvent storage.

2.3.2 Local Groundwater Conditions

The geology of the burial ground general area and the occurrence of groundwater islands because of dissection by streams was described in Volume I. Groundwater in these interstream areas moves by gravity flow toward the streams, outcropping on the

surface in springs and swamps along stream courses. Figure 2.3-2 shows an idealized flow net in such an interstream area; in this figure, all sediments are equally permeable to water, and the streams are at equal elevation. Lines without arrowheads are lines of equal pressure. Lines with arrowheads are flow lines. Seen in plan view, pressure lines at the water table appear as elevation contours, because elevation is equivalent to pressure head. Contours can be determined by head measurements in wells penetrating just into the water table. Pressure lines below the water table can be determined by means of clusters of wells penetrating to successively deeper depths. Figure 2.3-3 shows shallow wells and five-well clusters used for water table and flow net observations. These wells were installed over many years beginning in 1956 and continuing to the present. Measurements were taken at monthly or bimonthly intervals during this time.

Results show two major differences from the ideal case. Figure 2.3-4 gives a cross section extending across the interstream area from Four Mile Creek to Upper Three Runs Creek through the burial ground. The difference in elevation between the two stream beds is apparent. Upper Three Runs is a much larger stream than Four Mile Creek. Upper Three Runs rises near Aiken, and only its lower part crosses SRP. Four Mile rises on the Plant just a few miles above the burial ground. As a result, the bed of Upper Three Runs Creek is about 55 ft deeper than Four Mile Creek at the burial ground area. This difference in bed elevation causes the water table divide to be displaced about 1000 ft toward the Four Mile Creek side. Flow paths toward Four Mile Creek are thus more shallow and shorter than flow paths toward Upper Three Runs Creek.

The two low-permeability clay beds described in Volume I can also be seen in Figure 2.3-4. The effect of these low-permeability horizons on lateral movement of the groundwater is shown in Figure 2.3-5. Water moving along flow paths from the burial ground to Four Mile Creek crosses the upper clay horizon. The decrease in head across this clay is 5 ft, which causes the flow paths to be refracted as shown. After crossing the clay, the path is refracted an equal amount in the opposite direction. The overall effect is to increase the time required to traverse the flow paths. A similar effect occurs at the lower clay, but to a greater degree because the permeability is even lower. Measured head drop across the lower clay is around 50 ft. Measurements in wells show that the pressure in sediments in the Congaree Formation is lower than pressures both above and below. Thus, water flows to the Congaree from both above and below, limiting the depth of circulation of water from the burial ground as shown in Figure 2.3-5.

The water table in the interstream area (Figure 2.3-6) shows that about 80% of groundwater beneath the burial ground drains to Four Mile Creek while the rest moves to Upper Three Runs Creek.

Figure 2.3-7 is a detailed map of the Four Mile side based on the closely spaced wells shown in the figure. This map shows that flow is from east to west, turning south at the west end, and leading to an outcrop zone on the Four Mile Creek floodplain south of the west end of the burial ground.

Though sediments in the burial ground, as elsewhere, are heterogeneous, flow over a distance of several hundred feet reduces the effect of this variability. Sixteen groundwater velocity tracer tests using tritium were made throughout the area. The results of these tests show a strong correlation between velocity and the gradient. Groundwater velocity in this area was found to be 47 ft/yr/1% gradient.

Water flowing through porous media such as the burial ground sediments exhibits a distribution of velocities in the small flow channels. This is caused by a friction gradient extending from the channel walls out to the center where friction is least. As a result, tracer released into the system will assume a normal distribution in the longitudinal direction as flow proceeds. The leading edge of the distribution will precede the centroid by some factor of the centroid velocity that depends on pore and grain characteristics.[2-6] A tracer experiment conducted from 1957 to 1970 at the burial ground showed that the centroid moved 250 ft, but that the leading edge had not yet arrived at wells 250 ft beyond the centroid. Thus, hydrodynamic dispersion causes the leading edge to move no more than twice as fast as the centroid.

Application of these rates to observed water table gradients on flow paths originating in the east, middle, and southwest parts of 643-G gives the results shown in Figure 2.3-8. The figure shows the estimated time required for tritium released at the head of the flow path to move to the outcrop. Both average (centroid) and leading edge estimates are shown. Other nuclides will require greater times that depend on the degree of retention of the nuclide by sediments.

2.3.3 Groundwater Monitoring Program and Results

History

Burial practices at the Savannah River Plant result in waste in direct contact with earth in a near-surface backfilled trench. Monitoring this buried waste begins at the burial point, extends through the unsaturated zone, and into the saturated zone below the water table. In the early 1970's, when operations in 643-G (the original burial ground) began diminishing, a grid of water table wells of the type described in Volume I was installed on 200 ft centers. In 1974-75, a grid of wells on 400-ft centers was

installed in the downgradient area south of 643-G. The grid of wells in 643-7G was started in the late 1970's as burial space was filled. All 125 wells in the system are shown in Figure 2.3-9.

Well Inventory

Figures 2.3-10, 2.3-11, and 2.3-12 show the locations of interior and perimeter wells on a scale large enough to permit identification of individual wells. Wells in the downgradient area south of the burial ground are not shown.

Deeper flow paths resulting from curvilinear water movement are monitored by clusters of wells screened at successively deeper levels. Figure 2.3-13 shows screen placements in relation to important hydrostratographic units in well clusters located at intervals along the south fence of 643-G. Wells are identified at each cluster by letters beginning with the deepest well.

In addition to groundwater wells, 643-G also contains 22 trench wells and 11 dry boreholes. The trench wells monitor for perched water in contact with waste, a condition that occasionally has been found. The dry boreholes are used to make in-situ gamma radiation measurements.

Soil cores assayed by segment for tritium have been used to define the three-dimensional tritium distribution in the burial ground flow path. Approximately 2140 ft of core were logged and assayed in this work. Figure 2.3-14 shows locations of cores and of cross sections developed from core information.

Monitoring Results

Tables 2.3-2 and 2.3-3 show annual averages of bimonthly samples for the latest three years in the 643-G grid wells. Table 2.3-2 is for gross alpha emitters, and Table 2.3-3 shows gross nonvolatile beta emitters. Assays are available back to 1973 for the earliest wells installed in this system. Only 10 grid wells ever have shown significant amounts of alpha (>6 pCi/L) and/or nonvolatile beta (>100 pCi/L) activity at any time in their histories. Eighteen more grid wells have shown marginally detectable amounts greater than background of alpha (>3 pCi/L) and/or nonvolatile beta (>50 pCi/L) activity. Plots of results show that about 8% of the horizontal extent of 643-G groundwater contains alpha emitters and 4% contains nonvolatile beta emitters greater than background. Table 2.3-4 shows similar data for wells in 643-7G, and Table 2.3-5 shows results for wells around the perimeter of the burial ground. Measurements in the dry boreholes over 17 years have shown virtually no vertical movement of gamma-emitting radionuclides.[7,8]

Assays for individual radionuclides in 643-G groundwater also have been performed, by methods capable of detecting ultra-low levels. Such assays were performed on samples from selected wells with a history of gross alpha and/or gross nonvolatile beta radioactivity. Table 2.3-6 summarizes the results of these measurements. Twenty wells were analyzed for gamma emitters; as shown in Table 2.3-6, ^{60}Co and ^{137}Cs were the only gamma emitters observed, other than natural radioactivity, at levels >8 pCi/L. Seventeen wells showed no gamma emitters, two wells contained only ^{137}Cs, and one well contained both ^{60}Co and ^{137}Cs.

Table 2.3-6 shows results for 12 wells assayed for ^{90}Sr, at levels >6 pCi/L. Seven of the wells showed no ^{90}Sr, four wells contained small detectable levels, and one well was significantly higher in ^{90}Sr than the others. The high well (G-21 in Tables 2.3-2 and 2.3-3) is also high in alpha emitters and is chemically anomalous.

Table 2.3-6 also shows results for 12 wells assayed by low-level alpha pulse height analysis. ^{238}Pu and ^{239}Pu were the only plutonium alpha emitters observed at levels >1 pCi/L. Four of the wells showed no plutonium alpha emitters, five wells contained only ^{238}Pu, and three wells contained both ^{238}Pu and ^{239}Pu.

Evidence for small amounts of ^{99}Tc and ^{129}I in the groundwater flow path outside the 643-G burial ground has been obtained in preliminary experiments with ultra-low-level analytical techniques. About 20 pCi/L of ^{99}Tc and 1 pCi/L of ^{129}I were found.

A detailed chemical analysis of groundwater from 643-G burial ground wells has been completed.[9] Chemical properties are summarized in Table 2.3-7 from those wells considered "normal" or probably not affected chemically by the presence of nearby waste. However, usually one or more wells were identified as "anomalous" for each chemical property measured. This generally could be taken as evidence that the nearby waste was affecting these wells. Thus, about 20 different wells were identified as anomalous in one or more chemical properties. Work on establishing a correlation between wells with anomalous chemistry and wells containing measurable low-level radioactivity is still in progress.

The mechanisms most likely to enhance radionuclide mobility are: (1) complex formation, with organics, carbonate, and phosphate; (2) competitive cation exchange in the soil, for groundwaters with high conductivity and concentrations of various cations. Other conditions that might increase radionuclide migration are abnormal pH, low Eh or dissolved oxygen, and high iron concentration.[9]

Unlike other radionuclides, tritium exchanges with hydrogen in water, is thus readily leached, and moves freely with flowing groundwater. Table 2.3-8 shows average annual tritium concentrations in 643-G grid wells for the latest three years, and Table 2.3-9 shows similar data for 643-7G wells. Figure 2.3-15 shows zones containing tritium within the burial grounds. The isoconcentration lines shown are at background, 0.1 µCi/L, and the depth of penetration can be inferred from vertical core studies made downslope of the burial ground.

The volume of water in each 643-G tritium zone was calculated from the measured area, the estimated thickness of the zone, and the average sediment porosity. This volume multiplied by the observed average concentration gives an estimate of the total amount of tritium in 643-G groundwater. Estimates since 1974 are shown in Table 2.3-10. The quantity of tritium in 643-G groundwater appears to be stable at an average of 28,200 Ci. Tritium content in burial ground perimeter wells is given in Table 2.3-11. These results show that tritium is in groundwater on the southwest perimeter in the principal flow path. One well on the northeast perimeter, in a flow path in the Upper Three Runs drainage, shows a small amount of tritium. This tritium extends about 600 ft northward from the burial ground fence, where the plume ends.

Tritium distribution in the burial ground flow path between the south fence and outcrop zone is shown on cross sections located as shown in Figure 2.3-14. The point of view for the M-M' and Q-Q' sections is toward the north. For the FP-FP' section the point of view is toward the west.

The tritium flow at M-M', Figure 2.3-16, is about 1700 ft wide, 26 ft thick, and about 14 ft below the water table. A second, minor tritium flow is present below the main flow. At Q-Q', Figure 2.3-17, the flow is deeper, about 21 ft below the water table, but is only 600 ft wide and is thicker. The flow path section, Figure 2.3-18, shows the expected curvilinear flow path, but with foreshortening by diversion to the incised bed of the F-Area effluent stream. There is a concentration gradient down the flow path with a reduction in concentration by a factor of 30. The portion of the plume down gradient of the burial ground contains 2000 Ci of tritium (calculated by multiplying plume water volume by average concentration). Measurements in the F-Area effluent stream showed that about 850 Ci/yr of tritium from the burial ground were outcropping into the effluent stream.

Although the core measurements found no flow paths deeper than those shown, some tritium nevertheless enters deeper flow paths in the McBean formation. This is probably caused by the 5 ft head difference across the tan clay and the discontinuous areal extent of the clay. Where tritium passes over openings in the clay, some

is diverted downwards into the McBean formation. Table 2.3-12 shows annual tritium concentrations in cluster wells located along the south 643-G fence. Figure 2.3-19 shows the average concentrations over the last three years at the various depths and locations measured with the cluster wells. Although concentrations up to 750 µCi/L have been observed in the upper McBean well in cluster 3, flows in the McBean are slow (see Volume I). Available information suggests that McBean flow paths are less important than the main (Barnwell) flow path for transport of tritium.

2.3.4 Evaluation of Impact on Groundwater Quality

Operation of the burial ground has had minimal impact on groundwater. Intensive monitoring of the burial site has shown only limited migration of specific radionuclides from the waste emplacements; most of the migration is tritium, a radionuclide of low biological hazard. Traces of alpha and beta-gamma emitters, and less than 1% of the buried tritium are in groundwater after 30 years of burial ground operation. Traces of alpha and beta-gamma emitters have moved short distances (up to a few hundred feet) from the point of entry. Small amounts of tritium have migrated about 1000 ft to outcrop at an annual rate of about 0.5% of the quantity (Table 2.3-10) in the saturated zone under the burial ground.

Travel of groundwater along flow paths that dip as deep as the Congaree Formation is slow because of the low hydraulic conductivity of this clay. Even though, theoretically, the potential exists for radionuclides to enter the Congaree, water entering the burial ground when its use first started has not yet reached the Congaree Formation.

The head reversal at the Congaree Formation makes contamination of the Tuscaloosa Formation from this source impossible under the present hydrologic regime.

The incisions by Upper Three Runs Creek and Four Mile Creek create a groundwater island in this area, and migration of radionuclides offsite through the shallow sediments is not possible. Water in the deeper sediments moves toward the Savannah River and discharges there.

2.3.5 Remedial Action

The F-Area effluent stream was a small, wet weather, intermittent stream prior to construction of F Area. After construction of F Area it carried storm run-off from most of the paved surfaces in F Area plus a continuous flow of cooling water from the process.

This flow of additional water deepened the stream bed and shortened the subsurface flow path from the burial ground by about 50%. The erosion of the effluent channel had advanced the natural outcrop zone toward the burial ground by about 1000 ft, causing early release of tritium to the surface stream. This condition was detected in 1978. Repair of the eroded stream bed and restoration of the natural flow path was started in 1979. Continued erosion would have further shortened the flow path and increased the potential for migration of nuclides other than tritium in the future.

The repair work proceeded in two stages: in the first stage, completed in May 1980, an engineered channel 2100 ft long and 30 ft wide was constructed parallel to the eroded effluent bed, as shown in Figure 2.3-20. The base of the new channel was hardened with graded rock to inhibit erosion and preclude return of the original problem. The old effluent channel, now isolated, was repaired in two steps. The upper 900 ft, where the stream bed was higher than the water table, was simply filled with sandy clay from the contiguous ground surface. Greater care was taken with the lower 1000 ft. Stream banks were widened and the bed base, enlarged to six feet, was excavated to several feet below the eroded surface. Selected clay of low permeability was laid into the base of the excavation in successive one-foot increments. After each addition, the clay was compacted to 85% of maximum density with a vibratory compactor. The final two feet of the excavation was completed with top soil, which was graded and planted with grass seed for erosion control. Repair was completed in November 1980.

The effect of the repair work was determined by recoring in the early months of 1982 at the original core sites down the flow path. Core sites are shown in Figure 2.3-21. Figure 2.3-22 shows the resulting cross-section and can be compared with Figure 2.3-18. The foreshortening of the flow path has diminished, and the flow is flattening toward the normal outcrop.

References for Section 2.3

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TABLE 2.3-1

Radionuclide Inventory from 1953 through 1982 for Waste Buried in Trenches at SRP Burial Grounds

Radionuclide Buried	Volume (M^3)	Amount Buried (Ci)	
		Original	Decayed
^{3}H	19,500	3,900,000	1,900,000
Fission products*	235,500	710,000	20,000
Induced activity	27,500	3,400,000	460,000
^{60}Co	3,700	1,100,000	540,000
^{137}Cs**	1,300	2,300	2,000
^{90}Sr**	30	1,800	1,500
^{238}Pu	12,000	3,900	3,400
^{239}Pu	20,300	600	600
^{244}Cm	7,300	5,600	3,500
Other α emitters	46,000	59	56

* Mixed fission products containing ^{137}Cs and ^{90}Sr, estimated to be 2% each of the total before decay.

** ^{137}Cs and ^{90}Sr in waste other than fission product waste. Total amounts after decay estimated as 10,000 Ci each.

TABLE 2.3-2

Gross Alpha Concentration in 643-G Grid Wells

Well	Alpha (pCi/L) 1980	1981	1982
A-1	<0.5	<0.5	<0.5
A-3	<0.5	1	1
A-5	4	5	2
A-7	3	3	2
A-9	1	1	1
A-11	<0.5	2	4
A-19	1	6	1
A-21	1	<0.5	<0.5
A-23	<0.5	2	1
A-32	2	2	1
A-34	1	2	1
A-36	1	1	1
C-1	<0.5	1	1
C-3	1	2	1
C-5	1	2	2
C-7	1	1	1
C-9	1	1	1
C-11	1	1	1
C-13	3	5	4
C-15	8	7	5
C-17	12	7	4
C-19	1	1	1
C-21	2	3	2
C-23	1	1	1
C-30	2	2	3
C-32	2	2	2
C-34	1	1	3
C-36	1	<0.5	1
E-1	2	1	3
E-3	1	1	1
E-5	2	1	1
E-7	1	2	1
E-9	1	<0.5	<0.5
E-13	1	3	<0.5
E-15	2	2	-
E-17	<0.5	3	1
E-19	<0.5	1	1
E-21	2	1	1
E-23	2	1	2
E-30	1	1	1
E-32	4	3	2
E-34	1	<0.5	1
E-36	2	3	1
G-1	<0.5	1	1
G-3	2	2	3
G-5	1	4	2
G-7	1	1	2
G-9	2	4	4
G-13	4	5	5
G-15	1	1	1
G-17	1	1	1
G-19	<0.5	1	1
G-21	33	63	255
G-23	<0.5	<0.5	<0.5
G-28	1	1	1
G-30	1	1	1
G-32	2	1	4
G-34	1	2	1
G-36	<0.5	<0.5	2
I-1	6	7	6
I-3	-	-	-
I-5	1	1	1
I-7	<0.5	1	<0.5
I-9	<0.5	1	1
I-13	18	35	20
I-15	3	5	10
I-17	6	7	6

TABLE 2.3-3

Gross Nonvolatile Beta Concentration in 643-G Grid Wells

Well	Beta (pCi/L) 1980	1981	1982
A-1	10	0*	2*
A-3	66	61	51
A-5	7	9	23
A-7	3*	17	30
A-9	9	6*	0*
A-11	3*	7	20
A-19	4*	36	12
A-21	5*	3*	1*
A-23	11	7	0*
A-32	2*	10	15
A-34	9	15	20
A-36	2*	8	5*
C-1	28	21	42
C-3	17	12	12
C-5	4*	7	19
C-7	11	6*	23
C-9	5*	4*	5*
C-11	2*	5*	6*
C-13	7	28	36
C-15	17	26	20
C-17	2*	6*	14
C-19	6*	2*	1*
C-21	4*	23	20
C-23	2*	1*	2*
C-30	5*	26	7
C-32	9	11	6*
C-34	42	112	49
C-36	2*	3*	5*
E-1	17	13	11
E-3	21	30	15
E-5	7	14	16
E-7	5*	19	23
E-9	3*	0*	1*
E-13	5*	16	3*

Well	Beta (pCi/L) 1980	1981	1982
E-15	74	25	-
E-17	22	2*	38
E-19	9	29	22
E-21	3*	4*	5*
E-23	0*	9	4*
E-30	8	40	10
E-32	37	12	30
E-34	12	23	26
E-36	5*	17	9
G-1	0*	3*	11
G-3	0*	8	19
G-5	1*	9	21
G-7	15	11	8
G-9	7	24	31
G-13	14	37	20
G-15	1*	0*	3*
G-17	13	24	25
G-19	2*	5*	6*
G-21	452	3226	9128
G-23	4*	3*	2*
G-28	4*	3*	3*
G-30	4*	12	11
G-32	14	14	3
G-34	19	4*	7
G-36	1*	0*	2*
I-1	36	37	50
I-3	-	-	-
I-5	18	4*	20
I-7	2*	9	24
I-9	2*	6*	8
I-13	130	221	157
I-15	26	30	26
I-17	33	18	16

* Less than nominal lower limit of detection (7 pCi/L).

TABLE 2.3-4

Gross Alpha and Gross Nonvolatile Beta Concentration in 643-7G Grid Wells

Well	Alpha (pCi/L) 1981	Alpha (pCi/L) 1982	Beta (pCi/L) 1981	Beta (pCi/L) 1982
22.04	11	2	60	32
22.06	3	4	20	43
22.08	3	3	8	11
22.10	2	3	10	20
22.12	4	2	12	6*
22.16	3	4	31	18
22.18	8	9	44	16
22.20	1	1	17	2*
22.22	1	<0.5	6*	3*
24.02	3	2	10	17
24.04	2	3	26	3*
24.06	1	2	2*	14
24.08	1	2	10	18
24.10	2	2	16	18
24.20	2	5	1*	36
24.22	5	2	22	10
26.20	4	5	11	24
26.22	5	3	0*	9
28.18	4	3	14	33
28.20	2	2	46	73
28.22	7	8	34	20
28.24	<0.5	2	1*	6*

* Less than nominal lower limit of detection (7 pCi/L).

TABLE 2.3-5

Gross Alpha and Gross Nonvolatile Beta Concentration in Burial Ground Perimeter Wells

Well	Alpha (pCi/L) 1980	Alpha (pCi/L) 1981	Beta (pCi/L) 1980	Beta (pCi/L) 1981
BG26	1	2	17	13
BG27	<0.5	1	4*	5*
BG28	1	2	2*	11
BG29	1	1	0*	9
BG30	1	1	10	5*
BG31	1	2	4*	7
BG32	1	2	3*	6*
BG33	1	2	1*	7
BG34	1	1	4*	9
BG35	1	1	3*	4*
BG36	1	1	0*	1*
BG37	1	3	6*	14
BG38	1	1	5*	0*
BG39	2	3	10	19
BG40	1	1	2*	5*
BG41	1	1	0*	3
BG42	8	4	29	25
BG43	1	1	1*	4*
BG51	<0.5	1	3*	2*
BG52	<0.5	1	3*	11
BG53	<0.5	1	2*	4*
BG54	1	1	3*	4*
BG55	2	4	9	23
BG56	1	2	6*	7
BG57	<0.5	1	1*	2*
BG58	1	2	5*	12
BG59	1	<0.5	3*	1*
BG60	2	1	3*	7
BG61	1	1	5*	3*
BG62	<0.5	1	6*	6*
BG63	<0.5	1	1*	7
BG64	<0.5	1	4*	10
BG65	<0.5	1	0*	7
BG66	<0.5	1	2*	5*
BG67	1	1	1*	3*

* Less than nominal lower limit of detection (7 pCi/L).

TABLE 2.3-6

Radionuclide Content of Groundwater Wells at SRP Burial Ground

Radionuclide	Concentration (pCi/L) Average	Range	Number of Wells	Detection Limit (pCi/L)
^{60}Co	13	-	1 of 20	8
^{90}Sr*	19	7-30	4 of 11	6
^{137}Cs	12	10-16	3 of 20	8
^{238}Pu	5	2-17	8 of 12	1
^{239}Pu	3	2-4	3 of 12	1
Gamma**	-	-	0 of 20	8

* In addition, one well contained 1600 pCi/L of ^{90}Sr.

** No gamma emitters other than ^{60}Co and ^{137}Cs were observed. Tritium was present in each well (see Table 2.3-8).

TABLE 2.3-7

Chemical Composition of Groundwater from 643-G Grid Wells

Component*	Average**	Range**
Sodium	6	2-22
Potassium	2	0.2-10
Magnesium	1	0-8
Calcium	8	0.09-45
Strontium	0.09	0-0.5
Barium	0.2	0-1
Iron	0.05	0-0.8
Silicon	4	0.08-7
Fluoride	0.1	0-0.4
Chloride	4	0.9-16
Nitrate	10	0-28
Sulfate	2	0-16
Phosphate	<0.06	0-0.2
Dissolved oxygen	6	1.5-9
Carbon (inorganic)	11	0-49
Carbon (organic)	4	0-21
pH	5.4	2.9-7.2
Eh	523	345-683
Conductivity	64	15-270

* From measurements of 63 groundwater wells within 643-G; outlying data points (0 to 5 for each component) are omitted from the average and range.

** Units: mg/L, except for pH, Eh (mV versus normal hydrogen electrode), and specific conductivity (μmho/cm).

TABLE 2.3-8

Tritium Concentration in 643-G Grid Wells

Well	Tritium (µCi/L) 1980	1981	1982
A-1	11	4	7
A-3	39	32	26
A-5	235	121	130
A-7	8	4	9
A-9	0.1	0.03	0.1
A-11	0.2	0.09	0.3
A-19	0.1	0.1	0.2
A-21	0.07	0.1	0.1
A-23	0.3	0.4	0.2
A-32	0.1	0.09	0.06
A-34	0.06	0.06	0.06
A-36	0.4	0.3	0.5
C-1	22	10	2
C-3	999	619	296
C-5	213	70	166
C-7	243	334	127
C-9	15	10	7
C-11	0.03	0.02	0.03
C-13	0.04	0.04	0.04
C-15	0.04	0.03	0.03
C-17	0.03	0.03	0.03
C-19	0.04	0.04	0.04
C-21	8	5	5
C-23	25	50	44
C-30	0.3	0.2	0.1
C-32	3	0.7	3
C-34	0.3	0.2	0.1
C-36	0.6	0.3	0.9
E-1	1	2	2
E-3	40	58	45
E-5	12	48	42
E-7	3	12	5
E-9	0.03	0.1	0.02
E-13	0.02	0.02	0.04

Well	Tritium (µCi/L) 1980	1981	1982
E-15	0.06	0.05	-
E-17	0.06	-	0.02
E-19	0.6	0.5	0.4
E-21	0.03	0.03	0.2
E-23	2	0.2	0.1
E-30	0.1	0.1	0.1
E-32	0.5	0.3	3
E-34	0.7	0.4	0.7
E-36	0.7	0.5	2
G-1	0.5	8	3
G-3	0.8	1	1
G-5	1	0.9	0.9
G-7	27	30	17
G-9	35	27	40
G-13	402	249	117
G-15	6	17	13
G-17	10	7	5
G-19	0.08	0.06	0.06
G-21	325	292	94
G-23	6	1	1
G-28	0.06	0.05	0.3
G-30	5	5	3
G-32	214	224	175
G-34	2991	3290	2189
G-36	0.9	0.8	3
I-1	38	66	66
I-3	-	-	-
I-5	3	3	2
I-7	94	162	90
I-9	2	2	4
I-13	1	3	1
I-15	0.1	0.2	0.1
I-17	0.1	0.1	0.05

TABLE 2.3-9

Tritium Concentration in 643-7G Grid Wells

Well	Tritium (μCi/L) 1981	1982
22.04	0.09	0.04
22.06	2	10
22.08	5	13
22.10	0.1	0.4
22.12	0.02	0.05
22.16	0.02	0.03
22.18	0.03	0.03
22.20	0.03	0.02
22.22	0.02	0.02
24.02	0.02	0.05
24.04	0.04	0.2
24.06	0.5	0.7
24.08	0.03	0.09
24.10	0.02	0.02
24.20	0.1	0.2
24.22	0.05	0.02
26.20	0.08	1
26.22	0.05	0.5
28.18	0.02	0.08
28.20	0.05	0.5
28.22	4	34
28.24	-	0.02

TABLE 2.3-10

Calculated Tritium Inventory in Burial Ground Groundwater

	Average Concentration (μCi/L)	Tritium in 643-G Plume (Ci)
1974	31.6	13,300
1975	59.8	25,200
1976	58.0	24,400
1977	59.0	24,800
1978	90.4	38,000
1979	65.8	27,700
1980	91.6	38,600
1981	88.8	37,400
1982	57.7	24,300

TABLE 2.3-11

Tritium Concentration in Burial Ground Perimeter Wells

Well	Tritium (μCi/L) 1980	1981
BG26	0.02	0.02
BG27	0.04	0.04
BG28	0.04	0.03
BG29	0.06	0.05
BG30	0.06	0.04
BG31	0.02	0.02
BG32	<0.4	0.02
BG33	<0.4	0.02
BG34	<0.5	0.01
BG35	<0.5	0.07
BG36	<0.5	0.02
BG37	0.02	0.02
BG38	0.02	0.02
BG39	0.02	0.02
BG40	0.01	0.01
BG41	0.02	0.01
BG42	0.03	0.03
BG43	0.03	0.04
BG51	0.03	0.03
BG52	0.03	0.02
BG53	0.03	0.02
BG54	2	0.5
BG55	1	1
BG56	4	4
BG57	3	3
BG58	0.02	0.04
BG59	0.06	0.05
BG60	0.05	0.04
BG61	0.04	0.03
BG62	0.04	0.03
BG63	0.06	0.03
BG64	0.05	0.05
BG65	0.04	0.05
BG66	0.07	0.06
BG67	0.08	0.09

TABLE 2.3-12

Tritium Concentration in Cluster Wells Along South 643-G Fence

Well	Tritium (μCi/L) 1980	1981	1982
BGC1 A	0.01	0.01	0.02
BGC1 B	0.05	0.04	0.03
BGC1 C	0.05	0.07	0.05
BGC1 D	0.06	0.05	0.04
BGC1 E	0.04	0.04	0.04
BGC2 A	0.02	0.02	0.01
BGC2 B	0.1	0.02	0.1
BGC2 C	3	4	3
BGC2 D	0.2	0.1	0.2
BGC2 E	0.03	0.02	0.06
BGC3 A	1	0.9	1
BGC3 B	0.8	2	0.5
BGC3 C	71	468	441
BGC3 D	0.7	0.4	1
BGC3 E	6	5	4
BGC3 F	8	4	8
BGC3 G	0.3	0.2	0.3
BGC3 H	12	0.2	2

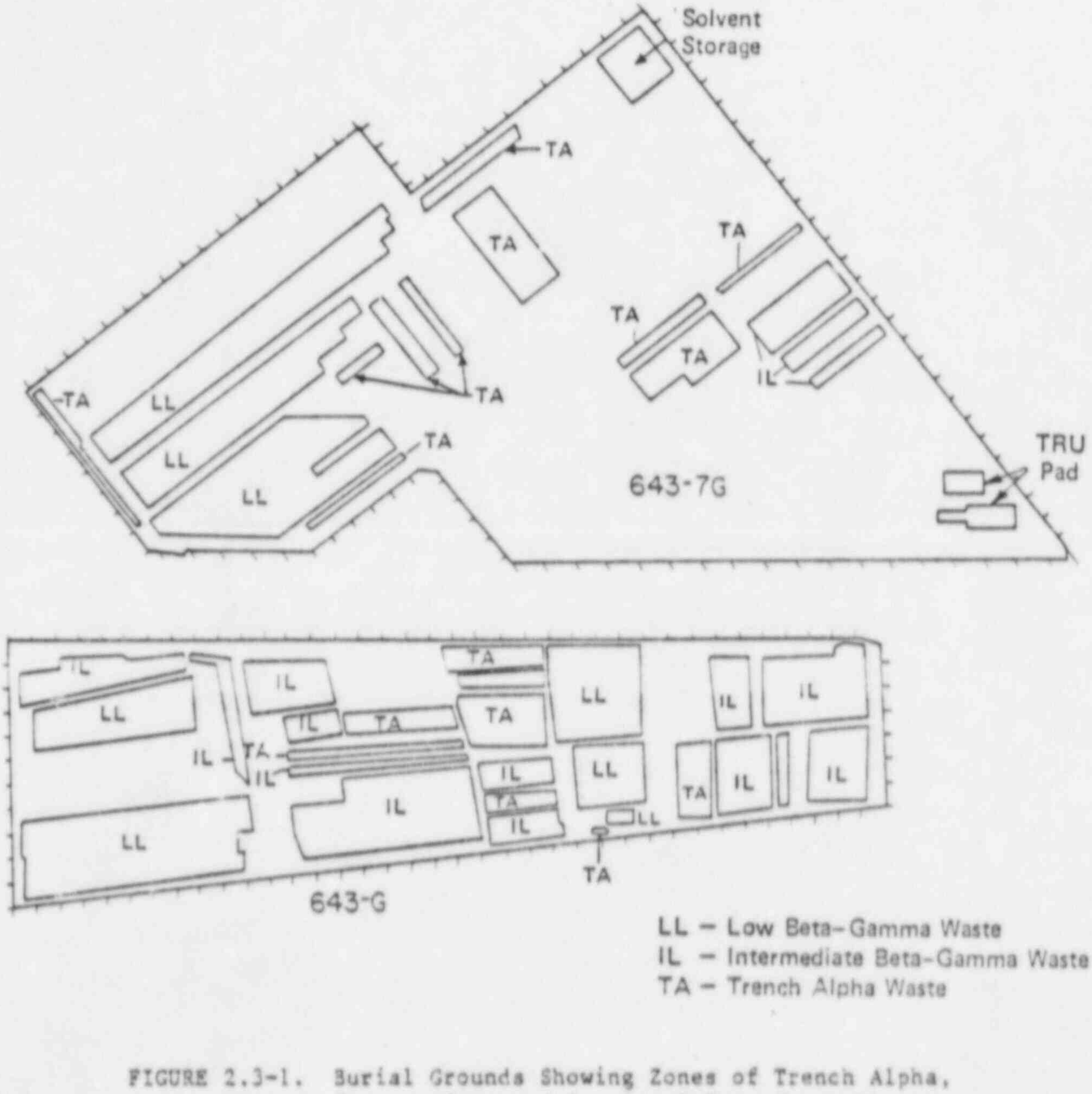

FIGURE 2.3-1. Burial Grounds Showing Zones of Trench Alpha, Intermediate and Low-Level Beta-Gamma Waste, and Solvent Storage

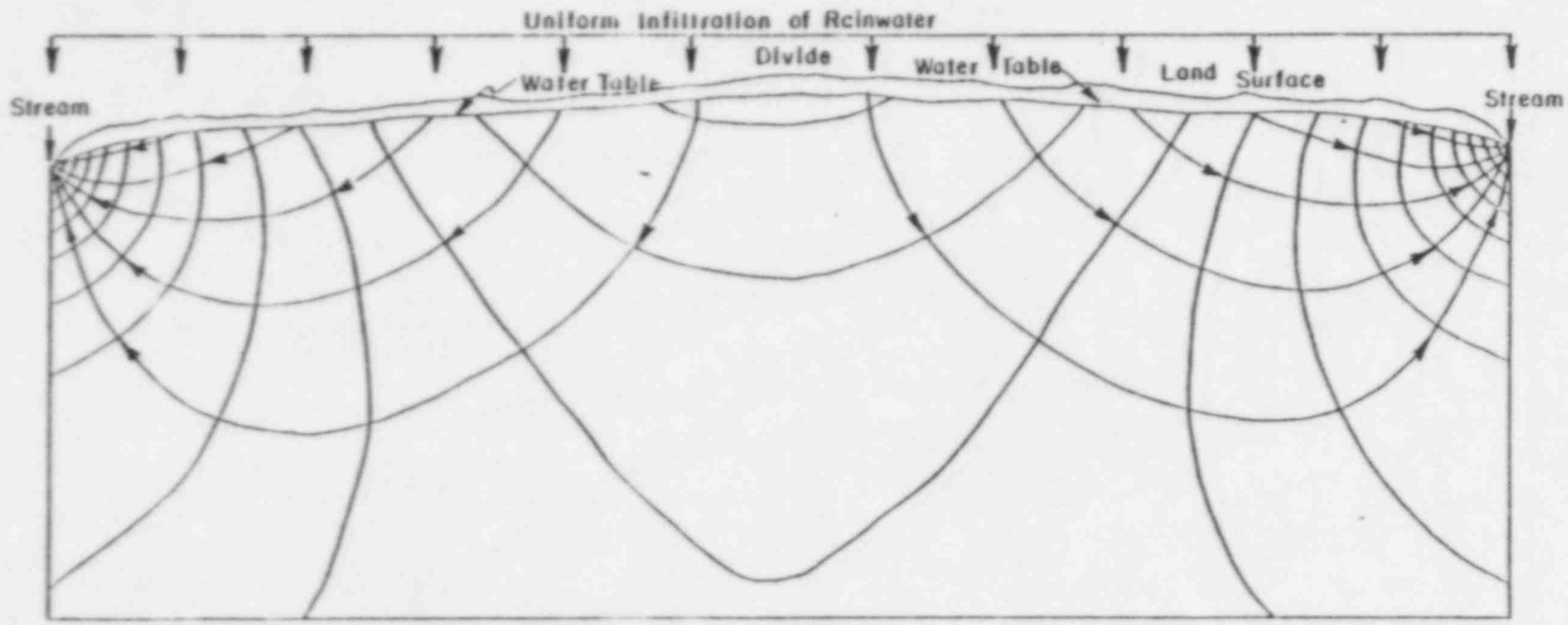

FIGURE 2.3-2. Groundwater Circulation in an Interstream Area Established in Homogeneous Sediments

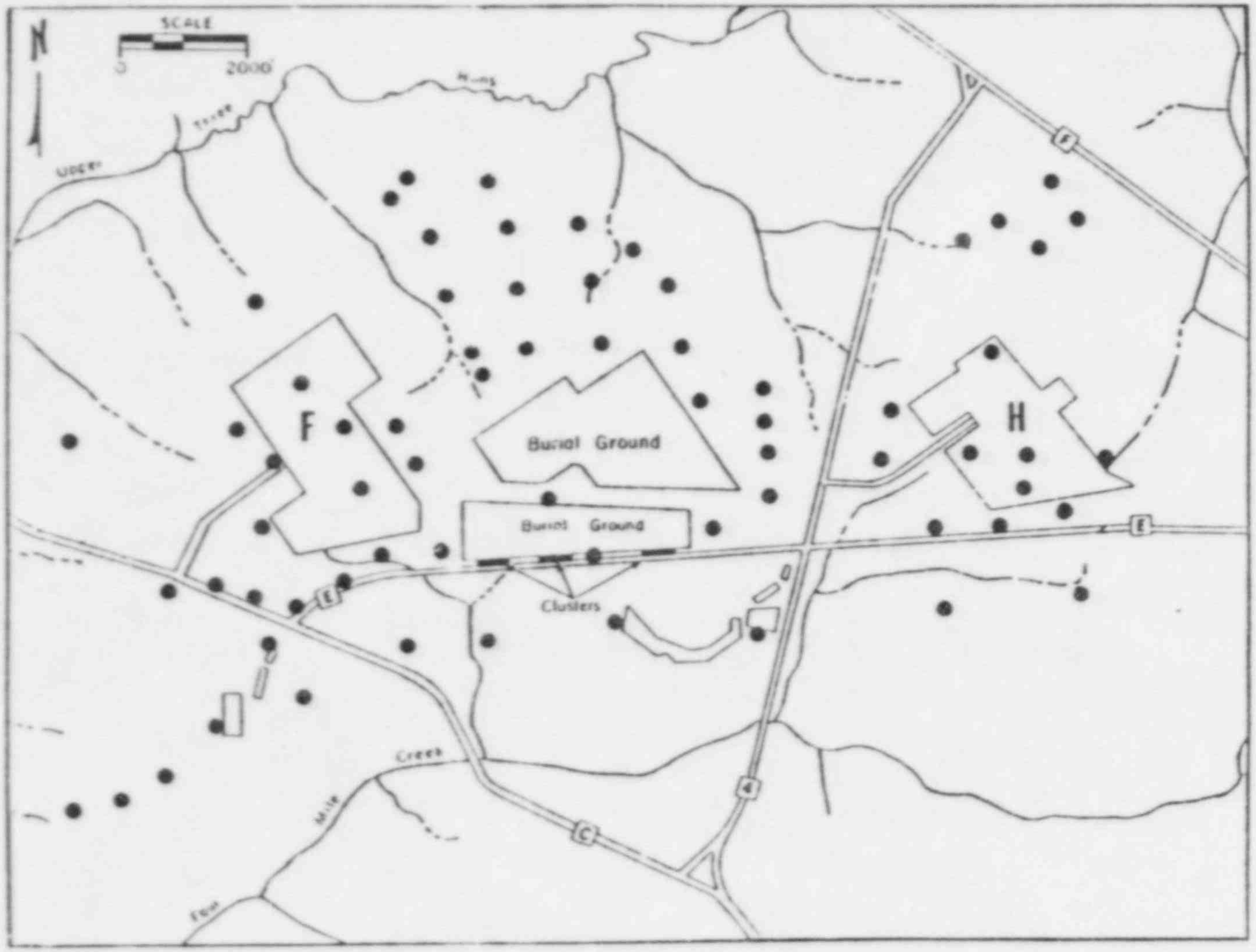

FIGURE 2.3-3 Groundwater Observation Wells in the Vicinity of the Radioactive Waste Burial Grounds

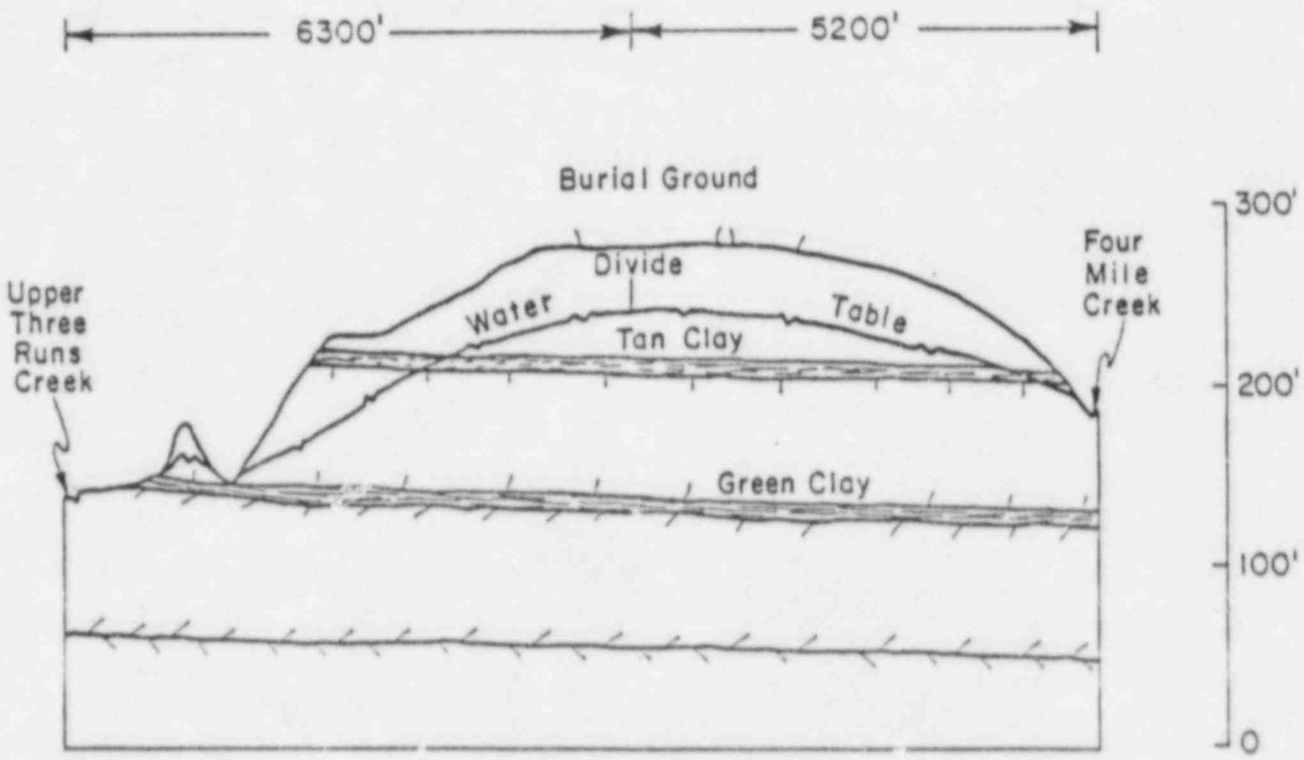

FIGURE 2.3-4. Cross Section Through Burial Grounds Showing Displacement of Water Table Divide Toward Four Mile Creek

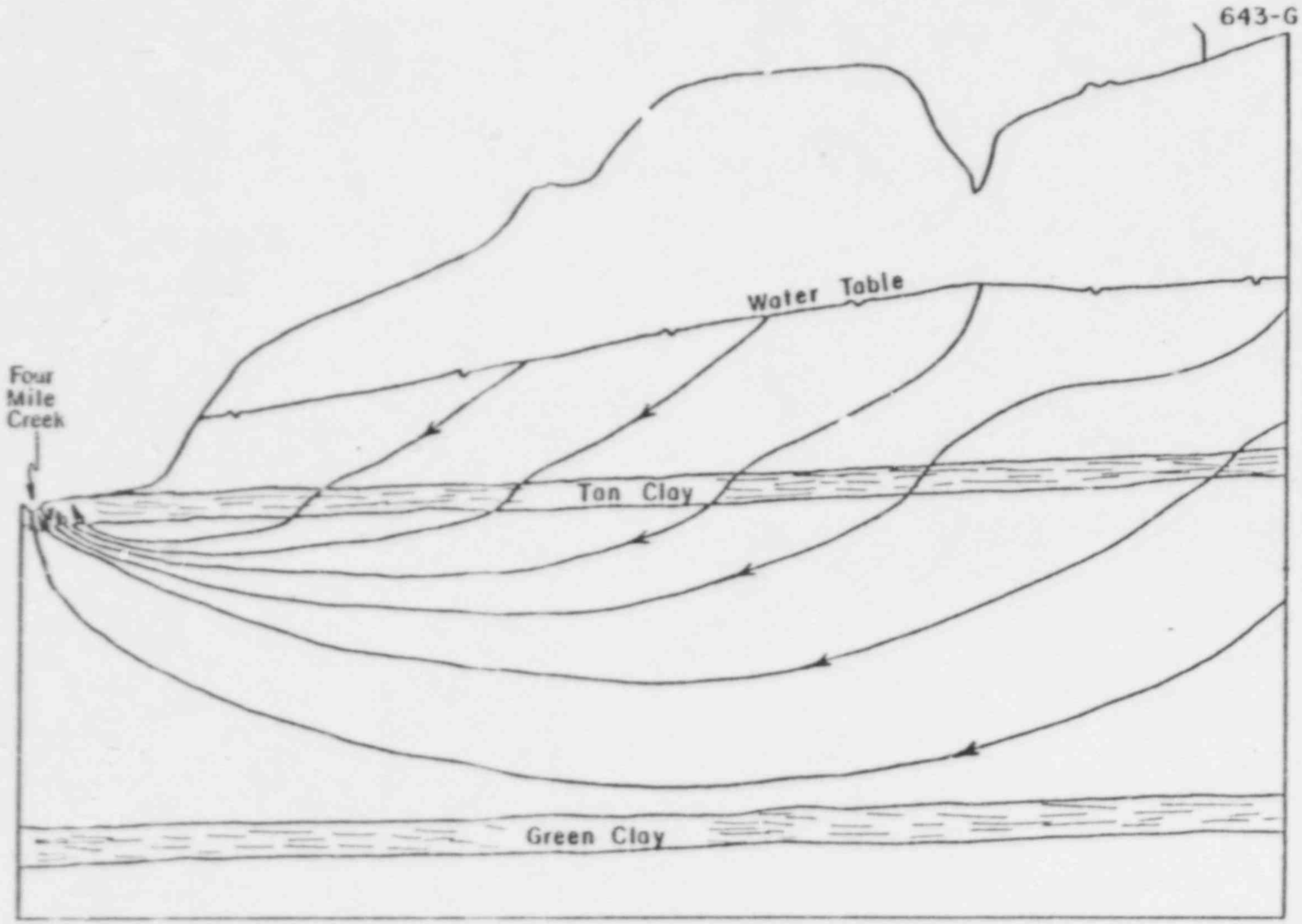

FIGURE 2.3-5. Cross Section From 643-G to Four Mile Creek Showing the Effect of Low Permeability Clay Beds on Flow Paths

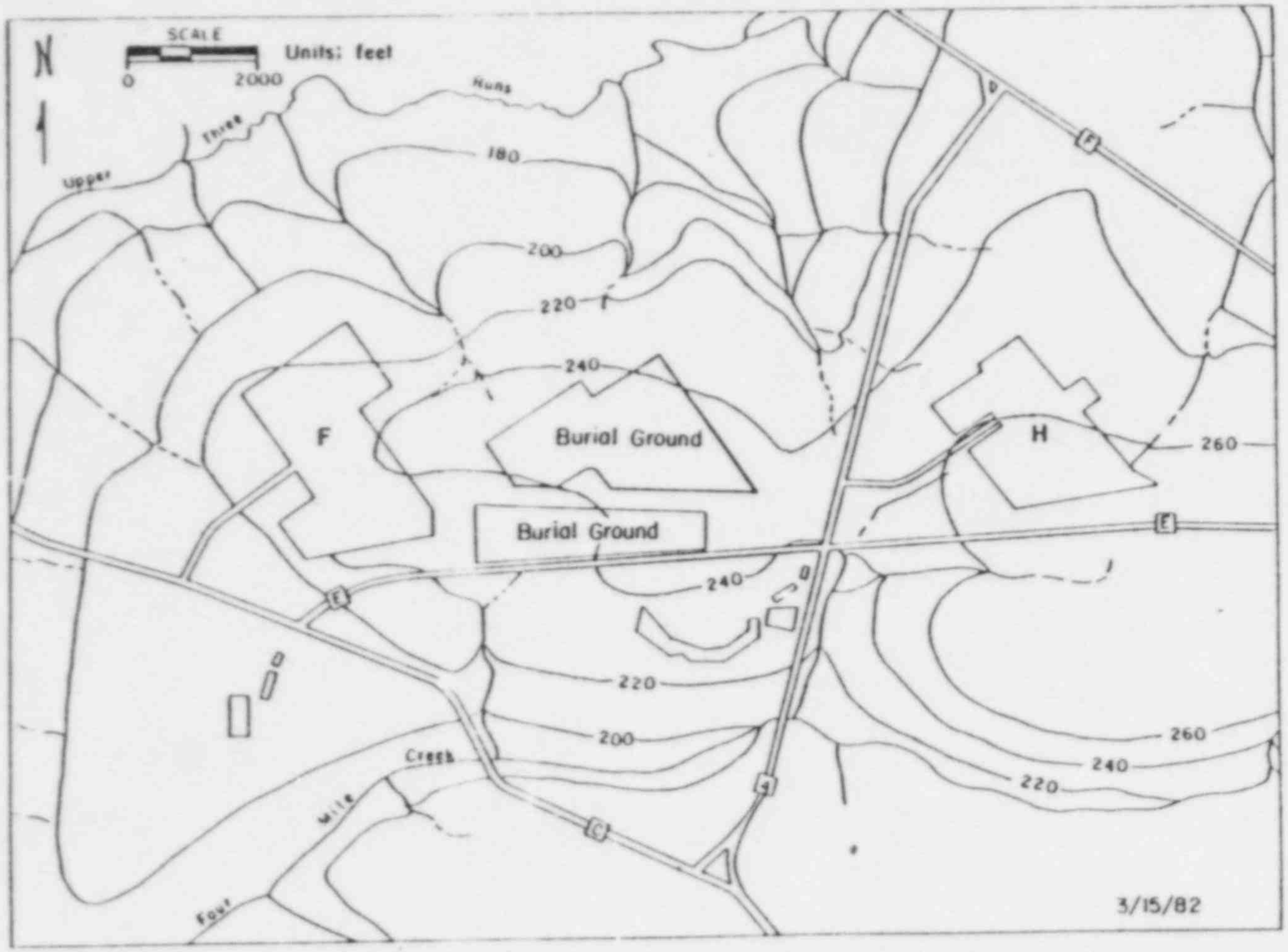

FIGURE 2.3-6 Water Table in the Vicinity of the Radioactive Waste Burial Grounds

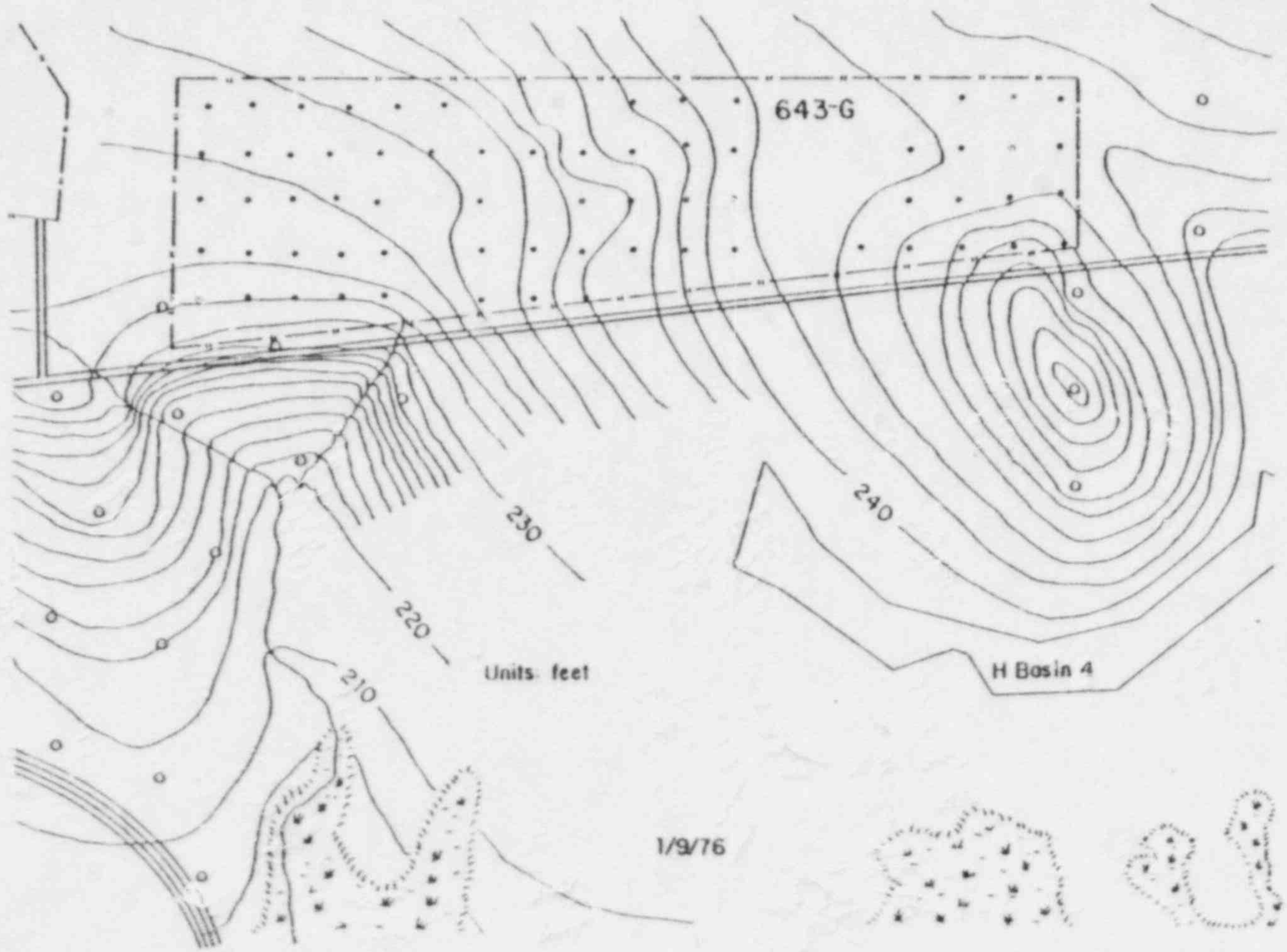

FIGURE 2.3-7. 643-G Water Table Map Detail

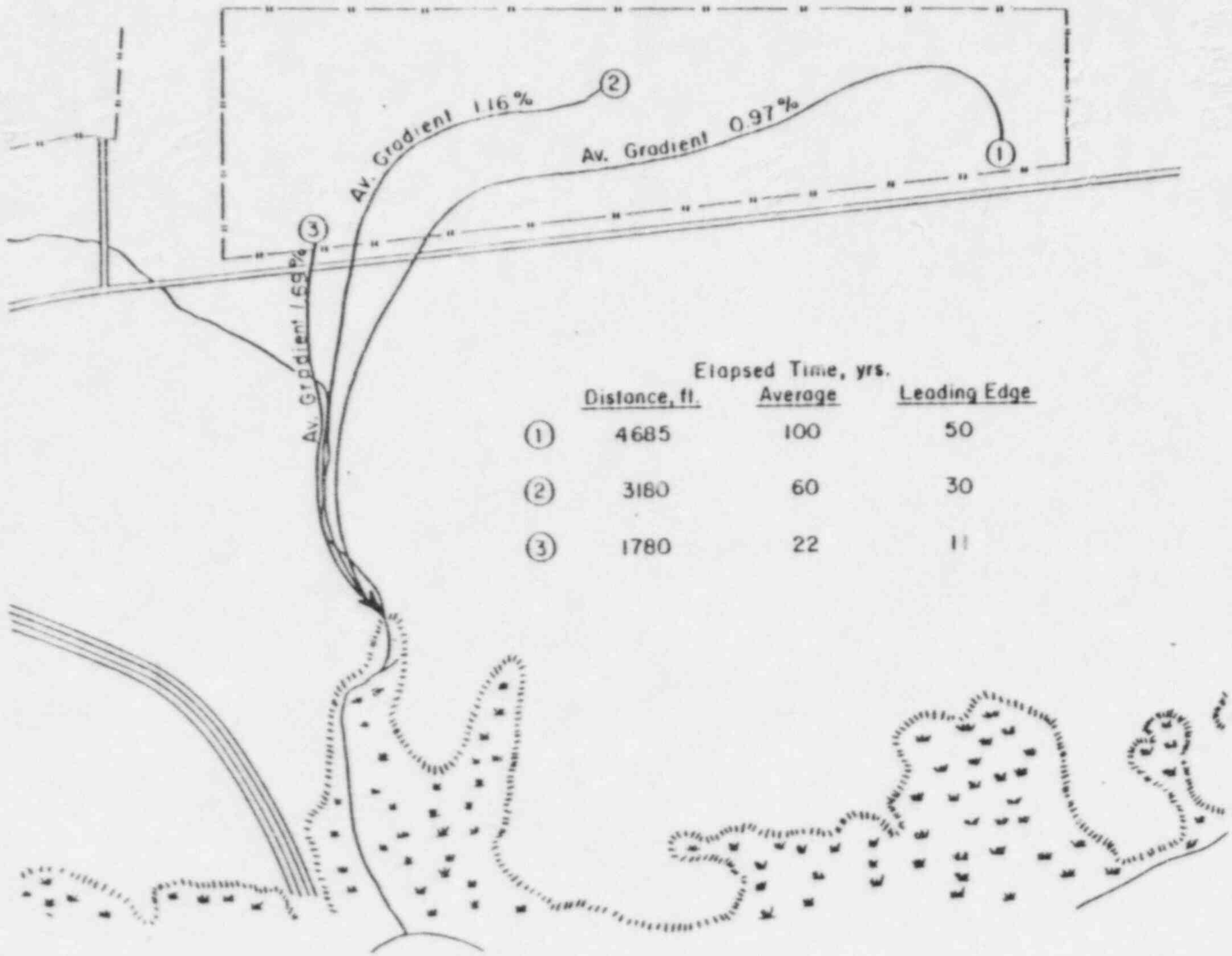

FIGURE 2.3-8. Time for Water and Tritium to Travel 643-G Flow Paths

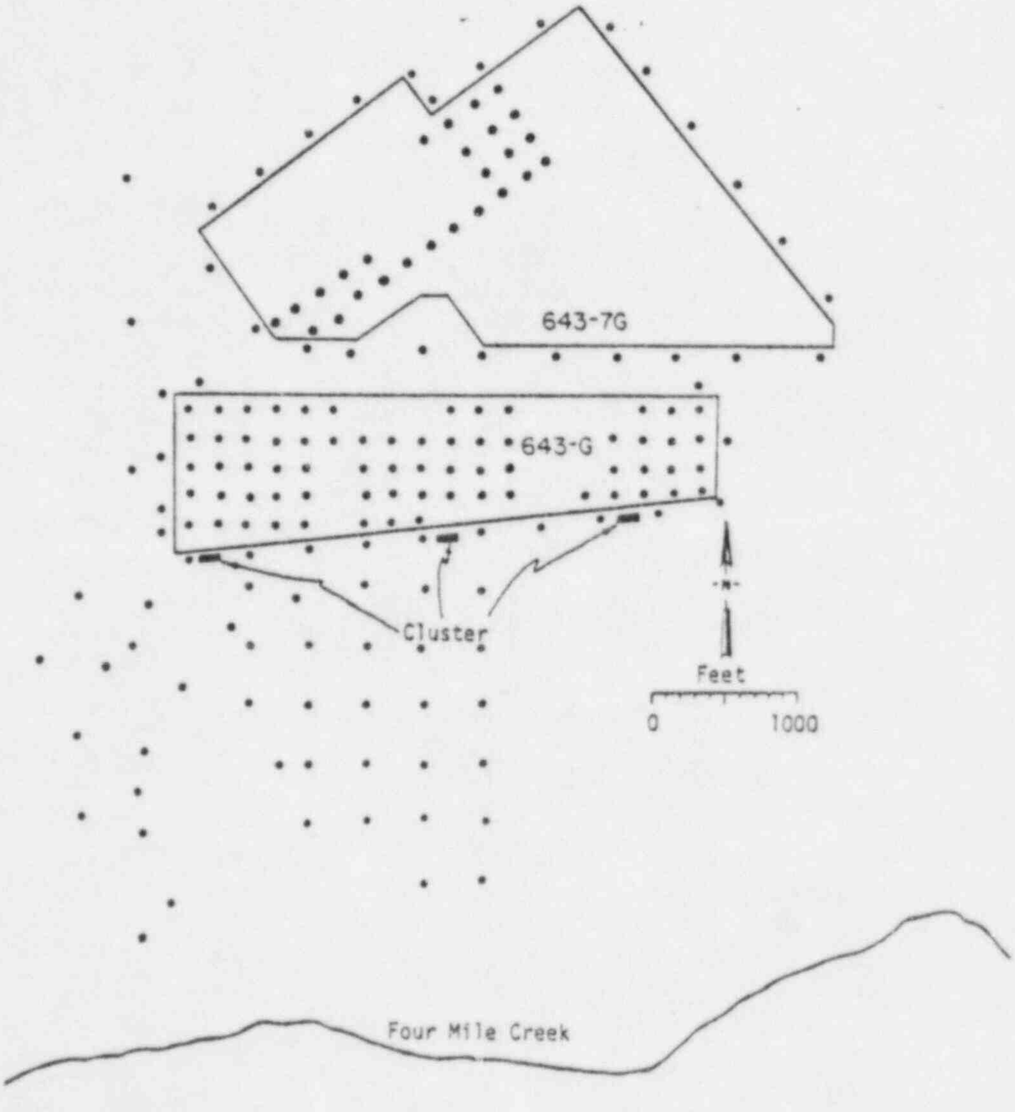

FIGURE 2.3-9. Burial Ground Monitoring Wells

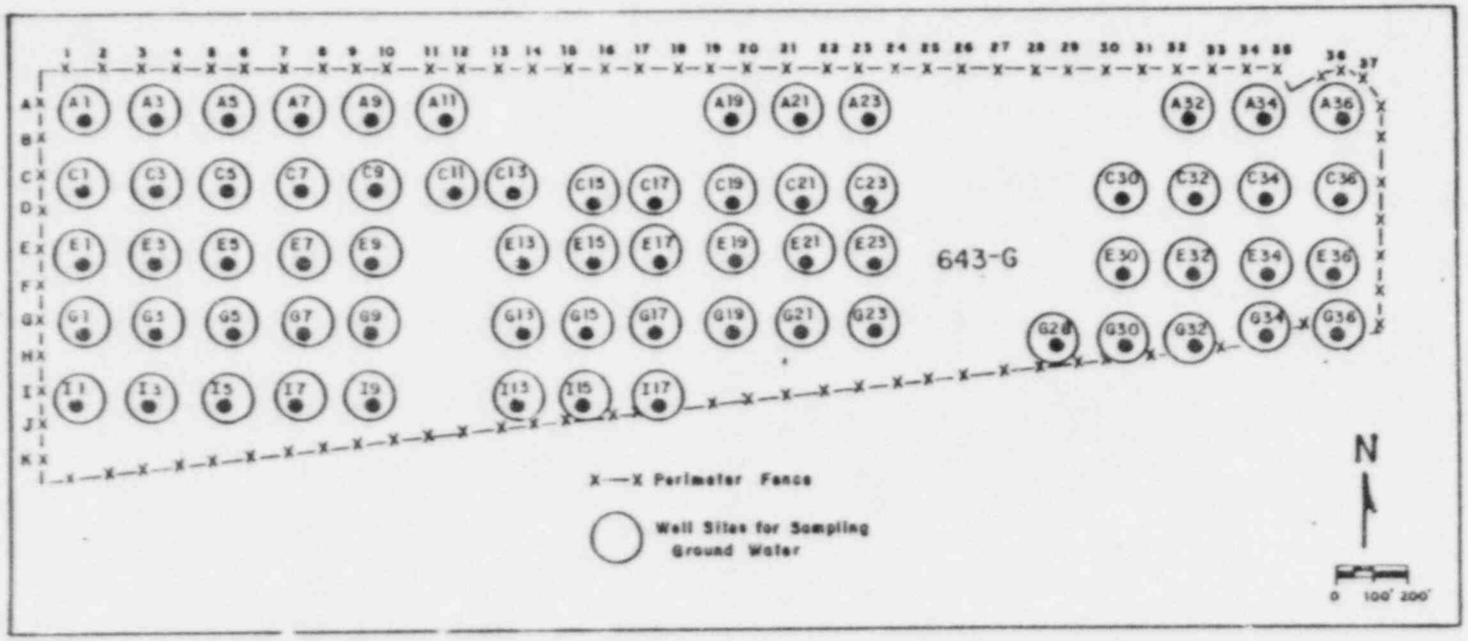

FIGURE 2.3-10. Groundwater Monitoring Well Locations in 643-G Radioactive Waste Burial Ground

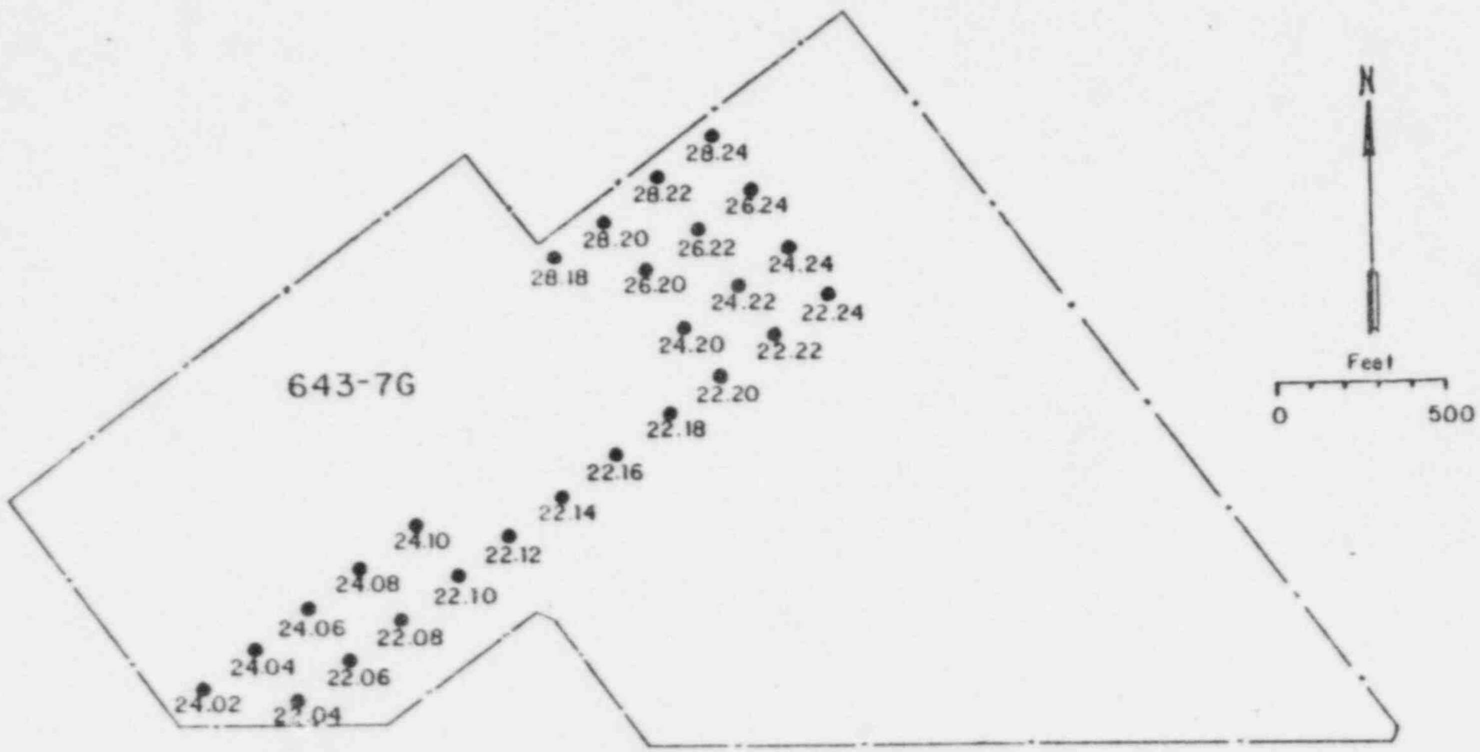

FIGURE 2.3-11. Groundwater Monitoring Well Locations in 643-7G Radioactive Waste Burial Ground

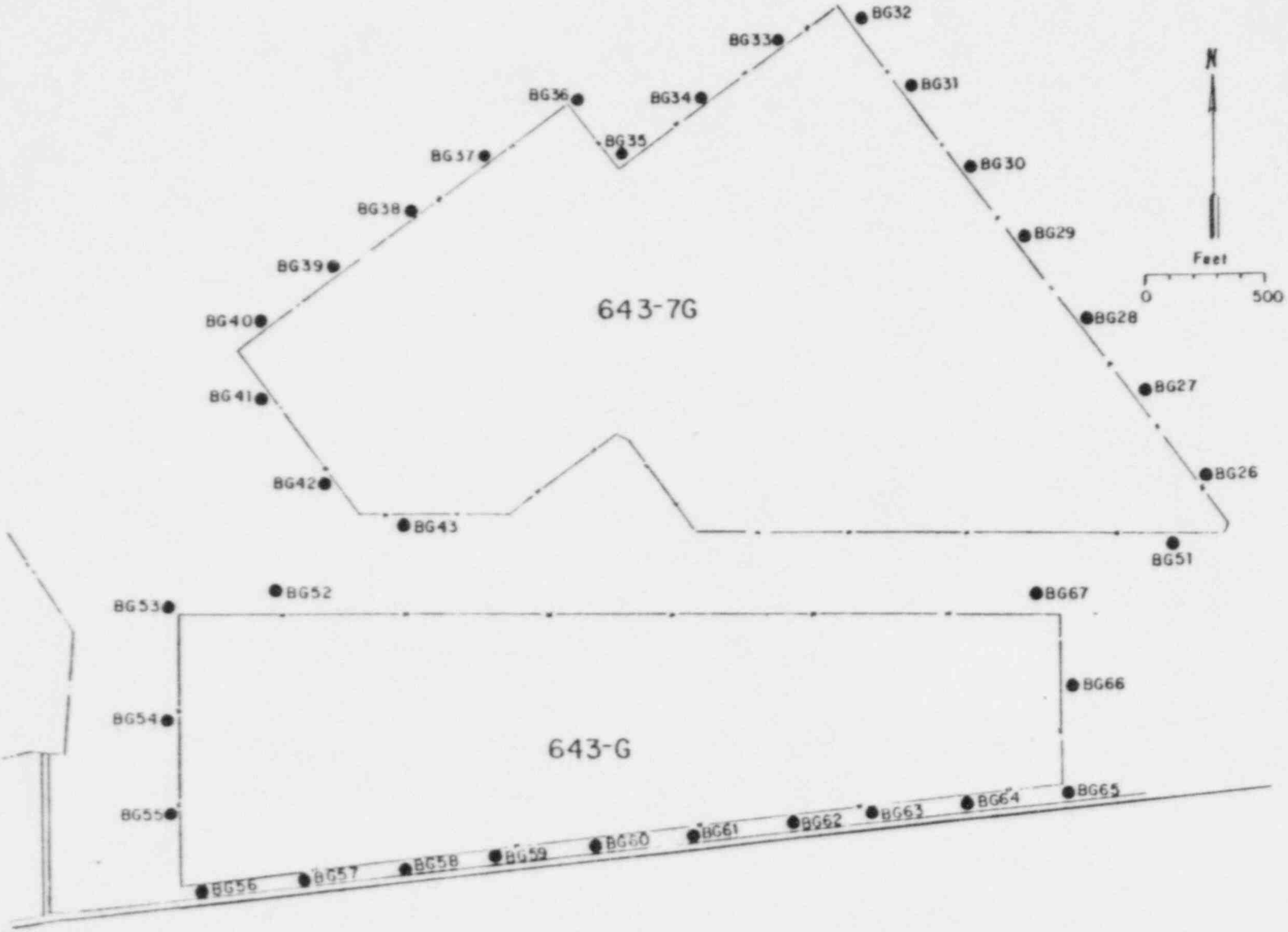

FIGURE 2.3-12. Groundwater Monitoring Well Locations Around the Perimeter of the Radioactive Waste Burial Grounds

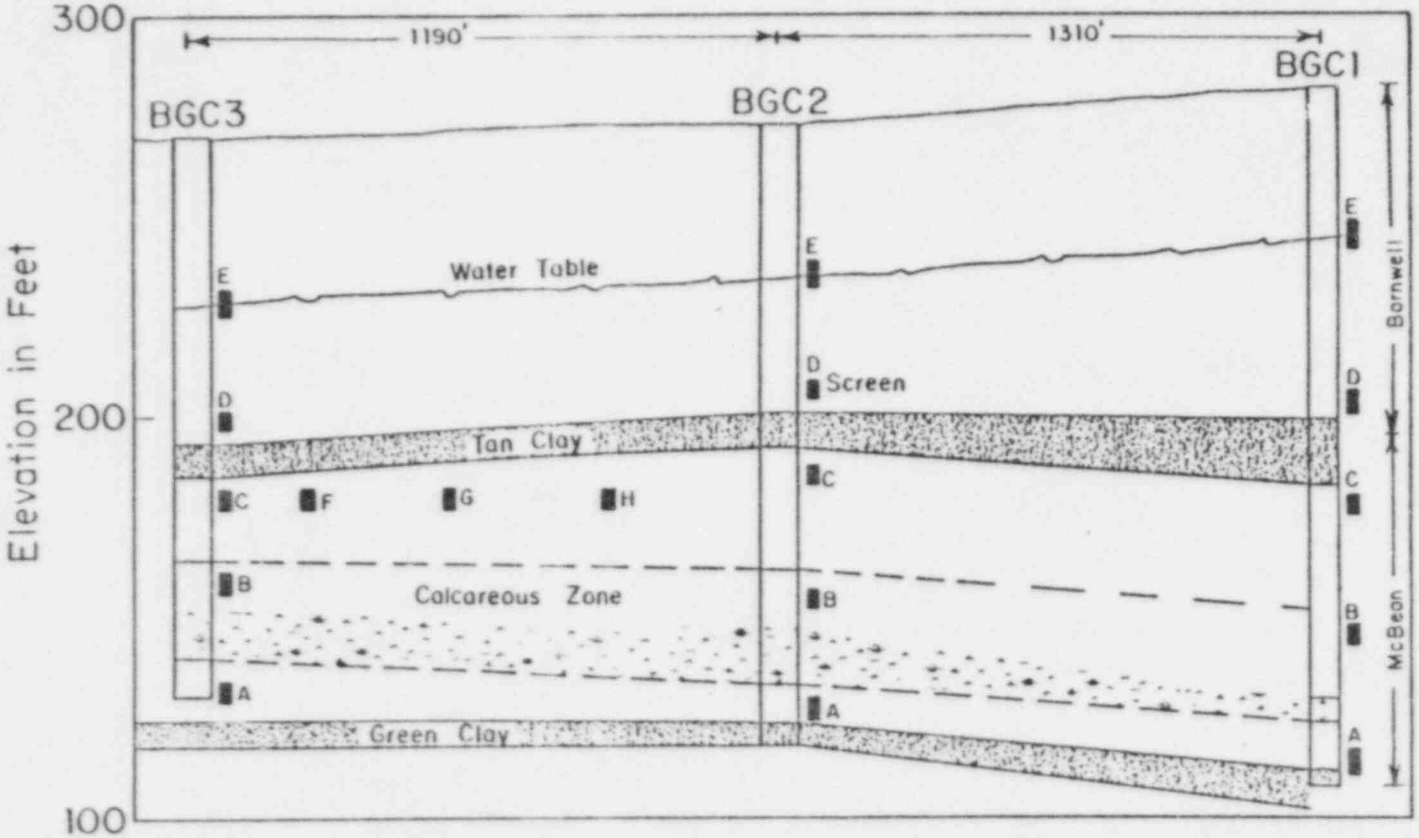

FIGURE 2.3-13. Cross Section Along South 643-G Fence, Showing Hydrostratigraphic Units, Water Table, and Screen Placement in Cluster Wells

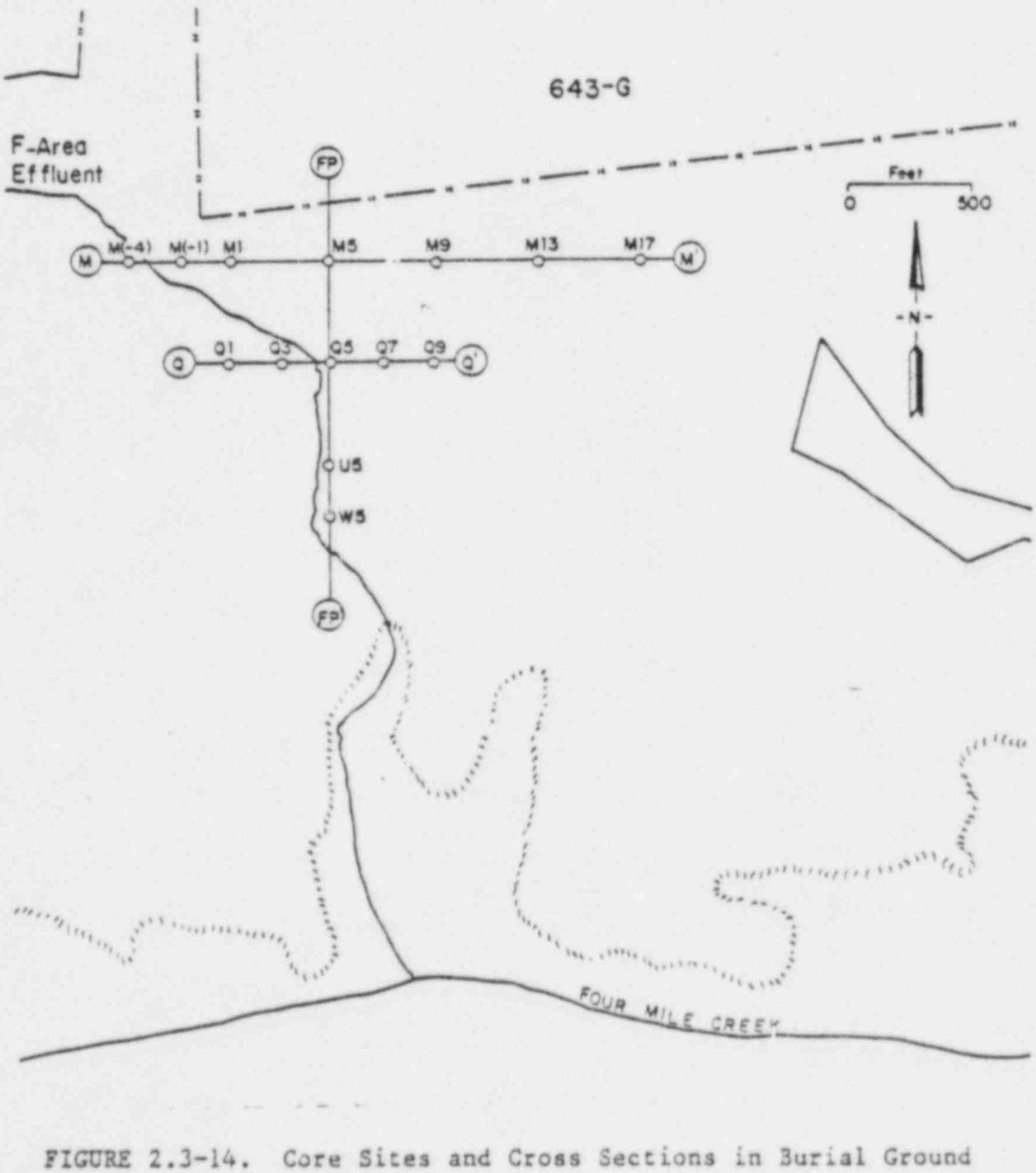

FIGURE 2.3-14. Core Sites and Cross Sections in Burial Ground Flow Path

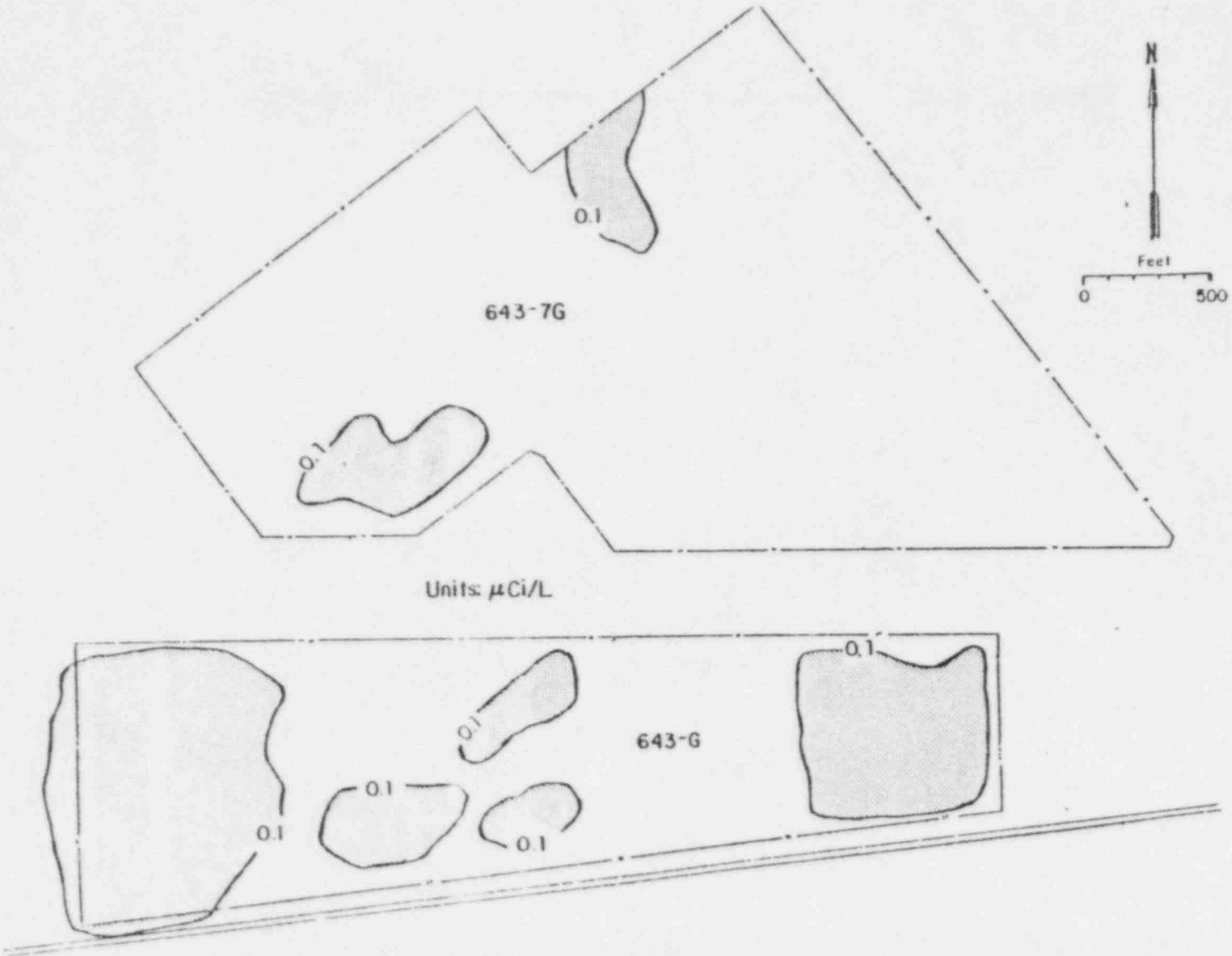

FIGURE 2.3-15. Tritium in Burial Ground Groundwater

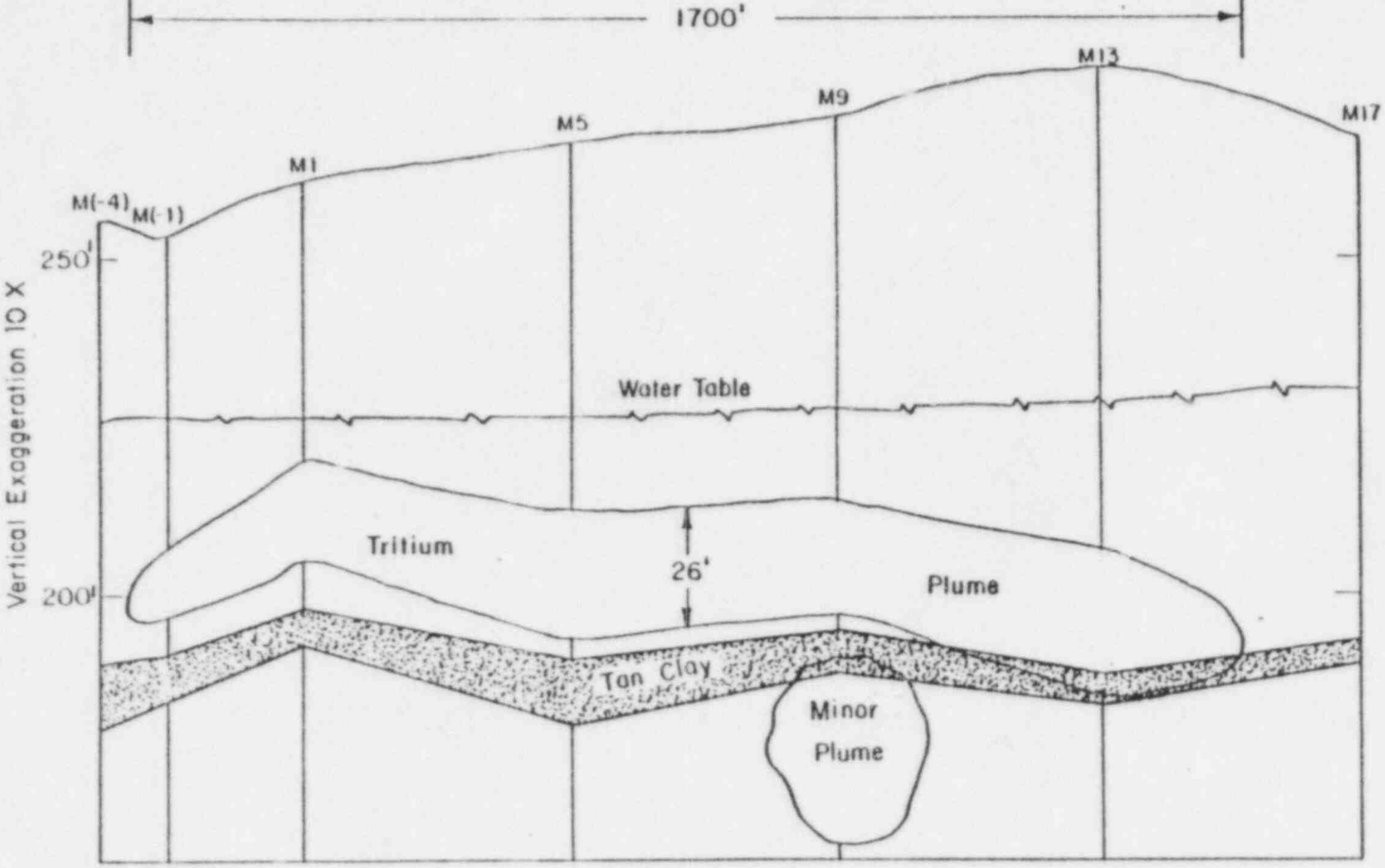

FIGURE 2.3-16. M-M' Cross Section of Tritium Plume

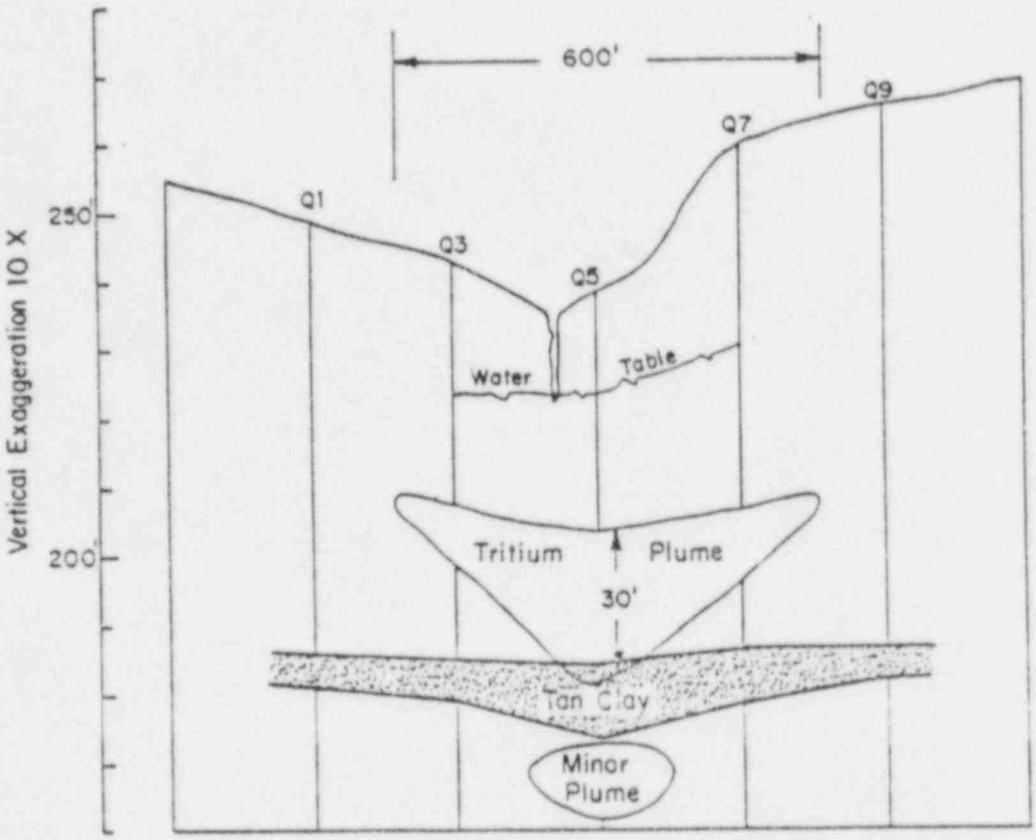

FIGURE 2.3-17. Q-Q' Cross Section of Tritium Plume

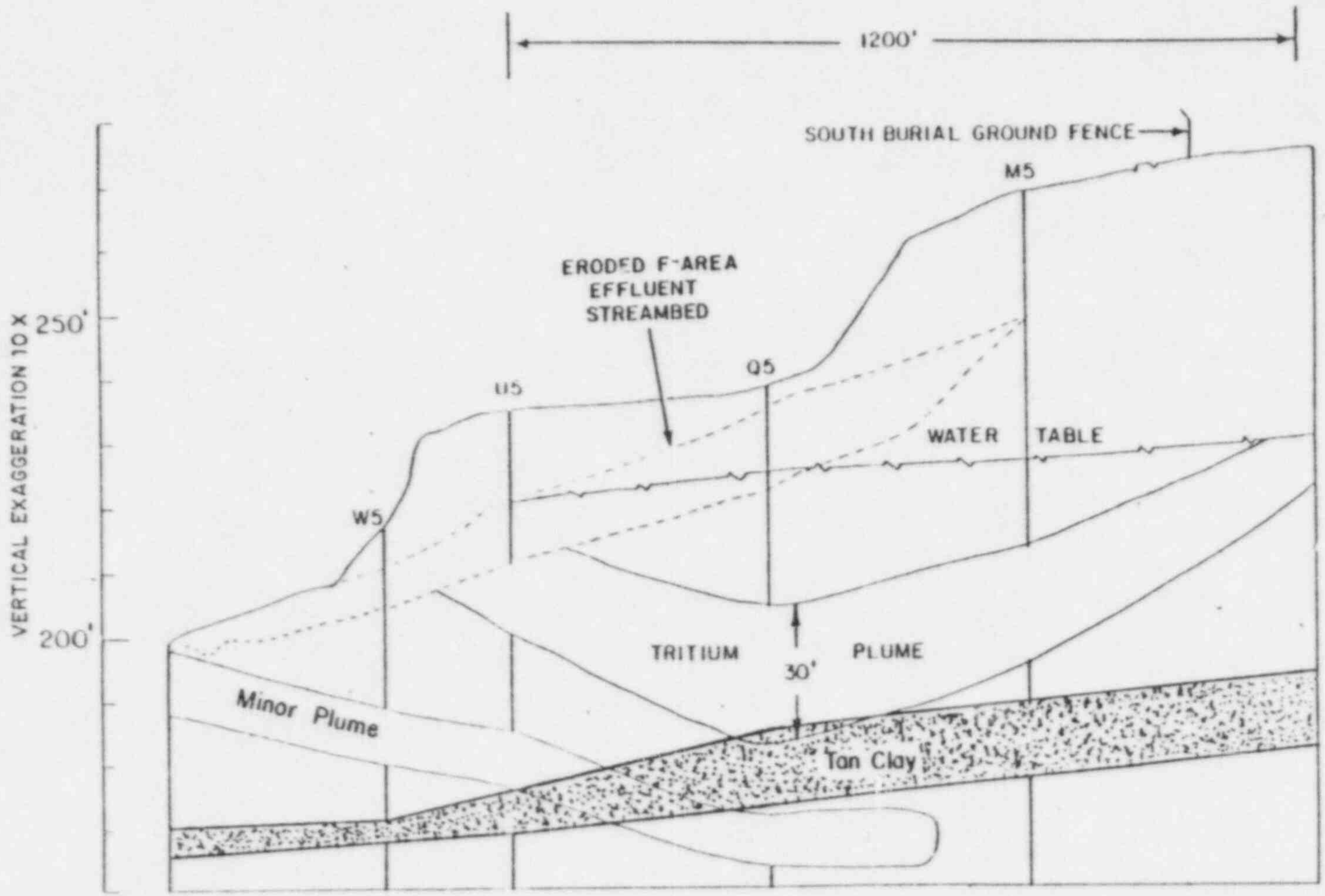

FIGURE 2.3-18. FP-FP' Flow Path Cross Section of Tritium Plume

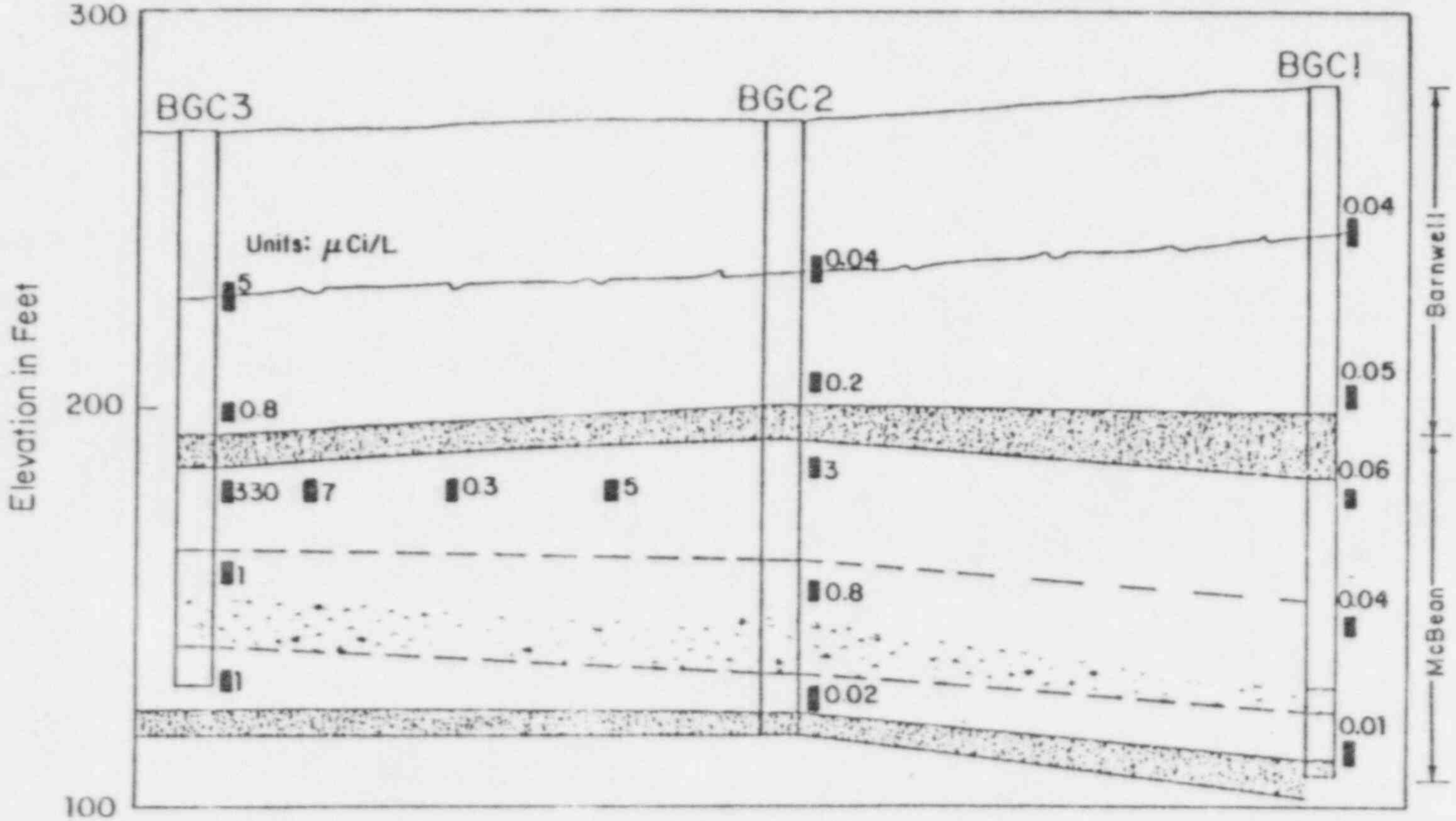

FIGURE 2.3-19. 643-G Cluster Wells — Three-Year Tritium Average

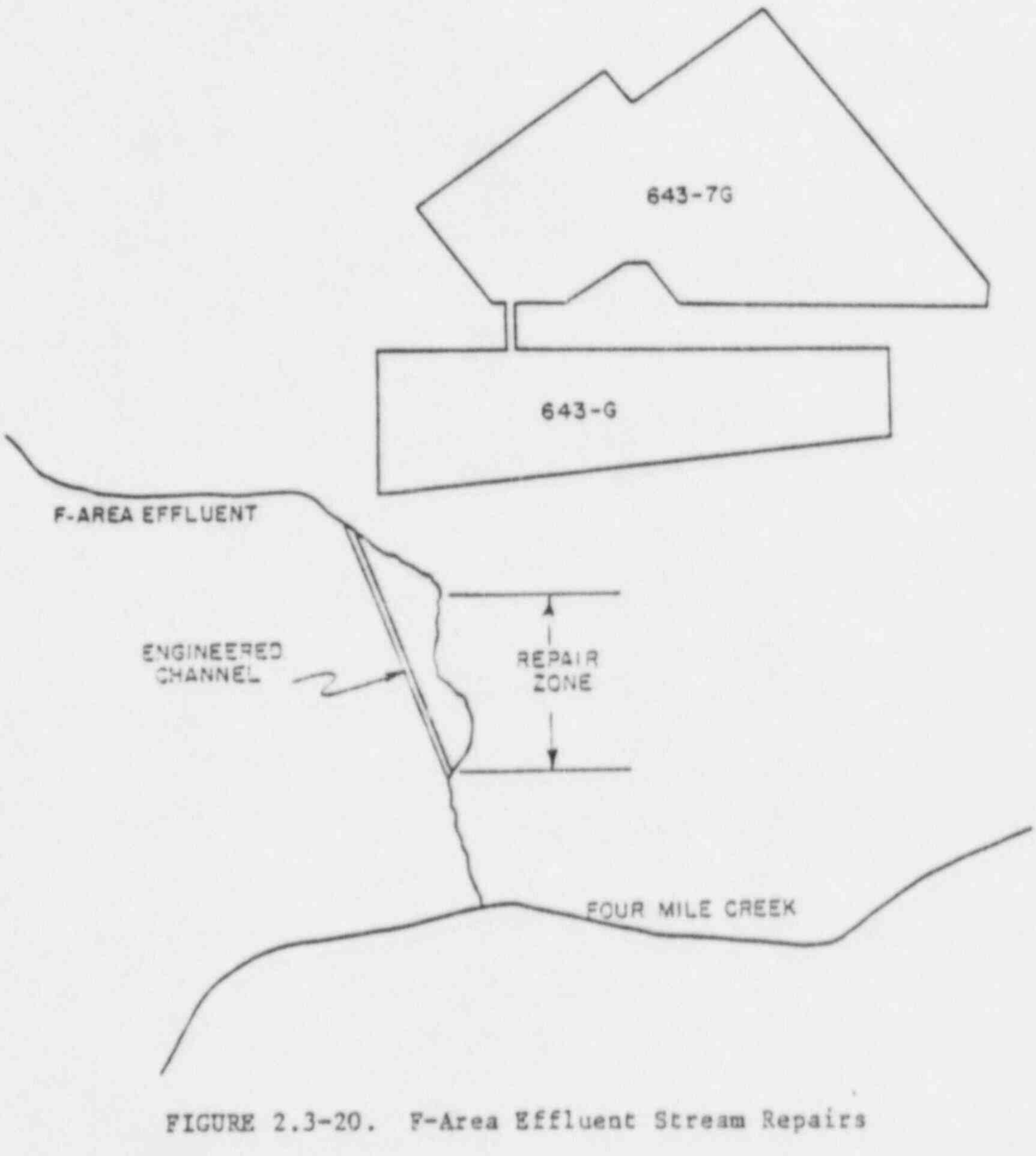

FIGURE 2.3-20. F-Area Effluent Stream Repairs

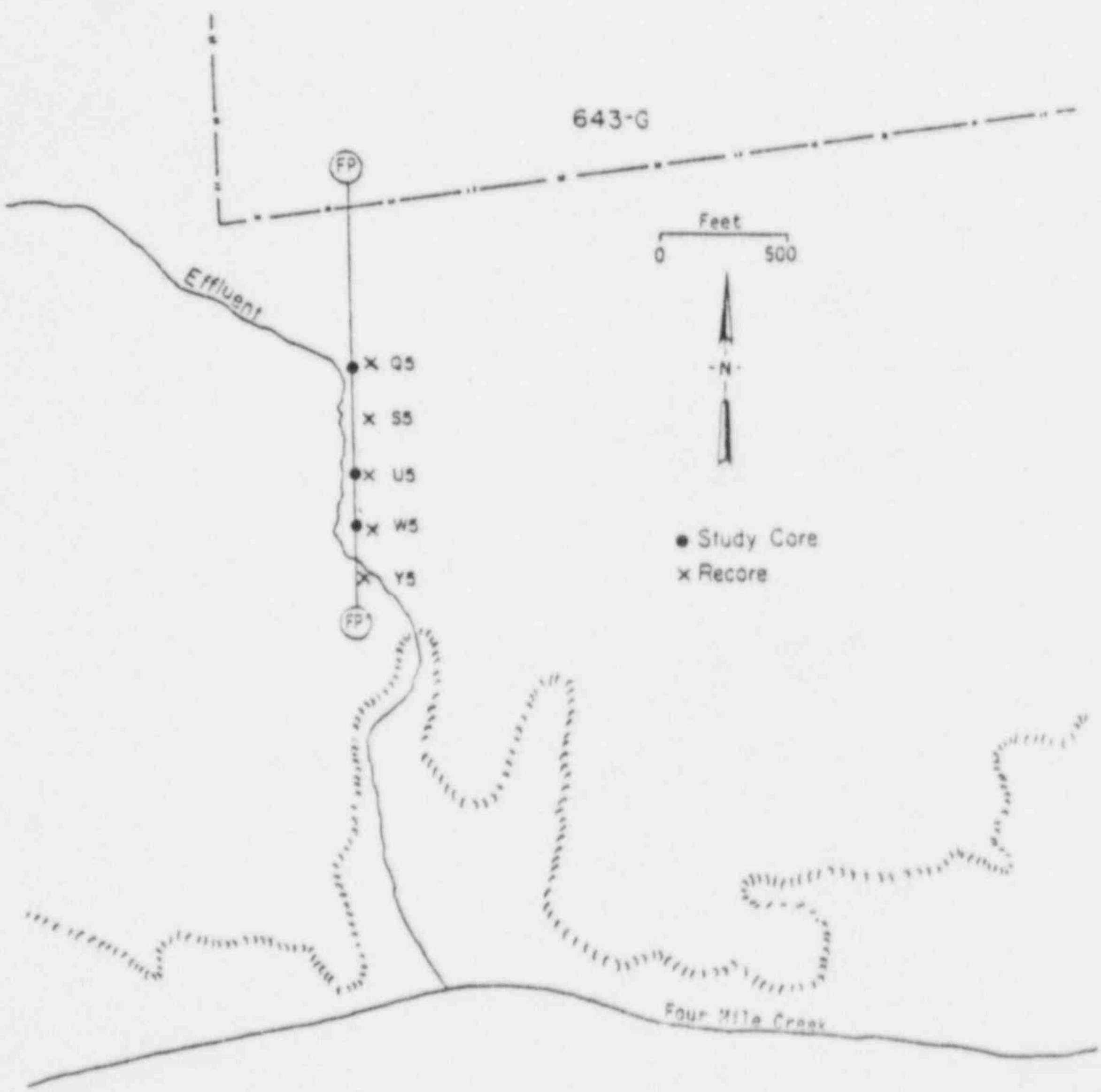

FIGURE 2.3-21. Cross Section and Core Sites for Recoring After Streambed Repairs

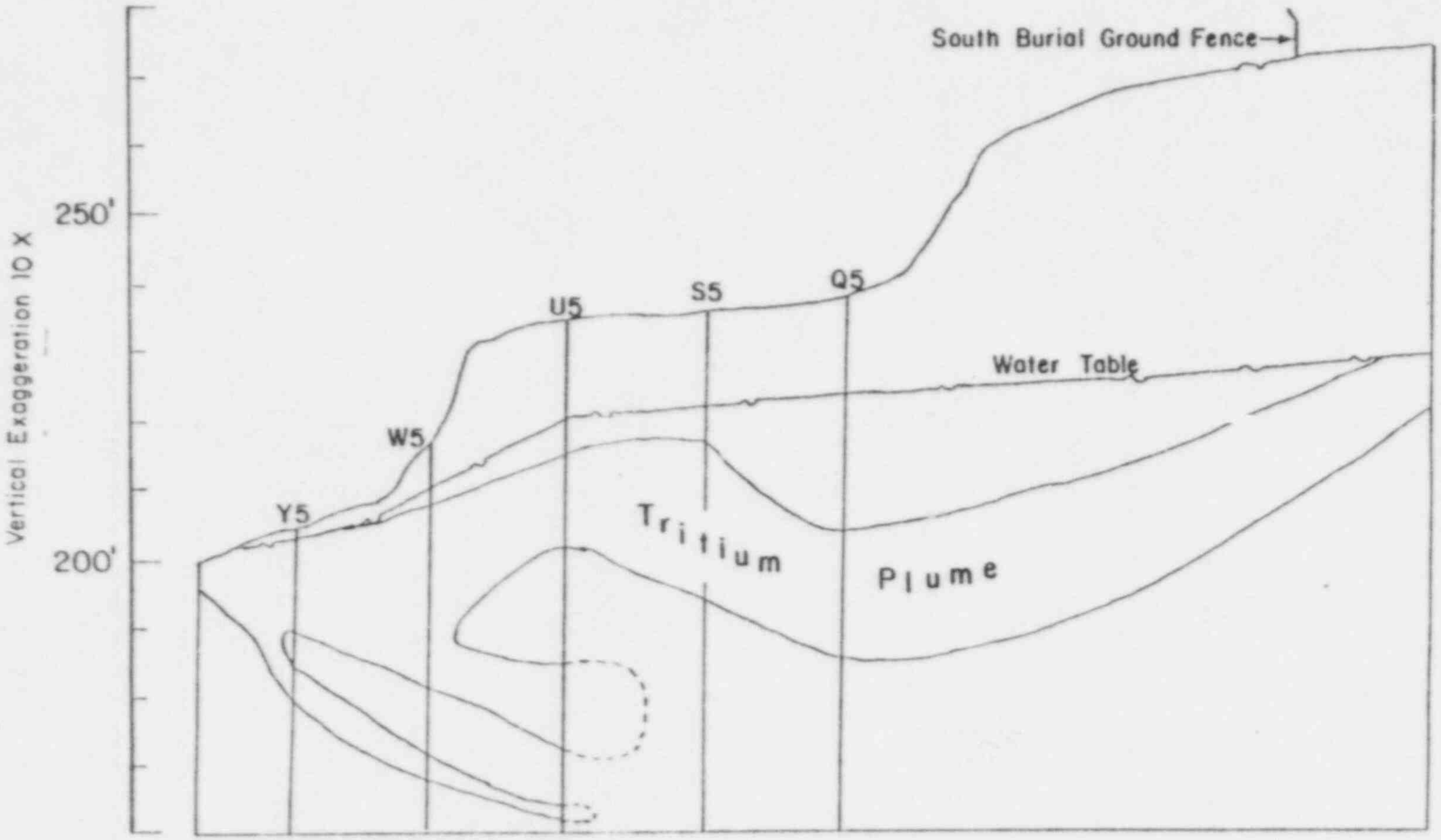

FIGURE 2.3-22. 643-G Tritium Plume, 1982, After Streambed Repairs

2.4 REACTOR SEEPAGE BASINS

2.4.1 Nature of Disposal

The reactor areas (100 Areas) at the Savannah River Plant have routinely used earthen seepage basins since 1957. The basins have been used almost exclusively for low-level radioactive water from the reactor process buildings. The five reactor areas contain a total of 18 seepage and containment basins. Of these, 17 basins have been put into radioactive service as shown in Table 2.4-1.

The basins contain approximately 20 different types of radionuclides. However, ^{3}H, ^{90}Sr, and ^{137}Cs account for almost all the radioactivity in the 100-Area basins. The decay-corrected basin inventories are shown in Table 2.4-2.

Current Practices

The seepage basins currently receive water from the disassembly basins within the reactor building. During the purging operation, water from the basins is passed through two mixed-bed deionizers in series to remove radionuclides (except tritium) before release to a seepage basin. Effluents from the deionizers are monitored during the purge. Should activity in the effluent from the second bed in series begin to rise, the first bed is replaced with regenerated resin, and the direction of flow through the deionizers is reversed. Spent deionizer resin is regenerated in the separations areas, and the activity is concentrated and stored in high-level waste tanks.

In addition to radionuclides, the discharge to the basin contains trace quantities of Al, Fe, Na, Cl, CO_3, NO_3, PO_4, SO_3, SO_4, oil, and grease. The chemicals enter the disassembly basin water from the sand filter backwash settler tank which receives water from a number of sources including reactor building sumps and pad runoff.

2.4.2 Local Groundwater Conditions

R Area

The R-Area seepage basins were excavated in the Aiken Plateau just north of the reactor building at an elevation of about 300 ft. The elevation of the water table at the R-Area seepage basins is about 280 ft (Figure 2.4-1; maps are for March-April 1965, a time of 100-year high water table elevations). The basins are located near the divide between Mill Creek (a tributary of Upper Three Runs Creek) to the north and Par Pond to the east. Thus, the water table gradient in the northwestern portion of the basin area is to

the north towards Upper Three Runs Creek, and the water table in the southwestern portion, which contains Basin No. 1 and most of the emplaced activity, is to the east towards Par Pond (and Lower Three Runs Creek).

The R-Area seepage basins are located in an area of SRP where the hydraulic gradient in the underlying formations has been shown to be downward to the Tuscaloosa aquifer (Figure 3-27, Volume I).

P Area

The P-Area seepage and containment basins are located on the Aiken Plateau at an elevation of about 320 ft. The elevation of the water table is about 290 ft (Figure 2.4-2), and the water table gradient is to the south, ultimately towards Meyers Branch (a tributary of Steel Creek). The hydraulic gradient in the formations underlying these basins has been shown to be downward to the Tuscaloosa aquifer (Figure 3-27, Volume I).

L Area

The L-Area seepage basin is located on the Aiken Plateau at an elevation of about 240 ft. The elevation of the water table is about 220 ft (Figure 2.4-3). The basin is on the water table slope between a mound northeast of L Area and Steel Creek.

The stratigraphic column at this location is believed to be similar to that in F and H Areas, except that the green clay may be thicker than in F and H Area. A regional map of head differences between the Tuscaloosa and Congaree aquifers (Figure 3-27, Volume I) indicates that a hydraulic reversal exists at the Congaree Formation in the vicinity of L Area, as there is in F and H Areas.

K Area

The K-Area seepage and containment basins are on the Aiken Plateau at an elevation of about 260 ft. The elevation of the water table is about 220 ft as shown on Figure 2.4-4. The water table gradient is westward to Indian Grave Branch, a tributary of Pen Branch.

The stratigraphic column at this location is believed to be similar to that in F and H Areas although the green clay may be thicker. A regional map of head differences between the Tuscaloosa and Congaree aquifers (Figure 3-27, Volume I) indicates that a head reversal exists at the Congaree Formation in the vicinity of K Area, as there is in F and H Areas.

C Area

The C-Area seepage basin is on the Aiken Plateau at an elevation of about 280 ft. The elevation of the water table is about 220 ft as shown in Figure 2.4-5. The water table gradient is generally southwestward toward Four Mile Creek. The stratigraphic column at this location is believed to be similar to that in F and H Areas. A regional map of head differences between the Tuscaloosa and Congaree aquifers (Figure 3-27, Volume I) indicates that a head reversal exists at the Congaree Formation in the vicinity of C Area, as there is in F and H Areas.

2.4.3 Groundwater Monitoring Program and Results

Groundwater monitoring began in 1958 around the seepage basins in the reactor areas, when 39 wells were drilled near the R-Area seepage basins. Monitoring wells also exist around the seepage basins in C and P Areas. Groundwater contiguous to these basins is monitored for gross alpha, nonvolatile beta, and tritium activity. Chemical analyses are not available. Monitoring wells have recently been installed around the seepage basin in L Area. Temporary monitoring wells, no longer in service, were installed around the K-Area seepage basin (904-65G); new wells are planned.

In K Area, the unlined 50-million-gallon containment basin (904-88G) is used as the area seepage basin and has been in use since 1966. Two monitoring wells (KWL-1 and KWL-8) were drilled in 1963 when the basin was constructed, and three additional monitoring wells (KWL-13, KWL-14, and KWL-15) were drilled in 1966.

There are 64 wells for monitoring in the vicinity of the 17 basins that have been in service in the 100 Areas. Seepage and containment basin monitoring wells are shown in Figures 2.4-6 through 2.4-9 for the R-, P-, and C-Area seepage basins, and the K-Area containment basin, respectively. Monitoring results for the years of 1979, 1980, and 1981 are shown in Tables 2.4-3 through 2.4-7.

2.4.4 Evaluation of Impact on Groundwater Quality

Tertiary Sediments

Tritium concentrations in groundwater around the P-Area seepage basin, the C-Area seepage basin, and the K-Area containment basin exceed the EPA drinking water standard (0.02 μCi/L), as shown in Tables 2.4-5, 2.4-6, and 2.4-7. In R Area, groundwater east of Basin 1 and north of Basin 3 contains ^{90}Sr in excess of the EPA drinking water standard (8 pCi/L). Analyses have shown that the nonvolatile beta activity in R-Area monitoring wells (Table 2.4-4)

is primarily ^{90}Sr. Similarly elevated levels of nonvolatile beta activity in monitoring wells near the P-Area seepage basins (Table 2.4-5), the C-Area seepage basins (Table 2.4-6), and the K-Area containment basin (Table 2.4-7) suggest that groundwater near these basins also contains ^{90}Sr above 8 pCi/L.

In R Area, radiostrontium has migrated approximately 500 ft in 25 years (the migration may have been facilitated by seepage along an abandoned sewer line). Because the flow path to a surface outcrop is at least 3500 ft, release of radiostrontium to surface outcrops will require at least an additional 150 years.

Tritium from the K-Area containment basin is currently migrating through tertiary sediments to surface outcrops at a rate of about 10,000 Ci/yr. As noted in Section 2.4.2, these outcrops flow to the Savannah River by way of Indian Grave Branch and Pen Branch. Tritium from ongoing discharges to seepage basins in P and C Areas is expected to reach surface outcrops after 1984 and then move rapidly to the Savannah River by way of Steel Creek and Four Mile Creek, respectively.

Tuscaloosa Formation

Deep monitoring wells are are not presently available at these basins. A potential exists for deep penetration of radionuclides in R and P Areas because of the inferred downward hydraulic gradient.

Offsite

Contaminated groundwater in the tertiary sediments from reactor area seepage basins is expected to reach surface outcrops before passing the Plant boundary. Any contamination of the deeper aquifers from R- and P-Area seepage basins would be expected to outcrop into the Savannah River.

2.4.5 Remedial Action

To date, remedial action has been taken only for the R-Area seepage basins. All six basins in that area have been backfilled, covered with asphalt, and marked with pylons. Periodically, treatment with herbicide and resurfacing is required to eliminate vegetation that is contaminated with radioactivity. Migration of radionuclides up to 500 feet in the shallow groundwater has been observed, but no immediate threat exists to public health or safety.

The P- and C-Area seepage basins and the K-Area containment basin are presently being used, and no remedial action is planned. The L-Area seepage basin currently is not in use, and no remedial action has been planned.

TABLE 2.4-1

Listing of Reactor Area Seepage and Containment Basins

Area	No. of Basins	Building No.	Past Service	Currently in Use
R	6	904-55G	Yes	No
		904-56G	Yes	No
		904-57G	Yes	No
		904-58G	Yes	No
		904-59G	Yes	No
		904-60G	Yes	No
P	4	904-61G	Yes	Yes
		904-62G	Yes	Yes
		904-63G	Yes	Yes
		904-86G*	Yes	No
L	2	904-64G	Yes	No
		904-87G*	No	No
K	2	904-65G	Yes	No
		904-88G*	Yes	Yes
C	4	904-66G	Yes	Yes
		904-67G	Yes	Yes
		904-68G	Yes	Yes
		904-89G*	Yes	No

* Fifty million gallon containment basins.

TABLE 2.4-2

Summary of Radioactive Releases to Major Reactor Area Seepage Basins

Isotope	Radioactivity Released to Basins* (Ci)					
	C	K	K**	L	P	R
^{3}H	2.9E+04	1.9E+03	1.9E+05	3.3E+03	3.3E+04	2.4E+03
^{35}S	1.1E-02	-	2.2E-02	-	1.0E-02	-
^{51}Cr	2.9E-03	-	3.8E-03	-	1.5E-03	-
^{54}Mn	-	-	7.3E-06	-	-	-
^{60}Co	7.4E-02	2.4E-02	2.0E-01	2.4E-01	1.1E-01	1.1E-01
^{65}Zn	-	-	3.3E-04	-	-	-
^{89}Sr	1.0E-05	-	2.2E-07	-	2.9E-04	-
^{90}Sr	2.7E-01	9.5E-02	4.8E+00	1.1E+00	2.7E+00	1.1E+02
^{91}Y	3.1E-04	-	2.4E-04	-	4.2E-04	-
^{95}Zr-Nb	5.0E-03	-	3.6E-05	-	1.5E-03	-
$^{103,106}Ru$	2.7E-04	-	1.2E-03	5.6E-06	1.4E-03	4.3E-0
^{125}Sb	-	-	1.3E-01	-	-	-
$^{124-125}Sb$	5.5E-03	-	1.6E-01	-	2.7E-03	-
^{134}Cs	7.4E-03	-	2.2E-02	-	7.2E-03	-
^{137}Cs	1.2E+00	8.1E-02	9.7E+00	7.0E-01	1.1E+01	5.0E+02
$^{141,144}Ce$	2.4E-03	-	6.4E-03	-	5.5E-03	-
^{147}Pm	8.1E-03	9,7E-05	3.7E-02	1.9E-03	1.7E-02	4.3E-03
^{239}Pu	-	-	-		-	3.0E-01
Alpha (unidentified)	1.9E-03	-	1.2E-02	-	3.9E-03	-
Beta-gamma (unidentified)	2.1E-04	-	1.6E+02	-	-	-

* Release values cumulative through 1982. All values are decay corrected.

** Containment basin (904-88G).

TABLE 2.4-3

Alpha Radioactivity in R-Area Seepage Basin Wells

Well No.	Annual Averages (pCi/L) 1979	1980	1981	Well No.	Annual Averages (pCi/L) 1979	1980	1981
A7	0.1*	0.0*	0.4	D7	<1.1	<0.9	0.5
A8	0.2*	0.0*	-	D8	<0.9	<1.3	0.4
A9	0.0*	0.2*	-	D9	<0.6	<0.6	0.5
A10	0.2*	0.1*	0.2*	D10	<0.8	0.7	0.6
B7	<0.8	<0.8	0.3	D11	0.4	<0.6	0.4
B8	0.6	<0.7	0.5	E1A	<1.4	0.9	0.5
B9	<0.6	<0.6	0.3	E1B	<1.9	<2.1	0.1*
C2	<0.6	0.1*	0.5	E1C	<0.5	<0.5	0.7
C3	0.4	0.4	0.1*	E2	<0.6	<0.8	0.3
C4	1.6	1.4	-	E3	<1.2	<1.2	0.7
C5	0.2*	0.1*	0.1*	E4A	2.0	2.0	1.5
C6	0.0*	0.1*	0.2*	E4B	3.9	3.9	-
C7	0.3	0.8	0.8	E4C	<3.2	1.9	0.5
C8	<0.7	0.5	0.3	E5	<1.4	1.0	0.4
C9	<0.6	0.2*	0.3	E7	<0.9	<0.6	0.3
C10	<0.6	<0.7	<0.5	E8	<1.4	1.3	0.9
D1	<0.5	<0.5	0.3	E9	<2.0	<1.0	0.7
D2A	<0.5	<1.3	0.2*	E10	<0.7	<0.6	0.3
D2B	2.9	2.5	-	E11	1.8	1.5	1.0
D2C	1.8	1.7	0.4	E12	<0.5	0.7	0.4
D3	0.3	0.1*	0.1*	E13	2.5	<2.2	1.8
D4	0.8	<1.1	0.6	E18	<0.7	<1.0	0.2*
D5	<0.3	<1.0	0.5	E19	<1.2	<1.1	1.0
D6	<0.8	0.5	0.3				

* Less than nominal lower limit of detection (0.25 pCi/L).

TABLE 2.4-4

Nonvolatile Beta Radioactivity in R-Area Seepage Basin Wells

Well No.	Annual Averages (pCi/L) 1979	1980	1981
A7	1*	2*	6*
A8	3*	1*	-
A9	4*	0*	-
A10	2*	4*	3*
B7	9	<7	10
B8	<10	<14	7
B9	<5	1*	1*
C2	<7	5*	2*
C3	1*	0*	2*
C4	7	6*	-
C5	2*	1*	6*
C6	2*	2*	1*
C7	6*	9	5*
C8	<7	2*	0*
C9	<7	4*	6*
C10	<7	<8	<8
D1	30	25	27
D2A	280	260	290
D2B	<190	140	-
D2C	3300	5000	2900
D3	6*	4*	4*
D4	<280	300	240
D5	780	570	610
D6	290	220	250

Well No.	Annual Averages (pCi/L) 1979	1980	1981
D7	<510	360	530
D8	<1500	470	350
D9	<27	<21	5*
D10	37	<27	47
D11	22	18	27
E1A	36	38	63
E1B	<15	<10	8
E1C	<22	<11	10
E2	<7	<8	22
E3	29	26	20
E4A	<1900	<1800	210
E4B	2300	2200	-
E4C	<1500	<2600	610
E5	59	66	46
E7	<5	<5	1*
E8	<6	<17	9
E9	<7	2*	3*
E10	<5	<9	4*
E11	640	690	1000
E12	140	150	180
E13	460	660	250
E18	<12	<320	3*
E19	<140	<140	68

* Less than nominal lower limit of detection (7 pCi/L).

TABLE 2.4-5

Radioactivity in P-Area Seepage Basin Wells

	Annual Averages		
	Alpha (pCi/L)		
Well No.	1979	1980	1981
1	0.4	0.6	0.6
2	1.1	1.9	1.3
3	0.5	1.2	0.4
4	0.2*	0.5	0.2*
5	0.8	0.7	0.6
6	0.2*	0.4	0.2*
7	0.3	0.5	0.4
	Nonvolatile Beta (pCi/L)		
1	4**	7	3**
2	19	24	13
3	0**	3**	1**
4	2**	1**	1**
5	0**	1**	2**
6	0**	0**	2**
7	1**	2**	4**
	Tritium (Ci/L)		
1	21	140	260
2	120	160	180
3	100	150	160
4	0.044	0.052	0.026
5	0.049	1.9	0.032
6	50	160	270
7	110	130	160

* Less than nominal lower limit of detection for alpha (0.25 pCi/L).

** Less than nominal lower limit of detection for beta (7 pCi/L).

TABLE 2.4-6

Radioactivity in C-Area Seepage Basin Wells

Well No.	Annual Averages Alpha (pCi/L) 1979	1980	1981
1	0.1*	0.4	0.2*
2	0.6	1.4	1.0
3	0.2*	0.7	0.4
4	0.0*	0.1*	0.0*
5	0.0*	0.3	0.1*
6	1.0	1.5	0.7
	Nonvolatile Beta (pCi/L)		
1	1**	1**	2**
2	4**	9	8
3	1**	1**	4**
4	12	2**	2**
5	0**	2**	2**
6	4**	3**	1**
	Tritium (μCi/L)		
1	0.088	0.033	0.035
2	0.053	0.12	0.052
3	0.50	0.71	0.79
4	0.082	0.12	0.062
5	0.37	0.45	0.46
6	40	4.6	1.7

* Less than nominal lower limit of detection for alpha (0.25 pCi/L).

** Less than nominal lower limit of detection for beta (7 pCi/L).

TABLE 2.4-7

Radioactivity in K-Area Containment Basin Wells

Well No.	1979	1980	1981
	Annual Averages		
	Alpha (pCi/L)		
1	<0.8	<0.7	<0.8
8	<2.1	<0.6	0.8
13	1.1	0.9	<1.0
14	0.9	1.2	<0.9
15	1.7	<1.4	<1.8
	Nonvolatile Beta (pCi/L)		
1	<10	<7	<15
8	<14	<6	<9
13	<130	<8	<20
14	<60	<15	<18
15	33	<48	40
	Tritium (μCi/L)		
1	<0.39	<0.23	0.67
8	66	54	49
13	130	93	72
14	110	<60	61
15	160	<81	120

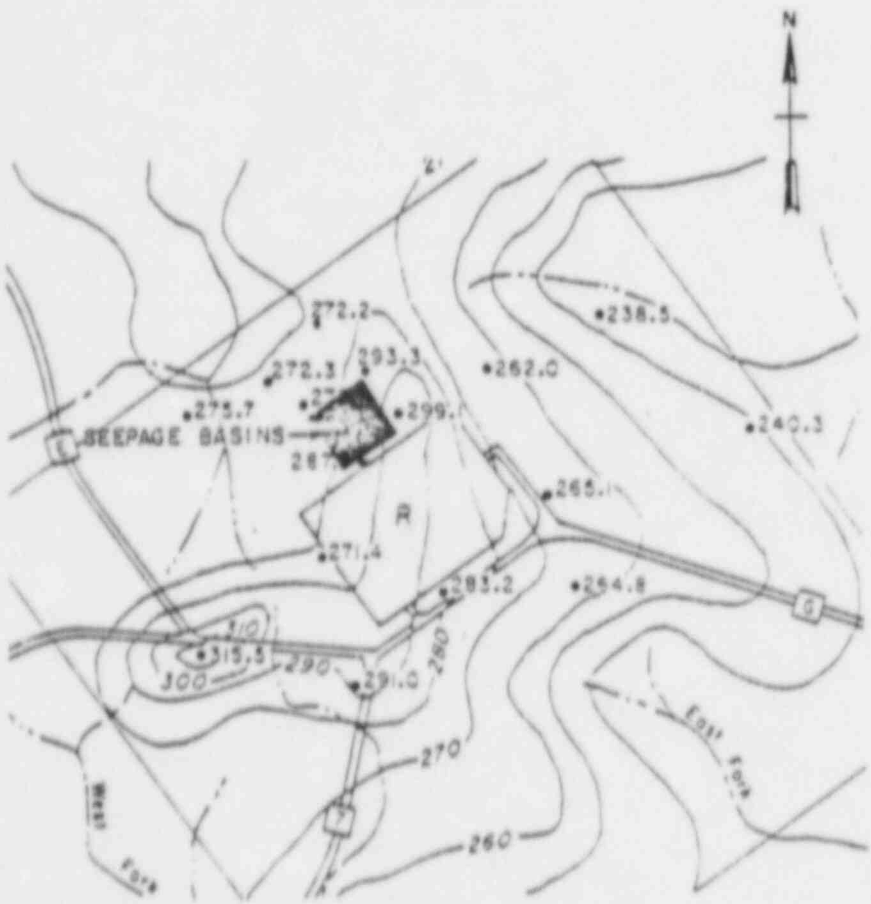

FIGURE 2.4-1. Water Table Map Near R Area (Contours in Feet Above Mean Sea Level)

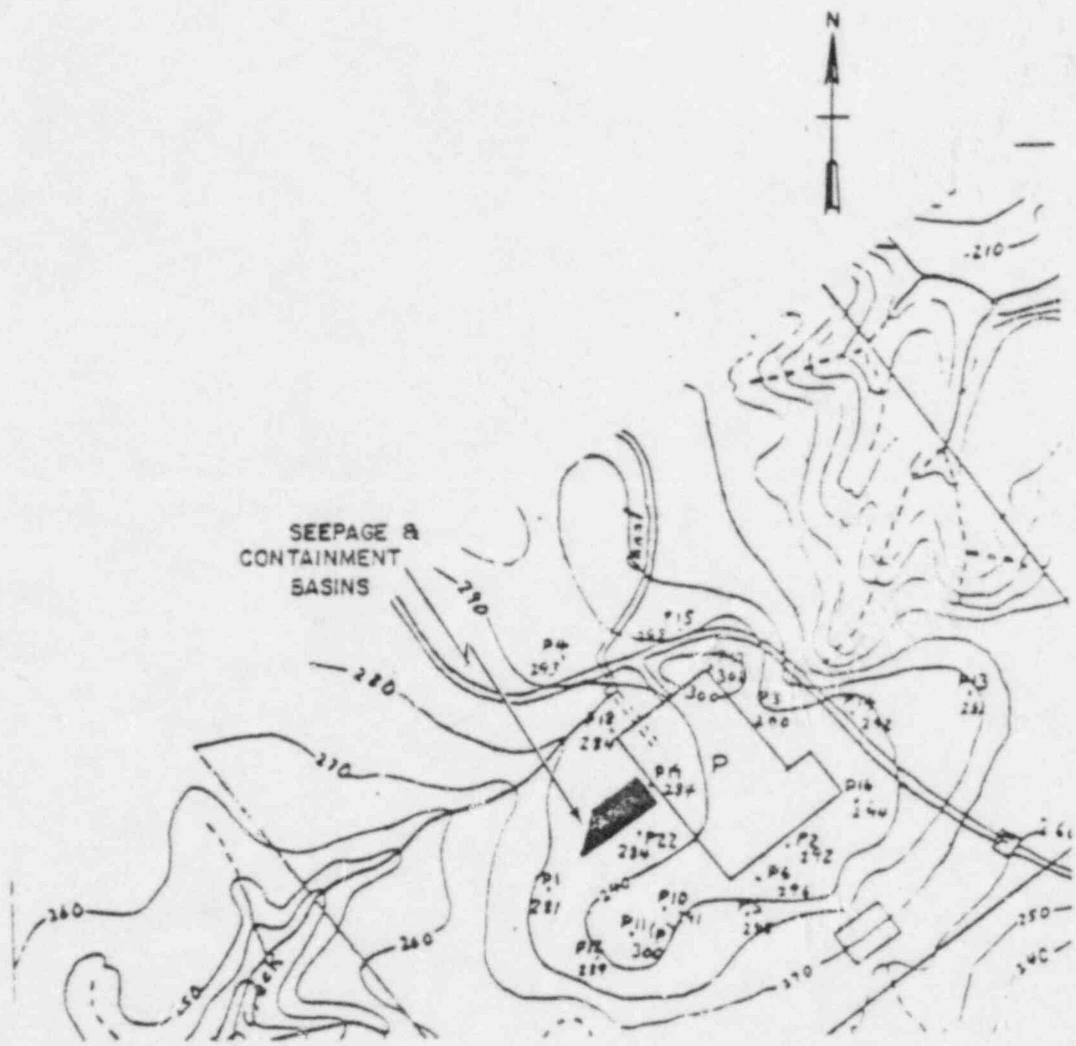

FIGURE 2.4-2. Water Table Map Near P Area (Contours in Feet Above Mean Sea Level)

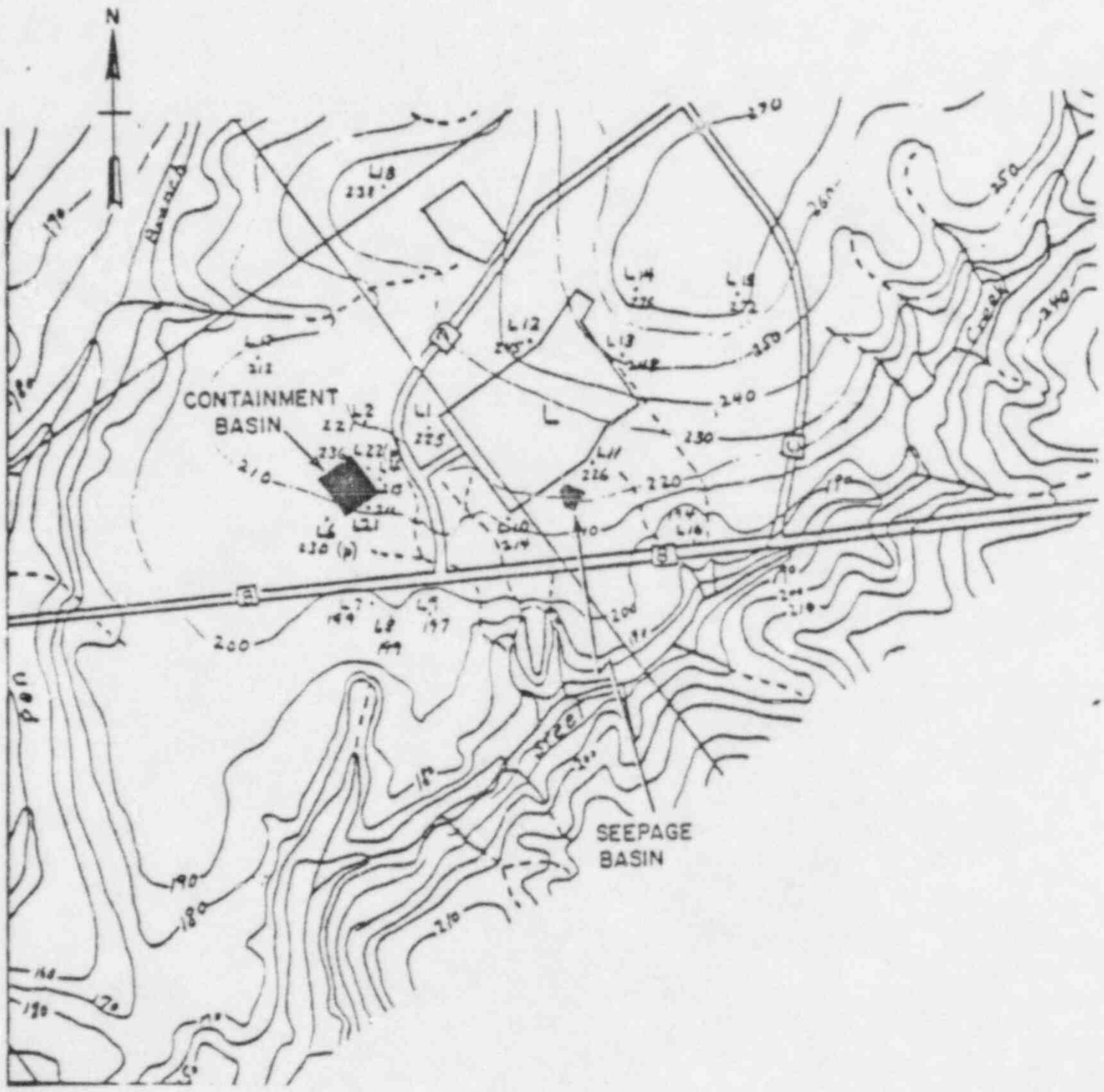

FIGURE 2.4-3. Water Table Map Near L Area (Contours in Feet Above Mean Sea Level)

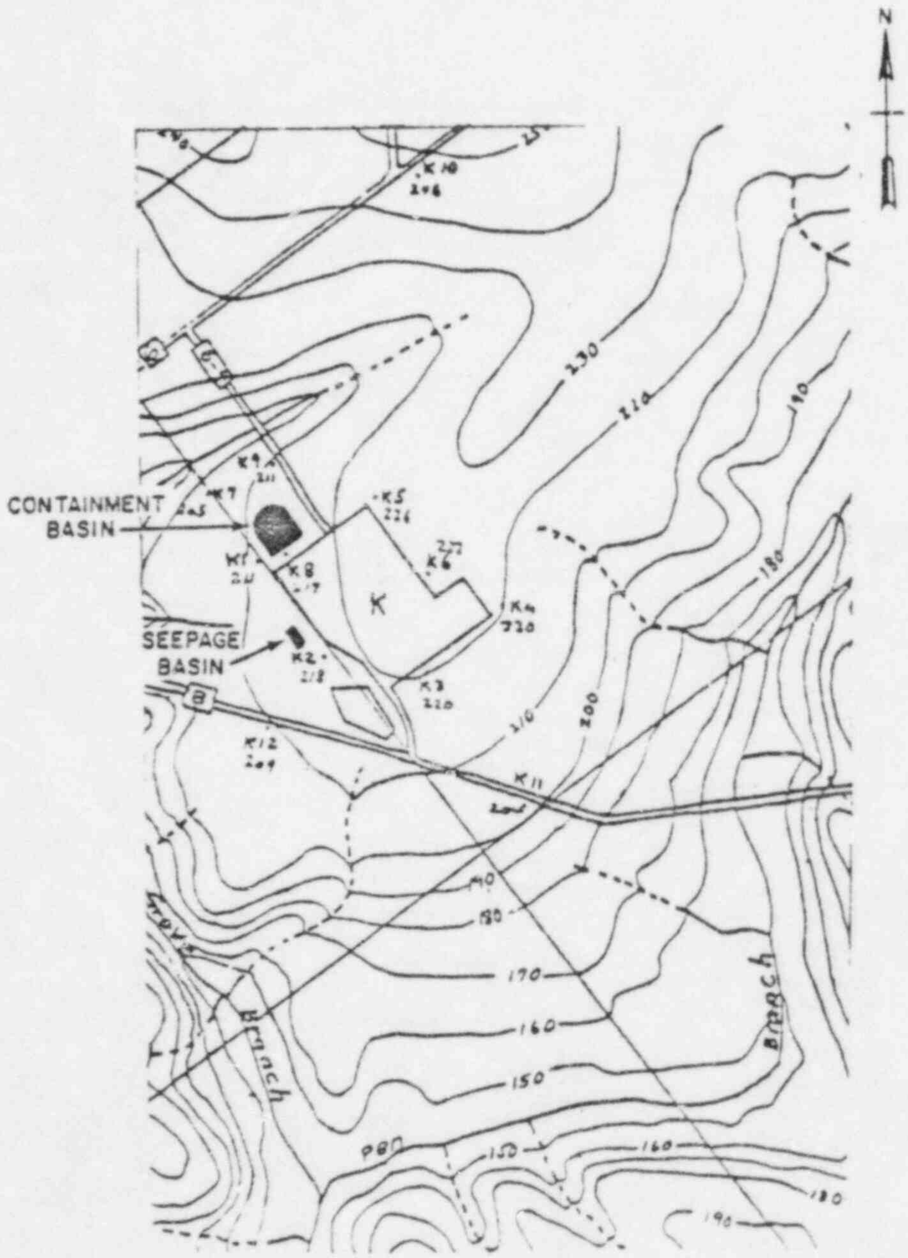

FIGURE 2.4-4. Water Table Map Near K Area (Contours in Feet Above Mean Sea Level)

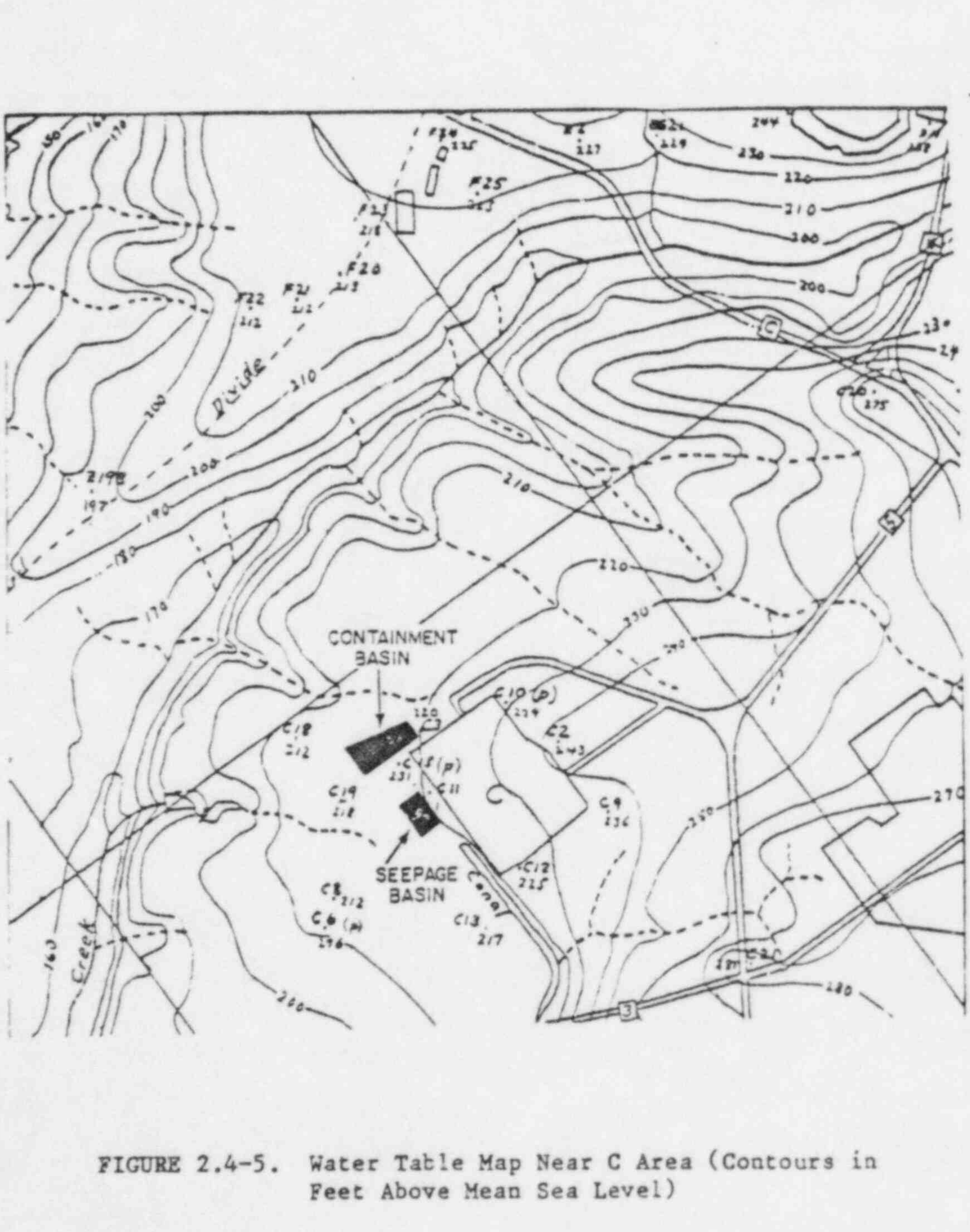

FIGURE 2.4-5. Water Table Map Near C Area (Contours in Feet Above Mean Sea Level)

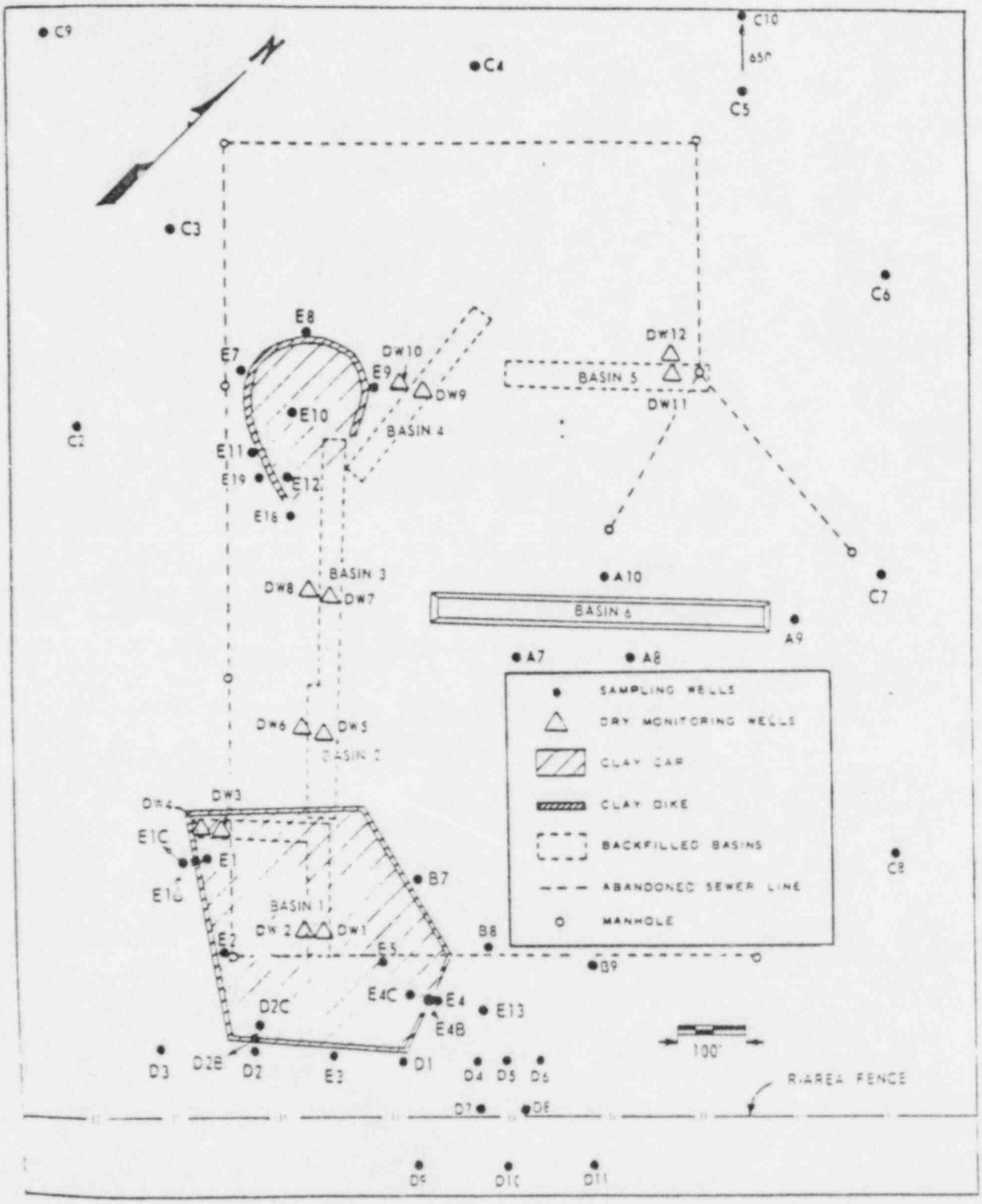

FIGURE 2.4-6. R-Area Seepage Basin Wells.

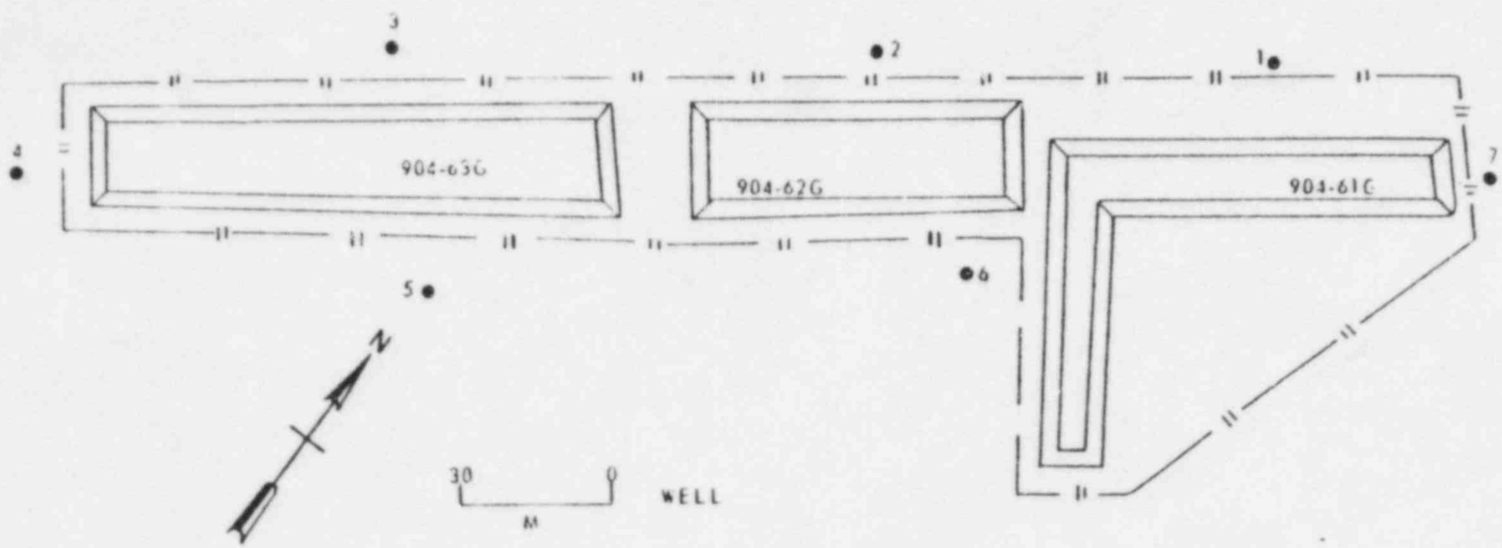

FIGURE 2.4-7. P-Area Seepage Basin Wells.

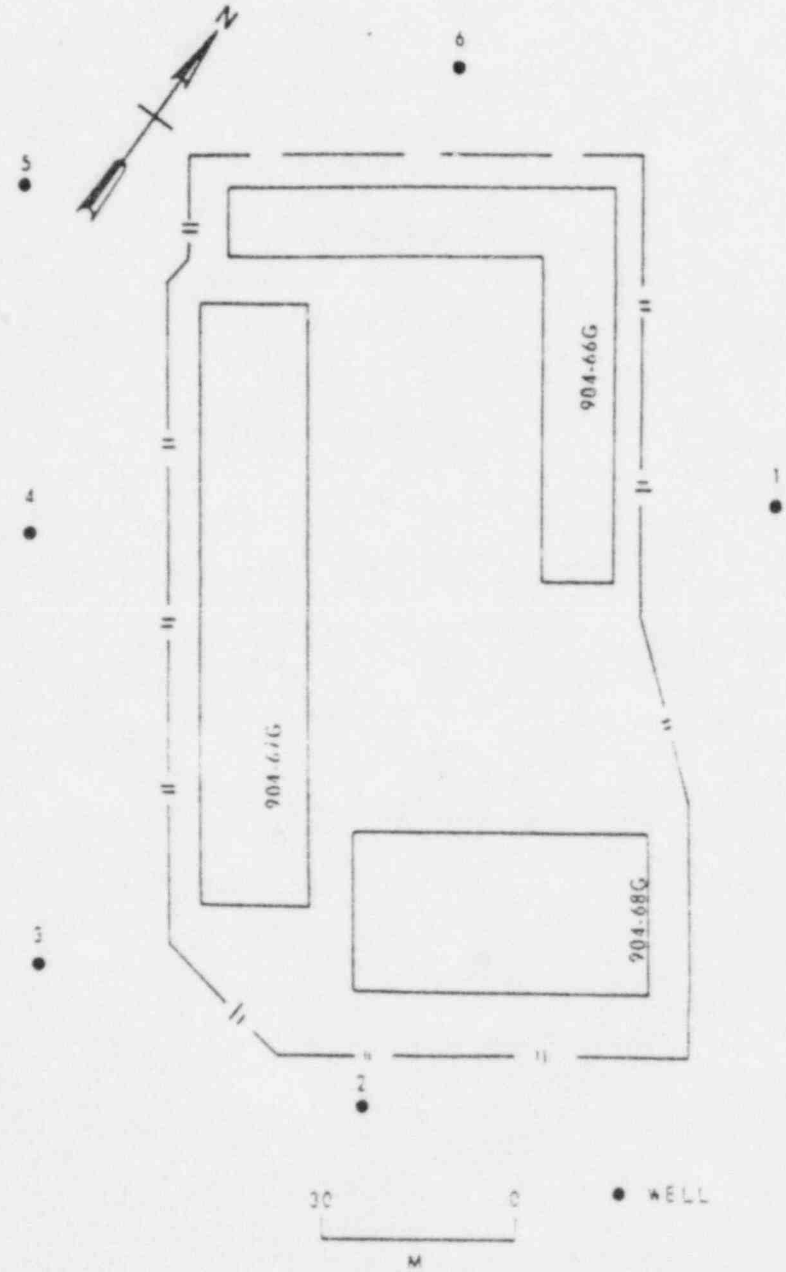

FIGURE 2.4-8. C-Area Seepage Basin Wells.

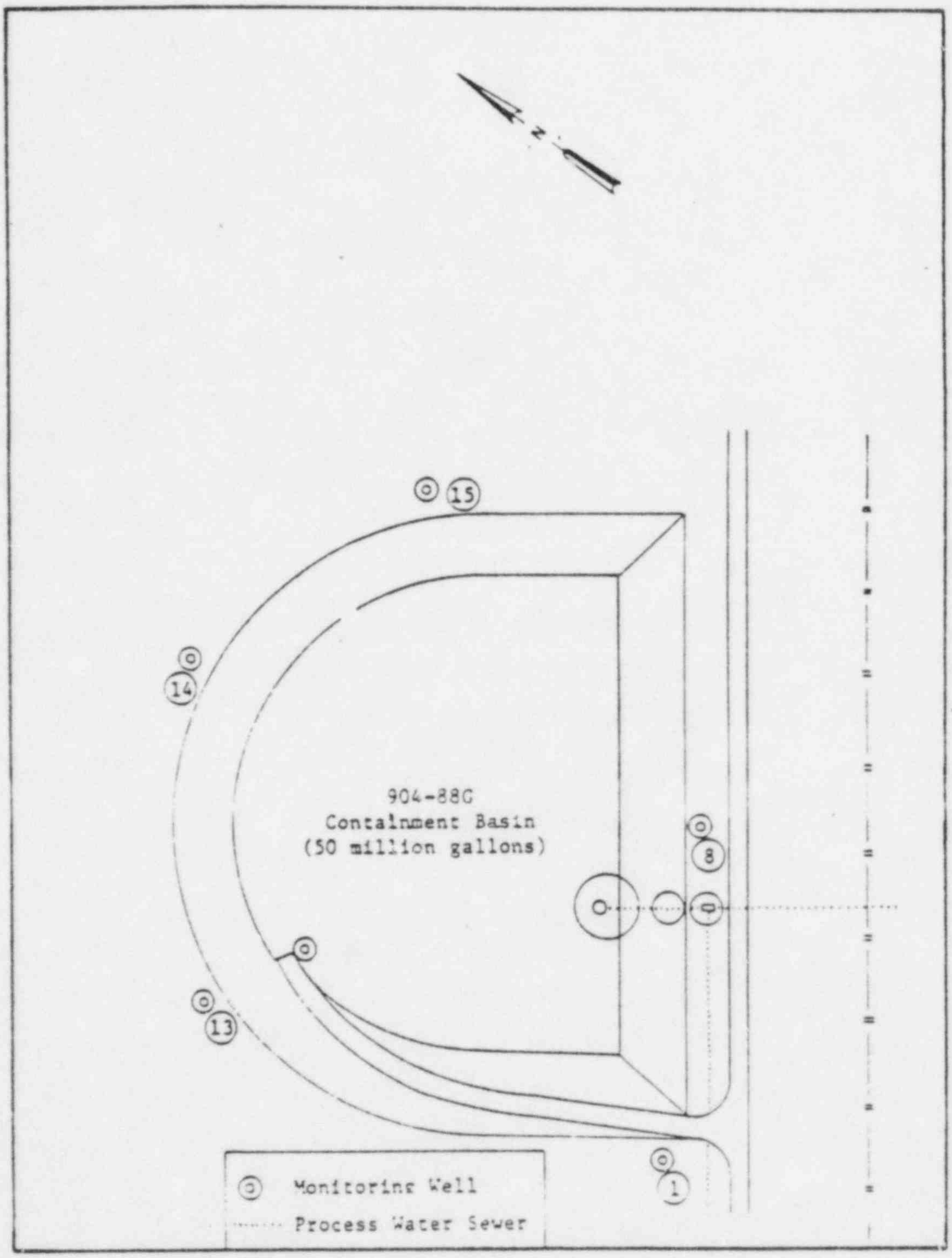

FIGURE 2.4-9. K-Area Containment Basin Wells.

2.5 L-AREA OIL AND CHEMICAL BASIN

2.5.1 Nature of Disposal

The L-Area oil and chemical pit (Building 904-83G) is an earthen unlined basin located about 230 ft northeast of the L-Area seepage basin (Figure 2.4-3; also Figure 6.8-2 of Volume I). The basin has a surface area of 9,600 ft^2 and a 250,000 gal capacity. Since 1961, the basin has received low levels of radioactive oil and chemical waste that had been used throughout the Plant. The purpose of the facility was to dispose of these small volumes of wastes that were not appropriate to discharge to effluent streams, regular seepage basins, or the 200-Area waste management system. The wastes were transported by tank truck, metal drums, or other containers, and were analyzed radiochemically before disposal. The waste came primarily from the reactor areas, but the facility has been used for wastes from all production and research areas of the Savannah River Plant. The facility received about 20,000 gal annually, with a total volume of 1,040,000 gal through 1979. The cumulative radioactivity in the basin is given in Table 2.5-1. The facility operated from 1961 to 1979; it is currently inactive but not backfilled.

2.5.2 Local Groundwater Conditions

The elevation of the water table at the L-Area oil and chemical basin is about 220 ft. The basin is on the water table slope between a mound northeast of L Area and Steel Creek. The water table at the basin is about 20 ft beneath the ground surface (Section 6.8, Volume I). The surface sediment at the basin is in the Barnwell Formation. The stratigraphic column at this location is expected to be similar to that given in Figure 3-5 of Volume I.

The regional piezometric map of the Congaree Formation (Figure 3-19, Volume I) shows that a downward gradient exists from the water table at a head of 220 ft above sea level down to the Congaree Formation at a head of 160 ft. The regional piezometric map of the Tuscaloosa Formation (Figure 3-11, Volume I) shows the elevation at L Area should be about 172 ft, indicating that there is a hydraulic reversal at the Congaree Formation, as there is in F and H Areas (Figure 3-27, Volume I).

2.5.3 Groundwater Monitoring Program and Results

Four wells have been drilled in the vicinity of the L-Area oil and chemical basin (Figure 6.8-3, Volume I). In 1982, quarterly monitoring was initiated. Groundwater monitoring results for radioactivity are summarized in Table 2.5-2.

2.5.4 Evaluation of Impact on Groundwater Quality

Radionuclides are present in the shallow Barnwell and McBean Formations. Based on experience in R Area, measured beta activity probably is from radiostrontium, which would exceed drinking water standards in well LCOB 1. The water table gradient is about 0.01, so that horizontal flow probably dominates over vertical flow. This, together with the probable increased thickness of the green clay, suggests that radioactive contamination of the Congaree Formation is unlikely.

Because of the head reversal at the Congaree Formation, migration of radioactivity to the Ellenton and Tuscaloosa Formations is not probable under the present hydrologic regime.

The closest Plant boundary to the L-Area oil and chemical basin is 5.5 miles to the south. Steel Creek represents a sink into which the groundwater in the Barnwell and McBean Formations discharges. The incision of the Aiken Plateau by Pen Branch to the northwest and Steel Creek to the south creates a groundwater island for the Barnwell and McBean Formations. Thus, even if radioactivity is present in these formations in L Area, it could not migrate offsite.

Although radioactivity in the Congaree is unlikely, if present it could not move northwesterly past Upper Three Runs Creek, but would move toward the Savannah River to the south and southwest. Higher heads would prevent movement to the southeast or east.

2.5.5 Remedial Action

Groundwater monitoring will continue in the L-Area oil and chemical basin.

TABLE 2.5-1

Total Radioactive Disposals at the L-Area Oil and Chemical Basin, 1961-1982

Radionuclide	Total (Ci)	Decay Corrected (Ci)
^{3}H	34600	12900
^{35}S	0.016	-
^{51}Cr	0.67	-
^{60}Co	3.79	0.36
^{89}Sr	0.002	-
^{90}Sr	0.37	0.23
^{95}Zr, ^{95}Nb	0.23	-
$^{103,106}Ru$	35.9	2.5×10^{-4}
^{124}Sb	8×10^{-4}	-
^{131}I	4×10^{-4}	-
^{134}Cs	1.1×10^{-3}	9×10^{-5}
^{137}Cs	1.62	1.04
^{140}Ba, ^{140}La	3×10^{-4}	-
$^{141,144}Ce$	0.095	1×10^{-5}
^{147}Pm	1.98	0.014
Alpha (unidentified)	2.3×10^{-3}	
Beta-Gamma (unidentified)	1.6×10^{-3}	

TABLE 2.5-2

Radioactivity in Monitoring Wells for the L-Area Oil and Chemical Basin

Well No.	Monitoring Period	Activity* (pCi/L) Gross Alpha	Gross Beta	Radium
LCOB 1	1QR-82	-	-	<0.13
	2QR-82	-	-	0.69
	3QR-82	1	5	0.37
	4QR-82	2	14	1.64
	1QR-83	1	11	0.57
LCOB 2	1QR-82	-	-	<0.15
	2QR-82	-	-	<0.52
	3QR-82	0.3	3	<0.20
	4QR-82	1	4	<0.53
	1QR-83	0.3	3	1.13
LCOB 3	1QR-82	-	-	<0.15
	2QR-82	-	-	<0.61
	3QR-82	0.2	1	<0.20
	4QR-82	1	4	<0.36
	1QR-83	2	8	<0.15
LCOB 4	1QR-82	-	-	1.74
	2QR-82	-	-	<0.40
	3QR-82	1	2	<0.21
	4QR-82	2	2	<0.44
	1QR-83	1	4	0.33

* Data from RCRA monitoring program; see Volume I, Tables 6.0-1, 6.8-1, 6.8-2, 6.8-3, and 6.8-4.

2.6 FORD BUILDING SEEPAGE BASIN

2.6.1 Nature of Disposal

History and Inventory

The Ford Building seepage basin (Building 904-91G) has been used to dispose of small volumes of wastewater from the Ford Building (690-G), produced during the repair of slightly contaminated equipment from throughout the Plant. Date of basin construction is circa 1964. The basin has received 344,000 gal of liquid waste containing small amounts of radioactivity, as shown in Table 2.6-1.

Current Practices

The basin is currently in use, primarily for water containing very low levels of radioactivity from testing and repair of heat exchangers. Wastewater containing higher levels of activity is trucked to the separations areas for processing.

2.6.2 Local Groundwater Conditions

The Central Shops (CS) Area is at an elevation of about 290 ft; the elevation of the water table is about 270 ft. The water table gradient near the Ford Building seepage basin is to the southeastward toward Pen Branch. Available data indicate that the stratigraphic column at this location should be similar to that in F and H Areas. A regional map of head differences between the Tuscaloosa and Congaree Formations (Figure 3-27, Volume I) shows that a head reversal exists at the Congaree Formation, as there is in F and H Areas.

2.6.3 Groundwater Monitoring Program

Three groundwater monitoring wells were recently installed in the vicinity of the Ford Building seepage basin.

2.6.4 Evaluation of Impact on Groundwater Quality

The shallow groundwater beneath the basin is expected to contain minor amounts of radioactivity. However, this water outcrops to the surface before reaching the Plant boundary. Because of the head reversal present in this area, little potential exists for migration of radioactivity to the Tuscaloosa aquifer.

2.6.5 Remedial Action

The basin is currently in use, and no plans exist for remedial action.

TABLE 2.6-1

Total Radioactive Disposals at the Ford Building Seepage Basin, 1964-1982

Radionuclide	Total (Ci)	Decay Corrected (Ci)
^{3}H	468	175
^{60}Co	4.9×10^{-4}	4.5×10^{-4}
$^{89,90}Sr$	4.4×10^{-5}	4.3×10^{-4}
^{137}Cs	6.2×10^{-5}	6.1×10^{-5}
Alpha (unidentified)	1.6×10^{-5}	
Beta-Gamma (unidentified)	1.9×10^{-2}	

2.7 SEPARATIONS AREA RETENTION BASINS

2.7.1 Nature of Disposal

History

Earthen retention basins (Buildings 281-3F and 281-3H) were used at the separations areas from 1955 to 1973. These basins received and held water that possibly contained radioactivity. After analysis, water was either returned to the areas for further processing or released to seepage basins. During the holding period, some quantity of water seeped into the ground. In 1972-73, the earthen retention basins were replaced with lined basins which do not seep.

Current Practices

Lined retention basins which do not seep to groundwater are currently used. Lined basins are not discussed in this report.

2.7.2 Local Groundwater Conditions

Figure 2.7-1 shows locations of the earthen separations area retention basins. Because they are located on flow paths similar to seepage basin flow paths, the local groundwater conditions are the same. These groundwater conditions are described in Section 2.1.2.

2.7.3 Groundwater Monitoring Program and Results

Figure 2.7-2 shows the water table map at the earthen retention basins. In F Area, the flow path extending from the retention basin passes through the seepage basin area. In H Area, the flow path goes to the same receiving stream as the seepage basins. Thus, contributions from possible seepage from the retention basins will appear with seepage basin results. Only relatively small quantities of radioactivity are estimated to have seeped from the earthen retention basins.

2.7.4 Evaluation of Impact on Groundwater Quality

The earthen retention basins were used only intermittently. When they were used, water was held usually for short times (weeks), so that seepage time was short. Because of the low total quantities

of radionuclides involved, these basins probably released only very small quantities of radionuclides and chemicals to groundwater and thus have had a minimal impact.

2.7.5 Remedial Action

In 1981, soil that contained 11.5 Ci of ^{137}Cs and 0.5 Ci of ^{90}Sr was excavated from the bottom of the F-Area earthen retention basin. The basin was backfilled, finished with a crowned surface, and sown with grass seed. For the H-Area retention basin, similar work is planned but not yet scheduled. The H-Area basin contains an estimated 10-30 Ci of alpha and beta-gamma emitters and is maintained as a controlled, fenced area.

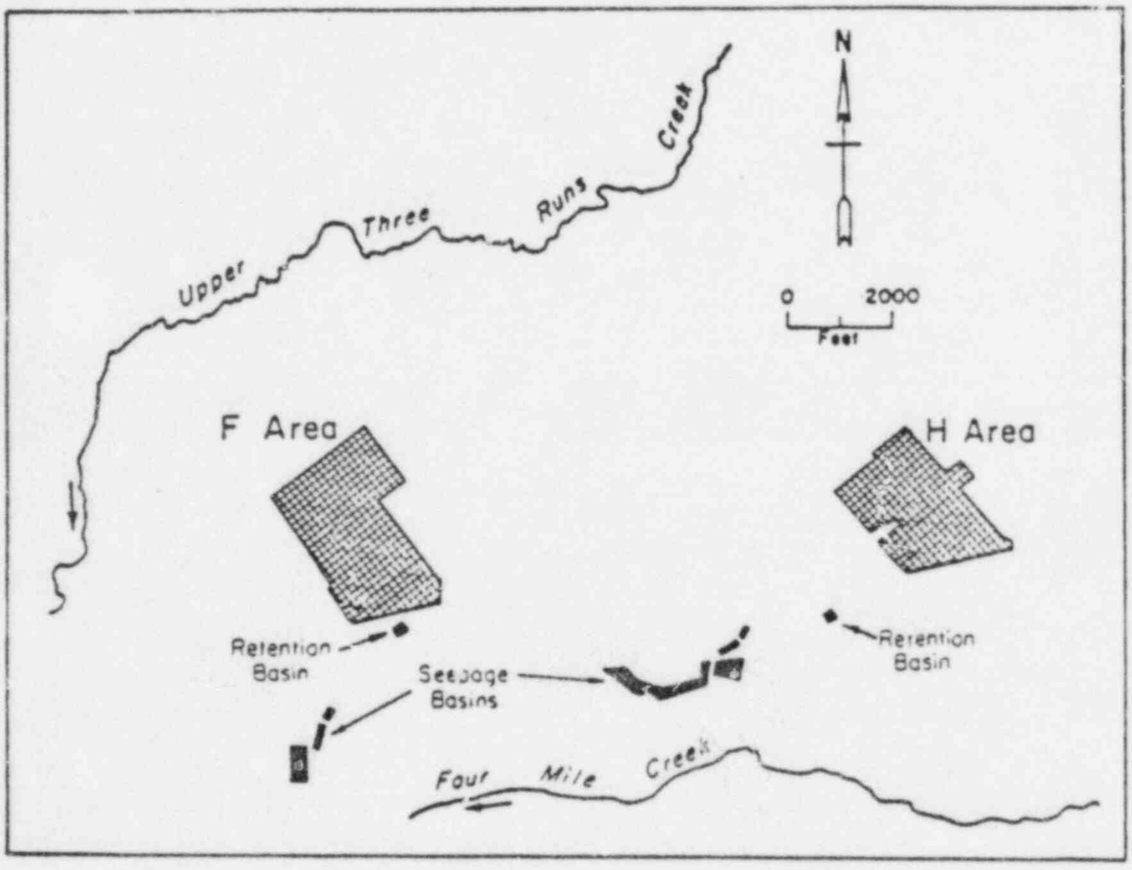

FIGURE 2.7-1. Location of Separations Area Earthen Retention Basins

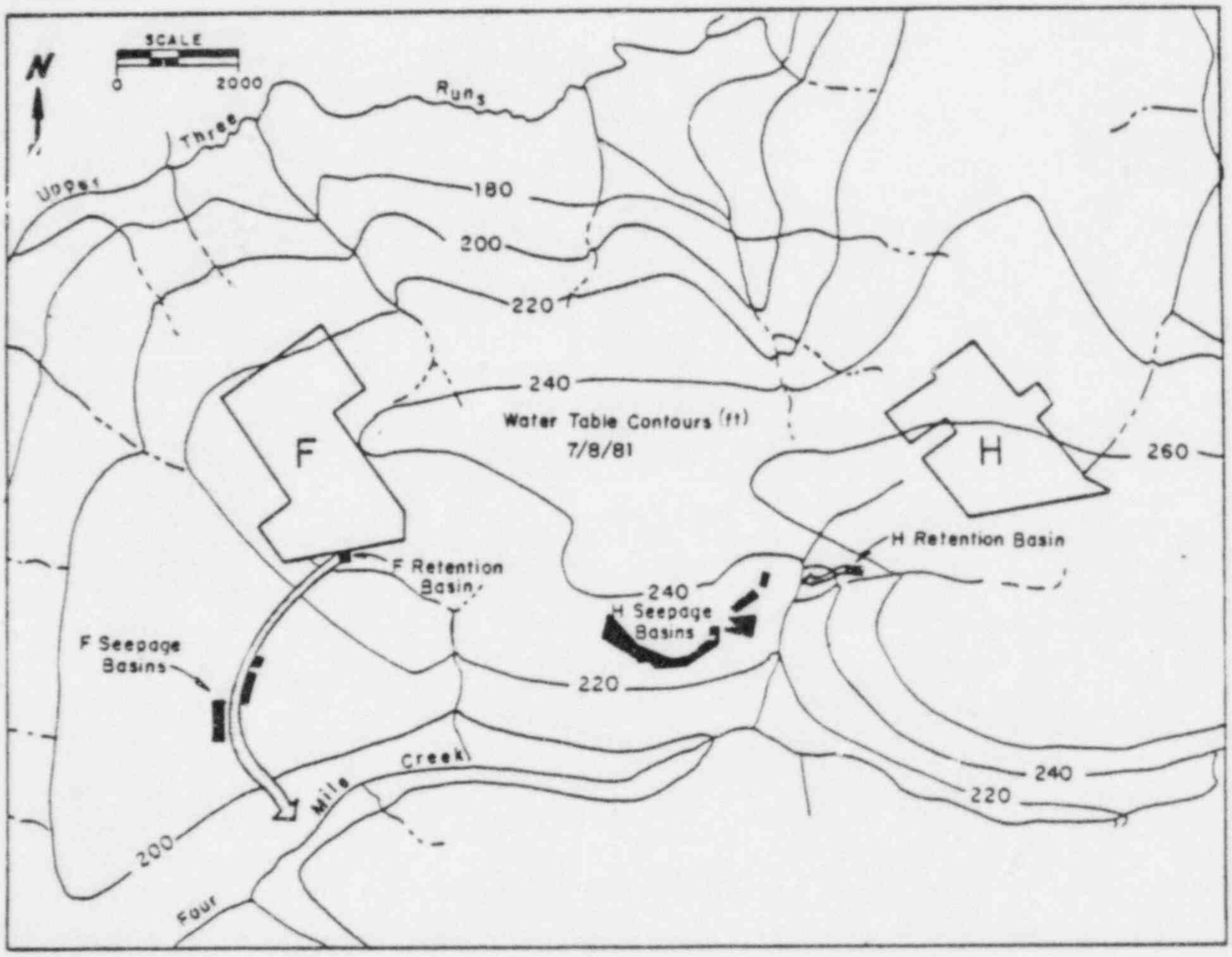

FIGURE 2.7-2. Retention Basin Flow Paths

APPENDIX A. ANALYTICAL METHODS FOR RADIONUCLIDES

Sample Collection and Analytical Procedures

Groundwater samples are generally withdrawn manually from monitoring wells, with a stainless-steel cup on a line. Each well has its own cup. Samples are transferred to polyethylene bottles for transport to a preparation laboratory and counting facility.

Streams are sampled continuously with a plastic water-wheel sampler suspended on two pontoons. As the wheel is turned by flowing water, a small cup (or cups) on one paddle picks up a sample of water and deposits it into a trough. The sampled water (up to 6 gal) flows by gravity from the trough through connecting tubing into a large polyethylene jug connected to the sampler.

Routine environmental water monitoring samples are analyzed for radionuclides at SRP by the following procedures. Research samples usually are analyzed by these or similar procedures. Special analytical procedures are available for other individual radionuclides.

Increased analytical sensitivity for water samples (containing insufficient radioactivity for direct processing) is achieved through concentration of radionuclides by ion exchange. The ion-exchange column is counted directly for gamma-emitting radionuclides.

Alpha- and Beta-Emitting Radionuclides are measured by direct count of the dried residue from 1 liter of water on a planchet. Alpha emitters are counted with a ZnS scintillation counter for 20 minutes, which gives a lower limit of detection of 0.25 pCi/L and precision (95% confidence level) of ±0.13 pCi/L. Beta emitters are counted with a gas flow proportional counter for 10 minutes, which gives a lower limit of detection of 7.1 pCi/L and precision of ±0.39 pCi/L.

Gamma-Emitting Radionuclides are measured by passing up to 25 liters of water through a cation-anion resin column and counting the column in a 9 x 9-inch NaI(Tl) well detector. The resin column is then eluted with nitric acid (first with 2N nitric acid and then with 14N nitric acid) for subsequent strontium analysis. For gamma spectrometry, the lower level of detection of a given radionuclide varies with the instrument background, the geometry and volume of sample analyzed, and number of radionuclides present in the sample.

^{90}Sr is recovered from an aliquot of the above eluate. The acid is evaporated to dryness and dissolved to 0.08N hydrochloric acid. ^{90}Y is stripped from the strontium using di-2-ethylhexyl phosphoric acid. Equilibrium of ^{90}Y is allowed over a 15-day

period; then the short-lived ^{90}Y daughter is stripped once again and transferred to a stainless steel planchet and counted in a gas flow beta proportional counter for 50 minutes. The lower limit of detection is 0.02 pCi/L, with precision of ±0.002 pCi/L.

Tritium is measured in water samples by distilling them and counting a 4-mL aliquot with a liquid scintillation spectrometer for 300 minutes. The lower limit of detection is 3 x 10^{-4} μCi/L with precision of ±1 x 10^{-5} μCi/L.

Data Evaluation

The counting facility performs approximately 100,000 radioanalyses on almost 20,000 samples annually. Two control samples (an internally spiked sample and a blank sample) are analyzed for every ten samples. Computer programs are used to calculate, store, and retrieve most radioactive and nonradioactive monitoring data and provide daily, monthly, and annual summaries of the data. Each analytical value is checked for reasonability by comparison with previous values. Daily computer printouts flag any value that is outside the minimum or maximum value of the previous year and also prints the previous average, maximum, and minimum values. Additionally, daily summaries include the four most recent previous values (regardless of sampling frequency). This method of reviewing data is helpful in screening for spurious results. The comparison of current monitoring data with earlier data also aids in evaluation of trends.

Quality Control

An internal quality control program is maintained by (1) monthly calibration of counting instruments, (2) daily source and background counts, (3) daily resolution checks and alignment of NaI and Ge(Li) detectors for gamma emitting radionuclides, (4) routine yield determinations of radiochemical procedures, (5) duplicate analyses to check precision, and (6) reagent blank analyses to check purity of all chemicals. Accuracy of radioactivity measurements is established by use of standards obtained from the National Bureau of Standards or their equivalent. Although most counting instruments are calibrated monthly, they are also calibrated if daily background or source counts do not fall within an acceptable range. Histories of the performance of each counting instrument are maintained in logbooks and, where applicable, on computer magnetic tape. Additional checks on accuracy are provided by participation in external quality control programs of the DOE Environmental Measurements Laboratory and of the U.S. Environmental Protection Agency.

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Volume 2 of 3

FINAL
ENVIRONMENTAL IMPACT STATEMENT

L-Reactor Operation Savannah River Plant

Aiken, S.C.

Volume 2

May 1984

U.S. Department of Energy

F.4.4 Effects of L-Reactor operation

As shown on Table F-10 in 1982 the pumpage at L-Area averaged only about 0.28 cubic meter per minute. When L-Area is operating, the pumping rate will be about 0.94 cubic meter per minute, slightly less than at the other operating reactors because there is no powerhouse located in L-Area. On two tests of pumping 2.8 cubic meters per minute one well (104L) had a drawdown of 8.2 meters and the other well (105L) had a drawdown of 12.2 meters; thus the average specific capacity is 0.27 cubic meter per minute per meter of drawdown. Thus, for a pumping rate of 0.94 cubic meter per minute a short-term drawdown of 3.5 meters would be expected in the pumping well (including well entrance losses). Calculated drawdowns in L-Area and in other SRP areas supporting L-Reactor operation are discussed in Sections 4.1.1.3, 5.1.1.4, and 5.2.3.

F.5 GROUND-WATER QUALITY

F.5.1 Natural ground-water quality

A detailed discussion of the natural ground-water quality of the hydrostratigraphic units is contained in previous sections of this appendix (F.2.1 to F.2.10). Chemical analyses are given in Tables F-2, F-4, and F-5. In general, the water in the coastal plain sediments is of good quality, suitable for industrial and municipal use with minimal treatment. It is generally soft, slightly acidic, and low in dissolved and suspended solids.

F.5.2 L-Area

Previous activities in L-Area have resulted in the discharge of radioactive and nonradioactive wastes into 10 basins and pits in and adjacent to the area. Currently only one of these sites is active (a rubble pit receiving solid waste that is neither radioactive nor hazardous).

Some contamination of the shallow ground water between the L-Area seepage basin and Steel Creek (about 600 meters to the southeast) is expected from the tritium previously discharged to the basin (about 3300 curies). Similarly minor amounts of strontium-90 are expected to have reached the ground water beneath the basin, but confirmation is presently lacking. Monitoring data from around the basin are not yet available; however, monitoring wells have recently been installed.

F.5.3 F- and H-Area seepage basins

Intensive ground-water monitoring studies around the F- and H-Area seepage basins have detected only tritium, strontium-90, and uranium in concentrations greater than 10 times the natural background. Companion studies have shown nitrate and mercury are also present.

Approximately 30 percent of the tritium discharged to the separations areas seepage basins evaporates to the atmosphere. The remaining tritium moves rapidly to the water table (at a depth of about 3 meters in H-Area and 15 meters in F-Area), and then moves at the same velocity as the ground water. In F-Area, the average flow rate of tritium from the basins to Four Mile Creek is estimated to be 0.15 meter per day (a travel time of 8.9 years to move 600 meters). Approximately 40 percent of the tritium decays before emerging in Four Mile Creek. Concentrations at seepline springs range from 40 to 60 microcuries per liter.*

TC

In H-Area, the flow rate of tritium from the seepage basins to Four Mile Creek is estimated to be 0.3 meter per day (a travel time of 1.1 to 3.8 years). Approximately 10 to 20 percent of the tritium decays before emerging in Four Mile Creek. Concentrations at the seepline springs range up to 40 microcuries per liter.

The maximum vertical penetration of tritium into the ground is about 15 to 20 meters, and throughout most of the distance from the basins to the seepline springs, the highest concentrations are 3 to 6 meters below the water table.

Strontium, unlike tritium, does not move at the same rate as ground water; its transport is retarded by the clay minerals in the Formation. Thus, it has been emerging into Four Mile Creek from F-Area only since about 1964, and from H-Area since 1959. The amount entering the creek annually is 2 percent of the ground-water load in F-Area and 0.19 percent of the load in H-Area. Under current conditions, F-Area is contributing about 40 times as much strontium to the creek as H-Area because of differing soil retention characteristics. Maximum concentrations of strontium-90 in ground water and emergent seep-lines range up to 0.34 microcurie per liter in F-Area, and 1.8×10^{-3} microcurie per liter in H-Area.

TC

Cesium is retained well by soils at Savannah River Plant, and none has migrated far enough to be detected in ground water between the separations areas seepage basins and Four Mile Creek. Alpha activity in ground water between the F- and H-Area basins and Four Mile Creek is attributed mostly to uranium discharged to the basin plus a small amount of natural radioactivity (plutonium is even more highly immobilized in SRP soils than cesium). Alpha concentrations in ground water and seepline springs range up to 6.5×10^{-3} microcurie per liter in F-Area and 7.5×10^{-6} microcurie per liter in H-Area.

Although most of the mercury released to the separations areas seepage basins is accounted for in the basin soil, studies made in 1971 on soils from the swampy outcrop along Four Mile Creek, bottom sediments, and of suspended solids from the creek show that mercury is slowly migrating into the creek (approximately 0.4 gram per day from both areas).

Nitrate and hydrogen ions are also migrating from the basins. Nitrate concentrations in the ground water measured in 1968 and 1969 ranged to 300 milligrams per liter in F- and H-Area. The pH of ground water in the vicinity of the

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*The EPA drinking water standard for tritium is 0.02 microcurie per liter.

basins is 4 to 6 compared to a pH range of 5 to 7 for natural ground water at Savannah River Plant.

Results of 1982 chemical analyses of ground-water samples from monitoring wells at F- and H-Area seepage basins are presented in Tables F-12 and F-13. The locations of these wells are shown in Figure F-34. | TC

F.5.4 M-Area

The M-Area settling basin was constructed in 1958 to settle out and contain uranium discharged in process streams from fuel fabrication facilities. The water discharged to the basin can best be characterized as a metal finishing-type process waste. The process discharges contain, among other things, uranium, aluminum, nitrate, nickel, and chlorinated organics; they can be classified as hazardous only because of the low pH. Waste effluents from M-Area operations have been drained to two process sewers. In May 1982 discharges to Tims Branch were discontinued and diverted instead to the M-Area basin, which now receives all process sewer flows except noncontact cooling water. Some of the process water released to this basin seeps into the ground, but most overflows the basin and seeps into the ground at Lost Lake (shown in Figure F-35). | EN-51

Extensive ground-water monitoring studies around M-Area have been conducted since volatile organics were discovered in the ground water beneath the M-Area basin in June 1981. The distribution of contaminants has been vertically and horizontally determined. A plume of chlorinated hydrocarbons extends about 1 kilometer southwest of the M-Area in 1983. The main body of this plume is moving slowly to the southwest (Figure F-35) at about 7.6 meters per year. Those studies establish that no volatile organics have migrated to the Plant boundary.

Contaminants in the soil beneath the M-Area basin have been characterized by the analyses of cores from coreholes drilled to a depth of about 5 meters below the bottom of the basin. Soil concentrations of lead and mercury ranged up to 125 and 0.16 milligram per kilogram (dry weight), respectively. In all cores, metal concentrations decreased with increasing depth beneath the basin and reached background values in the soil cores at or before 4 feet below the bottom of the basin.

Downward migration rates for metals were calculated using the corresponding depths at which the metal concentrations were equal to background values and a 24-year operation period since startup of the basin in 1958. The calculated migration rates were 0.04 meter per year for lead and 0.05 meter per year for uranium. At these migration rates and under the present operating conditions of the basin, these metals do not pose a significant problem for future contamination of the surrounding ground water. At the present rate of downward movement, it will take the uranium 700 years to travel the 37-meters distance to the ground water.

Soil concentrations of 1,1,1-trichloroethane, trichloroethylene ("triclene") and tetrachloroethylene ("perclene") ranged to 11, 90, and 2000 milligrams per kilogram (dry weight), respectively. However, migration rates could not be calculated because of wide variations in concentrations across the M-Area seepage basin.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
GEORGIA POWER COMPANY, et al.	)	Docket Nos. 50-424
	)	50-425
(Vogtle Electric Generating Plant, Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of (1) "Applicants' Reply to Intervenors' Response to Applicants' Motion for Summary Disposition of Contention 7," dated September 9, 1975, (2) "Affidavit of Walter R. Ferris," and (3) "Affidavit of Thomas W. Crosby and Lewis R. West" were served upon those persons on the attached Service List by deposit in the United States mail, postage prepaid, or where indicated by an asterisk by hand delivery, this 9th day of September, 1985.

David R. Lewis

Dated: September 9, 1985

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	)	50-425
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Units 1 and 2)	)	

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