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NEW LOW-LEVEL RADIOACTIVE WASTE STORAGE/DISPOSAL FACILITIES AT THE SAVANNAH RIVER PLANT

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ABSTRACT

Site selection, alternative facilities, and alternative operations are described for a new low-level solid radioactive waste storage/disposal operation at the Savannah River Plant. Performance assessments and cost estimates for the alternatives are presented.

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NEW LOW-LEVEL RADIOACTIVE WASTE STORAGE/DISPOSAL FACILITIES AT SRP

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SUMMARY

Siting, facility, and operational alternatives are described for a new low-level solid radioactive waste storage/disposal operation at the Savannah River Plant. Performance assessments and cost estimates are also provided.

Site Selection

Three candidate sites meet the performance criteria for waste storage/disposal operations. The sites are Site G (200 acres directly north of the present low-level waste disposal site 643-7G), Site B (300 acres northeast of H-Area), and Site L (100 acres southwest of F-Area).

Facility Alternatives

Storage or disposal facility options that can be used for different operational alternatives are: shallow land burial (called near surface disposal by the NRC), greater confinement disposal in trenches or in boreholes, above grade operation, above or below grade vaults, engineered storage, and engineered disposal.

The quantity of solid low-level waste to be stored, treated, or disposed of is about one million cubic feet annually at SRP. Pretreatment options such as reduction in the waste generation rate, volume reduction, waste stabilization, and waste containerization are described.

Seven major operational alternatives are:

ALTERNATIVE 1: PRESENT OPERATIONS AT NEW SITE

The present method of near surface disposal would be continued at an alternative site. Current operations consist of: trench disposal, greater confinement disposal in boreholes or a demonstration trench, disposal of low activity waste in metal containers that are stacked in an engineered low-level trench, and retrievable storage of contaminated but reusable equipment.

ALTERNATIVE 2: NEAR SURFACE DISPOSAL WITH EXCEPTIONS

Near surface disposal of low-level waste would continue at an alternative site as described in Alternative 1, but tritiated waste would be segregated for decay-in-place storage, and carbon-14 and iodine-129 waste would be segregated and stored.

ALTERNATIVE 3: COMBINATION OF FACILITIES

A combination of facilities especially suited to the SRP waste streams would be used. Examples of these facilities are: disposal of high activity waste in above or below ground vaults that have percolate water collection, or greater confinement disposal in engineered boreholes or trenches with percolate water collection systems; disposal of low activity waste in above or below ground vaults, or in above grade operations; a storage facility for tritiated waste to allow for decay-in-place; and retrievable storage of waste containing long-lived radionuclides like carbon-14 and iodine-129. Waste treatment to reduce volume or stabilize the waste, for example, would be emphasized.

ALTERNATIVE 4: ENGINEERED STORAGE

All waste would be stored in a combination of storage facilities -- boreholes, concrete bunkers, shielded cells, and storage buildings, for example -- depending on the radiation level of the waste. This alternative is similar to the waste storage operation at the Ontario Hydro facilities in Canada.

ALTERNATIVE 5: ENGINEERED DISPOSAL

High activity waste would be disposed of below ground in concrete monoliths with complete percolate water collection. The monoliths would be designed to be rigid engineered structures; a thick concrete pad is provided to cover the monoliths at the ground surface level. Low activity waste would be disposed of in containers on the concrete pads above the monoliths. Pads would be provided with a percolate water collection system. The above ground waste would be stabilized before being placed in containers. The stabilized containers would be covered with gravel and soil, and a low permeability cover would be added when the facility is closed. This design would be similar to that at the French facility for low-level waste disposal at Centre de la Manche near Cherbourg, France.

ALTERNATIVE 6: VAULT DISPOSAL OF UNTREATED WASTE

In this alternative, all of the waste would be placed untreated in an above or below grade vault and stabilized in place with grout. Vaults for high activity waste would have a percolate water collection system. The intent of this alternative would be to simplify waste treatment and emplacement methods as much as possible but still provide a final stabilized waste form.

ALTERNATIVE 7: NO ACTION

The present waste management practices would be continued at the present disposal site, and no new site would be developed. This alternative is not a viable option because the present site is nearing the end of its useful lifetime. It is not considered further in the performance assessments or cost estimates.

Alternatives 3, 4, 5, and 6 would be designed to have virtually no impact on ground water. Percolate water would be collected and monitored, and if monitoring results were above established limits the percolate water would be treated, stabilized, and disposed of in the facility or treated as low-level liquid waste in a separate facility.

Environmental monitoring requirements, closure alternatives, and site suitability for the different disposal operations also are discussed.

Performance Assessment

Long-term performance of the operational alternatives described above is discussed. Concentrations of radionuclides in well water, Upper Three Runs Creek wetlands, Upper Three Runs Creek, and the Savannah River were calculated for a period of 10,000 years after site closure. Particular emphasis was given to the first 1000 years. In addition, fifty-year whole-body dose commitments were determined for individuals in the general offsite population and for site intruders after the period of institutional control.

The impacts of radionuclides released from the facilities into the groundwater system were compared to the USEPA 4-mrem annual dose limit for drinking water and the DOE Interim Derived Concentration Guides for effluent streams. The drinking water limit was applied to the boundary well results and to the Savannah River results, while the concentration guides were applied only to the surface waters.

Tritium, most fission products, and activation products are beta-gamma emitters that have modest to short half lives. The time dependence of radionuclide concentrations at receptor locations reflects a complex interplay of leach rate, retardation, decay, and source term distribution. These short-lived species tend to exhibit distinct global maxima in concentration whereas long-lived species usually exhibit broad plateaus. Of the beta-gamma emitters, only short-lived tritium and long-lived technetium-99 have potentially significant impacts on the groundwater.

The long-lived alpha-emitting radionuclides behave much like nonradioactive species. In most cases, these radionuclides have moderate to large site equilibrium sorption coefficients and also have extended leach times. Thus, the concentrations of these isotopes will eventually build up to plateau values at each receptor location - the well, creek, and river - but usually at times greater than 1000 years after closure, and in some cases beyond 10,000 years after closure. These concentration plateaus may last for hundreds of years to tens of thousands of years, depending upon the radionuclide-specific leach times. Two short-lived alpha emitters, plutonium-238 and plutonium-241, have large sorption coefficients, so that the concentrations at the distant receptor locations are reduced to very low levels by the processes of redardation and decay.

The boundary-well pathway dominates the projected impacts. None of the other pathways - surface waters, the intruder food pathway, or direct gamma exposure - produce discernible impacts. For the boundary well, six radionuclides are of concern - tritium, the four uranium isotopes, and plutonium-239. All six species give doses greater than or equal to 4 mrem in one or more of the alternatives.

The tritium dose is largest for Alternative 1. The impact of tritium at the boundary well can be reduced by using the waste management practices of Alternatives 2, 3, 5 and 6. The exclusion of major tritium waste streams from the facilities or the use of improved waste forms and/or engineered barriers greatly reduce the projected doses from tritium in these alternatives.

Because of the large source terms, the very long half-lives, and the lack of solubility controls in the initial calculations, significant concentrations were initially estimated for uranium-234, 235, 236, and 238 in the groundwater at the boundary well. Uranium chemistry is quite complex, and it is likely that some sort of solubilty limit exists for uranium in the site environment. As a point of comparison, the uranium calculations were repeated with a total uranium solubility limit of 100 ppb. This value is representative of what might be expected in the environment, but it has not been established as the SRP site value. The resulting uranium doses are significantly lower when calculated with this solubility limit. The solubility of uranium in the site groundwater environment may be a major controlling factor in the release of the uranium isotopes to the biosphere.

Application of either the 4-mrem EPA drinking water standard or the DOE Derived Concentration Guides suggests that there are no discernable radiological impacts on the individual offsite user of Savannah River water. There is a small but finite collective risk to a population of 100,000 people who use the water.

Direct gamma exposure to an intruder who builds a house on the site was estimated. Immediately after the end of institutional control, the total direct gamma dose to the intruder is 4.4×10^{-4} mrem/yr. This is a peak value because decay continually depletes the source term.

The peak doses attributed to the ingestion of radionuclides via the intruder garden are below 0.002 mrem.

None of the facility alternatives produce a significant ecological impact. The DOE Derived Concentration Guides are not exceeded for any individual radionuclide or combination of radionuclides at any of the surface water receptor locations.

Risks to an onsite intruder, to an offsite individual, and to a population have been estimated. As expected, the greatest risks are those associated with the boundary well. The offsite individual is subjected to only infintesimal risks. In a downstream population of 100,000, the maximum risk resulting from one year's uptake of river water is only $1x10^{-5}$ excess deaths in the entire population.

Cost Estimates

Engineering cost estimates show a range from $350 million for Alternative 1 to $706 million for Alternative 4. These are total facility life costs expressed in constant 1985 dollars. The cost for Alternative 4 is highest because of the long term maintenance cost associated with storage, as well as because of high construction costs.

Initial facility costs range from $25 million for Alternative 3 to $42 million for Alternative 4. These are estimates of start-up costs that include site preparation, construction of facilities for two years of disposal or storage, and operating costs for the first two years.

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1. SITE SELECTION PROCESS FOR A NEW LOW-LEVEL RADIOACTIVE WASTE STORAGE/DISPOSAL FACILITY AT THE SAVANNAH RIVER PLANT

1.1 SITING ALTERNATIVES

1.1.1 Region of Interest

The first step taken in selecting a site for a new radioactive waste storage/disposal facility is to assume that the waste would continue to be disposed of at the Savannah River Plant. Thus the region of interest is taken to be the 300 square miles of the Savannah River Plant site.

1.1.2 Initial Screening

1.1.2.1 Screening Criteria

The subsurface geology and hydrology of the SRP site were evaluated for areas especially favorable for disposal and storage of low-level radioactive waste. Seventeen potential sites were identified for consideration, and the more favorable were subjected to more site specific geologic and hydrologic investigations including test borings to define the geohydrology. More extensive hydrologic studies to evaluate groundwater flow directions and velocities will be conducted to further characterize the three sites identified as being best suited to host the new facility. The top rated site will be proposed as the location for a new facility for storage/disposal of low-level radioactive waste.

The criteria established and applied in the identification of potential sites consider both economic and geotechnical constraints. However, since one evident mode of migration of radioactive nuclides from a disposal/storage site to the biosphere is through soil moisture and groundwater movement, the geohydrology of the site becomes an important consideration in site selection. Maximizing the retention capabilities of a geologically well chosen site can be accomplished through engineering design and construction techniques.

In humid regions such as South Carolina, the water table is a subdued expression of the land surface. The water table is always highest in elevation in the interstream areas and lowest in elevation in the stream valleys. Water in the form of precipitation enters the ground on the interstream areas of the Aiken Plateau and discharges in the low areas of the stream valleys.

Valleys of streams that are tributaries to the Savannah River at SRP are asymmetrical. The slope of the northwest side of the valley is gentle, being approximately 0.008, whereas the slope of the southeast side is steep being approximately 0.08. (These features are present only on those major streams that flow NE to SW as tributaries to the Savannah River do. They are not present on the smaller tributaries to the major streams that flow NW or SE.) These factors have a large influence on depth to the water table from the ground surface. However, the depth to the water table depends on the relative slope of the land surface versus the slope of the water table. Thus the greatest depth to the water table will occur below the tops of "cliffs", i.e., on the southeast flanks of the stream valleys tributary to the Savannah River. Figure 1.1-1 illustrates the principles just discussed.

Balanced against maximizing the depth to the water table is maximizing the distance to surface streams. Thus it may be prudent not to place the low-level waste storage/disposal site right at the lip of the "cliff" even though this would maximize the depth to water. Considerations of erosion and distance to the surface stream would dictate that the site be farther from the edge of the "cliff".

Criteria considered in the identification of potential sites include:

- Remoteness from Plant boundaries.
- Convenience to waste generators, transportation, and utility lines.
- Relatively flat topography to minimize erosion potential.
- Maximum reasonable horizontal and vertical distance to surface streams to increase the flow path and time of travel of subsurface water. This criterion also reduces the potential for flooding.
- Low hydraulic conductivities and hydraulic gradients to increase the time radionuclides spend in the disposal site area and therefore maximize radionuclide decay.
- Maximum distance between the bottom of the waste and the water table because horizontal travel in the ground does not begin until the radionuclides reach the zone of saturation.
- Minimum depth to water table should be on the order of 50 to 60 feet to allow placement of the waste above the zone of water table fluctuation while allowing for a minimum soil cover of 15 feet (5m) over the waste after placement.
- Sufficient areal extent (approximately 200 acres) to accommodate existing and projected waste inventories.

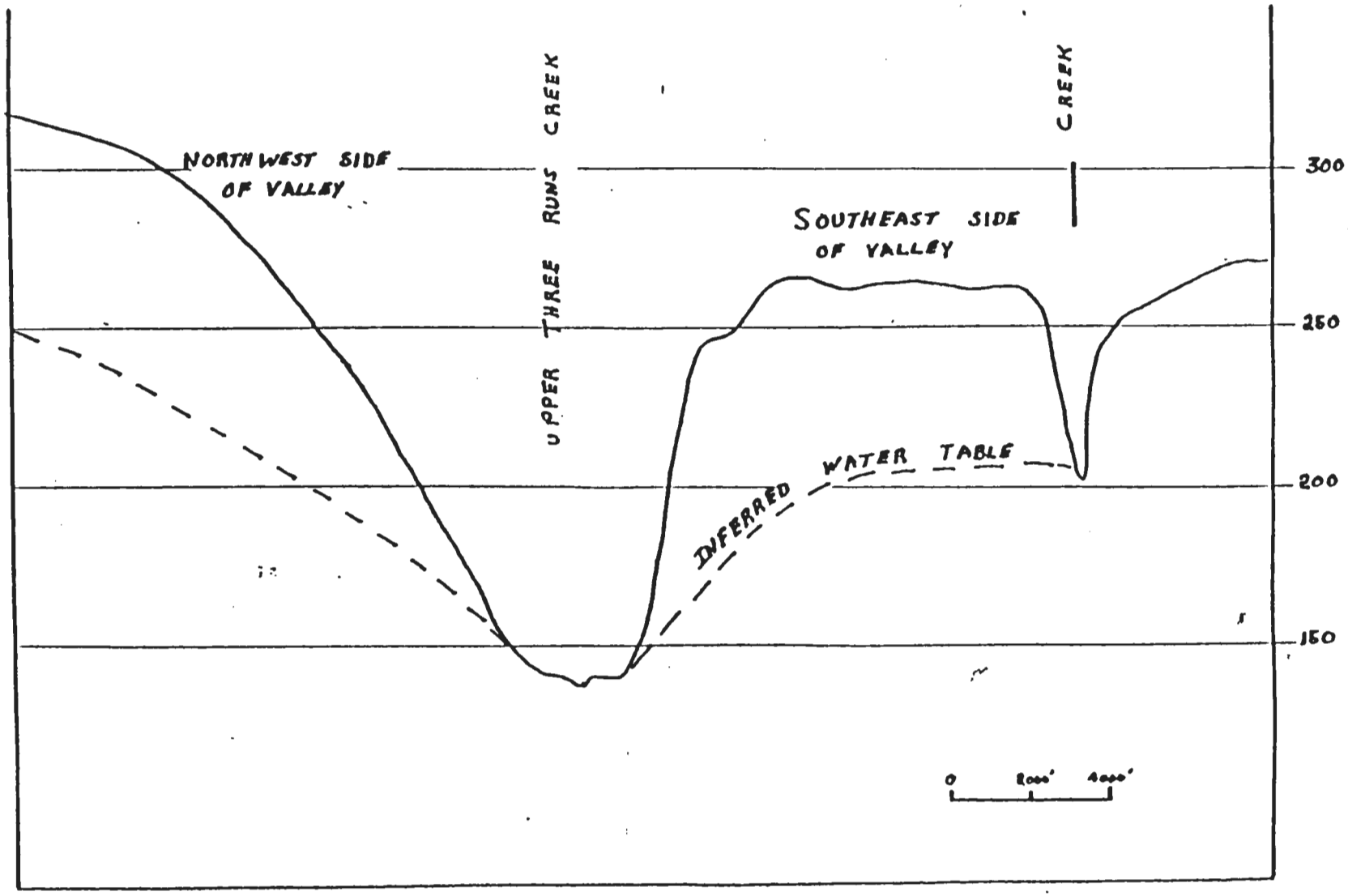

Figure 1.1-1 Hydrologic Principles

1.1.2.2 Identification of Potential Storage/Disposal Sites

Seventeen sites were identified by the criteria and principles discussed above. Existing data from topographic maps, monitoring wells, and water table maps were used. The approximate locations of the 17 sites, herein designated sites A-Q, are shown on Figure 1.1-2 (Savannah River Plant Site Map). More detailed locations and physical features for each of the seventeen sites are shown on Figures 1.1-3 through 1.1-12. A brief description of each site is presented below.

SITE A

Site A is located north of the intersection of Roads 2-1 and 2-1.1, west of Road 2-1.1 (Figure 1.1-3). The site is in an interstream area between two major streams, Upper Three Runs Creek and Tinker Creek. At the closest point the site is approximately 2500 feet east of the main channel of Upper Three Runs Creek and about 6000 feet west of the main channel of Tinker Creek, and some 14,000 feet (2.6 miles) north-northeast of the confluence of the two streams. The proposed site covers an area of approximately 135 acres (3000 feet x 2000 feet) with ground surface elevations ranging from about 280 to 350 feet above mean sea level. The western periphery of the site is about 1000 feet from the edge of a bluff which slopes steeply to Upper Three Runs Creek. The slope from the eastern side to Tinker Creek is relatively gentle. No standing or flowing surface waters are observed. No water table data are available.

SITE B

Site B is a rectangularly shaped area approximately 7300 feet long and 1800 feet wide occupying some 300 acres partly in Aiken County and partly in Barnwell County. The site is located parallel to Road E-2.1 about 11,000 feet (2.1 miles) northeast of H Area (Figure 1.1-4). Tinker Creek is located 5500 feet west at the closest point. Unnamed tributaries of Tinker Creek are located about 1000 feet to the west. Topographically the site is relatively flat with elevations ranging from 300 to 330 feet above mean sea level. No evidence of standing or flowing surface water is observed on a traverse of the site. Three borings have recently been drilled and piezometers installed as part of a site selection and evaluation study to determine the location of a non-radioactive hazardous waste landfill. The three borings were drilled to depths of 70.5 feet, 65.5 feet, and 70.5 feet. The borings indicate primarily fine to medium sand with varying amounts of clay to the depths explored. Depth to waters ranged from 54.6 feet to 65.0 feet below ground surface.

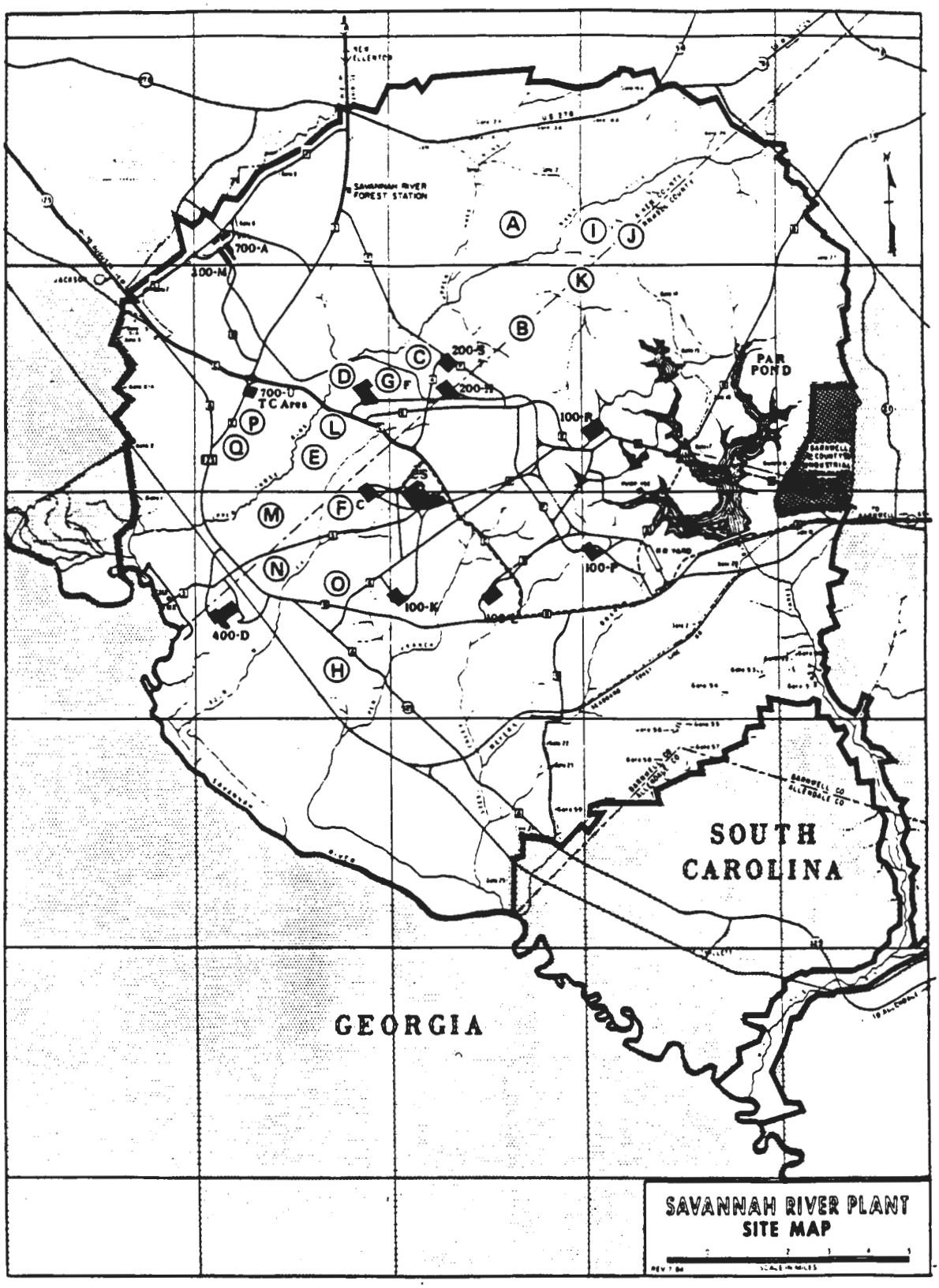

Figure 1.1-2 Potential Waste Disposal Sites

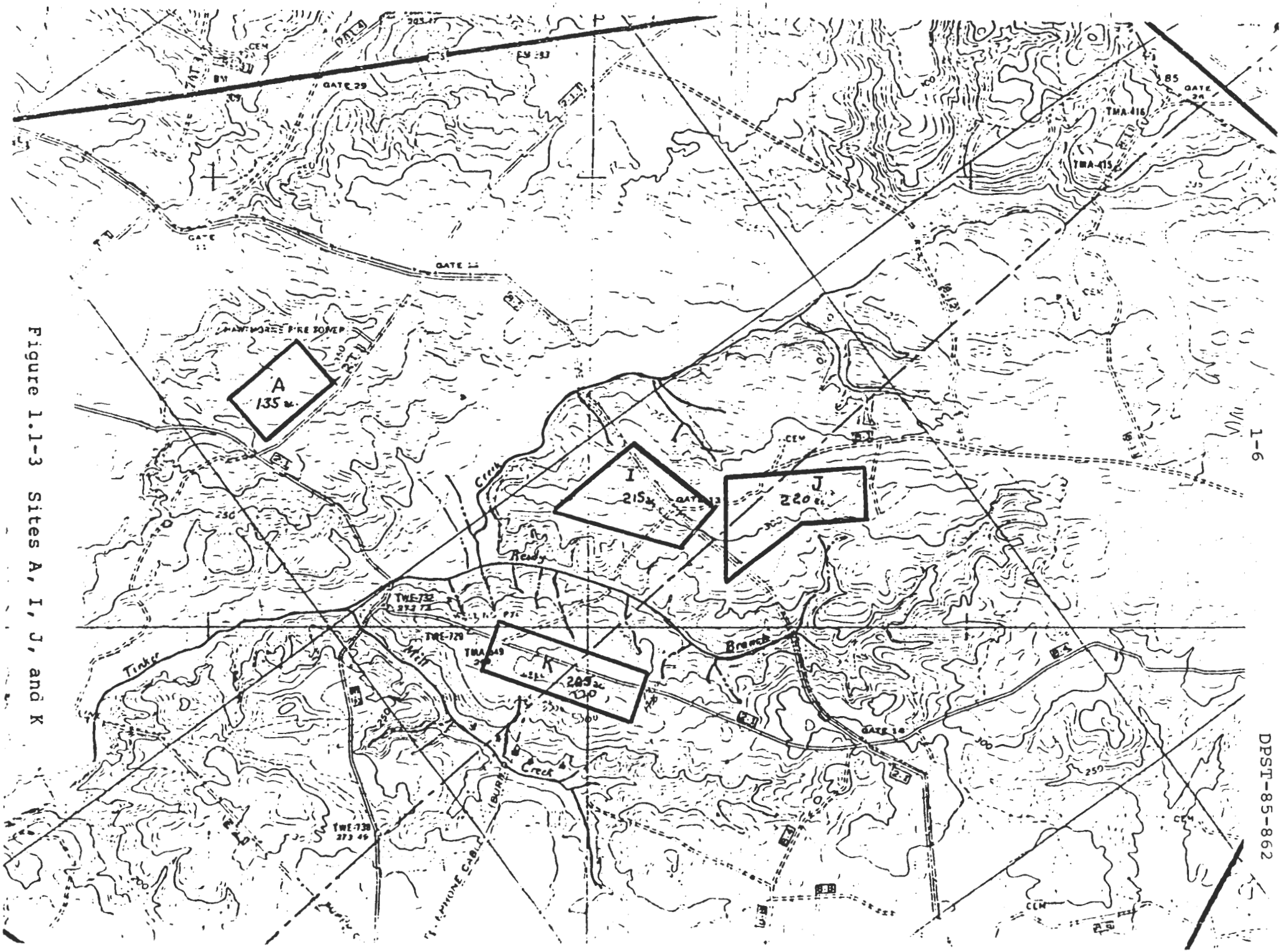

Figure 1.1-3 Sites A, I, J, and K

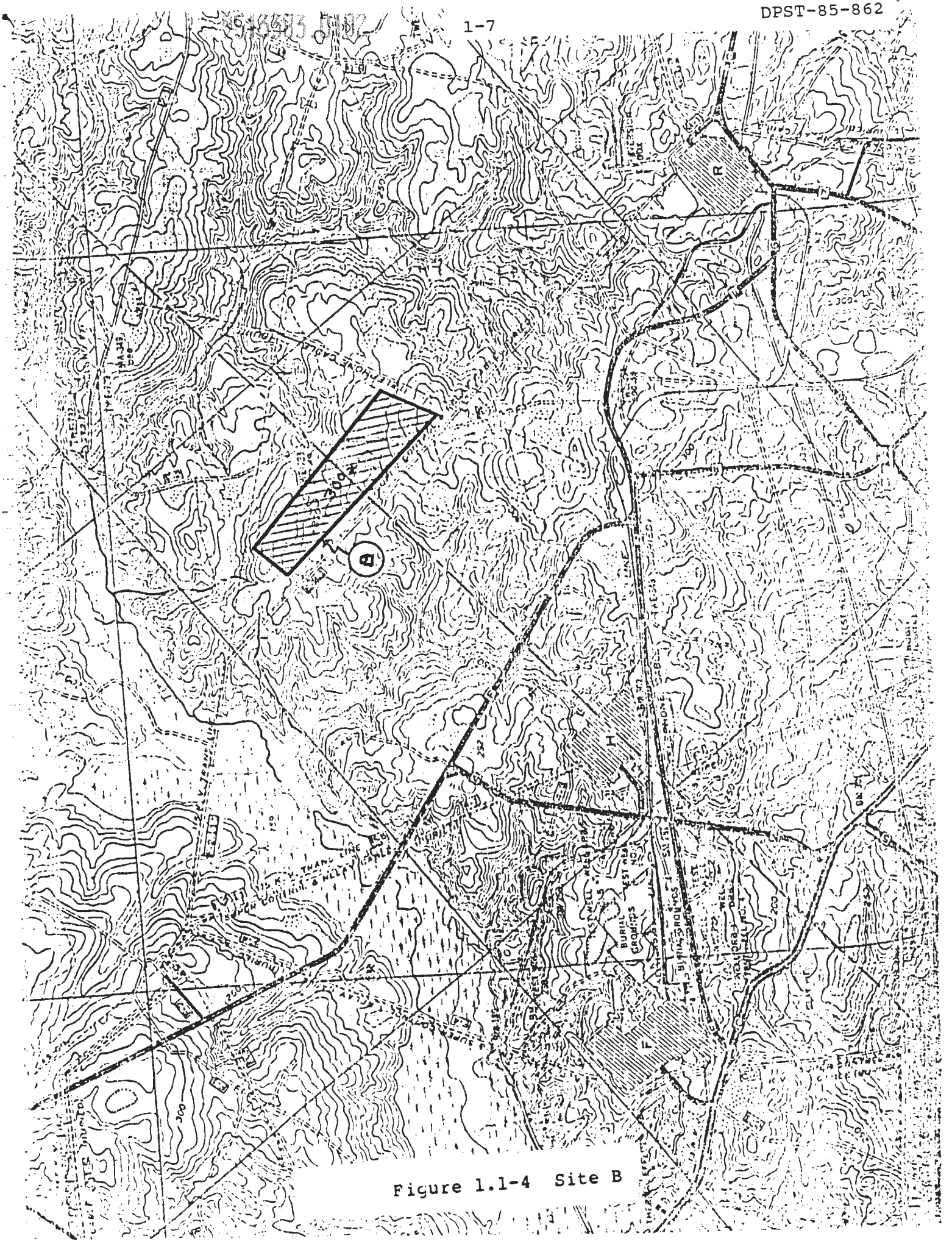

Figure 1.1-4 Site B

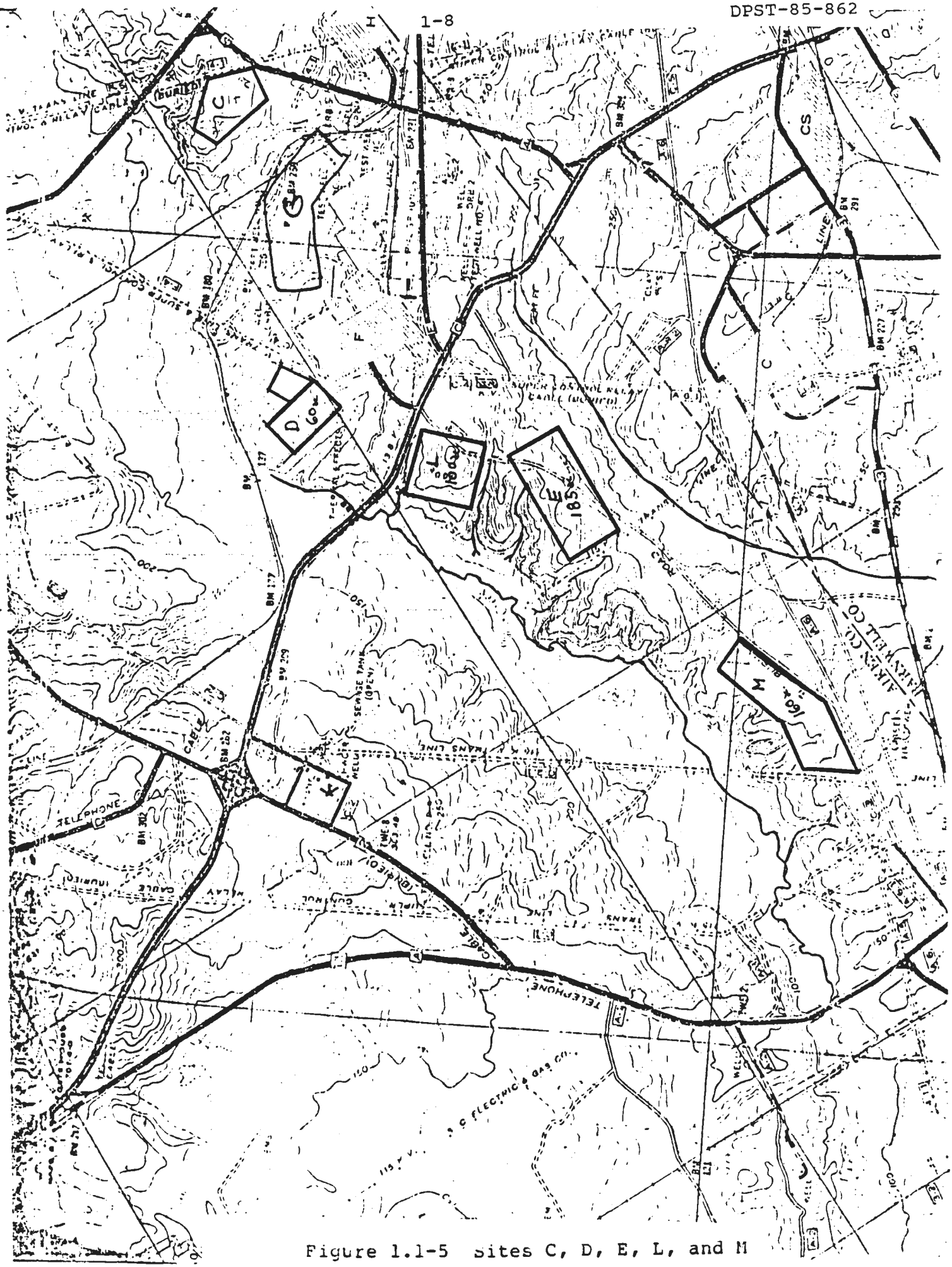

Figure 1.1-5 Sites C, D, E, L, and M

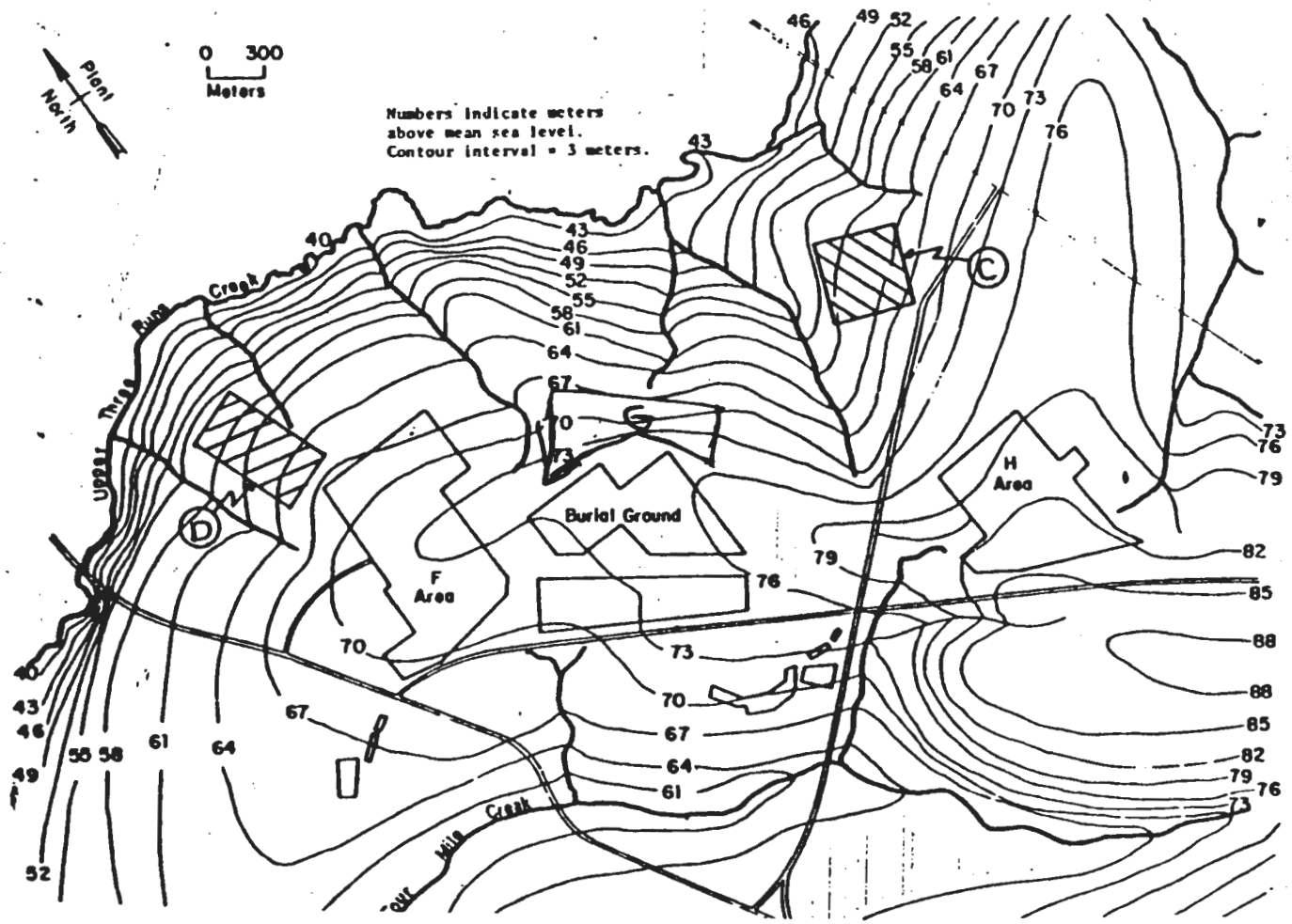

Figure 1.1-6 Average Elevation of the Water Table and Sites C, D, and G in 1968

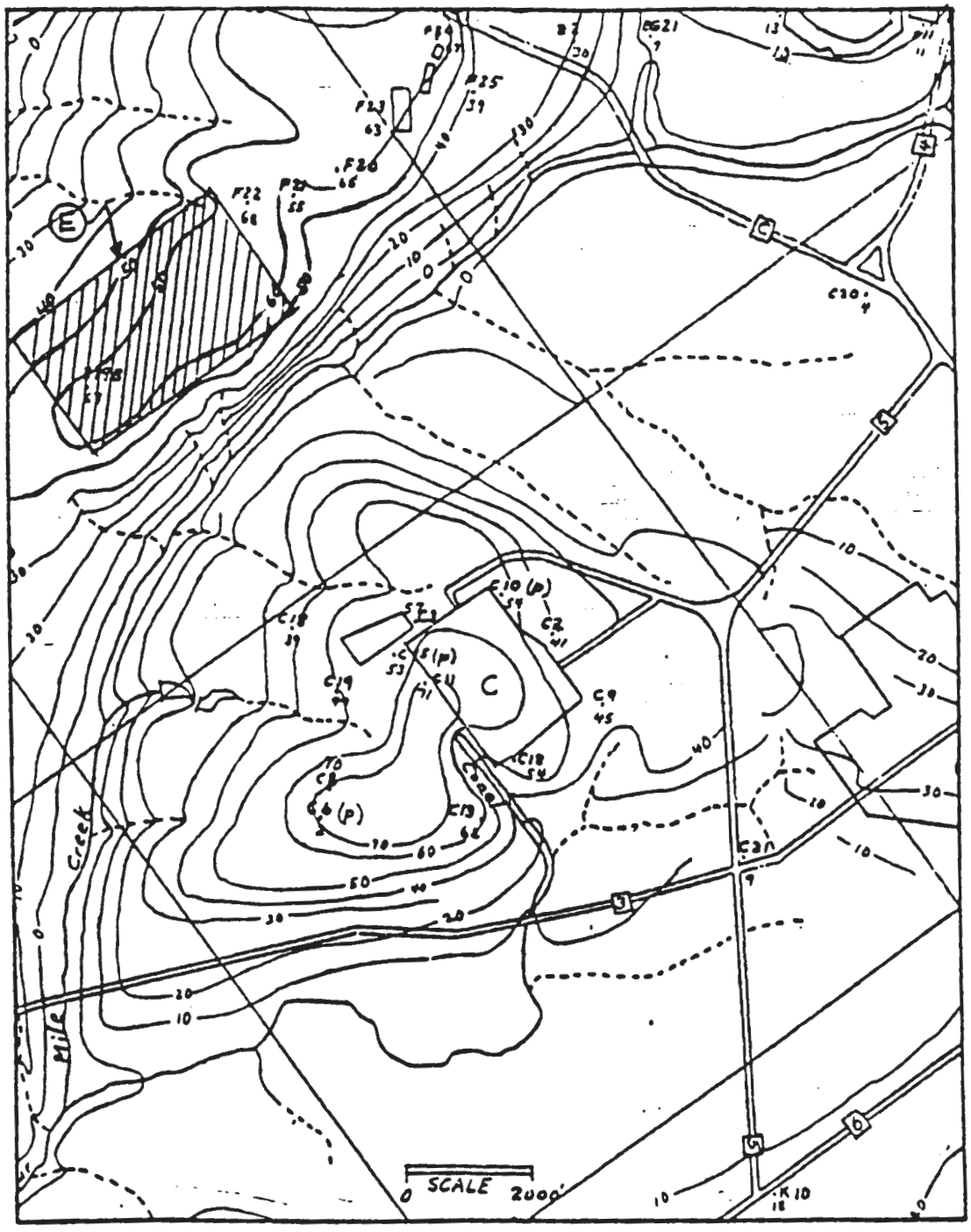

Figure 1.1-7 Depth to Water Table, Site E (April, 1965)

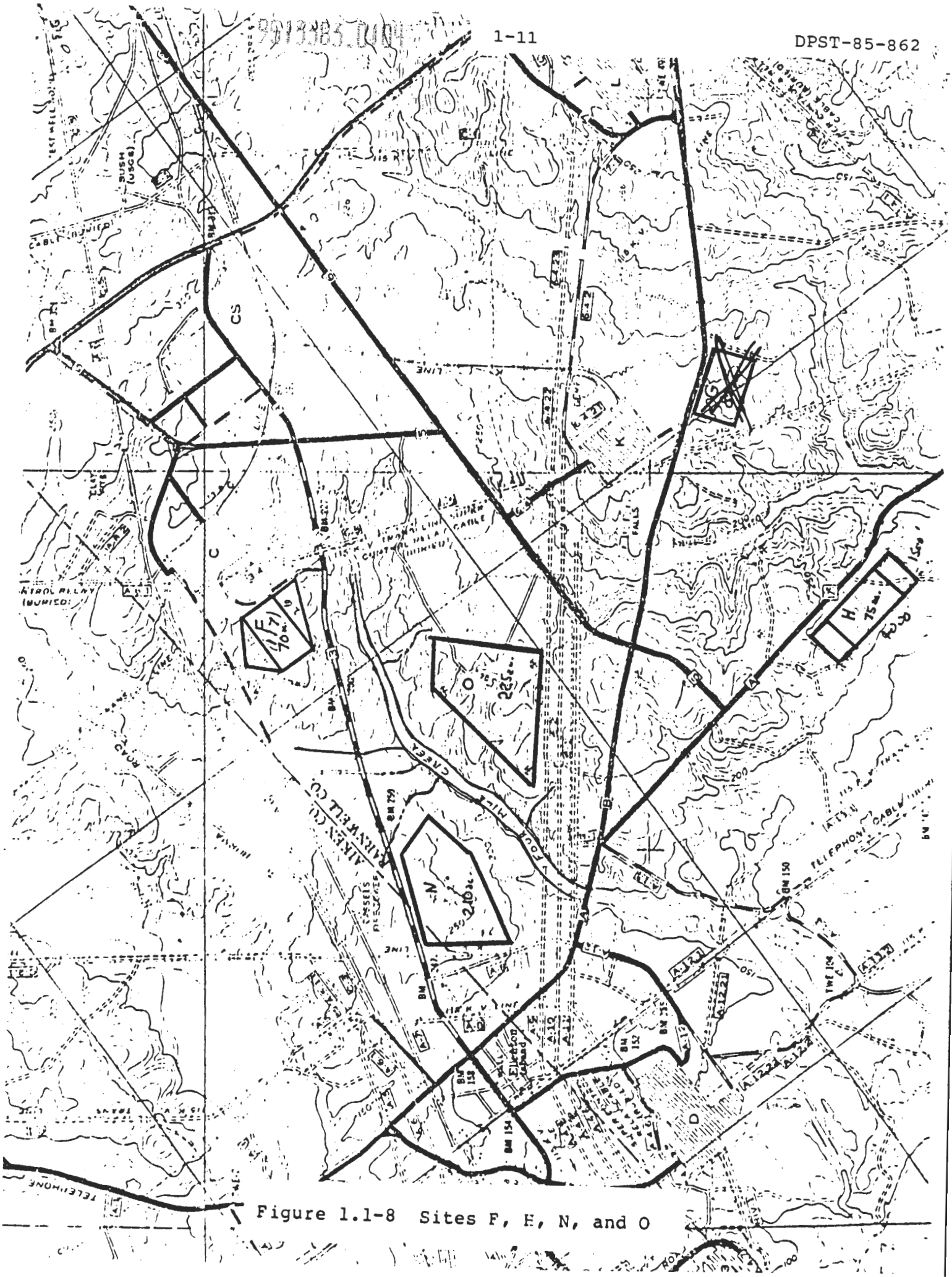

Figure 1.1-8 Sites F, H, N, and O

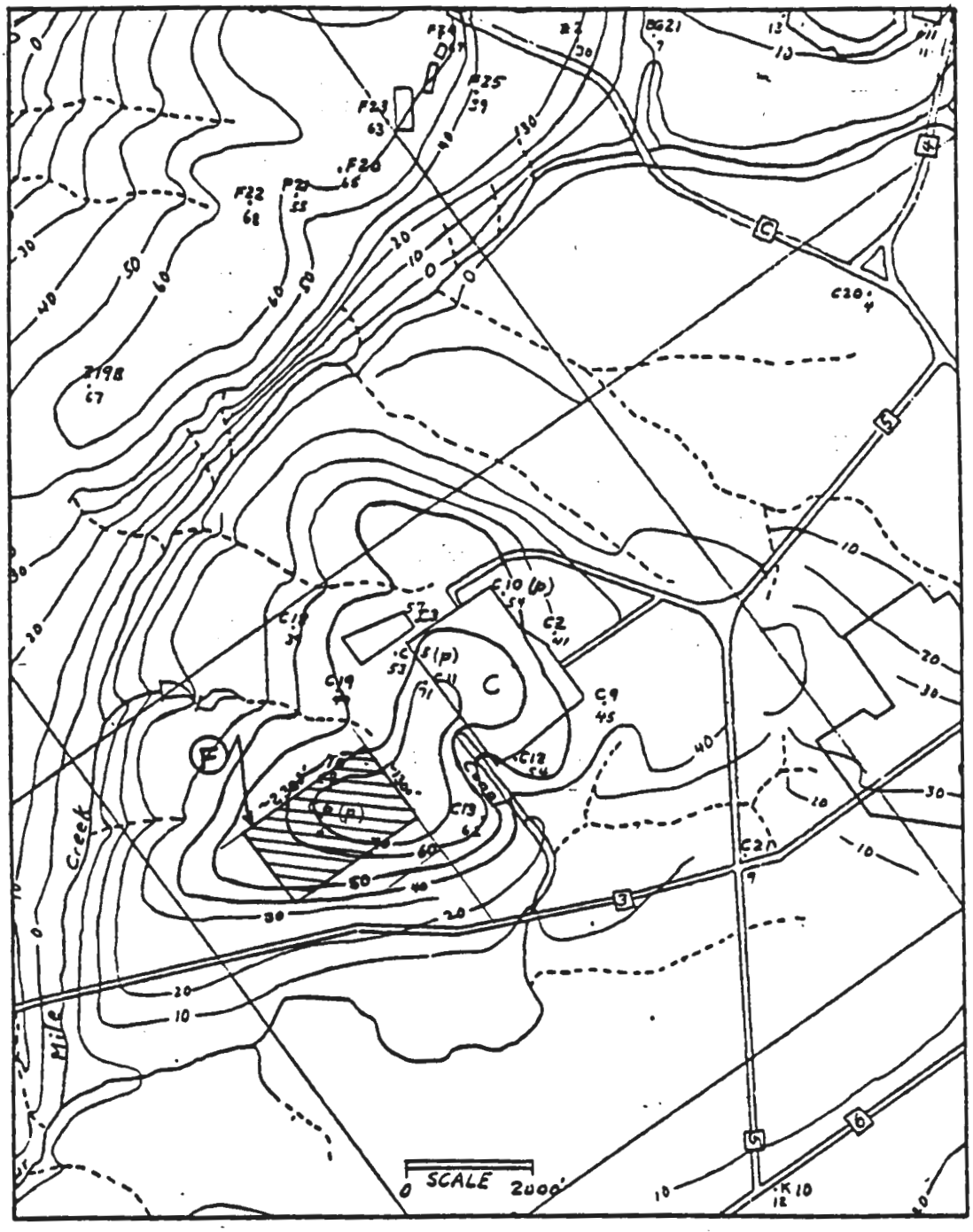

Figure 1.1-9 Depth to the Water Table, Site F (April, 1965)

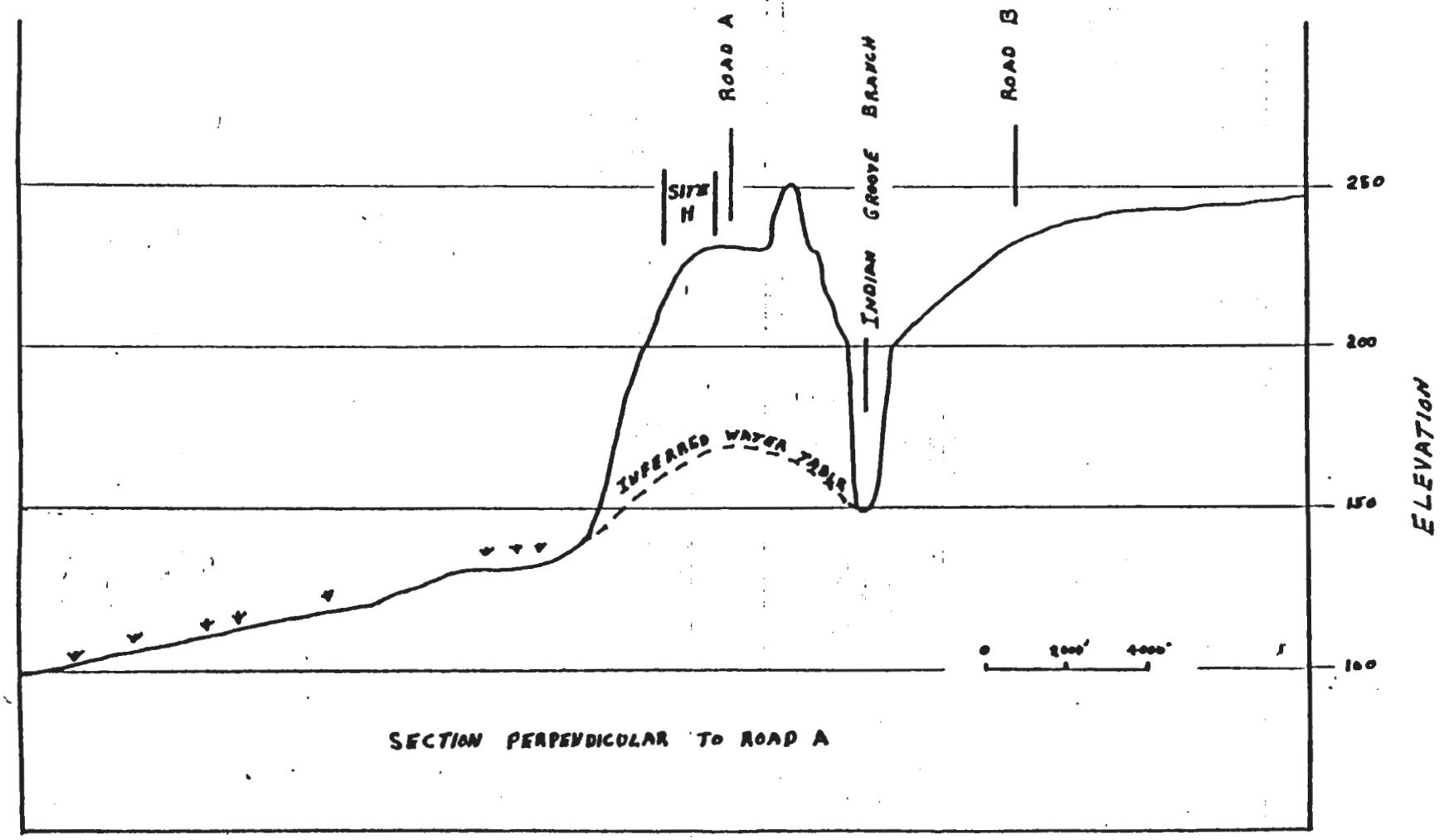

Figure 1.1-10 Cross Section, Site H

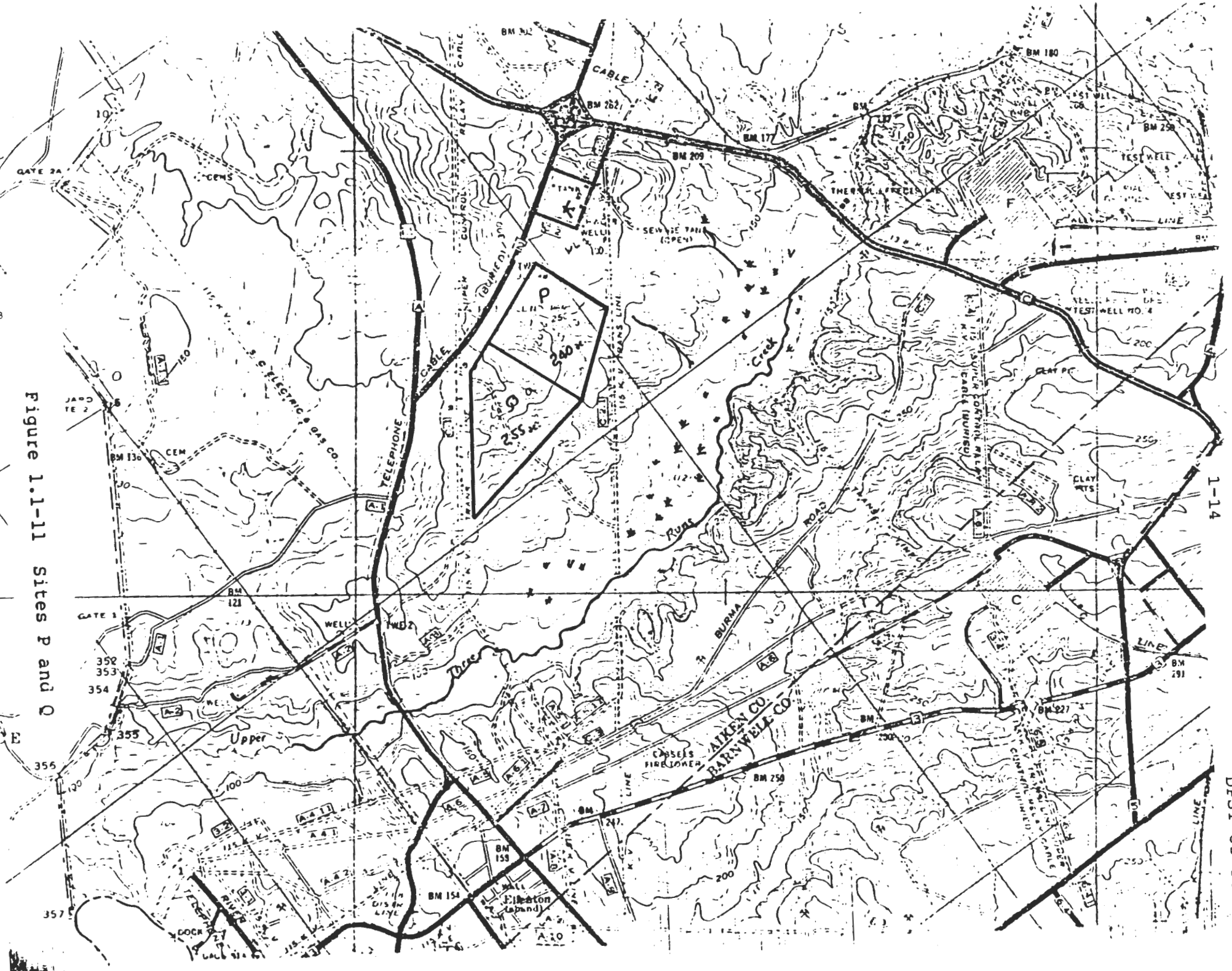

Figure 1.1-11 Sites P and Q

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20 X 20 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

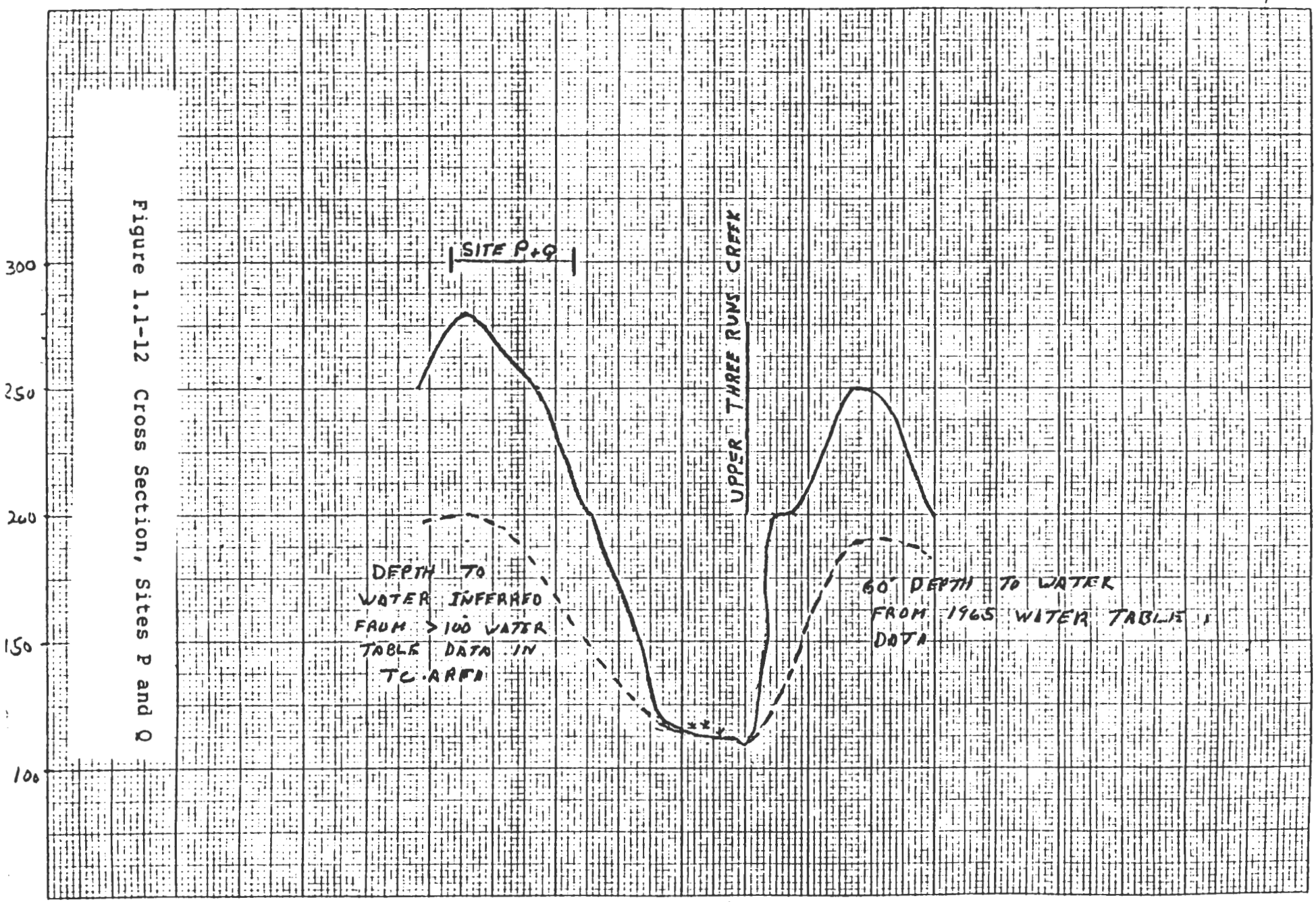

Figure 1.1-12 Cross Section, Sites P and Q

SITE C

Site C is located west of Road F approximately 3000 feet from H Area and 1500 feet east of Upper Three Runs Creek and 500 feet west of an unnamed flowing stream (Figure 1.10-5). This site encompasses an area of about 90 acres. Topographically the site is gently sloping to the south with elevations ranging from 250 to 280 feet above mean sea level. Outside the immediate site area the ground surface slopes steeply to the north and west in the direction of Upper Three Runs Creek and an unnamed tributary to the south. Water level data from a well drilled 300 to 400 feet from the eastern boundary of the site shows a depth to water of approximately 55 feet. Figure 1.1-6 shows the average elevation of the water table in the general area.

SITE D

Site D is located to the west of F Area between F Area and Upper Three Runs Creek (Figure 1.1-5). The site is about 80 acres in area. Topographically the site is gently undulating with surface elevations ranging from about 250 to 300 feet. However, the ground surface becomes steep on three sides in the direction of Upper Three Runs Creek, which is located at an elevation of about 130 to 120 feet, 1500 feet to the west of the site boundary. The slope is steep in the direction of unnamed tributaries to the north and south. The water table is at elevations ranging from about 190 to 225 feet above mean sea level or at an average depth of about 70 feet below the ground surface (Figure 1.1-6).

SITE E

Site E is located approximately 3000 feet south of Road C or about 5000 feet south of F Area (Figure 1.1-5). Burma Road cuts diagonally across the site. The retangular shaped site occupies an area of about 185 acres (about 4000 feet x 2000 feet). Upper Three Runs Creek is located 2500 feet west of the site at its closest point. A small stream or drainage approaches the western periphery of the site and two others are located about 500 feet from both the north and south boundaries. No standing bodies of water or marshy areas are observed on the site. Several monitoring wells are located on or near the site. Depth to the water table is 50 to 60 feet (Figure 1.1-7). Site E was also recently investigated as a potential site for a non-radioactive waste landfill. Three borings were drilled to depths of 74.5 feet each and 1.25" I.D. piezometers installed in each. All borings indicated fine to medium sand with clay to the depth of exploration. Water levels ranged from approximately 65 feet to 44 feet below ground surface. Topographically the site is gently rolling with elevations ranging from 210 to 270 feet. The ground surface slopes gently to the east-southeast and steeply to the west as Upper Three Runs Creek is approached.

SITE F

Site F is located southwest of C Area and north of Road 3 (Figure 1.1-8). The site occupies an area of approximately 115 acres. Topographically the ground surface is quite flat with elevations ranging from a high of about 290 feet towards the center to a low of about 250 feet. The water table in this area ranges from about 40 to 70 feet below the ground surface (Figure 1.1-9). However, standing surface water in the form of a Carolina bay is found over a relatively large portion of the site. This could be engineered away by grading, but this could introduce environmental problems. This feature could make this site low in priority. Four Mile Creek is located about 1500 feet to the south and east at its closest point.

SITE G

Site G is approximately 200 acres in area and is located immediately north of the present low-level radioactive waste burial ground (643-7G). The site slopes gently to the north in the direction of Upper Three Runs Creek which is located about 1500 feet from the site boundary. Elevations range from 300 to 250 feet above mean sea level. No standing surface water is observed in the area. The water table ranges from 60 feet to 40 feet (Figure 1.1-5).

SITE H

Site H is located approximately 9000 feet southwest of K Area, parallel to and south of Road A (Figure 1.1-8). The site is about 4000 feet x 1500 feet in dimension occupying an area of approximately 135 acres. Topographically the site is quite flat, sloping to the east in the direction of Pen Branch and to the south in the direction of the marshy area adjacent to the Savannah River. No flowing or standing surface waters are observed on the site and no data are presently available on the depth to the water table, however from a cross section of the site shown on Figure 1.1-10, the depth to water should be on the order of 50 feet.

SITE I

Site I is a 215 acre site located between Tinker Creek and its tributary, Reedy Branch (Figure 1.1-3). Road 8.1 passes through a portion of the site. Ground surface elevations range from approximately 270 to 330 feet above mean sea level. The site is relately flat with slopes becoming steep as Tinker Creek and Reedy Branch are approached. Tinker Creek, which is approximately 2000 feet west of the site at the closest approach, is located at an elevation of about 180 feet. Reedy Branch is about 2000 feet south of the site and is also found at an elevation of about 180 feet. A small drainage ditch or intermittent stream to Tinker Creek is located about 400 feet west of the site. No groundwater data are available for the site.

SITE J

Site J is located about 300 feet to the east of Site I (Figure 1.1-3). It is an irregularly shaped area to take advantage of the topography, encompassing a total area of about 220 acres. The main channel of Tinker Creek is located some 4000 feet to the west. The beginning of an intermittent stream is located about 500 feet to the northwest. What appears to be the headwaters of Reedy Branch is located 500 to 600 feet south of the site. Topographically the site is flatter than Site I with elevations ranging from a low of 290 to a high of 310 feet above mean sea level. The majority of the site lies between the elevations of 300 and 310 feet. No water table data are available for the site.

SITE K

Site K is approximately 4500 feet south of Site I and about 2000 feet south of Reedy Branch, Figure 1.1-3. The site is rectangular in shape roughly 5500 feet x 1800 feet occupying some 220 acres. Road 2.1 passes through the site. The site is located on a slight knoll with the ground surface sloping away gently on all sides. Elevations range from approximately 280 to 310 feet. Tinker Creek is located about 2000 feet to the west, Reedy Branch is about 2000 feet to the north, and Mill Creek is about 2000 feet to the south. The slope of the ground surface increases as the stream valleys are approached. The topographic map shows a well located close to the center of the site; however, no depth to the water table information has been obtained.

SITE L

Site L is located just south of F Area and Road C and just north of Site E (Figure 1.1-5). Burma Road cuts across the eastern-most portion of the site. The site is some 100 acres in area, approximately 2100 feet on a side. Elevations range from a high of about 300 feet to a low of about 200 feet along the western and southern periphery. Upper Three Runs Creek is located about 1300 feet west of the site at its closest point. Intermittent streams tributary to Upper Three Runs are located to the north and south of the site. The depth to the water table is on the order of 60 feet across the site (Figure 1.1-7).

SITE M

Site M is a dogleg shaped site located about 1 mile south-southwest of Site E along Burma Road (Figure 1.1-5). Elevations over this 160 acre tract range from a high of about 220 feet towards the northeastern part of the site to a low of about 160 feet along western edge. The ground surface is relatively flat over much of the site with slopes increasing to the south and west. Outside the site proper slopes are very steep in the direction of Upper Three

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Runs Creek, which is found at an elevation of about 100 feet some 2000 feet to the west. No water table data are available for the site.

SITE N

Site N is a 210 acre tract located between C Area and D Area within an area generally defined by Road 3, Road A-8, and Four Mile Creek (Figure 1.1-8). The site is relatively flat over the central portion with surface slopes becoming somewhat steeper to the east in the direction of Four Mile Creek, some 1500 feet from the site at the closest point. Surface elevations range from about 200 to 270 feet. The elevation along the creek bank is about 140 feet. No water table data are available from the site.

SITE O

Site O is located east of Four Mile Creek and Site N (Figure 1.1-8). It is roughly triangular in shape occupying about 225 acres. Four Mile Creek is located to the north and west, Roads A and B to the south, and Roads 5 and 6 to the east. Three clay pits are located on the site as shown on the SRP topographic map. The depth to which these have been mined in not known. Four Mile Creek is approximately 1000 feet to the west at its closest point. Two small intermittent streams tributary to Four Mile Creek are about 300 and 500 feet from the northeast and southwest corners of the site, respectively. Topographically the ground surface is somewhat irregular with several small draws or old drainage ways located on the site. The elevations range from about 190 feet to about 260 feet msl. Surface slopes increase to the west as Four Mile Creek, which is located at an elevation of about 150 feet, is approached. No water table information is available for the site area.

SITES P AND Q

Sites P and Q are adjacent and occupy areas of approximately 240 and 255 acres, respectively. They are located just south of the 700 U TC Area, east of Plant Road 2 and west of Upper Three Runs Creek (Figure 1.1-11).

Site P is rectangular in shape with ground surface elevations ranging from a low of about 220 feet to a high of about 280 feet. The ground slopes gently to the east in the direction of Upper Three Runs Creek. The low marshy area adjacent to Upper Three Runs is located about 2000 feet from the site while the main channel of the creek is some 4500 feet from the site at an elevation of about 110 feet. An intermittent stream tributary to Upper Three Runs is located about 1000 feet east of the site.

Site Q is triangular in shape and is located adjacent to the south-southwest part of Site P. Ground surface elevations are about the same as found at Site P. Upper Three Runs Creek is located about the same distance from Site Q as Site P, about 2000 to 4500 feet from the site.

The depths to the water table measured in two wells located in the TC Area indicate the water levels to be in excess of 100 feet. The actual depth to water at Sites P and Q is not known but should be quite deep because of the proximity to the TC Area. A cross section of the area with the anticipated water table is shown on Figure 1.1-12.

1.1.2.3 Application of Site Selection Criteria

The use of topographic maps, monitoring wells, water table maps, and application of geohydrologic principles are the main methods used in the selection of potential sites. Depth-to-water data exist at some of the proposed sites; however this type of data is not available over most of the SRP site, especially in areas that do not have facilities or have not been developed. Based on the known parameters of the 17 prospective sites, factors have been applied and an initial selection has been made. These factors were: distance to streams, distance to waste generators (and volume of waste generated by each), distance to public land or roads, topography and available area. Selected sites were: G, B, K, L, E, I, C, P, Q and F. Of these ten sites, specific information existed on the water table for five (G, B, E, C and F).

Since hydrologically the most critical first step in the evaluation of a potential site is an accurate approximation of the depth to the water table based on field observation, water table and soil characteristics, these data were determined for those five selected sites for which no such data existed (K, L, I, P and Q). This was accomplished by boring two holes at each site, and taking split-spoon samples. Since only one boring had been made at Site C, one additional hole at this site was also included. This required drilling a total of 11 holes.

1.1.3 Selection of Candidate Sites

1.1.3.1 Performance Criteria

Performance criteria have been identified to ensure that the objectives of the storage/disposal site will be incorporated into the site selection and design. These criteria all relate directly or indirectly to occupational radiation dose or dose to the public and apply to all methods of radioactive waste management. Radiation dose limits less than or equal to those in DOE Order 5480.1A and equivalent to those in Nuclear Regulatory Commission Rule 10CFR61 are set forth in the performance criteria. These limits are the ones presently used for all operations at the Savannah River Plant and are, therefore, considered achievable. The actual operating and

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design parameters will be such that members of the work force and the general public will receive actual doses orders of magnitude less than the current limits.

1. RADIOACTIVITY IN GROUNDWATER - The concentration of radionuclides in groundwater at the storage/disposal site boundary must not exceed those established in the EPA National Interim Primary Drinking Water Standards Regulations, 40CFR141 (1977).

2. RADIATION DOSE TO PERSONS - The radiation dose to any member of the public due to releases of radioactivity in the groundwater, surface water, air, soil, plants, etc., as given in DOE Order 5480.1A, must not be exceeded.

3. MINIMUM DEPTH BETWEEN WASTE AND WATER TABLE - The minimum distance between the waste and the groundwater table shall be at least 10 feet. Knowledge of variations in water table level should be based on water table data for the site.

4. DISTANCE BETWEEN ROOT ZONE AND WASTE - The waste should be emplaced below the root zones of plants which are indigenous to the area. At SRP this criterion can be met by placement of waste at a minimum depth of 16 feet (5 meters). The intent of the criterion might also be achieved by other means (for example, root barriers), but such barriers would be subject to breaching at flaws. Emplacement of waste below root zones is considered feasible at prospective sites at SRP.

5. SURFACE WATER AND EROSION CONTROL - Surface topography should be such as to minimize erosion (i.e., minimum slope) and surface water should be routed so as to avoid erosion and infiltration. Precipitation should be drained away from the site.

6. SUBSIDENCE - Subsidence of wastes and backfilled soil should be minimized to avoid undue maintenance of surface topography and to avoid enhanced water infiltration and potential unacceptable migration of radionuclides. To achieve this, wastes (or waste packages) must be physically stable and spaces between packages must be minimized or filled with compacted soil of other fill material.

7. POST-CLOSURE CONTROL - It is assumed for the purpose of projecting radionuclide movement that institutional control shall be maintained for 100 years following site closure. During this period it is assumed that the site will be well maintained to prevent surface erosion, intruder entry, etc.

This post-closure criterion also requires that the site be designed such that the above performance criteria will be met for an additional 200 years. The total of 300 years is approximately 10 half-lives of fission product elements of concern, Sr-90 and Cs-137. At the end of this period the radioactivity will have decreased sufficiently so that no significant hazard remains. The means of meeting this criterion will be 1) limitation on the inventory of radionuclides emplaced in the site, and 2) deeper burial or engineered barriers, and design of a disposal unit which will prevent the waste from reaching the environment before radioactivity has decayed to innocuous levels.

1.1.4 Site Selection Guides

The following is a series of characteristics considered important in site selection for a low-level radioactive waste storage/disposal facility at the Savannah River Plant. Each characteristic is given a weighting factor, ranging from 1 to 6, representing its relative importance in meeting the performance criteria set forth above. Values for each prospective site are assigned ratings for each characteristic which increase relative to their effect on meeting the performance criteria. The prospective sites are then evaluated by multiplying their ratings times the weighting factor for each characteristic and summing the results. The total scores should indicate the relative merit of each potential site. The characteristics are quantifiable for each site, but the break points for the ratings and the magnitude of the weighting factors are basically subjective. This system cannot be used to choose a single "best" site, but it can identify a smaller group of sites to target for detailed study. The detailed work can then be used to select the final site.

As an example of the procedure consider the depth to the water table. If a prospective site has a depth to the water table of 75 feet it then has a rating of 4. The weighting factor for this characteristic is 6, giving a score of 24. The scores for all of the characteristics are then added, giving the total points for that site.

The site selection guides listed below are specific to the Savannah River Plant site. Several facts are implicit in the criteria given. The Savannah River Plant site is located in the Atlantic Coastal Plain of the southeastern United States. This means that the upper 600-1000 feet (180-300 meters) of material consists of deeply weathered, loosely consolidated or unconsolidated sediments. The material itself is primarily sandy-clay to clayey-sand, and in general is quite homogeneous over the Plant site. Therefore, the emphasis given to geologic materials at prospective sites is not a factor considered here.

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Depth to Water Table (Weighting Factor - 6)

The present reference process for Greater Confinement Disposal calls for emplacing the waste in trenches and boreholes so that the bottom of the disposal unit is at least 10 feet (3 meters) above the water table, and the top of the waste is at least 16 feet below the final site grade. Therefore, for a twenty-foot waste zone, depth from the surface to the water must be at least 46 feet (14 meters). Since transport and is much slower in the unsaturated zone, depths greater than 60 feet are rated more highly.

Depth (ft)	Rating
> 80	5
71-80	4
61-70	3
46-60	2
< 45	0

Distance to the Public (weighting Factor = 6)

Placement of the storage/disposal facility a greater distance from the public has two beneficial effects. The farther the facility is from public water supplies the longer the time is available for radionuclides to decay before they have the possibility of interacting with the water supplies. If the site is remote from public access then the probability of accidental exposure to a member of the public during operations is minimized.

Distance (miles)	Rating
> 4	4
3 - 4	3
2 - 3	2
1 - 2	1
0 - 1	0

Distance to Waste Generators (Weighting Factor = 6)

The volume of waste and the distance that it must be transported from each generator has an impact on the dose to waste transport personnel, the probability of a transportation accident, and the economics of waste management. It is also desirable to avoid wide-spread dispersal of wastes within the plant site. At SRP there are multiple waste generators which are widely dispersed, so a volume-of-waste weighted method was used to rate the potential sites. The distance from each potential site to each operating area was rated, then weighted by the percentage of waste produced by each operating area, and finally multiplied by the criterion weight (6). The score for each potential area is then the total of the individual ratings. The ratings are:

Distance (miles)	Rating
< 2	4
2.0 - 3.9	3
4.0 - 5.9	2
6.0 - 8.0	1
> 8	0

Distance to Nearest Stream (weighting Factor = 5)

Since surface water in the humid eastern United States generally represents areas of groundwater discharge and since transport by surface water is much more rapid than by groundwater, it is desirable to maximize the distance from the waste to surface water.

Distance (feet)	Rating
> 2000	4
1500 - 2000	3
1000 - 1500	2
500 - 1000	1
< 500	0

Available Surface Area (Weighting Factor = 4)

The available surface area of a prospective storage/disposal site is important from an economic standpoint because the effort involved in characterizing sites and the desire to limit the number of sites containing waste. The useful life of a site is determined by the area of ground available for waste management activities.

Acres	Rating
> 200	4
100-200	3
50-100	2
25-50	1
< 25	0

Surface Topography (Weighting Factor = 2)

The energy available for erosion by surface runoff is directly proportional to the slope of the land surface. Therefore, the lower the slope, the more slowly the land surface will erode. This factor has a low weighting because it can be altered during site engineering.

Maximum Slope (%)	Rating
0 - 1.2	4
1.2 - 2.5	3
2.5 - 3.7	2
3.7 - 5.0	1
> 5	0

1.1.5 Site Rankings

The site selection guides were applied to the seventeen potential sites discussed above. Table 1.1-1 is a summary of the rating process, listing the sites in order of their apparent suitability. This table shows that sites B, G, and K are the highest rated sites, followed by sites L and I, which have virtually the same rating. Table 1.1-2 is a listing of the ratings, weightings and scores for each of the sites.

The data used in this evaluation are included in Tables 1.1-4 through 1.1-7. The distances to waste generators are in Table 1.1-3. Table 1.1-4 lists the distance of each potential site to an area of public access, either the plant boundary or South Carolina Highway 125. Table 1.1-5 is a list of the percentage of the plant waste generated by each operating area in 1981. Sources of waste for the years 1979-1981 were examined and are presented in Table 1.1-6. Only 1981 was used in the evaluation because it was the only year when L Area, the site of a production reactor due to be restarted, contributed significantly to the total. D and G Areas were excluded in the process, since D Area, the heavy water facility, is closed down, and G Area is a number of outlying areas which contribute only 2.6% of the waste. The area, distance to surface water, and depth to the water table for each site are presented in Table 1.1-7.

1.1.6 Selection of Candidate Sites

Of the five top ranked sites, only three are currently available. Shortly after the sites were ranked sites I and K were used for a training facility for the Security Department. Therefore, sites B, G, and L were chosen as the candidate sites. Site G, which is adjacent to the existing Burial Ground was chosen to be the preferred site because all the required support facilities (roads, railroad line, electric power, etc.) were already in place nearby. All three of these sites will be the subject of a site characterization program. If site G should prove to have some characteristics which would make it unsuitable for safe disposal of waste, then one of the other sites would become the preferred site.

Table 1.1-1. SITES RANKED BY RATINGS SCORE

SITE	SCORE
G	98
B	97
K	94
L	88
I	87
P	84
E	80
Q	78
D	75
C	72
F	71
J	66
A	60
H	55
M	55
N	45
O	37

Table 1.1-2. SITE SELECTION RATINGS

Site	Parameter	Rating	Fraction Waste	Weighting	Total
A	Depth to Water	no data		6	-
	Distance to Public	2		6	12.0
	Distance to Generator				
	A Area	1	0.063	6	0.378
	C Area	0	0.031	6	0.000
	F Area	2	0.373	6	4.476
	H Area	2	0.233	6	2.796
	K Area	0	0.036	6	0.000
	L Area	0	0.035	6	0.000
	M Area	1	0.069	6	0.414
	P Area	0	0.035	6	0.000

					8.064
	Distance to Stream	4		5	20.0
	Surface Area	3		4	12.0
	Topography	4		2	8.0
				Site Total	60.064

Site	Parameter	Rating	Fraction Waste	Weighting	Total
B	Depth to Water	3		6	18.0
	Distance to Public	4		6	24.0
	Distance to Generator				
	A Area	1	0.063	6	0.378
	C Area	2	0.031	6	0.372
	F Area	3	0.373	6	6.714
	H Area	3	0.233	6	4.194
	K Area	1	0.036	6	0.216
	L Area	1	0.035	6	0.210
	M Area	1	0.069	6	0.414
	P Area	1	0.035	6	0.210

					12.708
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	3		2	6.0
				Site Total	96.708

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
C	Depth to Water	2		6	12.0
	Distance to Public	4		6	24.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	3	0.031	6	0.558
	F Area	4	0.373	6	8.952
	H Area	4	0.233	6	5.592
	K Area	1	0.036	6	0.216
	L Area	1	0.035	6	0.210
	M Area	2	0.069	6	0.828
	P Area	1	0.035	6	0.210

					17.322
	Distance to Stream	1		5	5.0
	Surface Area	2		4	8.0
	Topography	3		2	6.0
				Site Total	72.332

Site	Parameter	Rating	Fraction Waste	Weighting	Total
D	Depth to Water	3		6	18.0
	Distance to Public	3		6	18.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	3	0.031	6	0.558
	F Area	4	0.373	6	8.952
	H Area	3	0.233	6	4.194
	K Area	2	0.036	6	0.432
	L Area	1	0.035	6	0.210
	M Area	2	0.069	6	0.828
	P Area	1	0.035	6	0.210

					16.140
	Distance to Stream	3		5	15.0
	Surface Area	2		4	8.0
	Topography	0		2	0.0
				Site Total	75.140

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
E	Depth to Water	2		6	12.0
	Distance to Public	2		6	12.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	4	0.031	6	0.744
	F Area	4	0.373	6	8.952
	H Area	3	0.233	6	4.194
	K Area	2	0.036	6	0.432
	L Area	1	0.035	6	0.210
	M Area	2	0.069	6	0.828
	P Area	1	0.035	6	0.210

					16.326
	Distance to Stream	4		5	20.0
	Surface Area	3		4	12.0
	Topography	4		2	8.0
				Site Total	80.326

Site	Parameter	Rating	Fraction Waste	Weighting	Total
F	Depth to Water	2		6	12.0
	Distance to Public	2		6	12.0
	Distance to Generator				
	A Area	1	0.063	6	0.378
	C Area	4	0.031	6	0.744
	F Area	3	0.373	6	6.714
	H Area	3	0.233	6	4.194
	K Area	3	0.036	6	0.648
	L Area	2	0.035	6	0.420
	M Area	1	0.069	6	0.414
	P Area	2	0.035	6	0.420

					13.932
	Distance to Stream	3		5	15.0
	Surface Area	3		4	12.0
	Topography	3		2	6.0
				Site Total	70.932

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
G	Depth to Water	2		6	12.0
	Distance to Public	4		6	24.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	3	0.031	6	0.558
	F Area	4	0.373	6	8.952
	H Area	4	0.233	6	5.592
	K Area	2	0.036	6	0.432
	L Area	2	0.035	6	0.422
	M Area	2	0.069	6	0.828
	P Area	1	0.035	6	0.210

					17.750
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	4		2	8.0
				Site Total	97.750

Site	Parameter	Rating	Fraction Waste	Weighting	Total
H	Depth to Water	2		6	12.0
	Distance to Public	0		6	0.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	2	0.031	6	0.372
	F Area	1	0.373	6	2.238
	H Area	1	0.233	6	1.398
	K Area	4	0.036	6	0.864
	L Area	3	0.035	6	0.630
	M Area	0	0.069	6	0.000
	P Area	1	0.035	6	0.210

					5.712
	Distance to Stream	4		5	20.0
	Surface Area	3		4	12.0
	Topography	3		2	6.0
				Site Total	55.712

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
I	Depth to Water	3		6	18.0
	Distance to Public	3		6	18.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	0	0.031	6	0.000
	F Area	1	0.373	6	2.238
	H Area	2	0.233	6	5.034
	K Area	0	0.036	6	0.000
	L Area	0	0.035	6	0.000
	M Area	0	0.069	6	0.000
	P Area	0	0.035	6	0.000

					7.272
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	4		2	8.0
				Site Total	87.272

Site	Parameter	Rating	Fraction Waste	Weighting	Total
J	Depth to Water	2		6	12.0
	Distance to Public	3		6	18.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	0	0.031	6	0.000
	F Area	1	0.373	6	2.238
	H Area	2	0.233	6	5.034
	K Area	0	0.036	6	0.000
	L Area	0	0.035	6	0.000
	M Area	0	0.069	6	0.000
	P Area	1	0.035	6	0.210

					7.482
	Distance to Stream	1		5	5.0
	Surface Area	4		4	16.0
	Topography	4		2	8.0
				Site Total	66.482

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
K	Depth to Water	3		6	18.0
	Distance to Public	4		6	24.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	1	0.031	6	0.186
	F Area	2	0.373	6	4.476
	H Area	2	0.233	6	2.676
	K Area	0	0.036	6	0.000
	L Area	0	0.035	6	0.000
	M Area	0	0.069	6	0.000
	P Area	1	0.035	6	0.210

					7.548
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	4		2	8.0
				Site Total	93.548

Site	Parameter	Rating	Fraction Waste	Weighting	Total
L	Depth to Water	3		6	18.0
	Distance to Public	3		6	18.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	4	0.031	6	0.744
	F Area	4	0.373	6	8.952
	H Area	3	0.233	6	4.194
	K Area	2	0.036	6	0.434
	L Area	2	0.035	6	0.420
	M Area	2	0.069	6	0.828
	P Area	1	0.035	6	0.210

					16.536
	Distance to Stream	3		5	15.0
	Surface Area	3		4	12.0
	Topography	4		2	8.0
				Site Total	87.536

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
M	Depth to Water	no data		6	-
	Distance to Public	1		6	6.0
	Distance to Generator				
	A Area	1	0.063	6	0.376
	C Area	3	0.031	6	0.558
	F Area	3	0.373	6	6.714
	H Area	2	0.233	6	2.796
	K Area	3	0.036	6	0.648
	L Area	2	0.035	6	0.420
	M Area	1	0.069	6	0.828
	P Area	1	0.035	6	0.210

					12.550
	Distance to Stream	4		5	20.0
	Surface Area	3		4	12.0
	Topography	2		2	4.0
				Site Total	54.550

Site	Parameter	Rating	Fraction Waste	Weighting	Total
N	Depth to Water	no data		6	-
	Distance to Public	0		6	0.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	3	0.031	6	0.558
	F Area	2	0.373	6	4.476
	H Area	1	0.233	6	1.398
	K Area	3	0.036	6	0.648
	L Area	2	0.035	6	0.420
	M Area	1	0.069	6	0.414
	P Area	0	0.035	6	0.000

					7.914
	Distance to Stream	3		5	15.0
	Surface Area	4		4	16.0
	Topography	3		2	6.0
				Site Total	44.914

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
O	Depth to Water	no data		6	-
	Distance to Public	0		6	0.0
	Distance to Generator				
	A Area	0	0.063	6	0.000
	C Area	3	0.031	6	0.558
	F Area	2	0.373	6	4.476
	H Area	2	0.233	6	2.796
	K Area	4	0.036	6	0.936
	L Area	3	0.035	6	0.630
	M Area	0	0.069	6	0.000
	P Area	1	0.035	6	0.210

					9.606
	Distance to Stream	2		5	10.0
	Surface Area	4		4	16.0
	Topography	2		2	4.0
				Site Total	39.606

Site	Parameter	Rating	Fraction Waste	Weighting	Total
P	Depth to Water	4		6	24.0
	Distance to Public	1		6	6.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	3	0.031	6	0.558
	F Area	3	0.373	6	6.714
	H Area	2	0.233	6	2.796
	K Area	2	0.036	6	0.432
	L Area	1	0.035	6	0.210
	M Area	2	0.069	6	0.828
	P Area	0	0.035	6	0.000

					12.294
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	3		2	6.0
				Site Total	84.294

Table 1.1-2 (continued)

Site	Parameter	Rating	Fraction Waste	Weighting	Total
Q	Depth to Water	4		6	24.0
	Distance to Public	0		6	0.0
	Distance to Generator				
	A Area	2	0.063	6	0.756
	C Area	3	0.031	6	0.558
	F Area	3	0.373	6	6.714
	H Area	2	0.233	6	2.796
	K Area	2	0.036	6	0.432
	L Area	1	0.035	6	0.210
	M Area	2	0.069	6	0.828
	P Area	0	0.035	6	0.000

					12.294
	Distance to Stream	4		5	20.0
	Surface Area	4		4	16.0
	Topography	3		2	6.0
				Site Total	78.294

Table 1.1-3 DISTANCE TO GENERATORS (miles)

	Operating Areas							
Sites	A	C	F	H	K	L	M	P
A	6.9	8.1	5.8	4.8	10.2	9.9	7.1	8.9
B	7.2	5.8	4.0	2.4	7.6	7.1	7.5	6.1
C	5.8	3.9	1.7	0.9	6.2	6.4	5.7	6.6
D	4.8	2.9	0.6	2.4	5.5	6.5	4.6	7.3
E	6.0	1.5	1.3	2.7	4.1	5.4	5.7	6.6
F	7.6	0.5	2.9	3.8	2.5	4.2	7.2	6.0
G	5.6	3.0	0.8	1.2	5.4	5.9	5.5	6.4
H	11.1	4.1	6.7	7.2	1.8	3.8	10.7	6.4
I	9.0	8.8	6.9	5.5	10.5	9.8	9.2	8.2
J	9.9	9.2	7.5	5.9	10.8	9.8	10.0	8.0
K	8.8	7.7	6.0	4.4	9.4	8.5	8.9	7.0
L	5.5	2.0	0.9	2.6	4.7	5.9	5.2	6.9
M	7.3	2.6	4.1	5.5	3.7	6.0	6.9	8.0
N	8.3	3.0	5.0	6.3	3.4	5.8	7.8	8.1
O	9.2	2.4	4.9	5.7	1.5	4.0	8.9	6.3
P	4.8	3.6	3.3	5.1	5.8	7.7	4.4	9.2
Q	5.4	3.5	3.6	5.4	5.5	7.5	4.9	9.1

Table 1.1-4 DISTANCE TO THE PUBLIC

Site	Distance (miles)
A	2.4
B	5.0
C	5.2
D	3.6
E	2.7
F	2.5
G	4.8
H	0.4
I	3.0
J	3.4
K	4.1
L	3.0
M	1.4
N	0.7
O	0.7
P	1.0
Q	0.6

Table 1.1-5 Percentage of Waste Generated by Operating Area
(Three year Average 1983-1985)

Area	% Waste
A	7.8
C	3.3
D	0.4
F	33.2
H	28.9
K	2.0
L	2.8
M	8.2
P	2.1
OS	7.7

1.2 DETAILED DESCRIPTION OF THE THREE TOP RATED SITES

In the near future a program will be conducted to obtain three dimensional information on the hydrologic, geologic, and geochemical nature of the three top rated sites. This detailed site characterization data will be reported as it becomes available.

The following is a description of each of the top rated sites based on the currently available information. A description of the regional environmental setting can be found in Appendix A.

1.2.1 Site B Description

Site B is a 300 acre tract of land with very gentle topography. The only site specific geologic information at this time comes from what was originally a three-well cluster at the site.

Examination of the cores from these wells showed calcareous material in a zone from 130 to 160 feet below ground surface. The Green Clay is shown in the geophysical logs at about 160 feet below the surface. There is about six feet of head reversal between the "Tuscaloosa" Formation and the Congaree Formation.

In 1984 the three-well cluster site was expanded to include wells installed into other hydrologic units. The expanded cluster was named P-14. Figure 1.2-1 is a diagram of the cluster showing the screened intervals. Figure 1.2-2 shows the geophysical logs from the deepest of the wells along with the stratigraphy and lithology.

1.2.2 Site G Description

Site G is located immediately north of the present Solid Radioactive Waste Management Facility (643-7G) and between the two Separations Facilities (200-F and 200-H Areas). Because of this location there are over thirty water table wells in and around the site. Additional borings were recently completed, and an engineering report will be issued in the near future. The existing vegetation is primarily pine trees.

Figure 1.2-3 shows the water table elevation at Site G from measurements made in April, 1985.

1.2.3 Site L Description

Site L is centrally located on the SRP site at the intersection of Road C and the Burma Road. The area of the site is approximately 100 acres. The surface slopes within the area are gentle, but increase greatly towards Upper Three Runs Creek. The existing vegetation consists mainly of pine trees and brush.

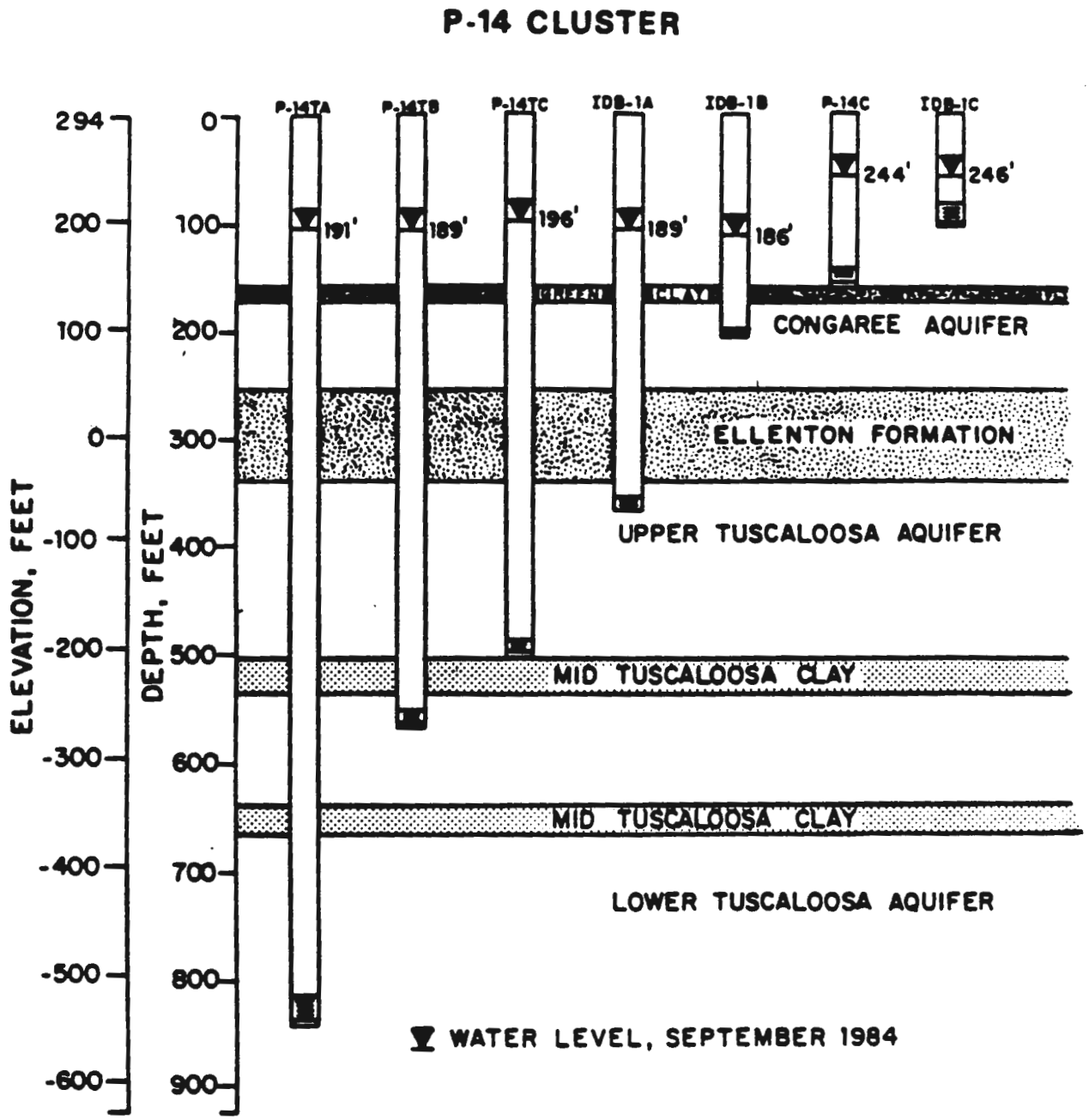

Figure 1.2-1 Vertical Head Distribution in Groundwater at Cluster P-14.

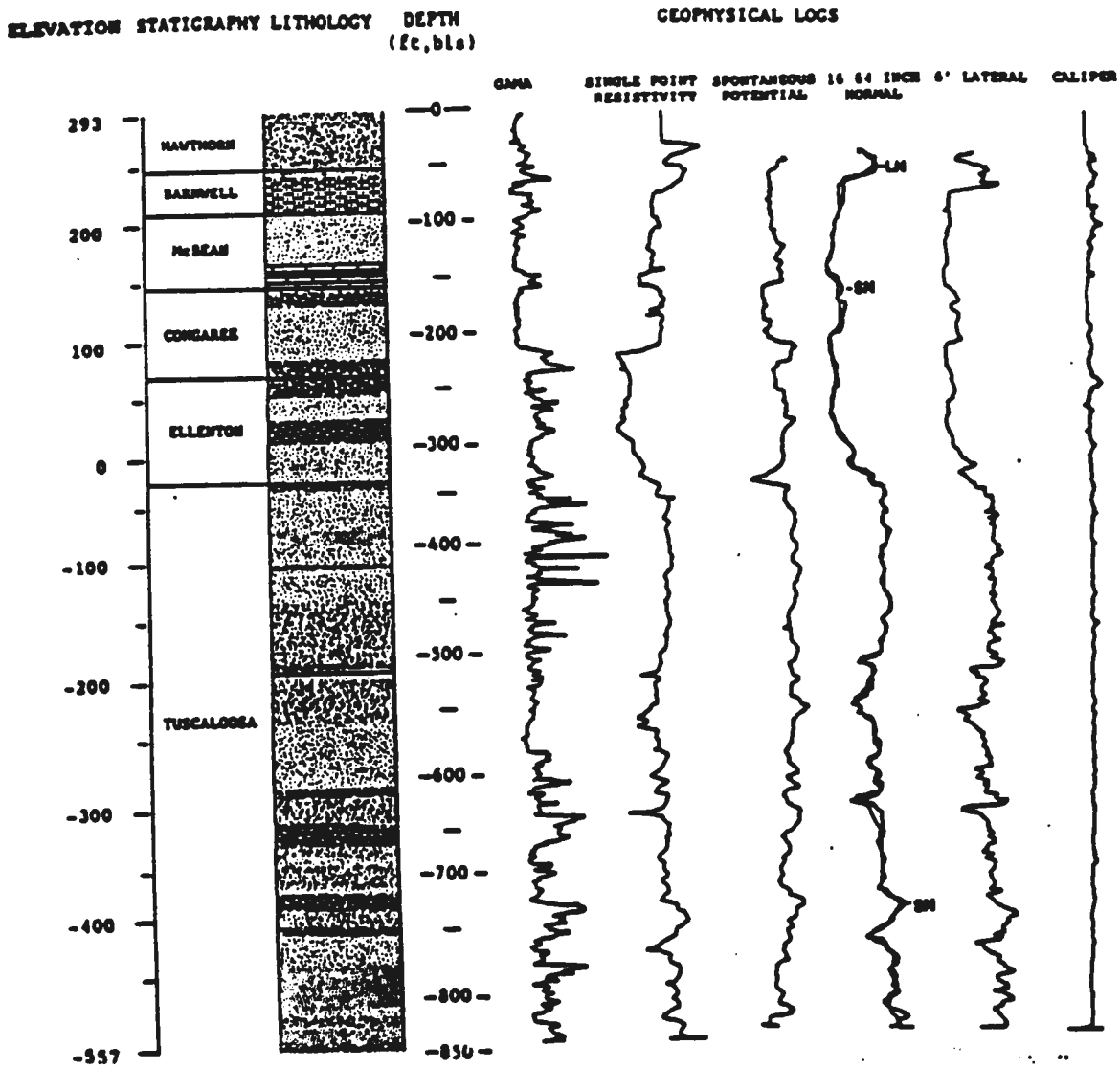

Figure 1.2-2a Graphic and Geophysical Logs for P-14TA

EXPLANATION

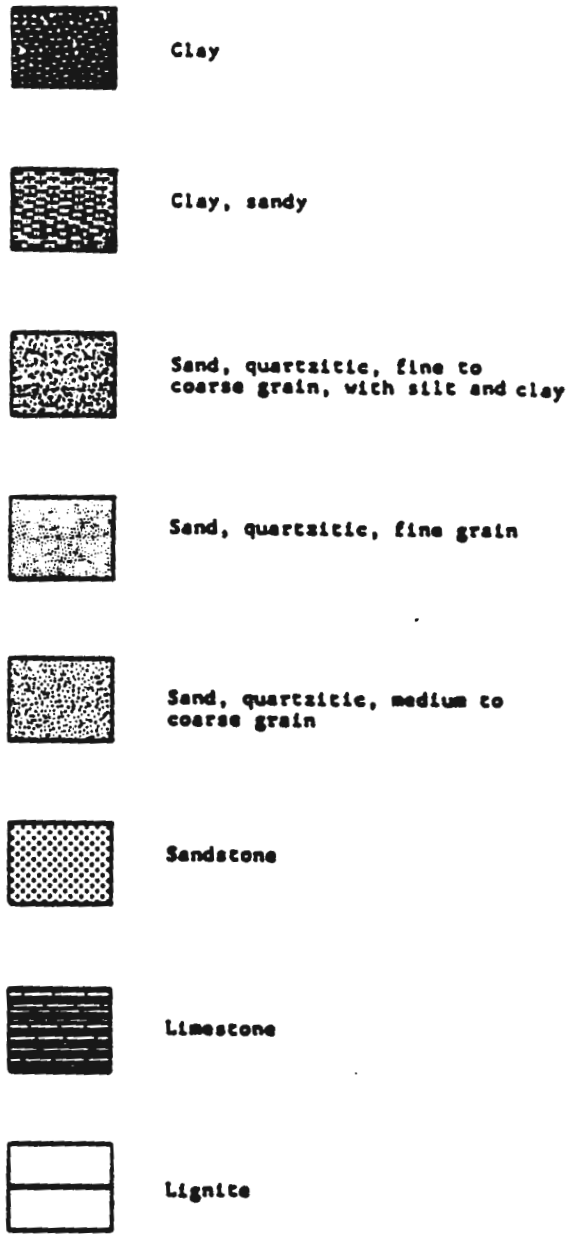

Figure 1.2-2b Graphic and Geophysical Logs for P-14TA

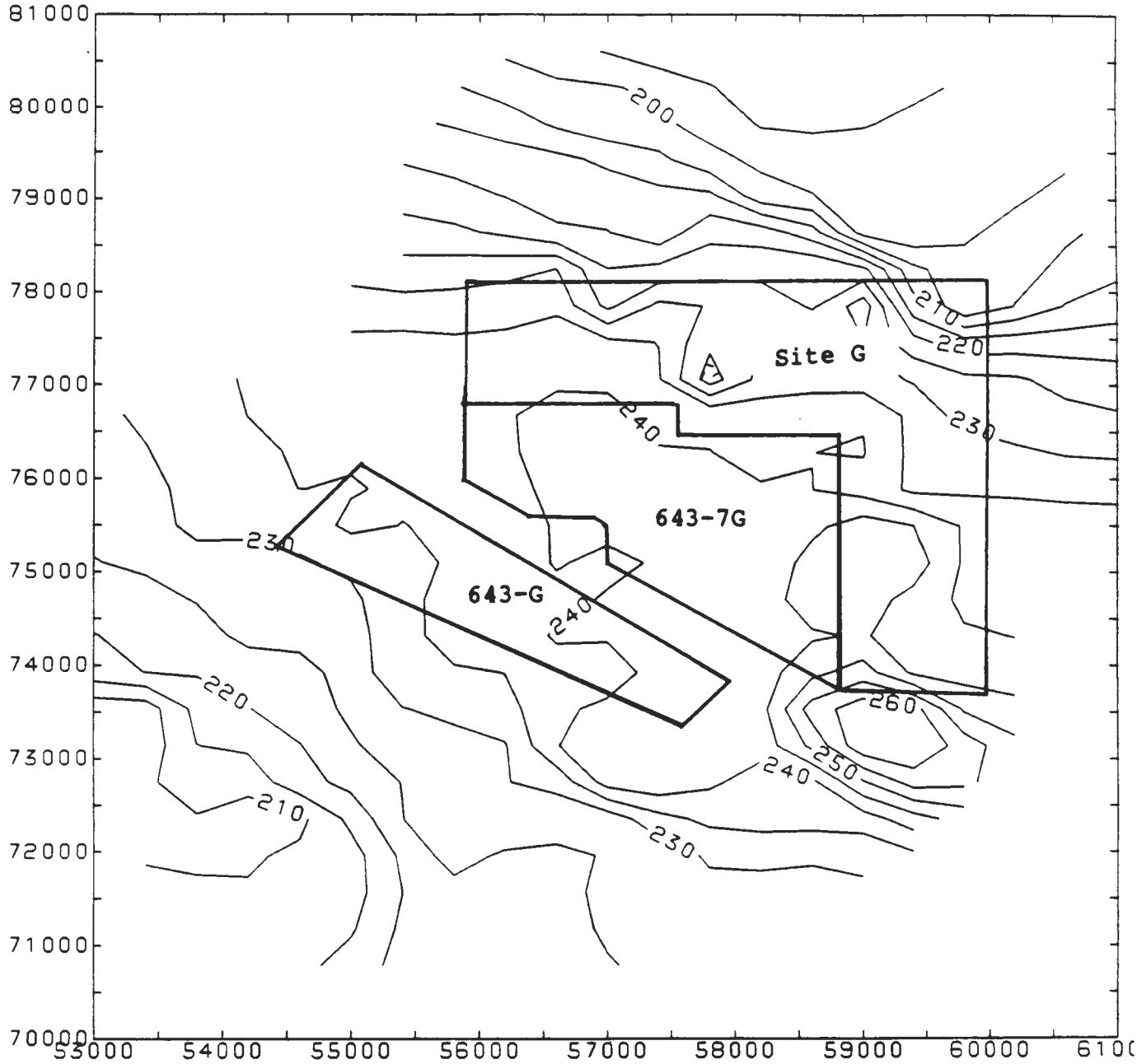

Figure 1.2-3 Water Table Elevation in the Vicinity of Site G.

A well cluster at the edge of the site shows a head reversal of about twenty feet between the top of the "Tuscaloosa" Formation and the top of the Congaree Formation. Cores from the well cluster show an interval of calcareous material from 88 to 98 feet below the surface. The driller's log records a rod drop from a depth of 84 feet down to 86 feet, which is the criterion by which the "Calcareous Zone" was originally defined by the U.S. Army Corps of Engineers. The gamma-ray geophysical logs show evidence of the Green Clay at a depth of approximately 95 feet.

Figure 1.2-4 is a contour map of the water table surface elevation based on seven wells and using the stream bed of Upper Three Runs Creek as a ground water outcrop location.

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2. LOW-LEVEL RADIOACTIVE WASTE STORAGE/DISPOSAL FACILITIES

2.1 FACILITY DESCRIPTIONS

This section describes facilities that may be used to store and/or dispose of low-level radioactive waste (LLW). In Section 2.6 these different facilities are grouped to describe seven operational alternatives for disposal or storage of LLW.

The Savannah River Plant is a large defense-related production unit that generates over a million cubic feet of solid low-level radioactive waste each year. LLW is generated in many forms --wood, metal, paper, plastic, and others. Radiation level from the waste ranges from background level to hundreds of rad/hour. The volume of individual waste pieces ranges from small cans to large, bulky items such as contaminated metal ducts and vessels. New waste storage or disposal facilities for the Savannah River Plant must be able to accommodate the many different kinds of waste generated at SRP. The waste streams are described in Section 2.3.

The Savannah River Plant has disposed of solid low-level radioactive waste since 1953. Early disposal operations are described in an Environmental Impact Statement issued in 1977[1]; current operations are described in Reference 2.

Disposal and storage technologies can be described generically by four basic attributes[3]:

- Facility has structure, has no structure, or waste form is modular
- Facility is above or below grade
- Facility has a cover, no cover, or waste is buried deep
- Waste is emplaced with or without fill

Of the 36 possibilities (3 x 2 x 3 x 2 = 36), 17 can be chosen as being feasible; 19 of the alternatives are deleted as either being impossible (e.g., an above grade structure that is buried deep), or, for example, the disposal is above grade with no cover and no fill. The 17 possibilities are listed in Table 2.1. Disposal Technology 1 (DT-1) describes a facility that has no engineered structural components; it is above grade, has a shallow earthen cover and an earthen fill. DT-1 would correspond to the Above Grade Operation described below. DT-2 describes a facility that has no engineered structural components; it is below grade with a shallow earthen cover and earthen fill. DT-2 describes near surface disposal currently used for disposal of LLW at SRP.

TABLE 2.1

GENERIC DEFINITION OF DISPOSAL TECHNOLOGIES[3]

DISPOSAL TECHNOLOGY	STRUCTURE	ABOVE/BELOW GRADE	COVER	FILL	GENERIC NAME
1	N	A	S	Y	Covered placement with fill.
2	N	B	S	Y	Buried placement with fill.
3	N	B	D	Y	Deep placement with fill.
4	Y	A	N	N	Uncovered structure without fill.
5	Y	A	N	Y	Uncovered structure with fill.
6	Y	A	S	N	Covered structure without fill.
7	Y	A	S	Y	Covered structure with fill.
8	Y	B	S	N	Buried structure without fill.
9	Y	B	S	Y	Buried structure with fill.
10	Y	B	D	N	Deep structure without fill.
11	Y	B	D	Y	Deep structure with fill.
12	M	A	S	N	Covered modules without fill.
13	M	A	S	Y	Covered modules with fill.
14	M	B	S	N	Buried modules without fill.
15	M	B	S	Y	Buried modules with fill.
16	M	B	D	N	Deep modules without fill.
17	M	B	D	Y	Deep modules with fill.

KEY: STRUCTURE: N=None, Y=With an engineered structure, M= Engineered modular waste form.

ABOVE/BELOW GRADE: A=Above, B= =Below

COVER: S=Shallow earthen cover, N= no cover, D= Deep cover.

FILL: Y=With fill, N=Without fill.

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Storage and disposal facilities are described in the following sections. The use of one or more of these facilities is combined into seven operational alternatives in Section 2.6. The facilities described below are:

- Near Surface Disposal Facility (DT-2)
- Greater Confinement Disposal Facility (DT-11)
- Above Grade Operation Facility (DT-1)
- Above or Below Grade Vaults (DT-7 and DT-9)
- Engineered Storage Facilities (DT-6 and DT-8)
- Engineered Disposal Facilities (DT-13 and DT-15)
- Combinations of the above

2.1.1 Near Surface Disposal Facility

2.1.1.1 Definitions, DOE Orders, and NRC Regulations

Near surface disposal, which is also called shallow land burial by the Department of Energy[4], is defined in DOE Order 5820.2 as "Disposal of waste in near-surface excavations that are covered with a protective overburden." Radioactive waste is defined in the same order as "Solid, liquid, or gaseous material of negligible value that contains radionuclides in excess of threshold quantities except for radioactive material from post weapons test activities." In Chapter III of that Order, under the Requirements Section, it is required that:

(1) Solid low-level waste be disposed of at DOE shallow land burial or greater confinement disposal sites (greater confinement is defined below), and

(2) disposal operations involving discharge of liquid low-level waste (LLW) directly to the environment or on natural soil columns shall be replaced by other techniques such as solidification prior to disposal or in-place immobilization.

DOE Order 5820.2 applies to radioactive waste produced at DOE operated sites.

Another DOE Order, 5480.1A[5], establishes the dose limit resulting from shallow land burial operations of 500 mrem/year as the maximum exposure any member of the public may receive, and requires that the doses be maintained at levels as low as reasonably achievable (ALARA)[6].

The Nuclear Regulatory Commission has provided regulations relating to licensing facilities for the disposal of commercially generated low-level solid radioactive waste[7]. These regulations, 10CFR61, are intended to apply to the land disposal of radioactive waste, and contain specific technical requirements for near-surface disposal of radioactive waste. A "near-surface disposal facility" is defined as a land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters (98 feet) of the earth's surface (10CFR61.7).

NRC limits the concentrations of radioactive material which may be released to the general environment as a result of low-level radioactive waste disposal operations such that an annual total dose to any member of the public must not exceed an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ. In addition, efforts must be made to maintain the releases to as low as reasonably achievable (ALARA) (10CFR61.41).

2.1.1.2 Description of a Near Surface Disposal Facility

Near surface disposal of LLW has been the most common practice for disposal of LLW at both commercial and Department of Energy facilities. The practice over the last 30 years at SRP has been to bury the wastes in earthen trenches that are 20 feet wide, 20 feet deep and approximately 400 feet long, or in Engineered Low-Level Trenches as described below. Each of the 20 foot wide trenches is separated from adjacent trenches by a 10 foot strip of undisturbed soil. The trench walls are vertical. The trenches are excavated using a drag line or a back-hoe. A cutaway view of a 20 ft x 20 ft trench is shown in Figure 2.1.

Containerized waste is placed into the trenches by a crane from the surface, or it is stacked using forklift trucks in the wider engineered trenches. Other waste such as rubble is emplaced at the end of the trench and covered with soil after emplacement. Waste is emplaced to a depth of 16 feet, after which a clean earthen soil cover of minimum thickness of 4 feet is provided to cover the waste.

Early waste containers were cardboard boxes and plastic bags. These containers provided adequate containment during transport to the waste disposal area, and allowed rapid subsidence to occur when the waste was covered with soil. Waste containers currently being used are metal boxes which allow for a more efficient use of trench space when they are stacked, but also will produce a delayed subsidence effect.

Narrow trenches provide adequate shielding for emplacement of LLW with high radiation intensities. Irradiated metal and other waste with high gamma radiation levels can be emplaced in the trenches and immediately covered with soil. This method of emplacement acts to keep occupational exposure at acceptable levels.

Control of surface water runoff is an important part of the design of the trench area. Surface water drains must be provided to channel rain water away from any of the open or closed trenches.

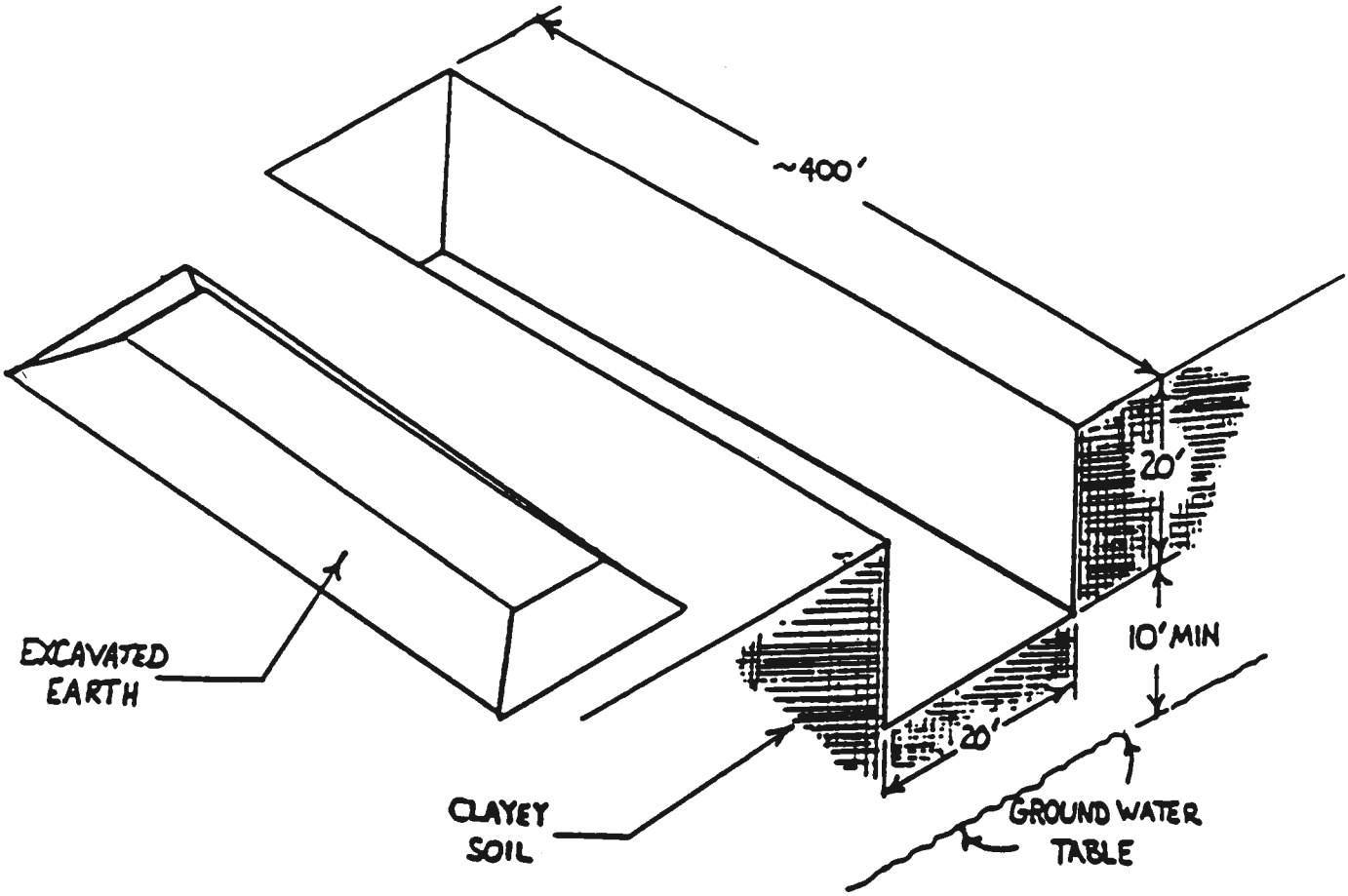


FIGURE 2.1 CUTAWAY VIEW OF A 20' X 20' TRENCH

Location of the trenches is also an important part of the overall design. The soil should be a combination of clayey sands and sandy clay. Soil structure must be able to support 20 foot vertical walls without slumping. The expected high water table must be at least 10 feet below the bottom of the 20 foot deep trenches.

Trench-use efficiency, however, is low for the 20 x 20 ft trenches, averaging only about 50%. Expected LLW generation rates of about one million cubic feet per year would require 6250 linear feet of trench. If each trench were 400 feet long, the area required for one year's production of LLW would be 4.3 acres, exclusive of access roads for cranes, trucks, and a railroad.

ENGINEERED LOW-LEVEL TRENCH

Trench-use efficiency can be improved by providing larger trenches. These larger trenches are called Engineered Low-Level Trenches, or ELLT. Plan and cross-section views are given in Figures 2.2 and 2.3. A typical trench would be about 500 feet long and 170 feet wide at the top. Sides are sloped at a 45 degree angle. A ramp is provided for truck access. Waste boxes, similar to the one shown in Figure 2.4, can be stacked such that the trench-use efficiency is 80% or greater.

The floor of the ELLT is covered with a layer of crusher-run stone. The floor is sloped about 1% to a corner of the excavation, such that rainwater is directed away from the emplaced boxes. Surface water intrusion is prevented by providing a protecting berm at the surface and by surface grading to drainage ditches.

Boxes can be stacked about four layers high in the ELLT. After the boxes have been emplaced, the trench is covered such that at least 4 feet of clean soil is placed on top of the boxes.

Near surface disposal of LLW can be used successfully for the disposal of low-level radioactive waste under the following conditions:

- The soil characteristics must be such that water does not collect in the closed trenches. The soil must not have sinkholes, large cracks, etc.

- If the waste forms are not stabilized, subsidence of trench covers must be corrected on a continuing basis, until the waste and soil beneath the cover has stabilized. Subsidence promotes ponding on the trench surface and increases the amount of water that infiltrates the trench.

The two conditions described above will not delay the migration of tritium from tritiated waste forms. Special encapsulation methods or special containers can be provided to prevent the migration of tritium.

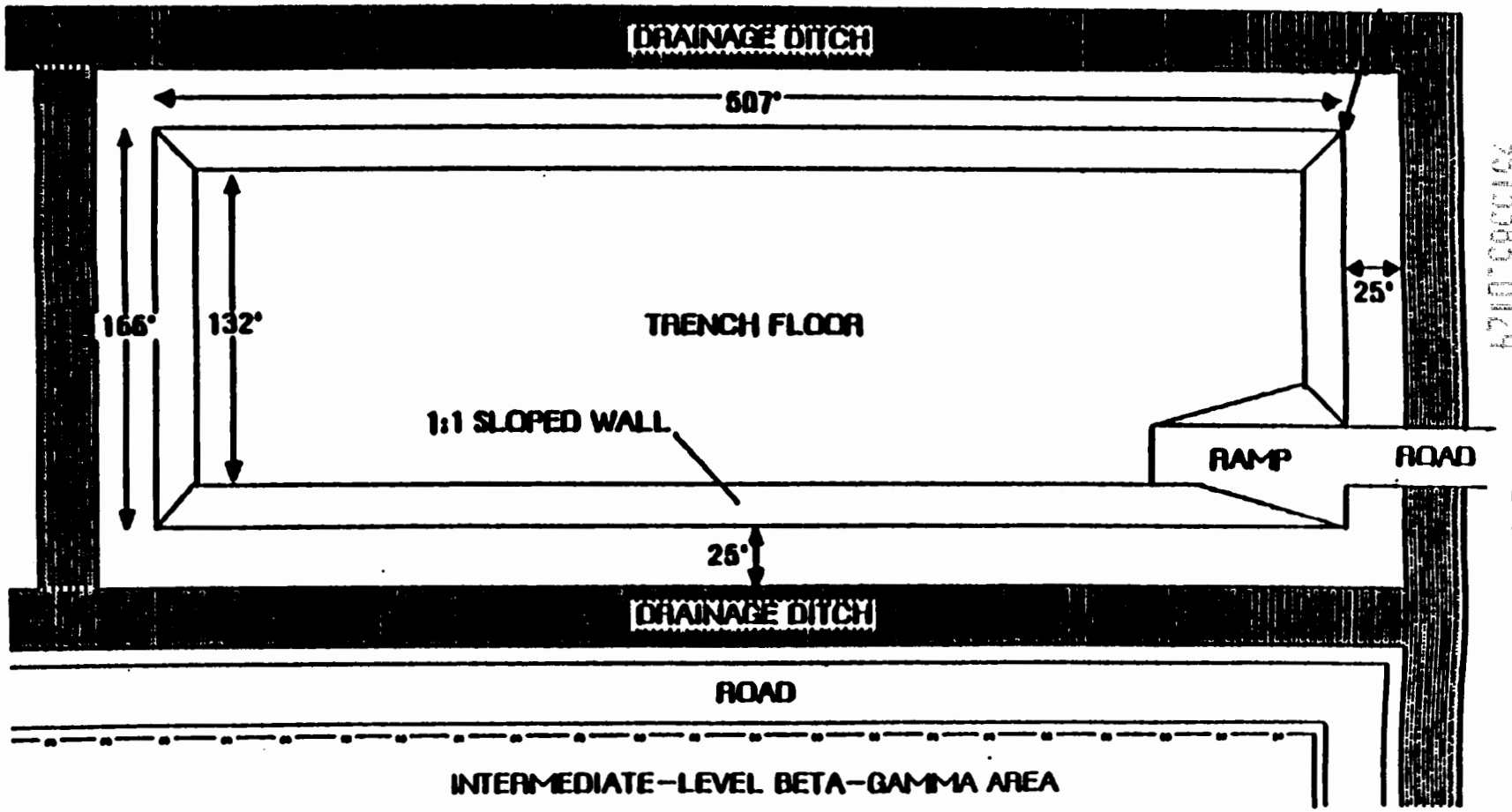


FIGURE 2.2 ENGINEERED LOW-LEVEL TRENCH

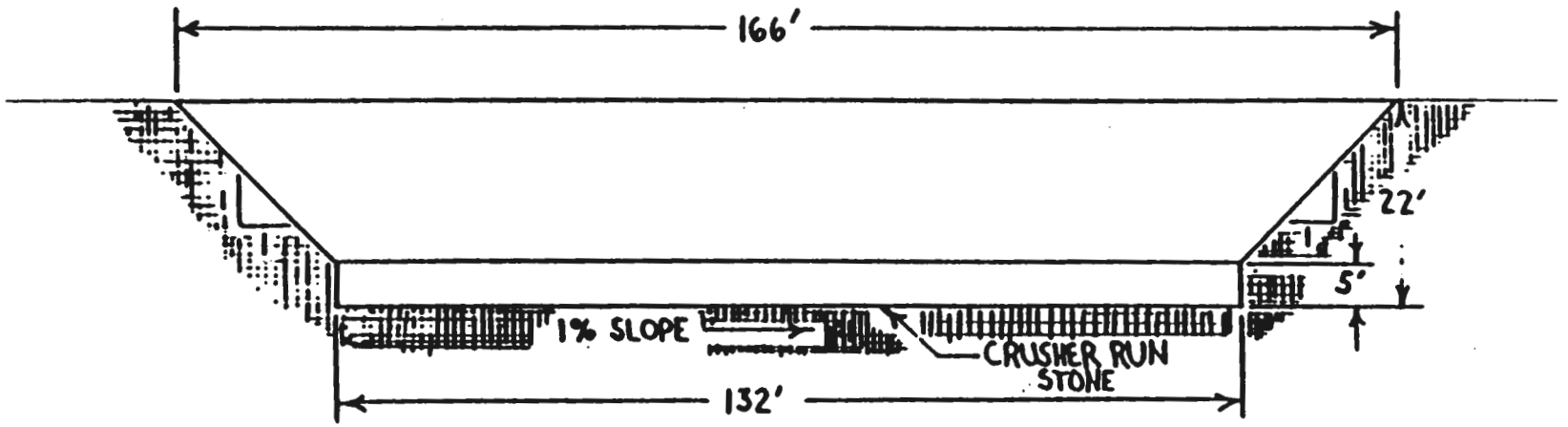
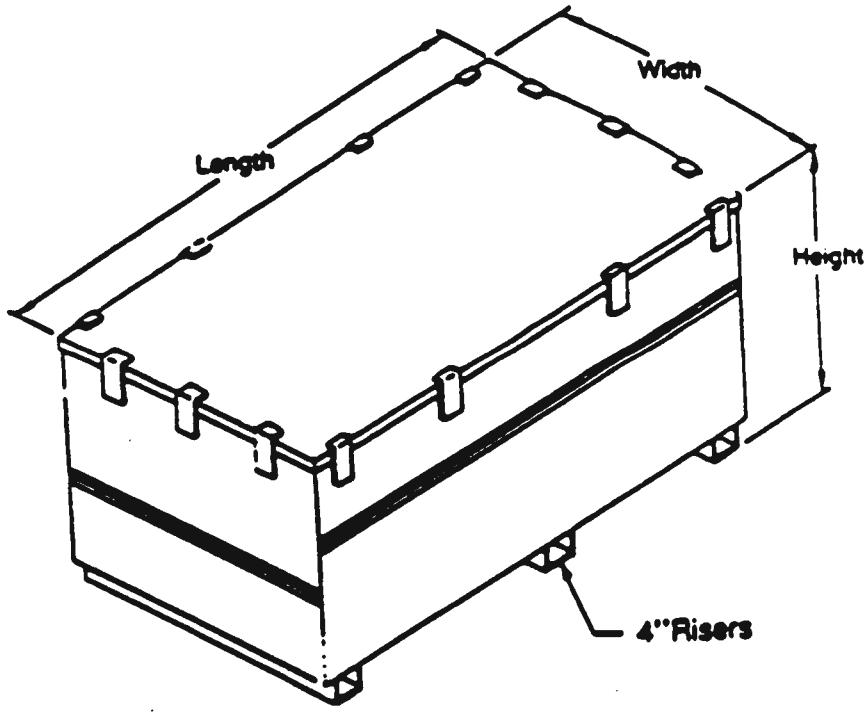


FIGURE 2.3 ENGINEERED LOW-LEVEL TRENCH SIDE VIEW



DIMENSIONS (INCHES)	INTERIOR	EXTERIOR
HEIGHT	47	51 7/8
WIDTH	46	46 15/16
LENGTH	72	72 15/16

DESCRIPTION

- Classification • Strong Tight Container
- Package Type • Container
- Capacity • 90 cu. ft.
- Material • 14 gauge low carbon hot rolled steel
- Gross wt. (empty) • 620 lbs.
- Payload • 4,000 lbs.*
- Max. loaded wt. • 4,620 lbs.*
- Shielding • Optional

FIGURE 2.4 TYPICAL METAL STORAGE BOX

2.1.1.3 Trench Disposal Performance at the Savannah River Plant

Low-level waste disposal in trenches has been studied extensively at the Savannah River Plant[8] for over 30 years. More than 15 million cubic feet of LLW have been emplaced. The waste contained more than 10 million curies when buried, but with decay the estimated present radioactivity content is about 3 million curies.

While intensive monitoring of the disposal site has indicated limited migration of specific radionuclides from the waste emplacements, the overall performance of the site, taken as a containment system, has been very good. Measurements of radiation intensities in 11 boreholes, repeated analysis of groundwater from more than 140 wells, and assays of more than 2000 feet of soil cores over a period of 25 years show that leaching and migration of buried radionuclides have been minimal[9]. Traces of alpha and beta-gamma emitters, and 1 to 2 percent of the disposed tritium are in groundwater after 30 years of disposal site operation. Of these radionuclides, 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 feet to outcrop at an annual rate of about 0.6% of the quantity in the saturated zone in the disposal site.

Several factors have contributed to the performance of the SRP disposal site in meeting the objective of long-term removal of waste radionuclides from man's environment. These are:

- Limited opportunity for waste leaching.
- A long groundwater flowpath that allows for both decay and dilution to occur.
- High soil adherence for leached radionuclides. Soil adherence effectively retards the migration of Sr-90, Cs-137, Pu-238, and Pu-239, but not tritium (H-3), Tc-99, or I-129.

The performance for waste emplacement at SRP can be characterized by a "containment factor", which is defined as the ratio of radioactivity buried to that which has reached the water table, as estimated from groundwater monitoring[8]. The containment factors are given in Table 2.2, which shows that about 2% of buried tritium has reached the water table, after which it undergoes decay and dilution in a long subsurface flow path. For other buried radionuclides, the containment factors are much greater and on the order of 10^6 to 10^7.

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TABLE 2.2 RADIONUCLIDE INVENTORY THROUGH 1984 FOR WASTE DISPOSED OF IN EARTHEN TRENCHES AT THE SRP LLW DISPOSAL FACILITY

RADIONUCLIDES	VOLUME, CUBIC METERS	QUANTITY DISPOSED, CURIES	CONTAINMENT FACTOR
TRITIUM	23,000	4×10^6	50
FISSION PRODUCTS, ACTIVATION PRODUCTS	303,000	5.2×10^6	4×10^7
ALPHA EMITTERS[a]	101,000	2.6×10^4	1×10^6

a. Does not include TRU waste stored retrievably above grade.

2.1.2 Greater Confinement Disposal

2.1.2.1 Definition

Greater confinement disposal is defined[4] in DOE Order 5820.2 as "a technique for disposal of waste that uses natural and/or engineered barriers which provide a degree of isolation greater than that of shallow land burial but possibly less than that of a geologic repository."

The NRC, in their regulations for licensing commercial LLW disposal facilities[7], does not use the term "greater confinement," but the concept is similar. The NRC defines an "engineered barrier" as a man-made structure or device that is intended to improve the land disposal facility's ability to meet performance criteria for waste with high specific concentrations of radionuclides, which are designated as Class B and C waste, as opposed to low concentration, or Class A waste.

In the facility description that follows, the major design objectives of a Greater Confinement Disposal (GCD) facility are:

- To provide deeper burial to minimize to the extent possible water, root, animal, and future human intrusion to the waste.
- To provide a stable waste form that will prevent future subsidence, which could lead to water intrusion.
- To provide a low permeability cap upon closure to reduce water infiltration to the waste.

The GCD concepts have been developed for the disposal of the high-activity fraction of LLW. This is waste that would correspond approximately to the categories of waste labeled Class B and Class C in the NRC regulation 10CFR61. The GCD concepts are also useful for the disposal of waste with half lives of 30 years or less, and for radionuclides with high mobility.

2.1.2.2 Description of Greater Confinement Disposal Facilities

Two subsets of Greater Confinement Disposal (GCD) facilities are described -- a GCD borehole design, and a GCD trench design. For both, the methodology is deeper burial (deeper than SLB), surrounding the waste forms with a foot or more of grout, stabilization of the waste forms after emplacement with grout, and closure methods to prevent root intrusion to the waste and to reduce to a minimum the percolation of water to the waste.

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GCD BOREHOLE DESIGN

The GCD borehole design is shown in Figure 2.5. Waste is emplaced in a 7-foot diameter, 20-foot high liner -- total volume 770 cubic feet. In the GCD demonstration at Savannah River, the liner is a half-inch-thick water tight fiberglass cylinder with an integral bottom. The liner is placed on a one-foot-thick concrete pad in a 9-foot-diameter augured hole. The top of the base pad is 30 feet below grade and 10 feet above the expected high water table. The top of the waste placed in the liner will be at least 10 feet below grade. The liner is surrounded by a one-foot-thick annulus of grout. Grout is poured around all waste forms placed in the liner, to form a solid cement-waste matrix inside the liner. After all waste is emplaced in the liner, a one-foot thick layer of grout is poured on top of the top waste form.

A removable steel liner is placed on top of the collar that prevents soil from collapsing on the liner during construction and waste emplacement. It also provides support for a steel rain cover and a safety fence.

The GCD boreholes are spaced 16.5 feet center-to center in two rows of ten (in the demonstration design). The area around the boreholes is graded to prevent surface water intrusion. The area is provided with a hard gravel surface for crane access to the boreholes.

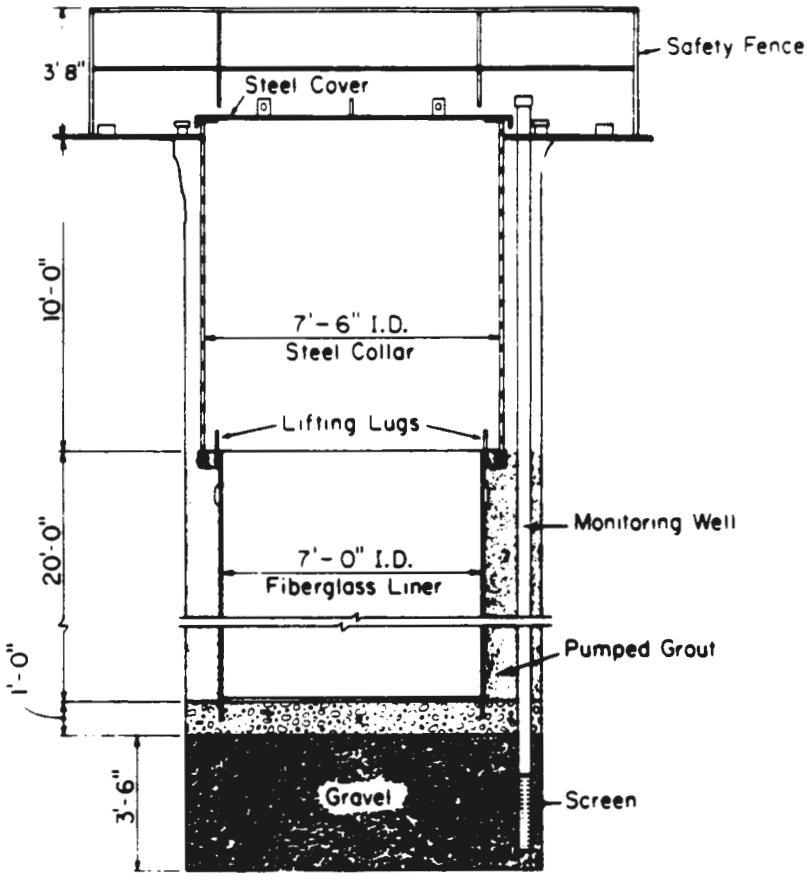
Each borehole can hold six layers of seven 55-gallon drums, or each can hold boxed waste but at less volume utilization. Borehole diameters can be made larger: the size of the 9-foot-diameter augured hole was chosen for the demonstration on the basis that this was the largest diameter that could be drilled with a mobile unit. Diameters of 12 feet can easily be attained, but at a larger expense and with a more complex drilling unit.

A typical closure of GCD boreholes is shown in Figure 2.6. A thick compacted clay cap is formed over the filled boreholes, and on top of this is placed native soil to make the total depth from surface to the waste at least 16 feet. This depth is chosen because it is the expected depth of maximum root penetration in the humid environment of the Southeastern sector of the U. S. The one-foot-thick grout cover over the waste will further discourage root, animal, and human intrusion.

GREATER CONFINEMENT DISPOSAL TRENCH FACILITY

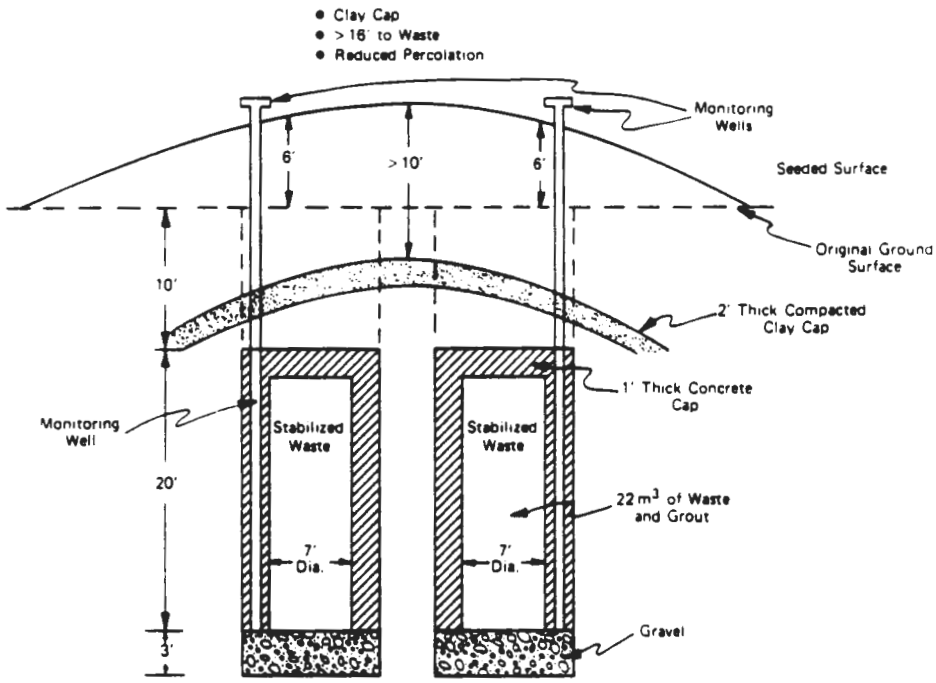
A GCD trench is built with the same objectives as a GCD borehole. A typical GCD trench would have four concrete lined cells, each about 25 x 50 feet, and about 20 feet deep. The bottom of the cells would typically be 30 feet below the surface. Each cell would have a rain-tight cover.

Waste would be emplaced in the cells about one foot from the walls, and this one-foot space would be filled with grout when the waste forms themselves were stabilized in place with grout. The



This shows the design of the borehole. A 9' diameter hole is augered to a depth of 34.5'. Then a steel collar with a safety fence, a monitoring well, and gravel to cover the screened portion of the well are placed. A concrete pad is poured on top of the gravel and allowed to set. Finally, a fiberglass liner is set on the concrete pad and a cement grout is poured in the annular space around the liner.

FIGURE 2.5 GCD BOREHOLE DESIGN



This is the design for closure of the GCD boreholes. After the boreholes are filled with waste, the collars will be removed and a low-permeability clay cap will be placed over the two rows as shown. Native soil will be added on top of this clay until the grade level is 6' above the original grade level. This will make the minimum distance between the waste and grade level 16' and will help prevent future root and animal intrusion.

FIGURE 2.6 GCD BOREHOLE CLOSURE

total volume in this GCD unit would be about 100,000 cubic feet. The GCD trench would be used for emplacement of high-activity waste forms too large to be emplaced in GCD boreholes.

GCD trenches would be closed in a manner similar to the boreholes. The intent would be to prevent to the extent possible future root, animal, and human intrusion to the waste.

2.1.2.3 Greater Confinement Disposal Performance

Greater Confinement Disposal designs have been assessed by Trevorrow, Gilbert, Luner, et al.[10], where they conclude that "the need for disposal technology offering greater confinement than SLB arises not only from the existence of wastes exceeding the regulatory limits for SLB, but also from individual policies of organizations and demands of concerned citizens." In this reference, the authors expand the GCD concepts by including improved waste forms and high-integrity containers for emplacement in GCD structures.

GCD boreholes have also been used at the Nevada Test Site[11]. In the NTS design, the boreholes are unlined, but much deeper than described above. This design is specific for the geologic and climatic conditions at the Nevada Test Site.

GCD boreholes at Savannah River have been in operation for only a few years. It is too early to assess long-term performance. However, the boreholes have been dry, indicating that no water is infiltrating to the waste. The grout liner is expected to last for hundreds of years, and while the lifetime of the inner fiberglass liner is not known, the fiberglass is made with a resin that is specifically unaffected by most chemicals. It is expected to be stable in the grout matrix for greater than one hundred years.

The volume of higher activity waste that should be placed in GCD boreholes or trenches has been estimated (more detail is given in Section 2.3). About 5% of the volume of SRP LLW, or about 50,000 cubic feet a year, has an activity level that would require GCD emplacement. Thus a GCD trench with a volume of about 100,000 cubic feet could last about 2 years if all of the GCD triggered waste were placed in a GCD trench.

2.1.3 Above-Grade Operation

2.1.3.1 Definition

An Above-Grade Operation (AGO) facility is defined as an above-ground engineered storage or disposal facility constructed at grade on a pad, with the main objective being to decouple percolate water from the ground or surface water. Prior to closure operations waste forms may be retrieved from the facility, and as such the facility could be considered a storage facility. After closure operations the waste could no longer be easily retrieved, and as such the facility would be considered a disposal facility.

An AGO can be constructed on top of existing SLB trenches. The design, which would include an impermeable base, would be part of the closure design for the SLB trenches. Closure of the AGO would provide additional closure for the below-grade SLB.

2.1.3.2 Description of an Above Grade Operation

DESIGN OBJECTIVES

The basic design objective is to provide above-ground storage and/or disposal for containerized waste forms. Other main design objectives are :

- To decouple the waste from the groundwater by use of a percolate water collection system.
- To be able to retrieve the waste forms for any purpose --for example -- repair of the facility, or repair of a container, or removal of containers to another storage/disposal facility.
- To reduce the percolate water reaching waste forms disposed of below the AGO facility (if the AGO is built over an existing waste disposal area).
- To divert surface water runoff from the AGO to areas that will not be impacted by the excess water.
- To extend the life of a given storage or disposal area.

SITE SELECTION

The criterion for site selection for an AGO facility is minimum potential for subsidence. Therefore, if the AGO is placed over a filled SLB trench, that trench must have a minimum potential for future subsidence.

DESIGN

The conceptual design consists of a stable sub-base made of clay and an impermeable geomembrane, a gravel surface for emplacement of waste containers, a percolate water collection system, and a cover consisting of filler material, an impermeable geomembrane, and soil formed to prevent surface erosion.

A typical design concept is shown in Figure 2.7. In this example, the sub-base is composed of a clay cover over existing waste disposal trenches, an impermeable plastic membrane, a layer of sand to protect the membrane, a second plastic layer to maintain separability between the layer of sand and the final layer of gravel. The sub-base is sloped to collect any water that appears while waste is being placed on the AGO and to collect percolate water after closure. If the closure is designed properly, no percolate water will be collected.

The waste shown in Figure 2.7 is boxed waste where the boxes can be stacked 2, 3, or 4 high. Other containers are acceptable. The criteria for containers are:

- The containers must be free of external contamination.
- To the extent practical the containers must contain stabilized waste to prevent collapse of the waste forms. The stabilization can be accomplished by compaction of the waste in the containers, or by stabilizing the waste in the containers by a cement grout or other stabilizing matrix.

The cover of the AGO consists of layers of sand, clay, an impermeable membrane and soil. The cover membrane would be sealed to the impermeable membrane on the bottom of the AGO to form a sealed envelope around the stacked waste forms. An end view of a facility constructed over a previously filled shallow land burial facility is shown in Figure 2.8.

All percolate water will be collected, monitored, and if contaminated, then stabilized and disposed of as low-level solid waste or treated as low-level liquid waste at a separate facility. Surface water would be channeled away from the AGO facilities to eliminate erosion of existing disposal facilities.

2.1.3.3 Above Grade Operation Performance

There has been no experience in the use and performance of an Above Grade Operation such as that described above; however the concept is similar to the storage pads used at the Savannah River Plant and other DOE facilities for transuranic waste material. The performance of these pads has been very good since their use began in 1972.

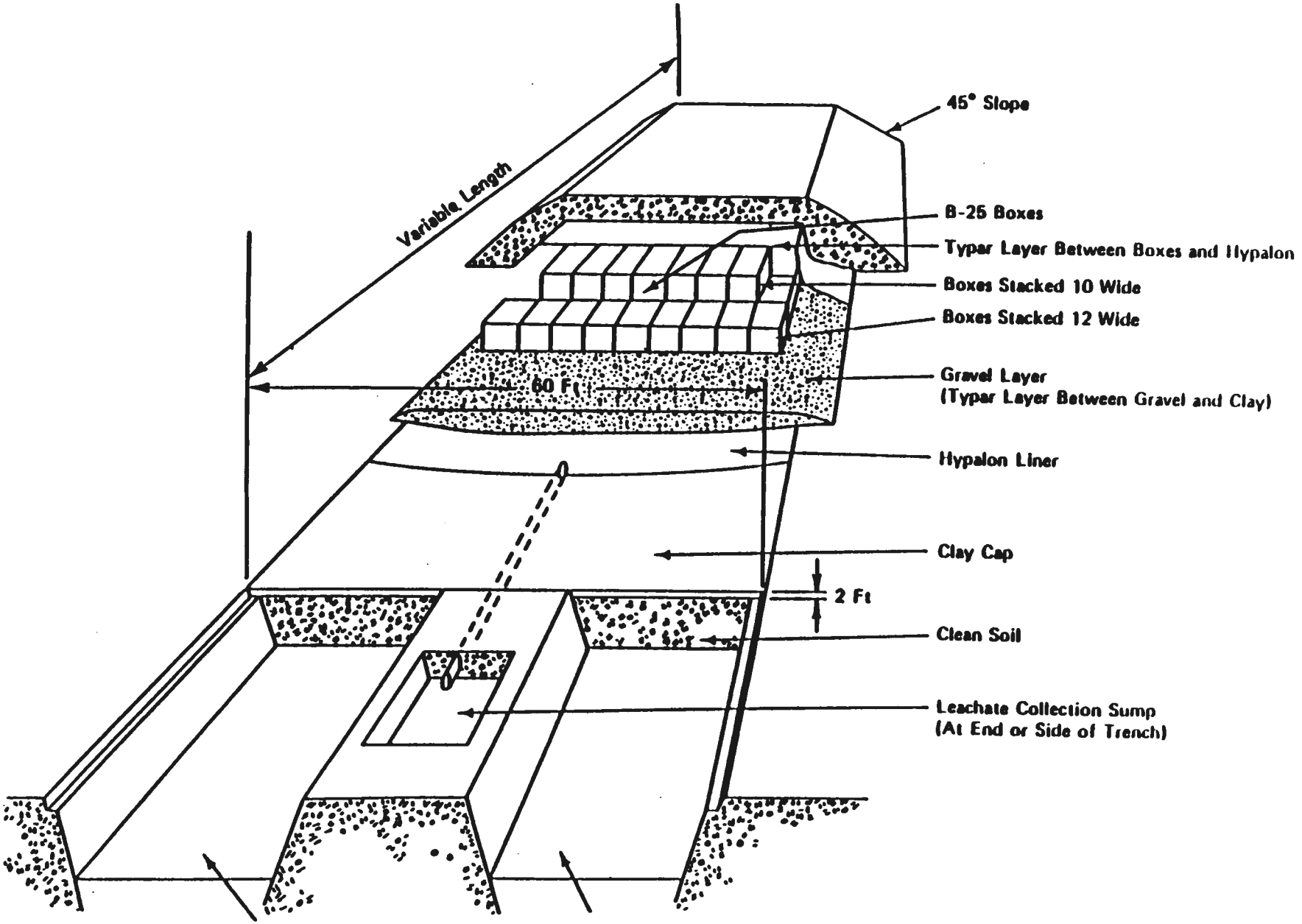


FIGURE 2.7 ABOVE GRADE STACKING CONCEPT

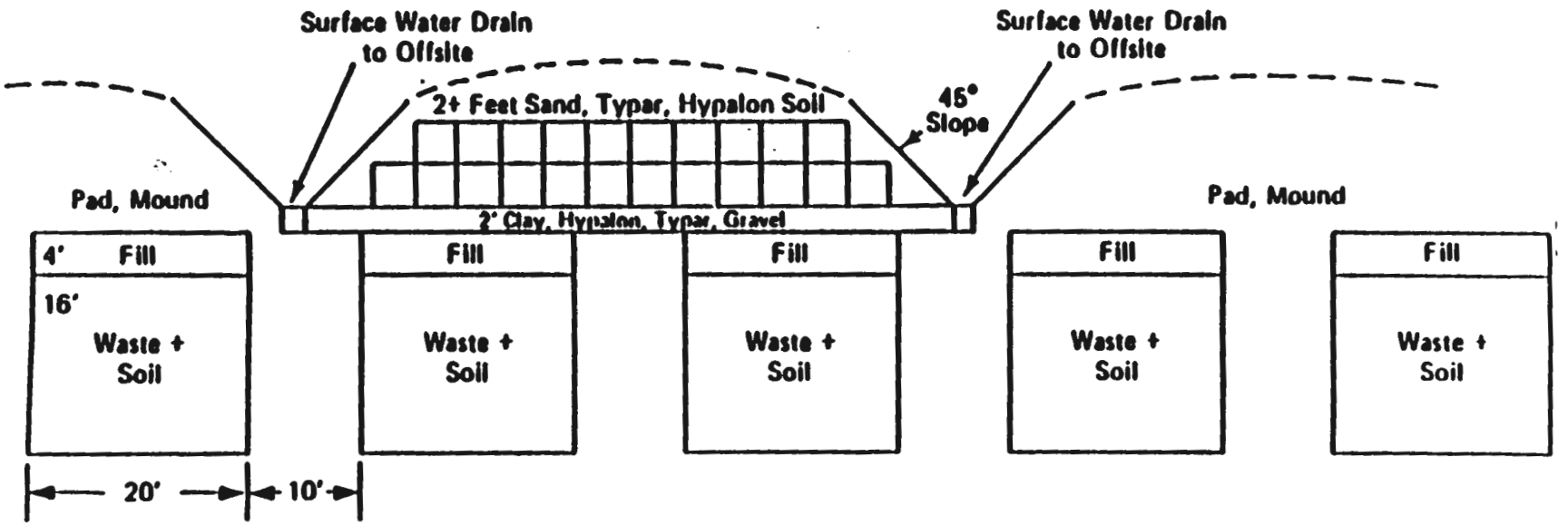


FIGURE 2.8 LAYOUT OF ABOVE GRADE PADS - CROSS-SECTION VIEW

2.1.4 Above and Below Grade Vaults

2.1.4.1 Above Grade Engineered Vault

2.1.4.1.1 Definition

An Above Grade Engineered Vault is a disposal system in which the waste material is completely enclosed within a structural framework. Depending upon the waste form the vault design may range from a massive concrete structure (e.g. TVA storage buildings at Brown's Ferry, which are designed to store relatively high activity wastes such as ion-exchange resins), to relatively simple metal structures (e.g. the Canadian storage building at the Bruce Station, which stores very low activity waste).

2.1.4.1.2 Description of Above Grade Engineered Vault

A conceptual design for an Above Grade Engineered Vault is shown in Figure 2.9. In this design the vault floor and walls are formed of two-foot thick concrete. There can be two variations of the design: in the first the vault has no chambers. Equipment that is used to stack containers therefore has free access to all parts of the vault. Figure 2.9 shows the first concept. In the second variation chambers are designed to allow the formation of concrete monoliths at convenient time intervals. This vault concept is shown in Figure 2.10. All percolate water is collected, monitored and treated if necessary by solidification and disposed of in the vault or treated as low-level liquid waste in a separate facility.

2.1.4.1.3 Above Grade Engineered Vault Performance

There has been no experience in the use and performance of an Above Grade Engineered Vault made of concrete; however, it should perform at least as well as a Below Grade Engineered Vault.

2.1.4.2 Below Grade Engineered Vault

2.1.4.2.1 Definition

The concept of waste disposal in a below grade engineered vault is actually a special case of Greater Confinement Disposal. In this case the excavation is lined with concrete walls, floor, and top. This concept provides a structural barrier between the waste and the surrounding soil.

2.1.4.2.2 Description of Below Grade Vault

A conceptual design for a Below Grade Engineered Vault is shown in Figure 2.11. The excavation is lined on the bottom and sides with two feet of concrete, which could be either poured in forms, precast, or formed of shotcrete. The vault would be divided into chambers which would be designed to support a rain cover for each chamber. A complete percolate water collection system is

Figure 2.9

ABOVE GROUND ENGINEERED VAULT CONCEPT

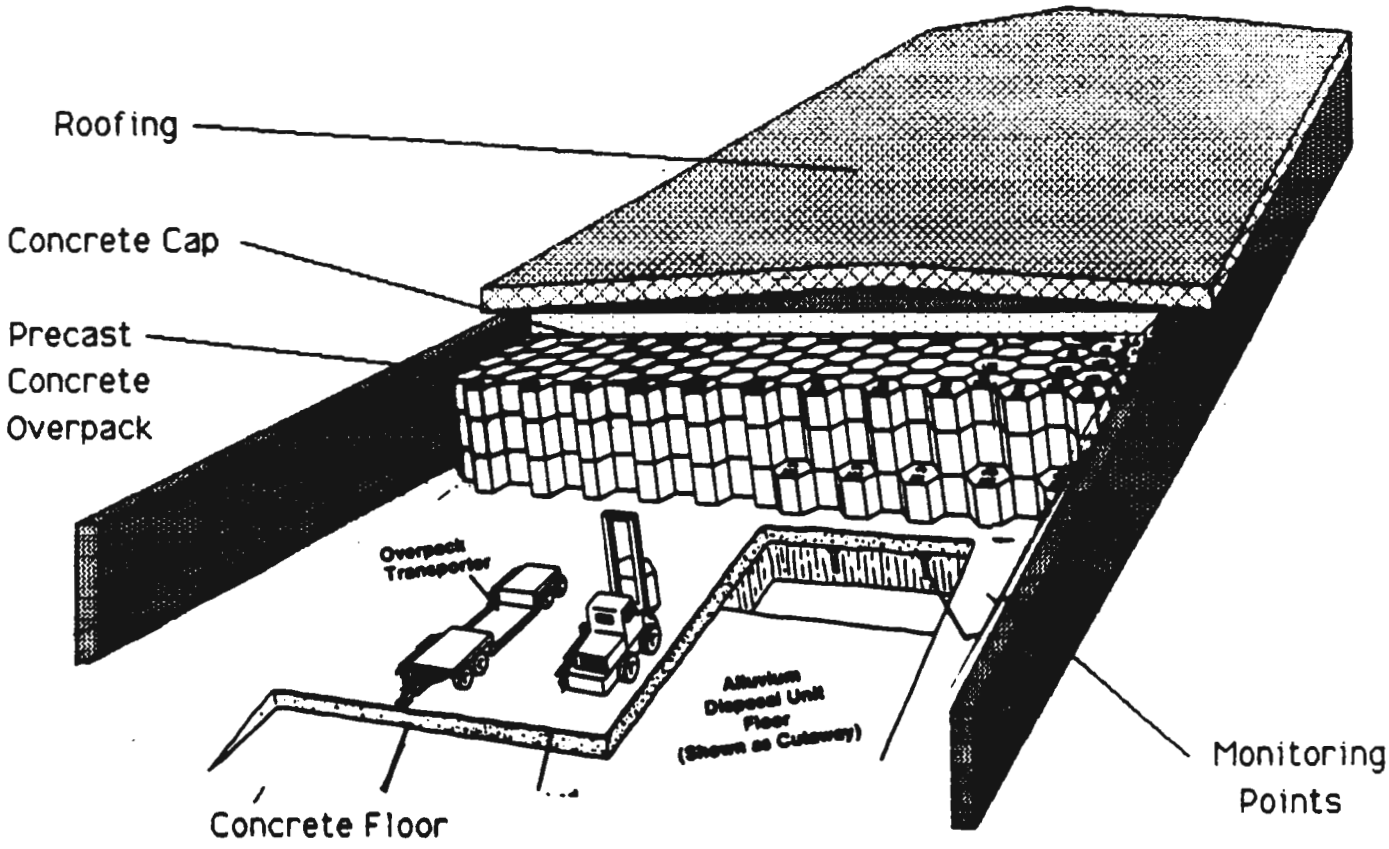


Figure 2.10

ABOVE GRADE VAULT FOR UNTREATED WASTE

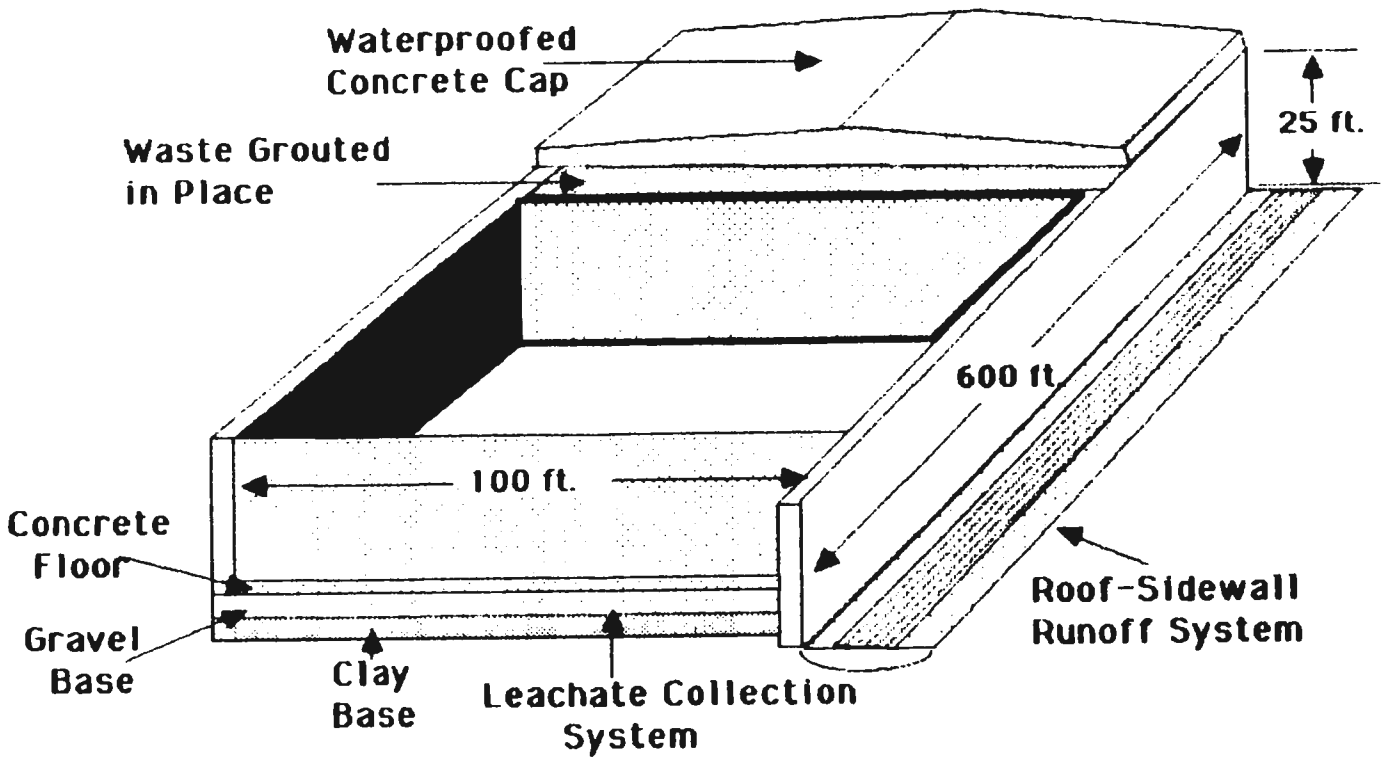
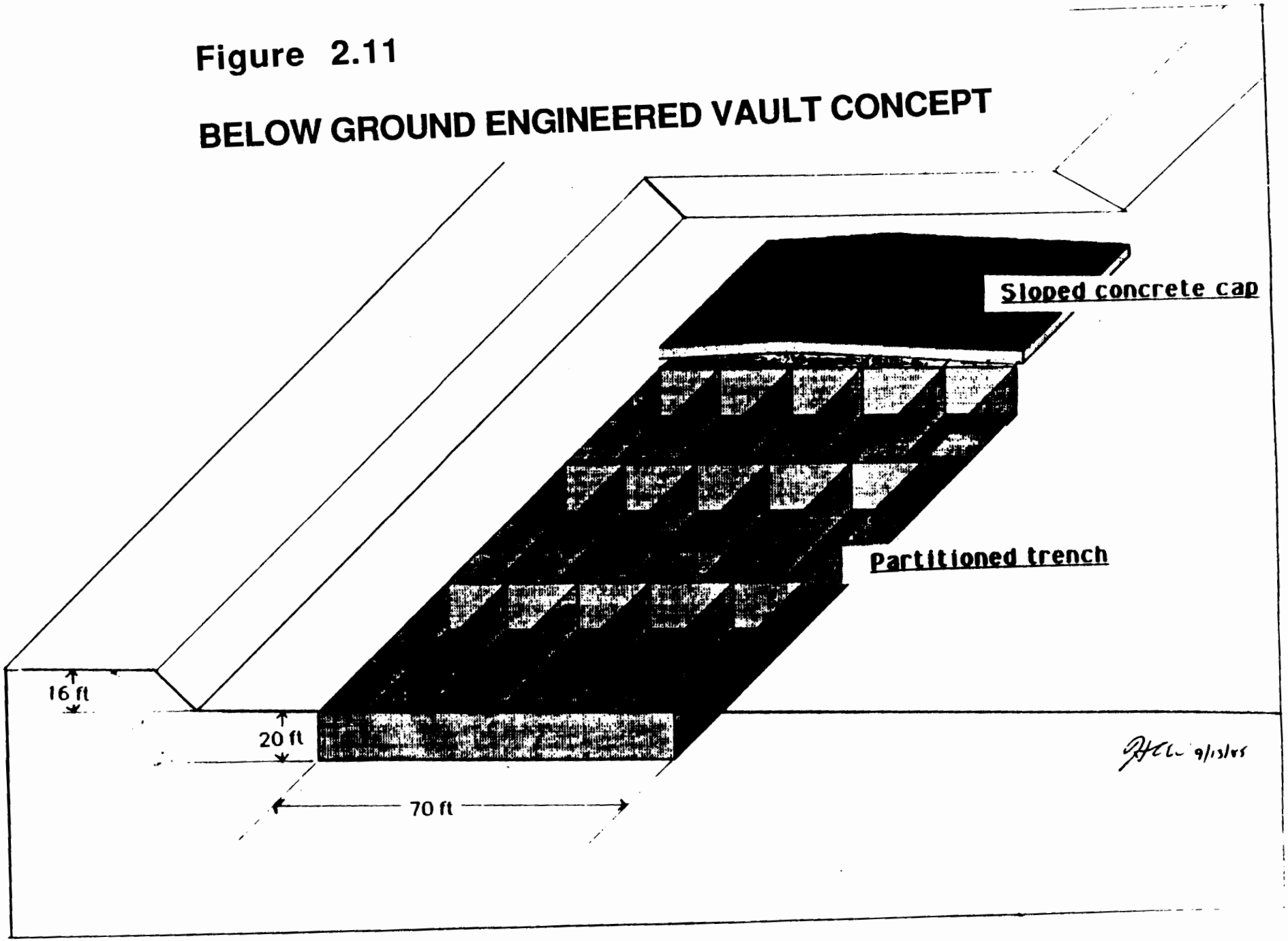


Figure 2.11

BELOW GROUND ENGINEERED VAULT CONCEPT



incorporated into the design. Percolate water could be collected, monitored, and treated if necessary to form a stabilized waste form that would be disposed of in the vault or treated as low-level liquid waste in a separate facility.

The waste material may be treated in a number of ways before emplacement into the vault. Stabilized waste forms -- that is, waste forms that would resist subsidence -- could be placed in the vault and grout poured directly around the forms. In another method that would prevent subsidence, the waste could be placed into concrete forms such as hexagons or cylinders, and these concrete waste forms would provide the desired degree of stabilization. Alternatively, the vault and cap could be designed to prevent subsidence without relying on the emplaced waste forms.

A two-foot thick concrete cap would be placed over a filled vault. This could be poured to form a solid monolith, or it could be precast in sections and placed by a crane. The precast cap would retain the possibility of retrieval of the waste forms.

A concrete cap could be designed to have structural properties that would provide the desired degree of protection against plant, animal, and human intrusion for closure (See Section 2.8 on Closure Plans).

2.1.4.2.3 Below Grade Engineered Vault Performance

Depending upon the waste emplacement option chosen the Engineered Below Grade Vault disposal system is similar to either the French monolith design, or the Canadian concrete bunker design. Both systems have been in operation for a number of years with no detectable release of activity (References 12 and 13). The structural characteristics of the design should ensure integrity of the system for hundreds of years.

2.1.5 Engineered Storage of Low-Level Waste

2.1.5.1 Definition

Engineered storage of low-level radioactive waste is a system where low-level waste is stored in an engineered structure under the following criteria:

- All materials are stored in a retrievable manner in facilities having a design life of about 50 years.
- All LLW is stored in engineered structures designed to decouple the waste from ground and surface water. No waste is placed directly in soil.
- Only solid waste is stored. Liquid waste has to undergo pre-treatment to ensure immobilization.

- All waste emplacement is treated as interim storage. Some of the waste will decay in place to low levels of activity, while other waste will be stored for later retrieval and ultimate disposal.

Engineered storage can consist of above or below ground concrete or steel (or other) structures that are specifically designed to isolate the waste from ground and surface water, and are designed for relatively easy retrievability of the waste forms. The structures for the most part will have shielding walls as an integral part of the design. The design aspects of engineered storage facilities make the location of these facilities site independent. The location is not dependent on soil structure or hydrology of the site.

2.1.5.2 Description of the Facility

The objectives of the designs are to store low-level radioactive waste retrievably for the purpose of either decay-in-place for short-lived radionuclides or later retrieval for disposal in a geologic repository. A necessary preliminary segregation step is required for storage, which is segregation of the waste according to the radiation level of the waste forms. Waste would be separated into at least three categories according to radiation level -- low activity, intermediate activity, and high activity. The activity levels referred to below are those used at the Ontario Hydro facility at the Bruce Station[12].

LOW ACTIVITY STORAGE BUILDING

Waste with low levels of radiation -- radiation levels of less than about 1 mrad/hour at 3 inches -- would be stored in an above-ground concrete building. Design features of the storage building would include:

- Concrete walls 15 to 18 inches thick, and a concrete roof 6 to 10 inches thick. Great attention must be placed on roof design to make it water tight.

- A poured concrete floor of suitable load bearing capacity, with an internal drainage collection system that is capable of collecting and monitoring drainage from individual sections of the building.

- The size of the building must be such that it can store about a year's generation of the low activity waste. A typical building would be about 150' long, 100' wide, and 30' high. Waste storage capacity is about 50% of the building volume, or 225,000 cubic feet.

- The building would have a smoke detection system, a fire extinguishing system, forced air ventilation with filters, internal lighting, and racks for stacking waste packages. The racks would be positioned to allow stacking the waste forms with a loading vehicle similar to a fork-lift truck, and to allow visual inspection of the waste forms.

- The building would be designed as a modular structure to allow for easy expansion by connecting similar buildings to it.

INTERMEDIATE ACTIVITY STORAGE FACILITY

The intermediate activity storage facility would be designed to store waste with radiation levels greater than 1 mrad/hour at three inches but less than or equal to 100 mrad/hour. Remote handling of all waste forms will be required. Design of the storage facilities could be along several different lines. Typical examples would be:

- Cylindrical holes bored into the ground, with water-tight steel liners and covers. The waste is emplaced into the liners and can be grouted in place. When the waste is retrieved, the liner itself is removed and becomes the new waste form.

- Underground watertight vaults, with concrete (or other) covers. The vaults are provided with a complete water collection and monitoring system. Waste forms are emplaced and removed from the vault by remote operation.

- Aboveground watertight vaults, with concrete (or other) covers. Waste is emplaced or removed remotely. The covers are shielded, sloped to provide runoff for precipitation, and provided with lifting lugs.

HIGH ACTIVITY STORAGE FACILITY

High activity storage facilities would be similar to the intermediate storage facilities, except that more shielding would be required. Waste placed in these facilities would have radiation levels in excess of 100 mrad/hour at three inches. If the facility is placed above ground, the side wall shielding would have to be three or more feet thick. Covers would have to be at least three feet thick and made in two or more pieces to reduce the weight of each piece. A possible design would be to have an inner concrete cover and a separate outer concrete cover.

Remote handling of all waste forms would be required. The facility would be designed with removable steel liners to facilitate retrieval.

GENERAL METHOD OF OPERATION

Waste packages would be assayed for isotopic content and radiation level. A decision would then be made as to which storage facility would receive the waste. The package information would be entered into a computer, and the computer would calculate the

estimated radiation level as a function of time. As decay occurs, the waste could be moved from the high to the intermediate and finally to the low activity storage building. The storage building could be expanded as needed. Waste would be removed from the low activity facility when a decision is made on the final disposition for the waste.

2.1.5.3 Performance of Engineered Storage

Engineered storage structures have been used with great success by Ontario Hydro in Canada[12] for storage of waste prior to emplacement in a repository, and in France for decay-in-place of tritiated waste forms.

2.1.6 Engineered Disposal Facility

2.1.6.1 Definition

An engineered disposal facility is similar to the storage facility described in Section 2.1.5, except that:

- Waste forms are disposed of without intent of retrievability.
- Waste forms are either stabilized (that is, compacted, grouted, or other) before emplacement by pretreatment (Section 2.5), or else the waste forms are stabilized with grout after emplacement, or waste is placed into containers which are inherently stable.
- The facility will undergo an engineered closure operation and post-closure phase when the facility is filled. (See Section 2.8 for closure plans.)

Similar to the engineered storage facility described above, the engineered disposal facility will be designed to isolate the waste from ground and surface water. The closure operation will be designed to reduce the amount of water percolating to the waste to a very low amount -- about 0.1% of normal.

2.1.6.2 Description of the Facility

The following description of the engineered disposal facility closely parallels the description of the low-level radioactive waste disposal facility operated by France at the Centre de la Manche, near Cherbourg.[13]

Prior to disposal the waste is segregated into three parts --high, intermediate, and low activity waste. Also prior to disposal the low activity waste is stabilized by:

- Compacting drummed waste and placing the crushed drums into cylindrical concrete forms that are subsequently filled with grout and sealed, or

- Incineration and subsequent stabilization of the ash in cement, or

- Stabilizing boxed waste by injecting grout into the boxes in a way that makes the waste form stable in the event the metal box corrodes or fails.

In general, the three waste classes are disposed of in an earth-mounded concrete bunker disposal facility. In this concept, waste containers that do not provide adequate isolation of radionuclides are disposed of in subsurface units composed of concrete monoliths or bunkers, while packages of very low level activity waste, or waste whose container does provide adequate radionuclide isolation (concrete cylinders or compacted drummed waste) are stacked on top of the monoliths at surface level in what are called "tumuli". Once a disposal unit is filled with monoliths and tumuli it is covered with layers of clay and soil to look like an earth-mounded concrete bunker.

The disposal method begins with the excavation of a 3000 square meter disposal unit (32,300 square feet, or about 180' x 180'). A concrete pad is formed that has a complete drainage and water collection system. The water collection system will collect any water that may percolate through the disposal unit and take it to individual checkpoints where it can be monitored for activity. If there is an abnormally large amount of water, or if it contains radioactivity above background levels, this signals a failure in the disposal unit's cap. The cap failure can be located and repaired, and if the water is contaminated it is processed directly on site by stabilizing it in cement and disposing of it in the facility. Another water collection system completely surrounds the facility to divert surface runoff away from the disposal units. The water collection system is a critical part of the design of the entire disposal facility.

On top of the concrete pad formed in the excavation, disposal cells, or monoliths, are formed side by side, either by pouring concrete into reusable steel molds or by using prefabricated concrete panels lined with reinforcing steel. Waste packages are lowered into the monoliths by cranes a layer at a time and covered with grout. Reinforcing steel is placed on the last layer of packages and covered with concrete. Two meter (6.5') wide channels are formed between selected rows of monoliths for disposal of waste that requires remote handling (that is above a contact radiation level of about 200 mrad/hour). The remote handled waste is lowered into the channels by a shielded crane or by use of a shielding bell that surrounds the waste form. After the high activity waste is placed in the channel it is also covered with concrete.

The excavation, when filled, thus becomes a large, solid concrete monolith. To help prevent rainwater from entering the monoliths during the time they are being filled, a transportable cover is placed over the openings. This cover enables waste operations to take place on rainy days and decreases the amount of water that is collected and monitored during disposal operations.

When the subsurface disposal unit has been filled with individual monoliths, and when all of the channels have been filled with the high activity waste, the unit is covered with a reinforced concrete pad that is surrounded by another water collection system. (This system is independent of the collection system for the below-grade monoliths.) Stabilized waste packages of low activity waste are arranged in stacks up to 20' high on top of the pad. Concrete cylinders are placed around the periphery of the pad to form a structural framework. Other waste forms are then placed inside the walls. When the pad surface area has been filled with waste forms, it is backfilled with gravel, clay or other material. It is then covered with a layer of impermeable clay and a layer of soil which is planted with local vegetation. These layers form a temporary closure, which will be altered when a permanent closure is accomplished.

The ratio of volume of waste to surface area used is about 3.3:1, or about 10,000 cubic meters of waste can be disposed of in a 3000 square meter area.

2.1.6.3 Performance of Engineered Disposal

The disposal system described above has been in use in France since 1979 for the disposal of both commercial and defense related low-level radioactive waste. The facility has met all of the French performance criteria for radioactive waste disposal, which are very similar to those in the United States.

2.1.7 Combination of the Above

A low-level solid radioactive waste disposal facility could use a combination of the disposal designs described above, or else it would be an engineered disposal facility as described in Section 2.1.6. In the combination form, the following disposal practices would take place:

- Beta-gamma activity waste would undergo rigorous segregation and pretreatment (discussed in Section 2.5) by the waste generators. Waste would be segregated into:
    - Combustible and non-combustible fractions.
    - Low, intermediate, and high activity fractions.
    - Tritiated and non-tritiated waste.

- Waste containing short half-life radionuclides --30 years or less, and waste with longer half-lives.
- Miscellaneous waste forms, such as large bulky waste that cannot be decontaminated or reduced in size.
- Offsite DOE waste and classified waste.

- All waste would be placed in contamination free containers

A typical combination of the above described facilities that could constitute a modern low-level waste disposal facility would be:

- Above or below grade vault disposal, or Greater Confinement Disposal, of the intermediate and high activity fractions of the waste, classified waste forms, and offsite waste if the activity levels exceed certain trigger values.
- Above-grade operation facilities for disposal of low-activity waste forms, and large bulky waste forms that cannot be size-reduced or decontaminated.
- Engineered storage facilities for:
  - Storage of tritiated waste forms, where the tritium would be allowed to decay in place for a length of time equal to ten or more half lives.
  - Storage of waste with long half lives, such as waste containing primarily carbon-14 (5730 year half-life) or iodine-129 (16 million year half-life). The final disposition of this waste would be determined at a later time.

As an alternative to the above, all waste except that containing tritium and long-lived radionuclides, such as carbon-14 and iodine-129, could be disposed of in an engineered disposal facility described in Section 2.1.6. Tritiated waste would be stored for decay-in-place, while the long-lived waste would be stored for as long as necessary.

2.2 FACILITY DESCRIPTIONS -- GENERAL

Site preparation for a new facility would be done before radioactive waste is stored or disposed of in the facility. Site preparation includes tree removal, grading, construction of railroad tracks, access roads, drainage areas, fencing, security gates, and lighting, including the installation of transformers and lighting panels.

Site preparations would also include the installation of monitoring facilities (discussed in Section 2.7), including air and water monitoring stations, office buildings (including computer facilities), and waste monitoring stations.

Site preparations would also include construction of storage and disposal facilities that would have a two-or-more year capacity for waste arisings.

Prior to construction of roads and fences, the selected area would be cleared and grubbed. All vegetation would be removed and the area prepared as land classified for a lawn. Only selected grasses would be planted to hold the top soil. Selection would be based on the depth of root penetration and amount of evapotranspiration afforded by the top growth.

2.2.1 Fencing, Roads, Drainage

FENCE

A chain-link fence topped with barbed wire would surround the new facility. An appropriate number of 30-foot wide gates -- at least four -- would be provided. One or more of these gates would be operated automatically.

ROADS AND RAILROADS

There would be a patrol road installed adjacent to the outer fence. The road would be constructed to provide clear viewing of the interior of the storage/disposal area, and provide access to perimeter air and water monitoring stations.

A paved access road would be provided for the main entrance gate.

Graveled service roads would be provided for access to the storage/disposal locations of the facility.

A standard gauge railroad would be constructed to serve the areas of the facility used to store or dispose of large or heavy waste containers.

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SEDIMENTATION CONTROL

Sedimentation control measures would be used to prevent silt runoff during construction operations.

DRAINAGE STRUCTURES

Surface water drainage structures would be designed to prevent surface water from running onto the disposal or storage areas from adjacent areas, and would be designed to facilitate surface water runoff and to prevent ponding.

2.2.2 Security and Access

Access to the area would be through one main gate that could be controlled by operating personnel. Other gates, including the railroad gate, would remain locked during normal operation.

Tall lighting poles would be constructed to make the entire area visible at night. Patrol personnel should be able to observe clearly all areas of the storage/disposal facility.

External speakers would be installed to enable communication with drivers arriving at the main access gate.

2.3 QUANTITY OF LOW-LEVEL WASTE GENERATED

The following sections describe the quantity of low-level radioactive waste that is expected to be stored or disposed of for the first few years of operation of the storage/disposal facility. In this section are listed the volume, curies, and isotopic distribution of the waste. The following section, Section 2.4, describes the waste streams produced by the different waste generators.

The present annual generation rate of beta-gamma waste is about 900,000 cubic feet per year. This waste contains about 100,000 curies of radioactivity at the time of disposal. Another 100,000 cubic feet of transuranic waste (TRU) is stored retrievably on pads above ground. The TRU waste storage is not a disposal operation.

2.3.1 Volume, Curies

2.3.1.1 Volume and Curies by Isotope

Waste disposal records are stored on the computerized burial record system, labeled COBRA, that is in use at the Savannah River Plant. On this system is recorded twenty isotopes, or groups of isotopes, by volume buried and quantity buried in curies or mass. The isotopes listed are:

cobalt	curium-244
cesium	californium-252
fission products	plutonium-239
induced activity	uranium-233
plutonium-241	natural uranium
strontium	neptunium-237
depleted uranium	plutonium-238
enriched uranium	tritium
plutonium-242	thorium
americium-241	

The isotopes are also listed according to the type of radiation level emitted by the waste forms. Burial Code 1, or low-activity waste, is waste with a radiation level less than 300 mr/hour at 3 inches from the waste package or alpha waste that contains less than 10 nanocuries per gram of alpha activity. Burial Code 2, or Intermediate Level waste, is waste with a radiation level in excess of 300 mr/hour at 3 inches.

Table 2.3 lists the three-year average of volume, in cubic feet per year, and activity, in curies disposed of per year, for the nineteen isotopes (or isotope groups, such as in the general label for fission products.)

Table 2.4 lists the isotopic distribution for fission product waste, decayed for five years[14]. The values listed in this table are to be used as relative values only, although the units are

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TABLE 2.3
LOW-LEVEL WASTE ARISINGS
THREE YEAR AVERAGE (1983, 1984, 1985)

(Volume is listed in cubic feet/year, activity in curies/year)

ISOTOPE	VOLUME	CURIES	ISOTOPE	VOLUME	CURIES
Cobalt	16200	7900	Curium	550	0.05
Cesium	8600	4.9	Cf-252	1800	9.2
Fission Products	532000	770	Pu-239	125000	0.06
Induced Activity	48000	9700	U-233	1400	0.05
Pu-241	270	0	Natural Uranium	630	0.005
Strontium	660	3.0	Np-237	31	0
Depleted Uranium	67000	4	Pu-238	47900	0.5
Enriched Uranium	53600	0.06	Tritium	60300	74800
Pu-242	140	0	Thorium	13700	0.001
Am-241	120	1.2			

THREE-YEAR AVERAGE GENERATION RATE BY RADIATION LEVEL

WASTE TYPE	VOLUME, CUBIC FEET/YEAR	ACTIVITY, CURIES/YEAR
Low Activity Level	847,000	7,800
Intermediate Level	137,000	85,400
Total	984,000	93,200

TABLE 2.4 RADIONUCLIDE CONTENT OF 5-YEAR WASTE

ISOTOPE	CI/GAL	ISOTOPE	CI/GAL	ISOTOPE	CI/GAL
H 3	4.12E-03	Te129M	4.07E-16	Pb212	3.46E-07
C 14	1.73E-07	I 129	9.42E-07	Pb214	2.47E-12
Cr 51	1.05E-20	Xe131M	2.72E-48	Bi210	1.61E-13
Co 60	1.93E-02	Cs134	3.89E-01	Bi210M	5.37E-22
Ni 59	1.56E-04	Cs135	6.72E-06	Bi211	7.99E-12
Ni 63	3.85E-02	Cs136	1.15E-42	Bi212	3.46E-07
Se 79	1.61E-05	Cs137	3.59E+00	Bi213	2.34E-14
Rb 87	1.02E-09	Ba136M	3.68E-48	Bi214	2.47E-12
Sr 89	3.07E-09	Ba137M	3.40E+00	Po210	1.27E-13
Sr 90	3.43E+00	Ba140	4.26E-41	Po212	2.22E-07
Y 90	3.43E+00	La140	4.91E-41	Po213	2.29E-14
Y 91	1.06E-07	Ce141	4.07E-15	Po214	2.47E-12
Zr 93	1.27E-04	Ce142	1.08E-09	Po215	8.01E-12
Zr 95	1.12E-06	Ce144	1.12E+00	Po216	3.46E-07
Nb 94	3.65E-09	Pr148	1.36E-38	Po218	2.47E-12
Nb 95	2.40E-06	Pr144	1.12E+00	At217	2.34E-14
Nb 95M	1.42E-08	Pr144M	1.34E-02	Rn219	8.01E-12
Tc 99	5.53E-04	Nd144	5.45E-14	Rn220	3.46E-07
Ru103	2.56E-12	Nd147	1.44E-48	Rn222	2.47E-12
Ru106	3.35E-01	Pm147	2.74E+00	Fr221	2.34E-14
Rh103M	2.56E-12	Pm148	7.88E-15	Fr223	9.96E-13
Rh106	3.34E-01	Pm148M	1.14E-18	Ra223	8.01E-12
Pd107	1.08E-06	Sm147	2.16E-10	Ra224	3.46E-07
Ag110	1.93E-05	Sm148	6.38E-16	Ra225	2.37E-14
Ag110M	1.45E-03	Sm149	1.98E-16	Ra226	2.48E-12
Cd115M	1.08E-13	Sm151	2.67E-02	Ra228	1.58E-15
In115	7.34E-16	Eu152	4.27E-04	Ac225	2.34E-14
In115M	9.81E-18	Eu154	7.02E-02	Ac227	7.22E-12
Sn121M	3.71E-06	Eu155	5.56E-02	Ac228	1.58E-15
Sn123	3.01E-05	Eu156	5.92E-36	Th227	7.09E-12
Sn126	1.71E-05	Gd152	7.86E-18	Th228	3.47E-07
Sb124	8.12E-12	Tb160	1.27E-10	Th229	2.40E-14
Sb125	9.60E-02	Tl206	5.37E-22	Th230	1.30E-09
Sb126	2.40E-06	Tl207	7.97E-12	Th231	5.95E-09
Sb126M	1.71E-05	Tl208	1.24E-07	Th232	1.90E-15
Te125M	2.34E-02	Tl209	5.06E-16	Th234	3.27E-08
Te127	1.02E-05	Pb209	2.34E-14	Pa231	5.17E-11
Te127M	1.04E-05	Pb210	1.64E-13	Pa233	9.91E-07
Te129	2.59E-16	Pb211	7.99E-12	Pa234	6.54E-08

TABLE 2.4 (CONTINUED)

ISOTOPE	CI/GAL	ISOTOPE	CI/GAL	ISOTOPE	CI/GAL
U 232	5.76E-07	Pu239	7.96E-04	Cm245	7.47E-10
U 233	6.78E-11	Pu240	5.03E-04	Cm246	5.97E-11
U 234	1.80E-06	Pu241	9.45E-02	Cm247	7.33E-17
U 235	5.94E-09	Pu242	6.70E-07	Cm248	7.66E-17
U 236	1.29E-07	Am241	1.22E-03	Bk249	3.23E-15
U 238	3.27E-08	Am242	1.61E-06	Cf249	4.46E-16
Np236	1.95E-12	Am242M	1.61E-06	Cf250	1.76E-15
Np237	9.91E-07	Am243	6.49E-07	Cf251	7.41E-18
Pu236	7.04E-06	Cm242	3.94E-06	Cf252	1.88E-16
Pu237	5.14E-16	Cm243	6.25E-07	Cf253	9.44E-48
Pu238	8.45E-02	Cm244	1.83E-05		

Total Activity	2.04E+01 CI/GAL
Decay Heat	
Total Primary	4.29E-02 WATT/GAL
Total Gammas	1.75E-02 WATT/GAL

given in curies per gallon. For example, given that the activity in a waste container is 150 curies of fission products, an estimate of the amount of any fission isotope (cesium-137, for example) can be obtained by taking the value of that isotope from Table 2.4 (3.59 curies/gallon), dividing by the total activity of 20.4 curies/gallon, and multiplying by 150 curies.

Table 2.5 lists the expected isotopic distribution in waste that has the generic label of induced activity.

TABLE 2.5

ISOTOPIC BREAKDOWN OF INDUCED ACTIVITY IN REACTOR SCRAP METAL

RADIONUCLIDE	HALF LIFE, YRS	PERCENT OF ACTIVITY
Co-60	5.3	62
Ni-63	100	9.5
Mn-59	0.85	7
Zn-65	0.7	12.5
Se-75	0.3	9

NOTE: Over the last six years, 75% of the activity labeled as induced activity has come from the reactor areas, 21% from the tritium area, and 4% from RBOF. Thus, about 80% of the total IA should have the isotopic distribution listed above.

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FISSION PRODUCT WASTE

Table 2.4 shows the radionuclide content of 5-year-old fission product waste[14]. (Five-year-old waste means five years out of the reactor.) The table is to be used to determine the relative amounts of radionuclides in the waste listed under the generic name of Fission Products in Table 2.3. (The absolute values in Table 2.4 have no meaning in this context.) Of the 149 isotopes listed:

- 23 isotopes ($>10^{-3}$ Ci/Gal) contain 99.89% of the activity.
- 21 isotopes ($>10^{-2}$ Ci/Gal) contain 99.86% of the activity.
- 10 isotopes ($>10^{-1}$ Ci/Gal) contain 97.5% of the activity.

These ten isotopes containing 97.5% of the activity are:

Sr-90	Cs-137
Y -90	Ba-137m
Ru-106	Ce-144
Rh-106	Pr-144
Cs-134	Pm-147

Waste from the canyon buildings (221-F and 221-H) and the 772-F laboratory should have the isotopic distribution of fission product waste back-calculated for a radionuclide distribution of only two years out of the reactor. Waste from the waste management operations (tank farms, diversion boxes, etc.) should be treated as five-year-old waste. The age split of fission product activity has been estimated and averaged over the last six years of waste generation. The split is:

ESTIMATED AGE	PERCENT OF TOTAL ACTIVITY
Five-year-old waste	42
Two-year-old waste	58

INDUCED ACTIVITY WASTE

Table 2.5 gives the isotopic breakdown for waste labeled as induced activity. All of the curies in this waste are produced by reactor irradiation of aluminum and stainless steel. The aluminum waste is radioactive primarily as a result of small quantities of tramp metal in the irradiated aluminum. The activity distribution given in the table is the expected isotopic distribution for reactor scrap metal when the irradiated metal arrives at the disposal area. No decay corrections are required, except for decay after disposal.

For waste labeled as induced activity that comes from the tritium production areas, a practical assumption would be that half of the activity results from Zn-65 and half from Ni-63. Past measurements by the gamma monitor located in the present disposal area have shown that irradiated aluminum contains up to six times the amount of Ni-63 activity as does reactor scrap metal[15].

2.3.2 Quantity of Waste Produced by Generators

The volume of waste produced by the generating facilities is listed below. The values listed are a twelve month moving average, current to August 1985.

FACILITY	VOLUME, CUBIC FEET PER MONTH	PERCENT
Tritium	5070	5
Raw Materials	8780	9
Reactors	7250	8
Separations	30830	32
Waste Management	18160	20
Laboratories	5920	6
Services	910	1
Savannah River Lab.	6480	7
Offsite	4790	5
Others	6940	7
Total	95130	100

About 60% of the waste generated is classed as combustible waste, and about 40% is classed as non-combustible (five-year average).

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2.4 DESCRIPTION OF RADIOACTIVE WASTE STREAMS

The following types of waste will have to be disposed of or stored at a new facility. The list cannot be made all inclusive because changing defense requirements alter production facilities and therefore alter the waste streams.

- Contaminated equipment: obsolete or failed tanks, pipe, jumpers, process vessels, and other hardware. Some of the equipment is stored if there is a possibility that a certain process would require that piece of equipment at a future time.

- Reactor and reactor fuel and target hardware: irradiated metal fuel components, housings, flow restrictors, gripper knobs, and other pieces of irradiated metal. The metal is stainless steel and aluminum. Uranium or other fuel and target material has been removed.

- Spent lithium-aluminum targets: the irradiated Li-Al alloy from which most of the tritium has been extracted.

- Operating and laboratory waste: small equipment, protective clothing, analytical waste, decontamination residue, plastic sheeting, gloves, shoe covers, etc.

- Spent deionizer resin, dewatered, from the reactor areas. The resin is packaged in a sealed stainless steel vessel.

- Rubble and soil from slightly contaminated areas.

- Equipment and building materials resulting from major renovations. Includes flooring, walls, office equipment, obsolete instruments, tubing, wiring, etc.

- Shipments from offsite: naval hardware, tritiated waste from other DOE facilities (Mound Laboratory and Pinellas), job control waste from Westinghouse-Bettis Atomic Laboratory, Shippingport Atomic Laboratory, Knolls Atomic Laboratory, and classified wastes from the Naval Reactor Program and other DOE facilities.

Waste is segregated into the following categories:

- Waste containing less than 10 nanocuries of alpha activity per gram of waste and no measurable beta-gamma activity is classed and disposed of as low-level waste.

- Waste containing alpha activity in the range 10 to 100 nanocuries/gram may be disposed of by Greater Confinement Disposal.

- Waste containing greater than 100 nanocuries/gram of alpha activity is stored retrievably or sent to a separate alpha facility to prepare it for transport to a geologic repository.

- Low-activity-level beta-gamma waste has radiation levels of <300 mrads/hour or <300 mrem/hour at three inches from the unshielded container. This waste can be contact-handled and requires little or no shielding. This waste also may contain less than 10 nanocuries/gram of alpha activity.

- Intermediate-activity-level beta-gamma waste has radiation levels greater than 300 mrads or 300 mrem/hour at 3 inches, and contains less than 10 nanocuries of alpha activity/gram of waste. This waste cannot be contact-handled, but must be handled by shielded equipment or by remotely operated equipment. For the most part, this waste is induced activity waste coming from the reactor facilities or the tritium separation facility.

- Beta-gamma waste with radionuclide concentrations over certain values is classed as Greater Confinement Disposal (GCD) waste.

Tables 2.6 and 2.7 show the solid radioactive waste volumes and activity distribution for the years 1983 through 1985 for waste classes divided into low activity level, intermediate activity level, alpha waste less than 10 nanocuries/gram and alpha waste equal to or over 10 nanocuries/gram. Table 2.8 shows the radioactivity trigger values for GCD type waste. If the concentration limits are greater than the values listed in Table 2.8 the waste should go to a Greater Confinement Disposal facility.

Because of the particular activity distribution in SRP produced waste, over 98% of the activity in the solid radioactive waste is contained in 5% or less of the volume of waste. This calculation can be made on a piece-by-piece basis for the SRP waste forms. The present GCD trigger values are being used on a test basis only, for demonstration purposes. When the demonstration phase is concluded, the trigger values may be moved up or down, depending on the ability to segregate the waste forms.

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TABLE 2.6 SOLID RADIOACTIVE WASTE VOLUMES, 1000 FT^3

Combustible Waste

Burial Code	Type	1983	1984	1985
1	Low-Level Beta-Gamma	436	373	613
2	Int. Level Beta-Gamma	39	34	37
3	Alpha, < 10nCi/g	67	67	--
4	Alpha, drums, retr.	2	1	1
6	Alpha, culverts, retr.	2	2	5
	Total Combustible	546	477	656

Non-Combustible Waste

Burial Code	Type	1983	1984	1985
1	Low-Level Beta-Gamma	238	300	342
2	Int. Level Beta-Gamma	116	93	93
3	Alpha, < 10nCi/g	46	60	--
4	Alpha, drums, retr.	5	7	2
6	Alpha, culverts, retr.	6	8	11
	Total Non-Combustible	411	468	448
	Total Volume	957	945	1104

TABLE 2.7 SOLID RADIOACTIVE WASTE ACTIVITY, CURIES

Combustible Waste

Burial Code	Type	1983	1984	1985
1	Low-Level Beta-Gamma	110	2000	320
2	Int. Level Beta-Gamma	90	29000	7300
3	Alpha, < 10nCi/g	<1	<1	--
4	Alpha, drums, retr.	18000	10000	200
6	Alpha, culverts, retr.	20	30	70
	Total Combustible	18000	41000	7900

Non-Combustible Waste

Burial Code	Type	1983	1984	1985
1	Low-Level Beta-Gamma	16000	5400	20
2	Int. Level Beta-Gamma	85000	91000	44000
3	Alpha, < 10nCi/g	4	<1	--
4	Alpha, drums, retr.	75000	6600	27000
6	Alpha, culverts, retr.	1500	270	400
	Total Non-Combustible	180000	103000	71000
	Total Activity	198000	144000	79000

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TABLE 2.8

RADIOACTIVITY CONCENTRATION CRITERIA FOR GREATER CONFINEMENT DISPOSAL (TEST DEMONSTRATION)

RADIONUCLIDE	MicroCi/CC	Ci/FT^3
H-3	2.0	0.06
Co-60	100	2.8
Sr-90	0.04	$1.1x10^{-3}$
Cs-137	1	0.03
Fission Products	0.04	$1.1x10^{-3}$
Induced Activity	1	0.03
Enriched Uranium	$5x10^{-3}$	$1.4x10^{-4}$

NOTE: If the radionuclide concentration is greater than the values listed in the above columns, the waste may go to a Greater Confinement Disposal Facility.

Waste containing greater than 10 nCi/gm and less than 100 nCi/gm of alpha activity may be disposed of in a Greater Confinement Disposal Facility.

2.5 DESCRIPTION OF PRE-DISPOSAL TREATMENT

Pre-disposal treatment of waste is desirable for the operation of a modern low-level waste storage/disposal facility. Volume reduction in any form is beneficial because less land is required for storage/disposal, and because volume reduction almost always results in a more stable waste form. Waste forms that are not stable tend to collapse with time, which causes the disposal area to collapse in turn and would increase the water infiltration rate to the waste if remedial action is not taken.

2.5.1 Waste Reduction

Waste reduction means reducing the volume of waste generated by a facility by limiting the kind and amount of material that enters the facility. Waste reduction requires a concerted and continual effort of planning and education by supervisors for it to be effective. Waste reduction can be accomplished in many ways, among which are:

- Removing packing material and unnecessary containers from equipment before the equipment or material is moved into a regulated area (an area in which work with radioactive material is performed).
- Re-use of laboratory clothing -- coats, gloves, shoe covers -- if not contaminated.
- Recycling and reuse of laboratory materials and tools.

An example of waste reduction would be: When leaving a regulated area, coats, shoe covers, and gloves are monitored with a sensitive instrument. If no radioactivity is found, the articles would be declared clean, and would not be disposed of in a container designated for low-level radioactive waste disposal.

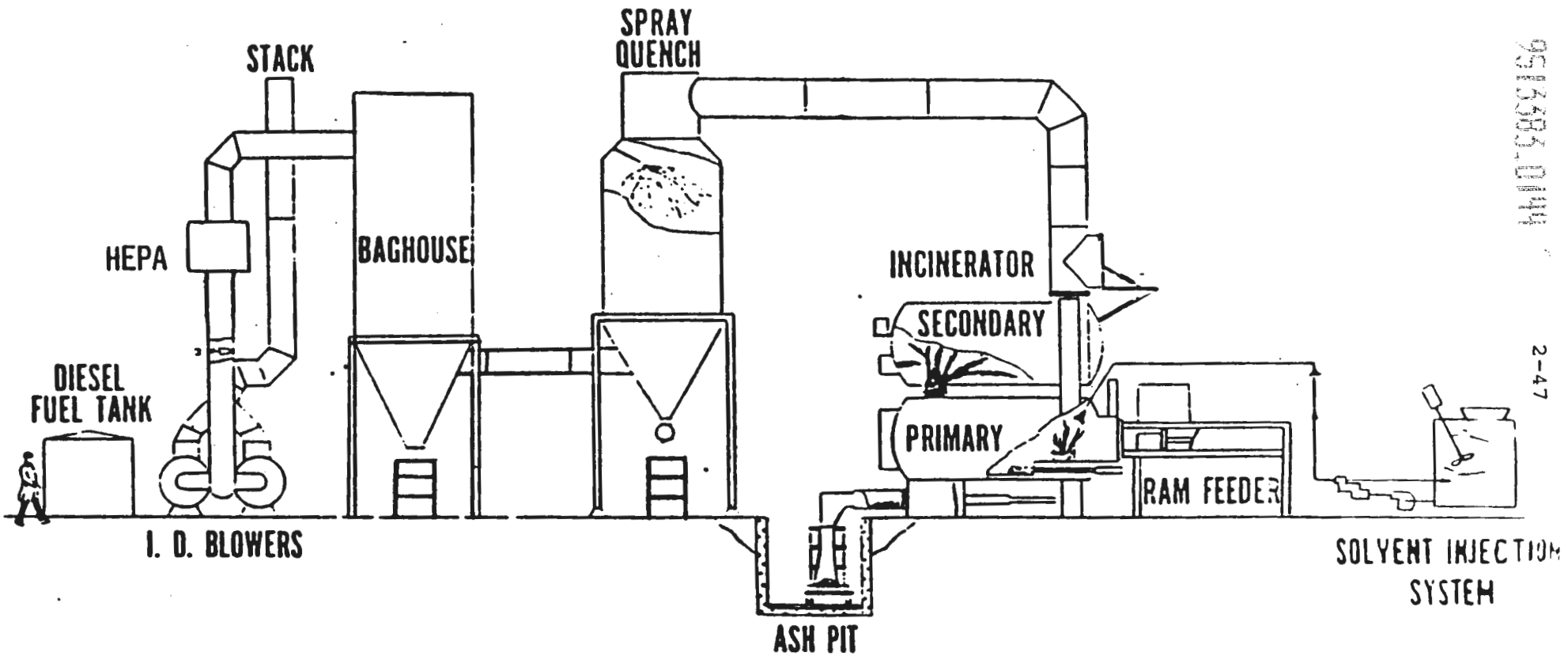
2.5.2 Volume Reduction

2.5.2.1 Incineration

Incineration of low-activity solid waste is a tested process of volume reduction that can achieve volume reduction ratios of thirty or forty to one, or more[16].

Incineration tests are underway at the Savannah River Plant for solid low-level radioactive waste. Cardboard boxes filled with low-activity waste are being burned in a demonstration incinerator. A sketch of the process equipment is shown in Figure 2.12.

FIGURE 2.12 INCINERATOR PROCESS EQUIPMENT



Waste boxes are x-rayed and assayed with a sensitive gamma-spectrometer before being charged to the incinerator. Typical solid waste components are shown in Table 2.9. The waste products consist mostly of paper, plastic, rubber-like materials, and cloth. Radiation from the boxes, under the present demonstration, has to be less than 1 mr/hour at 3 inches. The feed limit used during the demonstration is given in Table 2.10. The concentration limit in microcuries per pound of waste is given for 22 radionuclides.

Typical operation of this pretreatment is described in the following paragraphs.

Solid waste is transported to the incinerator facility in 21" or 24" cubic waste cartons. Cartons are hand-monitored for radiation when the cartons are unloaded into the facility lag storage area. Cartons are examined for liquid and non-combustible content with an X-ray inspection unit. Boxes are rejected and returned to the generator if they are shown to contain liquids, or metal or glass pieces greater than six inches in any dimension.

The cartons are weighed and assayed for radionuclide content with a segmented gamma scanner system capable of measuring the low limit values specified in Table 2.10. The feed limits shown in Table 2.10 are for startup and test purposes only; they can be raised as decontamination factors are determined for the entire system.

If the cartons are accepted they are fed manually to the incinerator. Feed rates will average about 80,000 cubic feet per year. Short term rates are expected to be about 400 cartons per day, but this rate could be increased with an increased rate of waste inspection with the assay equipment.

Combustion is completed in a secondary chamber at 1000 to 1100 degrees Celcius in an excess air environment. An off-gas treatment system provides for cooling, filtering, and monitoring of gaseous effluents. Off-gases leave the last HEPA filter units at temperatures above the dew point and are exhausted through a 65-foot high stack. The gases are continuously monitored for radioactivity. Releases should not exceed the atmospheric release guidelines established for the chemical separation area (shown in Table 2.11).

Incineration facilities have to comply with the South Carolina Department of Health and Environmental Control regulations concerning chemical and particulate emissions to the environment. Permits for construction and operation are required.

Incinerator ash is collected in drums or similar containers. In the future, the ash may be wetted and immobilized with cement to produce a solid waste form. This process can be mechanized and controlled remotely.

TABLE 2.9 SOLID WASTE COMPONENTS

Rubbers - Latex, Neoprene

Plastics - Polyethylene, PVC

Cellulosics - Paper, Cardboard, Cotton Fiber

Special Polymers - Teflon

*Standard Waste Mix -	Cellulosics	40%
	Polyethylene	23%
	Latex	19%
	PVC	8%
	Moisture	5%
	Noncombustibles	5%

*Represents the average composition of a typical waste carton.

TABLE 2.10 SOLID WASTE CONTAMINATION FEED CRITERIA

Isotope	DOE 5480 Insoluble Offgas Limit (uCi/Ft^3)	Feed Limit (uCi/lb)***
^{90}Y	2.83×10^{-3}	4.25
^{91}Y	8.50×10^{-4}	1.27
^{95}Zr	8.50×10^{-4}	1.27
^{95}Nb	2.83×10^{-3}	4.25
^{103}Ru	2.27×10^{-3}	3.40
^{106}Ru	1.70×10^{-4}	.255
^{134}Cs	2.83×10^{-4}	.925
^{137}Ba	(Not Specified)**	.925
^{140}Ba	1.13×10^{-3}	1.70
^{144}Ce	1.70×10^{-4}	.255
^{58}Co	1.42×10^{-3}	2.12
^{59}Co	(Not Specified)**	2.12
^{60}Co	2.55×10^{-4}	.382
^{32}P	2.27×10^{-3}	3.40
^{35}S	8.50×10^{-3}	12.74
^{59}Fe	1.42×10^{-3}	2.12
^{51}Cr	5.66×10^{-2}	84.95
^{144}Pr	(Not Specified)**	.225
^{137}Cs	2.83×10^{-4}	.425
^{106}Rh	(Not Specified)**	.255
^{89}Sr	1.13×10^{-3}	1.70
^{90}Sr	1.42×10^{-4}	.212

*Assumes no decontamination factor for the incinerator, baghouse, or HEPA filters.

**Use parent-daughter isotopic relationship to establish feed limit i.e. ^{137}Cs-Ba, ^{59}Co-Fe, etc.

***Based on Stack effluent rate of 10,000 cfm.

TABLE 2.11 DPSOP 40 - F/H ATMOSPHERIC RELEASE GUIDES

Radionuclide	Incinerator Projected Release (mCi/yr)	DPSOP 40 F/H Atmospheric Release Guide (mCi/yr)
Tritium	22,000	275,000,000
$^{89,90}Sr$	1.0	10
^{95}Zr	0.7	25
^{95}Nb	2.2	75
^{103}Ru	1.8	100
^{106}Ru	0.1	300
^{134}Cs	0.2	0.5
^{137}Cs	0.3	3
^{144}Ce	0.1	30
^{58}Co	1.1	1.1
^{60}Co	0.2	0.2
Other	55.8	60

2.5.2.2 Compaction

Compaction of low-activity waste is a feasible volume reduction process that is currently in use in many countries and in power reactor facilities in the U. S. Volume reduction ratios of two to four to one can be accomplished. Compaction can take several forms:

- Baling of low-activity paper waste. The waste is placed in a paper baler where the waste is compressed and strapped to hold its shape.

- Drum compactors: Drum compaction units are readily available. Bagged waste is placed in drums that are placed in a special enclosure where a ram compacts the waste inside of the drum. More bagged waste is placed in the drum until a pre-determined height is reached. Anti-springback devices are used to keep the last-placed waste in the drum.

  Drum compactors are useful for small waste generators. Because of their small volume (7.5 cubic feet), compaction in drums is manpower intensive. Most waste generators opt for larger compaction units.

- Box compactors: Box compactors are also available as commercially built units. Boxes, usually with volumes of about 100 cubic feet, are placed in a sealed enclosure. Air in the enclosure is exhausted through HEPA filters. The boxes are supported on all sides to prevent box rupture as the waste is compacted in the box. A typical compactor has a rectangular ram driven by two pistons that can exert forces of 30 to 40 psi. Air is exhausted through holes in the ram as the ram compresses the waste. The compaction process is done slowly to prevent violent agitation of the waste. After compaction, a gasketed lid is placed on the box.

- Super compactors: Super compactors are available for drummed waste. Compaction ratios of seven to ten to one are feasible. In typical use four or five or more drums of waste can be compacted to fit into one drum. The outer drum is filled with grout or another stabilizing matrix.

2.5.3 Waste Stabilization

Waste packages or boxes for which incineration or compaction is not feasible because of the components in the waste could be stabilized to provide a solid waste package for disposal or storage. If the waste is not stabilized the boxes can collapse at a future date and can cause breaching of the waste confinement system.

A typical method of stabilizing metal boxes filled with waste is to backfill the boxes with a thin grout mixture. One possible method has been in use in France for many years. In this method the box lids contain three ports. One port is fitted with a pipe which extends to the bottom of the box through which the grout is

injected. A second port is fitted with a level detector that prevents overflow of the grout. The third port is connected to an offgas filtering system. The ports have caps which are removed when the box is placed in the grouting station. A specially designed injection lid is placed over the ports; this lid is connected to the level detector, the grout source, and the offgas system. After injection the special lid is removed, the port caps are replaced, and the box is set aside for the grout to cure. This method has been successful in forming solid waste forms that will not undergo subsidence for long periods of time (estimated to be in excess of 300 years).

Bitumen has also been used as a stabilizing matrix; however, it is subject to combustion and softening when warm, and is not a preferred choice for stabilization of waste forms.

2.5.4 Waste Encapsulation

Waste encapsulation means enclosing waste forms that are externally contaminated in containers that can be transported, handled with cranes or other equipment, and emplaced in the disposal facility without contaminating the facility or the workers.

Some waste forms produced at Savannah River are presently disposed of in the externally contaminated state. These forms are jumpers used in the canyon buildings, reactor scrap metal, and spent melts from the tritium facility. Containerization of these particular waste forms is a difficult task that is still being developed.

Possible concepts for containerization are:

- Jumpers: Present method of disposal is to wrap the metal jumpers in canvas in the generator area, deliver the wrapped jumpers to the burial ground in a covered box; the box is set on a trench ledge, the jumpers removed and lowered to the trench bottom, and the box is returned to the generator. A possible scenario for containerization is: cut the jumpers into small pieces, place the pieces in drums or boxes, stabilize the drums or boxes with a cement-based grout, and deliver to the disposal area in a shielding bell. The drum or box containing the jumper pieces could then be lowered inside the shielding bell into a disposal unit.

- Reactor scrap metal: About 300 deliveries of contaminated reactor scrap metal are made each year. Scrap metal is presently dropped into the bottom of an earthen trench from a shielded scrap cask. The metal pieces are then covered with soil to provide shielding. A possible scenario for containerization is: The small metal pieces -- gripper knobs, retaining rings, flow splitters and the like, are placed in a special container and raised inside of a special shielded section of the disassembly area of the reactor building. Some of the areas already have a shielded section called the "slug inspection station" or the old "control rod

breaking station." The long pieces of metal scrap -- tubes, rods, etc. -- are also delivered to this section where they are cut into small relatively uniform-length pieces. The pieces are placed in the special container and stabilized with grout. The container is then raised through a hole in the roof into a shielding bell and delivered to the disposal area.

- Spent melt crucibles: These waste containers, which are also externally contaminated, contain tritium waste forms. The present method of disposal is to deliver the waste forms to a trench inside of a shielded cask. The cask is inverted over the trench and the waste form is dropped to the bottom of the trench and covered with soil to provide shielding. A possible scenario for containerization is: One or more tritium waste forms are placed in a disposable sealed box, which is delivered to the disposal area on a flatbed truck that is provided with a permanent shield for the boxed waste form. The box is removed from the truck with a shielded crane and placed into the disposal facility.

2.6 WASTE STORAGE/DISPOSAL OPERATIONAL ALTERNATIVES

This section describes the operational alternatives for storage or disposal of solid low-level radioactive waste at the Savannah River Plant. The facilities that could be used singly or in combination for the different alternatives are described in Section 2.1 The seven alternatives addressed in this section are:

ALTERNATIVE 1: CONTINUE PRESENT OPERATION AT NEW SITE

ALTERNATIVE 2: NEAR SURFACE DISPOSAL WITH EXCEPTIONS

ALTERNATIVE 3: COMBINATION OF FACILITIES

ALTERNATIVE 4: ENGINEERED STORAGE OF ALL WASTE

ALTERNATIVE 5: ENGINEERED DISPOSAL OF ALL WASTE

ALTERNATIVE 6: VAULT DISPOSAL OF UNTREATED WASTE

ALTERNATIVE 7: NO ACTION - CONTINUE PRESENT OPERATION AT CURRENT SITE

Disposal alternatives not addressed in this section are sea disposal, which is prohibited by the U. S. unless authorized by the U. S. Congress; deep well injection (or hydrofracture) of slurried solid waste, which cannot be considered at SRP because of the presence of a major aquifer beneath SRP; and transport of solid LLW off site to another Department of Energy site, which is not considered because the waste can be disposed of or stored safely on the 300 square mile SRP site.

2.6.1 ALTERNATIVE 1: CONTINUE PRESENT OPERATION AT NEW SITE

In this alternative present disposal operations would be continued at a new disposal site location. Disposal operations that are presently being performed are described in the examples given below:

- Disposal of low activity waste in metal containers by stacking the containers in an Engineered Low-Level Trench (ELLT) at about a 20-foot depth and covering the boxes with at least four feet of soil. Low activity waste, which is also called low-level waste, is differentiated from high activity waste by a bench mark radiation level -- for example, 300 mR/hour at 3 inches. The ELLT is constructed with an access ramp to allow for truck delivery of the waste containers. The floor of the trench is large to allow for efficient stacking of the waste containers.

- Disposal of bulky low activity waste directly into 20-foot deep trenches.

- Disposal of higher activity fraction of the waste either into Greater Confinement Disposal boreholes or directly into Intermediate Level Waste trenches. Intermediate Level Waste trenches can be accessed from the side with a shielded crane. A Greater Confinement Disposal trench is being constructed for disposal of high activity waste that is too large to be disposed of into GCD boreholes.

- Incineration of a fraction of the low activity waste (waste reading less than or equal to 1 mR/hour at 3"). The ash is disposed of in metal containers.

- Compaction of a fraction of the low activity waste in cardboard boxes. Compaction ratios of four or five to one, for example are achieved. The compacted waste boxes are placed into metal containers before disposal in the ELLT. A compactor to compact waste directly in metal boxes is being constructed.

- Disposal of alpha activity waste at concentration levels of less than 10 nanocuries/gram as low level waste, as defined by DOE Order 5820.2, and disposal of alpha activity waste with concentrations of 10 to 100 nanocuries/gram by Greater Confinement Disposal.

This alternative would continue the present disposal of low-level solid radioactive waste by near surface disposal, or shallow land burial, as it is defined in DOE Order 5820.2.

2.6.2 ALTERNATIVE 2: NEAR SURFACE DISPOSAL WITH EXCEPTIONS

In this alternative, near surface trench disposal of LLW would continue as described in Alternative 1, but with the following exceptions:

- High radiation level tritium-containing waste would be stored in an above ground vault, for example, while low radiation level tritium-containing waste would be stored in a storage building. This waste would be stored for ten half-lives or about 120 years to allow for decay-in-place of the tritium. The storage method would be designed to allow for retrievability; storage would be dry and monitorable. At the end of the storage period, the waste would be disposed of as low-level waste. The intent here would be to not allow tritium waste to be in contact with soil until a large fraction of it has decayed.

- Waste containing long-lived activity, such as carbon-14 and iodine-129, would be stored retrievably.

- Other waste whose chemical form would tend to enhance migration of radionuclides in soil would also be stored for treatment, for example, or for later disposal by other than near surface disposal.

2.6.3 ALTERNATIVE 3: DISPOSAL AND STORAGE BY A COMBINATION OF FACILITIES

Disposal or storage operations would proceed with a combination of facilities as described in Section 2.1. Designs for the combination of facilities will be matched to the different waste streams generated by the Savannah River Plant. Examples of typical operations are given below:

- PRETREATMENT

  Pretreatment of low activity waste by incineration or compaction, and stabilization would be encouraged. High activity waste which cannot be reduced in volume by incineration or compaction because of radiation levels would be stabilized to the extent possible, either by grout injection, for example, or containerization in a stable waste container.

- ENGINEERED DISPOSAL OF HIGH ACTIVITY WASTE

  High activity waste is waste that emits high radiation levels. What constitutes high activity waste depends on the limits imposed upon personnel and upon the equipment available for handling the waste. A typical cut point between high and low activity waste would be, for example, a radiation level of 300 mr/hour at 3 inches from the waste form.

  High activity waste would be disposed of in Greater Confinement Disposal boreholes or trenches, or in above or below grade concrete vaults. These disposal facilities would be provided with shielding materials to keep radiation exposure to acceptable working levels. The GCD or vault designs would provide for percolate water collection within the waste emplacement volume.

  It is estimated that about five percent of the volume of SRP waste is waste that would be triggered into GCD or vault disposal, based either on the radiation level or the concentration of radionuclides in the waste.

- ENGINEERED DISPOSAL OF LOW ACTIVITY WASTE

  Low activity waste would be treated to reduce its volume and, to the extent possible, to stabilize it. The waste would be disposed of in an Above Grade Operation (AGO) facility, or else in above or below grade concrete vaults.

- ENGINEERED STORAGE OF SPECIAL WASTE FORMS

  An engineered storage facility would provide for dry, monitorable, and retrievable storage for special waste forms such as waste containing tritium, and waste that contains long-lived radionuclides such as carbon-14 and iodine-129.

The intent of Alternative 3 would be to provide a cost and environmentally effective combination of treatment, storage, and disposal methods for the SRP solid waste streams, that would decouple the waste from the ground water and maintain low personnel exposure.

2.6.4 ALTERNATIVE 4: ENGINEERED STORAGE OF ALL WASTE

In this alternative, LLW would be stored retrievably in structures with various degrees of shielding -- ranging from heavily shielded structures such as boreholes or vaults, to moderately shielded structures such as concrete bunkers, to lightly shielded structures such as a storage building on a concrete pad. The storage structures would be designed to be dry, and to have a percolate water collection system in addition. Storage structures would be designed to last for 100 years or more. As the radiation levels in the waste decrease because of decay, waste would be moved from more heavily shielded structures to those with less shielding. It is estimated that about 5% of the volume of generated waste would require the more heavily shielded structures for storage.

Waste reduction methods and volume reduction methods would be employed to the extent possible.

The storage method of operation is in use in Canada (Reference 12), where LLW is stored in cylindrical tile holes, concrete bunkers, heavily shielded quadracells, and a storage building. A search is proceeding in Canada for a geologic repository for the waste.

2.6.5 ALTERNATIVE 5: ENGINEERED DISPOSAL OF ALL WASTE

In this alternative an engineered structure would be built that would be similar to the LLW disposal facility designed and used by the French at the Centre de la Manche (Reference 13). High activity waste would be placed in concrete monolithic structures below grade, while lower activity waste would be volume reduced, stabilized, or placed in stable containers, and placed on top of the monoliths in an earth mounded tumulus.

Pretreatment of waste to the extent possible would be required. Both below and above ground structures would be provided with a percolate water collection system.

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The above ground tumulus would require closure to reduce the amount of percolation water entering the mound. The entire structure has been designed to last for 300 years, or about 10 half lives of the waste emplaced in it. Long-lived radionuclides are stored for geologic disposal, while waste containing tritium is stored above grade for decay-in-place.

2.6.6 ALTERNATIVE 6: VAULT DISPOSAL OF UNTREATED WASTE

In this alternative all waste would be disposed of untreated in above or below grade concrete vaults. Vaults containing higher activity waste would have a percolate water collection system. The waste would be grouted in place in the vault cells. The intent of this operation would be to provide as simple as possible a disposal method that would not require pretreatment facilities, and yet would decouple the waste from the ground water.

Waste would be emplaced in the cells by an overhead gantry crane, for example. The cells being filled with waste would have a removable rain cover to keep the waste dry until the cell would be filled. When waste has filled the cell a heavy metal screen, for example, would be placed over the waste while self-leveling grout would be poured around the waste to form a monolithic structure. The purpose of the screen would be to prevent waste from floating on the grout.

When a vault cell has been filled with grout, a one or more foot deep layer of concrete would be poured to form a temporary closure for the cell. When all cells in the vault have been filled, a permanent reinforced and sloped concrete roof would be placed over the cells.

The vaults containing higher activity waste would have a leachate collection system designed to collect and treat any water that percolates into the vault cells.

A typical vault volume would be about 1.5 million cubic feet, which would be sufficient to hold the million cubic feet of LLW generated at SRP each year and about one-half million cubic feet of grout used to stabilize the waste.

In this alternative the plan would be to make the waste disposal operations simple -- waste would go from the waste generators directly to a vault and be grouted in place.

2.6.7 ALTERNATIVE 7: NO ACTION - CONTINUE PRESENT OPERATION AT CURRENT SITE

The waste disposal operations currently in use are described above in the discussion of Alternative 1. They include use of an Engineered Low-Level Trench, Greater Confinement Disposal, and Shallow Land Burial. Predisposal treatment by incineration and compaction is also utilized. If a new site is not chosen in the future no further Low-Level waste disposal operations will be possible. Because of this, the "No Action" alternative will not be considered in any of the analyses for performance assessment or cost estimation.

2.6.8 Partitioning of Projected Waste Volume and Radioactivity for the Seven Alternatives

The following analysis of waste volume and radioactivity that would be emplaced for the seven different operational alternatives described above is based on the previous three years of plant operation. For the most part the waste generation was routine during the three years, but non-recurring operations included a special clean-up at Tank 13 and renovation of both FB and HB production lines. The following tables do not include predictions of waste volumes and activities associated with future renovations or decommissionings.

The volumes and activities are based on computerized disposal records. Zero- or suspect-level waste is defined as waste showing zero radioactivity for both Quantity 1 and Quantity 2 activities in the records. Waste assigned to Greater Confinement Disposal (GCD) is waste with activities greater than the trigger values for GCD given in Table 2.8.

ALTERNATIVE 1: CONTINUE PRESENT OPERATION AT NEW SITE

All beta-gamma waste and waste with alpha activity less than 100 nCi/gram would be disposed of by near surface disposal. The engineered low-level trench design would be used, as shown in Figures 2.2 and 2.3. Waste with activity exceeding the GCD trigger values shown in Table 2.8 would be disposed of in either GCD boreholes or trenches. The volume and curies of activity for each disposal method are given below for the years 1983 - 1985. Values have been rounded.

WASTE SUITABLE FOR ENGINEERED LOW LEVEL TRENCH DISPOSAL

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	900,000	2,500
1984	880,000	100
1985	1,000,000	100

WASTE SUITABLE FOR GREATER CONFINEMENT DISPOSAL

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	42,000	97,700
1984	51,000	126,600
1985	81,000	51,100

ALTERNATIVE 2: NEAR SURFACE DISPOSAL WITH EXCEPTIONS

The total volume and activity of waste is the same as shown above; however, tritium waste will be stored for decay-in-place for ten half-lives (120 years), and deionizer vessels containing carbon-14 and berl saddles containing iodine-129 will be stored for as long as necessary. The volume and activity of waste containing tritium are given below.

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	72,000	84,000
1984	64,000	105,000
1985	59,000	47,000

Of the waste listed above the following is the amount which exceeds the GCD trigger values.

TRITIUM WASTE SUITABLE FOR GREATER CONFINEMENT DISPOSAL

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	11,000	84,000
1984	6,000	105,000
1985	4,000	47,100

Carbon-14 is on deionizer resin which is disposed of in sealed stainless steel vessels. The annual volume and activity is estimated to be 15 to 30 cubic feet and 100 to 200 curies of carbon-14. (The carbon-14 activity is not shown on the disposal records). Iodine-129 is contained on berl saddles. This waste would to be placed in special sealed and shielded containers. The estimated volume and activity is 40 cubic feet per year and 0.5 curies.

ALTERNATIVE 3: COMBINATION OF FACILITIES

The higher activity fraction of the waste would be placed into a Greater Confinement Disposal facility. Tritium containing wastes are not included in the volumes and curies shown below.

WASTE SUITABLE FOR GREATER CONFINEMENT DISPOSAL

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	31,000	14,000
1984	51,000	21,000
1985	77,000	4,000

The remaining waste, with the exception of tritium containing waste, would go to an Above Grade Operation. The volumes and curies of this waste are shown below:

WASTE SUITABLE FOR AN ABOVE-GRADE FACILITY

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	839,000	2,500
1984	818,000	100
1985	948,000	100

Tritium-containing wastes would be the same as for Alternative 2 above, i.e.:

TRITIUM WASTE FOR DECAY-IN-PLACE STORAGE

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	72,000	84,000
1984	64,000	105,000
1985	59,000	47,000

The special waste containing iodine-129 and carbon-14 would be placed in shielded storage areas within the tritium storage facility. Volume and activity would be the same as in Alternative 2.

ALTERNATIVE 4: ENGINEERED STORAGE OF ALL WASTE

All suspect-level waste, including such waste from the tritium facilities, would be placed in a minimally shielded storage facility.

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	515,000	0
1984	592,000	0
1985	729,000	0

GCD level wastes would be emplaced in a highly shielded storage facility. This facility would also store the deionizer vessels and the containers with berl saddles.

GCD WASTE LEVEL WASTE SUITABLE FOR SHIELDED STORAGE

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	42,000	98,000
1984	51,000	127,000
1985	81,000	51,000

For Alternative 4, the remaining waste would go to a moderately shielded facility.

WASTE SUITABLE FOR MODERATELY SHIELDED STORAGE FACILITY

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	384,000	2,500
1984	285,000	100
1985	274,000	100

ALTERNATIVE 5: ENGINEERED DISPOSAL OF ALL WASTE

Suspect-level waste would be placed in an above-grade tumulus after treatment for stabilization.

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	515,000	0
1984	592,000	0
1985	729,000	0

Waste containing measurable activity would be encapsulated in concrete or grout in the below-grade monolith. The volumes listed below do not include the volume of grout. A practical estimate would be to increase the volumes listed below by 50% to account for the volume of grout or concrete added to form the monoliths.

YEAR	VOLUME, ft^3	ACTIVITY, Ci
1983	355,000	17,000
1984	272,000	22,000
1985	296,000	4,000

The volumes and activities of tritium containing wastes, and those wastes containing long-lived isotopes would be the same as in Alternative 2.

ALTERNATIVE 6: DISPOSAL OF UNTREATED WASTE IN ABOVE-GRADE VAULT

The volume and activity of the waste are the same as listed above for Alternative 1. Waste volumes should be increased by 50% to account for grout added for stabilization.

ALTERNATIVE 7: NO ACTION - CONTINUE CURRENT OPERATION AT PRESENT LOCATION

Partitioning of the waste streams would be identical to that of Alternative 1.

For any of the waste volumes given above, approximately two-thirds of the waste is combustible and one-third is compactable.

2.7 ENVIRONMENTAL MEASUREMENTS AND MONITORING PROGRAM

2.7.1 On Site

On site monitoring means monitoring in or near the waste storage/disposal facility and within the Savannah River site boundary.

2.7.1.1 Groundwater Monitoring

The groundwater monitoring system must be capable of determining the impact of the alternative facilities on groundwater in any aquifer above the "Tuscaloosa" Aquifer. The design of the monitoring system must take into consideration the following:

- The placement and depth of monitoring wells that are necessary to obtain representative samples of groundwater both upgradient and downgradient of the facility.
- Casing design that will maintain the integrity of the monitoring well.
- Casing and screen design that will not interfere with groundwater sampling and analysis.

To meet the above requirements the monitoring system will consist of a series of well clusters spaced about every 150 feet along the perimeter of the facility. The wells will have twenty-foot screens placed at fifty foot depth intervals to the top of the Ellenton formation. Screens and casings will be made of stainless steel. Well specifications will meet RCRA regulations if required. Specific construction details have been formulated for monitoring wells at the Savannah River Plant[17].

The monitoring program will consist of monthly (or more often if situations warrant) samples being analyzed from each monitoring position for waste constituents of concern. The monitoring samples will be analyzed for chemical (inorganic and organic) and radionuclide species expected to be in the waste that is disposed of or stored in the facilities.

Groundwater has been monitored extensively at the Savannah River Plant, as detailed in References 18 and 19. On site monitoring results from these wells are reported annually (Reference 20).

2.7.1.2 Surface Water Monitoring

Surface water is considered as overland flow of rain water and the water in streams that draw water from the land area around the storage/disposal facilities.

The storage/disposal facilities will have an engineered surface water drainage system that will impound the water in one or more locations for monitoring purposes before release to plant streams.

Water in surface streams adjacent to the facilities will also be monitored for chemicals and radionuclides, using the appropriate sampling and analysis protocols.

2.7.1.3 Atmospheric Monitoring

Air and rainfall collection and monitoring systems will be located on the perimeter of the storage/disposal facilities. Rainfall will be collected and monitored for radioactivity, and air samples will be collected on filters and also monitored.

2.7.2 Off Site Monitoring

The Savannah River Plant conducts routine offsite radionuclide monitoring of surface streams and air up to distances of 100 miles from the site boundary. Off site monitoring results are reported annually in the site Environmental Report (Reference 20).

2.8 CLOSURE PLANS

2.8.1 Closure Alternatives

The primary objective of closure is to reduce to the extent possible the transport of radionuclides in the waste in the disposal facilities to areas outside of the waste disposal area. This is accomplished by removing the major transport mechanism, i. e., removing or reducing by large fractions the infiltration of water to the waste, and by preventing the intrusion of plant roots and animals to the waste for periods of time of about 300 years.

The closure alternatives discussed in this section are:

1. No action
2. Closure of below and above grade disposal facilities; no waste removal.
3. Exhumation of the waste followed by remedial action.

The methods generally employed to reduce water infiltration and the probability of root and animal intrusion are:

- Capping the facility with soil, clay, compacted clay, man-made materials such as cement or plastics, or combinations of these materials.
- Installing barrier walls around the facility with materials such as cement or a bentonite-clay mixture. Barrier walls, which are sometimes called cutoff walls, can be partial, enclosing one or two sides of the facility, or they can be encompassing.
- Combinations of capping and barrier walls.

CAPPING AND BARRIER WALL METHODOLOGY

Site caps will reduce the amount of vertical water infiltration to waste disposal areas, and thus reduce the amount of water that passes through and around the waste. Barrier walls are intended to reduce the amount of water flowing in the ground water beneath the waste disposal volume, and thus retard the rate of flow to the nearest outcrop. The thickness and hardness of the cap can be varied depending on the concern for human intrusion. The final soil cover on the cap can be made to support a variety of plant life. Deep-rooted vegetation can be prevented for long periods of time by providing for a long-lasting altered climax vegetation of dense plant life such as bamboo or honeysuckle.

Studies have been made (Reference 21) on the effectiveness and cost of providing caps and barrier walls on and around a portion (76 acres out of 195 acres) of the present SRP solid waste disposal area. The modeling studies in Reference 21 show that capping alone can reduce water flow under the disposal site by 63 to 66%. The caps studied ranged from sandy topsoil, with a permeability of 7×10^{-4} cm/sec to clayey soil with a permeability of 6×10^{-5} cm/sec, and to soils containing a 2-foot-thick layer of compacted bentonite clay with an assumed permeability of 10^{-8} cm/sec. Cap thicknesses ranged from 1.2 to 4.3 m (4 to 14 feet).

Flow reduction in the ground water beneath the waste volume afforded by barrier or cutoff walls was also modeled and reported in Reference 21. The cutoff walls were assumed to be 30.5 m (100 feet) deep and 0.9 m (3 feet) thick. Two types of walls were studied as examples -- a soil-bentonite clay wall, and a cement-bentonite wall. Other types of walls such as one made of a synthetic material could also be modeled. Permeabilities were assumed to be 10^{-6} and 10^{-7} cm/sec for clay and synthetic material, respectively. The model calculations show that the addition of barrier or cutoff walls to capping would give greater flow reductions in the ground water. A partial cutoff wall on the upgradient side of the waste disposal area would result in a flow reduction of 80 to 85%, while an encompassing cutoff wall in addition to a cap would result in a flow reduction of 90 to 95%.

2.8.1.1 No Action Closure Alternative

The No Action alternative is defined as continuing present operation until SRP operation ceases, followed by a period of institutional control (Section 2.8.2). Continued operations would consist of:

- Maintaining present fencing and surface drainage patterns.
- Correcting subsidence and surface erosion if it occurs by backfilling with clean soil.
- Reseeding as required to maintain a shallow-rooted ground cover.
- Frequent mowing to prevent the onset of deep-rooted vegetation.
- Monitoring for chemicals and radioactivity in the perimeter wells and well clusters.
- Maintaining control of access to the facility (security) for the period of institutional control.

No closure actions -- capping and/or barrier wall construction -- would take place at the end of the control period.

2.8.1.2 Closure of Above and Below Grade Facilities Without Waste Removal.

Closure of below grade facilities would take place with a capping, or a combination of capping and barrier wall emplacement, as described in Section 2.8.1. Closure of the above grade facilities would be an additional cap placed over the top of the above grade facility.

2.8.1.3 Exhumation of Waste Followed by Remedial Action

Exhumation means removal of waste previously emplaced, repackaging of the waste, and placing it in another disposal facility. The designs presented for most of the new disposal facilities preclude exhumation. Concrete monolithic forms containing radioactive waste are engineered to contain the radionuclides and to prevent inadvertent intrusion into the waste. This design makes retrieval of the waste impractical.

2.8.2 Period of Institutional Control

The period of institutional control is not defined in either DOE Order 5820.2 (Reference 4) or in the NRC regulation 10CFR61 (Reference 7). It is generally accepted that the period of control is 100 years, a period of time for which stable governmental control is assumed.

2.8.3 Post-Institutional Control

Post-institutional control is the period after about 100 years in which it is postulated that control of access to the disposal site is lost. It is assumed for calculational purposes that the general population can occupy the site and build houses, farm the land, etc.

It is the intent of the closure plan to provide protection to the public after the period of institutional control.

2.8.4 Correlation of Closure Alternatives with Operational Alternatives

This section correlates closure alternatives with the operational alternatives described in Section 2.6 to provide consistency for environmental modeling and costing analysis.

Closure is to be an integral part of the operational mode. Closure would follow as soon as practical after a disposal unit, such as a vault, has been filled. The objectives of closure are to:

1. Stabilize the waste facility to prevent future subsidence.

2. Provide additional protection if needed to reduce the probability of intrusion by plants or animals.

3. Reduce water infiltration to the waste forms to no more than 0.1% of normal.

Each of the seven operational alternatives described in Section 2.6 has one or more closure options. The correlations are presented in matrix form on the next page.

CORRELATION OF CLOSURE OPTIONS WITH OPERATIONAL ALTERNATIVES

ALT.	BRIEF DESCRIPTION	CLOSURE WHEN	CLOSURE OPTIONS
1.	Near surface disposal continued at new site	When unit or cluster of units is filled	A. No closure action B. Close with earth-clay-synthetic cap, or concrete cap C. Exhume waste, treat it, send offsite; remedial action to decontaminate area
2.	Near surface disposal with exceptions: o H-3 decay in place o C-14, I-129 to storage	.1 When unit is filled .2 After 120 years .3 When technology developed	A. Same as 1.A, 1.B, 1.C above B. Near surface disposal of containers; then 1A,B,or C C. To be determined
3.	Combination of facilities: o Vault disposal of high act. waste o H-3 decay in place o C-14, I-129 to storage o Above grade disposal for low activity waste	.1 When unit is filled .2 After 120 years .3 When technology developed .4 When unit is filled	A. Vaults closed as in 1.B above B. Same as 2.B above C. To be determined D. Close as in 1.B above
4.	Engineered storage of all low-level waste	When technology developed	To be determined
5.	Engineered disposal of all low-level waste	When monolith and above grade tumulus are filled	A. Monoliths closed by concrete cap B. Tumulus closed as in 1.B above
6.	Vault disposal of untreated waste	When each vault unit is filled	Individual vault units closed by concrete cap, then mounded with soil
7.	No Action	When unit or cluster of units is filled	Same as 1.A,B,C above

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2.9 SITE SUITABILITY FOR DISPOSAL AND STORAGE FACILITY ALTERNATIVES

2.9.1 Greater Confinement Disposal

The disposal alternative of Greater Confinement Disposal is used to develop the site selection criteria because it is the alternative which depends to the greatest extent upon site specific properties. Greater Confinement Disposal is defined as an integrated system of waste management which provides a greater degree of isolation of radionuclides from the environment than is provided by Shallow Land Burial. The Greater Confinement Disposal system developed at the Savannah River Plant for low-level solid waste includes solidification and stabilization in a cement matrix, burial below the zone of root intrusion and above the seasonal high water table, a low permeability cover, and a monitoring network. In this disposal system the primary requirement for the site is that the wasteform not come in contact with groundwater. Depth to the water table is the most heavily weighted characteristic in the site selection criteria described in Section 1.1.4. Each of the candidate sites has a large enough area with sufficient depth to the water table to meet the Greater Confinement Disposal requirements. By meeting the other site selection criteria--surface area and surface topography -- the top ranked sites will be large enough to accommodate the anticipated volume of waste, and will have minimal long term erosion potential. Therefore, any of the top ranked sites would be suitable for Greater Confinement Disposal of the solidified low-level waste on a technical basis.

2.9.2 Engineered Low Level Trench

As explained above the siting criteria for Greater Confinement Disposal are the most restrictive of any required for the facility alternatives described in this document. Any of the top rated sites would be suitable for use with Engineered Low Level Trenches.

2.9.3 Below Ground Engineered Vault

This disposal alternative is similar to the practice employed in France to dispose of high activity waste. It consists of an underground concrete structure with a water collection system. The waste is stabilized either by the wasteform or after emplacement by grouting. The vault is covered with concrete when full. The final cover can be soil, or a clay cap covered with soil.

The below ground engineered vault need not be built any deeper than the Greater Confinement Disposal system. Therefore the depth to the water table at any of the candidate sites is sufficient. Since the vault is completely engineered there are no other site requirements for this disposal system. All of the sites are suitable.

2.9.4 Above Ground Engineered Vault

Above ground engineered vaults are used for waste storage in Canada, and the Tennessee Valley Authority has constructed several, although they have not been used. The construction and operation is essentially the same as the underground vault.

The above ground vault design would decouple the facility from the surrounding environment. Therefore, any location on the Savannah River Plant site could be used, and each of the candidate sites is suitable. The major requirement would be to ensure a stable soil base for construction of the vaults.

2.9.5 Above Ground Facility

Above Ground Pads are used at the Savannah River Plant and other DOE facilities for storage of TRU waste, and in France for the disposal of low-activity radioactive waste. In both cases a water collection system is included in the design to monitor system performance. The Above Ground Pad system would completely separate the waste from the environment. Any of the candidate sites would be suitable.

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3. PERFORMANCE ASSESSMENTS FOR THE NEW LLW DISPOSAL FACILITY

Performance assessment calculations have been made for the new LLW Disposal alternatives using the PATHRAE computer code[1] and parameters appropriate to the disposal technologies described in Chapter 2. Concentrations of radionuclides in the soil, well water, Upper Three Runs Creek wetlands, Upper Three Runs Creek, and the Savannah River have been calculated over a period of 10,000 years after site closure. Special emphasis was given to the first 1000 years. Estimates are reported for the peak values of concentrations of the radionuclides and the times at which they occurred. The corresponding fifty year whole-body dose commitments to both post-institutional control site intruders and individuals in the general population offsite have also been determined. Although only peak values are reported in this document, the calculations were performed at a number of uniformly spaced times in the first 1000 years after closure.

For radioactive components in the wastes, annual equivalent whole-body dose commitments to individuals exposed are given. Where populations are involved, these doses are converted to collective doses by multiplying the individual doses by the number of exposed individuals. The individual and population doses have been related to statistical health impacts, specifically the expected number of cancer and genetic deaths in the exposed population, via the use of a risk conversion factor or risk estimator. The quantification of such factors is still the subject of much debate (Appendix D).

Alternatives 1 and 3 both consider two facilities at each site - one for low activity wastes and one for intermediate activity wastes (see Appendix E). Although there is segregation and separate disposal of these two types of wastes in alternative 5 the net result at the time of closure is a single structure built at one site. Consequently, this alternative is modelled as one facility.

The base case considered for each alternative assumes normal site infiltration at the facility. That is, no cover having reduced permeability has been installed over the facility at closure, and the normal, site average infiltration of $0.38 m^3/yr/m^2$ percolates either through the waste if it is in trenches or around the waste when it has been disposed of in structures. The installation at closure of a low permeability cover is likely and will have different effects on the various alternatives. Thus an attempt has been made to model, in addition to the base cases, covered facilities using long-term infiltrations which might be realized using current technologies.

3.1 Pathways Analyzed

The migration/exposure pathways analyzed as a part of the performance assessments include:

- Movement through groundwater to a well at the boundary of the disposal area
- Movement through groundwater to surface water (Upper Three Runs Creek and the Savannah River)
- Mixing with soil and subsequent uptakes in crops of an intruder
- Intruder exposure to gamma radiation at the site.

These are described in greater detail in the following paragraphs.

One other pathway was considered initially ---overland transport to surface water via erosion of the cover over the waste and then of the waste itself. This pathway was not analyzed in detail because the applicable erosion rate for the SRP area would not remove all of the 5 m cover from any of the disposal alternatives in the period of time being investigated.

3.1.1 Movement Through Groundwater to a Boundary Well

This pathway considers the migration of the radionuclides released from the wastes into percolating groundwater. The radionuclides move vertically through the unsaturated zone to the water table below the disposal site. In the saturated zone the movement is downgradient along flow lines to a well located at the boundary of the disposal area. The models which are used to describe transport of the radionuclides in both the vadose and the saturated zones account for any retardation, i.e., differences between the radionuclide velocities and water velocities that may occur as a result of sorption effects.

Once withdrawn from the well, the water is assumed to be consumed directly by individuals and used to irrigate crops for a part of the growing season. In addition the contaminated well water supplies a fraction of the livestock water requirements. These livestock and their products, i.e., milk, are then consumed by the same individuals.

The scenario has been analyzed for each alternative using the PATHRAE computer code.[1] The transport and dosimetry methodologies used in PATHRAE are summarized in Appendices B and C. The uptake/dosimetry database is also given in Appendix C while site and facility specific parameters are compiled in Appendix E.

3.1.2 Movement Through Groundwater to Upper Three Runs Creek and the Savannah River

This pathway is similar to the boundary well pathway, but the radionuclides are assumed to continue to move through the saturated zone until released to surface waters (i.e., Upper Three Runs Creek and, ultimately, the Savannah River). For the purpose of analyzing the potential impacts of releases through this pathway to a large population downstream on the river, the radionuclide releases into Upper Three Runs Creek are assumed to be transported immediately into the Savannah River by the creek. Complete mixing of the waters of Upper Three Runs Creek and the Savannah River is also assumed. Concentrations in the wetlands where the groundwater discharges into Upper Three Runs Creek are also estimated. These concentrations provide information on potential impacts on the wetlands wildlife and plant habitats.

Uptakes of radionuclides in the river by a population of 100,000 downstream are assumed to occur as a result of the use of river water both for culinary water and a part-time source of irrigation water as well as via the consumption of aquatic foods taken directly from the river.

3.1.3 Mixing With Soil and Subsequent Uptake in Crops

This pathway represents the mixing of some of the waste with surface soil, the uptake of radionuclides by crops grown in that soil, and consumption of those crops by humans and animals in the human food chain. These events are assumed to occur at the end of institutional control of the site, i.e., 80 years after closure. The mechanisms for disturbing the waste and bringing it to the surface are drilling wells through the waste and digging basements for homes. Usually, the waste excavated by these two activities is assumed to be completely mixed with a volume of surface soil. A mixing depth of three feet is used. The soil/waste mixture is subsequently used to grow a representative set of edible crops and forage for milk and meat-producing animals. Exposed individuals are assumed to get some fraction of their food needs from contaminated crops, meat, and milk. The basements typically are dug to three meters below grade. A well approximately 5 inches in diameter is assumed to pass through each acre of waste area. As a five meter cover is installed at closure in all alternatives, excavation for a basement results in no contamination being brought to the surface. Therefore, only the well drilling will bring material to the surface.

3.1.4 Direct Gamma Exposure of Intruder

Analyses of direct gamma exposure by an intruder who, 80 years after closure, digs three meters into the facility cover and builds a house on the site were not performed for all disposal alternatives. By virtue of geometry and source strength the facility described in alternative 5 is expected to result in the largest

gamma dose to an intruder. Thus the direct gamma dose rate has been determined only for this facility. In year 80, immediately after the end of institutional control, the total direct gamma dose to the intruder is 4.4×10^{-4} mrem/yr. The doses for the other alternatives will be below this value. It should be noted that the quantity calculated for this pathway is an annual dose rate. There is no extended dose commitment as exposure due to gamma radiation occurs only when the individual is in the presence of that radiation.

3.2 Projected Contaminant Concentrations in Ground and Surface Water

3.2.1 Peak Concentrations of Radioactive Contaminants

The peak concentrations at the boundary well, the wetlands, Upper Three Runs Creek, and the Savannah River of the radioactive components in the waste are presented for the case of normal site infiltration in Tables 3-1 through 3-4 for alternatives 1,3,5, and 6, and in Tables 3-5 through 3-8 for the low-infiltration cases. The performance assessment of alternative 2 is a subcase of alternative 1. A blank entry in the tables indicates that no significant activity arrives at the particular receptor location within 10,000 years after closure. The times of the peak concentrations - as determined by PATHRAE - are also indicated in these tables. These times are referenced to the year of closure. The negative entries which are given in several cases for the more mobile species at the boundary well indicate that the peak value is actually obtained at the well location prior to closure. Peak concentrations at the boundary well location which occur before 80 years after closure are not of concern as the site is still under institutional control.

Alternative 2 is the same as alternative 1 except that tritium, carbon-14 and iodine-129 sources have been removed. This does not significantly alter the total facility volume. Thus the impact of alternative 2 may be evaluated in terms of the alternative 1 results by merely eliminating those radionuclides from the latter's tables. Alternative 4 is an option entailing storage with active monitoring and maintenance, and consequently no performance assessments have been made of that alternative.

Tritium, most fission products, and activation products have modest to short half lives. The time dependences of their concentrations at the receptor locations reflect a complex interplay of leach rate, retardation, decay, and source term distribution. These species tend to exhibit distinct global maxima in concentration as opposed to the broad plateaus of the long-lived species. Of these radionuclides only tritium and technetium-99 have potentially significant impacts on the groundwater.

The long-lived alpha emitting radionuclides, i.e. uranium and a number of the transuranics, behave very much like nonradioactive species. In most cases these radionuclides have moderate to large site equilibrium sorption coefficients and extended leach times. Thus, the concentrations of these isotopes will eventually build up

Table 3-1 Peak Concentrations - Alternative 1 - Normal Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.45E-10	-13.8	1.83E-11	1.83E-14	3.42E-16	24.4
Co-60	3.13E-27	325				
H-3	2.82E-08	-14.3	9.26E-10	9.26E-13	1.73E-14	12.0
I-129	5.37E-12	-3.4	5.73E-13	5.73E-16	1.07E-17	68.7
Ni-63	3.37E-18	3450				
Rb-87	5.87E-16	259	4.66E-17	4.66E-20	8.70E-22	1230
Se-79	1.83E-11	122	1.47E-12	1.47E-15	2.74E-17	631
Tc-99	4.89E-09	-14.3	6.21E-10	6.21E-13	1.16E-14	22.6
Sr-90	2.61E-10	281	2.97E-19	2.97E-22	5.54E-24	795
Y-90	2.61E-10	281	2.97E-19	2.97E-22	5.54E-24	795
Th-232	3.13E-10	5460				
U-234	4.33E-07	2180	3.31E-08	3.31E-11	6.18E-13	9670
U-235	2.52E-08	2180	1.97E-09	1.97E-12	3.68E-14	9670
U-236	7.44E-08	2180	5.83E-09	5.83E-12	1.09E-13	9670
U-238	1.26E-06	2180	9.85E-08	9.85E-11	1.84E-12	9670
Np-237	2.92E-13	533	2.30E-14	2.30E-17	4.29E-19	2440
Pu-238	4.34E-22	3430				
Pu-239	7.08E-08	5460				
Pu-242	2.00E-14	5460				
Am-241	4.04E-14	3770				
Am-243	1.18E-14	5460				

Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	9.29E-09	-13.4	2.49E-10	2.49E-13	4.66E-15	24.8
Co-60	2.06E-25	367				
H-3	1.73E-06	-13.9	1.21E-08	1.21E-11	2.26E-13	12.4
I-129	3.34E-10	-2.2	7.60E-12	7.60E-15	1.42E-16	69.9
Ni-63	1.50E-17	3870				
Rb-87	3.65E-14	280	6.21E-16	6.21E-19	1.16E-20	1250
Se-79	1.09E-09	133	1.87E-11	1.87E-14	3.49E-16	642
Tc-99	3.05E-07	-13.9	8.30E-09	8.30E-12	1.55E-13	23
Sr-90	7.47E-09	315	1.81E-18	1.81E-21	3.38E-23	830
Y-90	7.47E-09	315	1.81E-18	1.81E-21	3.38E-23	830
Th-232	6.47E-13	5880				
U-234	7.47E-13	2350	1.22E-14	1.22E-17	2.28E-19	9840
U-235	1.40E-13	2350	2.33E-15	2.33E-18	4.35E-20	9840
U-236	5.91E-11	2350	9.85E-13	9.85E-16	1.84E-17	9840
U-238	1.50E-13	2350	2.51E-15	2.51E-18	4.68E-20	9840
Np-237	1.81E-11	576	3.04E-13	3.04E-16	5.67E-18	2480
Pu-238	1.43E-20	3860				
Pu-239	3.83E-08	5880				
Pu-242	1.26E-12	5880				
Am-241	1.38E-12	4190				
Am-243	7.06E-13	5880				

(Table 3-1 continued)

High Activity Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	3.63E-10	46.9	1.41E-11	1.41E-14	2.64E-16	81.6
Co-60	3.53E-13	144				
H-3	8.48E-03	31.9	9.10E-05	9.10E-08	1.70E-09	49.7
I-129	2.00E-11	144	7.82E-13	7.82E-16	1.46E-17	268
Ni-63	7.19E-08	1370				
Rb-87	2.17E-14	2150	8.51E-16	8.51E-19	1.59E-20	2930
Se-79	3.41E-10	419	1.32E-11	1.32E-14	2.47E-16	1160
Tc-99	1.20E-08	62.3	4.69E-10	4.69E-13	8.77E-15	105
Sr-90	4.98E-07	145	1.44E-16	1.44E-19	2.69E-21	649
Y-90	4.98E-07	145	1.44E-16	1.44E-19	2.69E-21	649
Th-232	6.53E-12	3740				
U-234	2.51E-08	3130	4.69E-10	4.69E-13	8.76E-15	8220
U-235	2.81E-10	3130	5.33E-12	5.33E-15	9.96E-17	8220
U-236	2.03E-09	3130	3.84E-11	3.84E-14	7.17E-16	8220
U-238	1.24E-09	3130	2.34E-11	2.34E-14	4.38E-16	8220
Np-237	2.06E-11	2130	7.87E-13	7.87E-16	1.47E-17	3560
Pu-238	4.87E-12	1350				
Pu-239	1.35E-08	3740				
Pu-242	1.25E-11	3740				
Am-241	7.82E-10	1700	4.15E-18	4.15E-21	7.76E-23	8630
Am-243	8.47E-12	3740				

Table 3-2 Peak Concentrations - Alternative 3 - Normal Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.35E-10	-10.5	1.83E-11	1.83E-14	3.41E-16	26.8
H-3	2.23E-08	-11.3	7.92E-10	7.92E-13	1.48E-14	14.8
I-129	4.98E-12	6.5	5.73E-13	5.73E-16	1.07E-17	79.4
Ni-63	2.28E-26	6400				
Rb-87	5.19E-16	429	4.64E-17	4.64E-20	8.67E-22	1420
Se-79	1.60E-11	209	1.46E-12	1.46E-15	2.73E-17	712
Tc-99	4.55E-09	-11.3	6.21E-10	6.21E-13	1.16E-14	24.8
Sr-90	6.45E-13	519	7.71E-22	7.71E-25	1.44E-26	1030
Y-90	6.45E-13	519	7.71E-22	7.71E-25	1.44E-26	1030
Th-232	2.75E-10	8800				
U-234	3.80E-07	3510				
U-235	2.22E-08	3510				
U-236	6.57E-08	3510				
U-238	1.11E-06	3510				
Np-237	2.59E-13	867	2.29E-14	2.29E-17	4.28E-19	2790
Pu-239	5.76E-08	8800				
Pu-242	1.75E-14	8800				
Am-241	3.77E-16	6720				
Am-243	7.60E-15	8790				

Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	3.12E-11	-10.5	1.89E-12	1.89E-15	3.53E-17	175
Co-60	1.42E-19	245				
H-3	6.07E-12	-11.3	6.10E-14	6.10E-17	1.14E-18	140
I-129	1.74E-12	6.5	1.06E-13	1.06E-16	1.98E-18	395
Ni-63	1.29E-11	6400				
Rb-87	1.89E-15	429	1.15E-16	1.15E-19	2.15E-21	4850
Se-79	2.95E-11	209	1.78E-12	1.78E-15	3.33E-17	1520
Tc-99	1.02E-09	-11.3	6.21E-11	6.21E-14	1.16E-15	207
Sr-90	2.34E-09	519	4.27E-19	4.27E-22	7.97E-24	754
Y-90	2.34E-09	519	4.27E-19	4.27E-22	7.97E-24	754
Th-232	5.59E-13	8800				
U-234	2.90E-13	3510				
U-235	5.47E-14	3510				
U-236	2.31E-11	3510				
U-238	5.89E-14	3510				
Np-237	1.82E-12	867	1.11E-13	1.11E-16	2.07E-18	5540
Pu-238	4.49E-13	1610				
Pu-239	3.28E-08	8800				
Pu-242	1.09E-12	8800				
Am-241	2.53E-11	6720	9.47E-20	9.47E-23	1.77E-24	9050
Am-243	6.08E-13	8790				

(Table 3-2 continued)

High Activity Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
Co-60	3.53E-13	144				
Ni-63	7.19E-08	1370				
Rb-87	2.17E-14	2150	8.51E-16	8.51E-19	1.59E-20	2930
Se-79	3.41E-10	419	1.32E-11	1.32E-14	2.47E-16	1160
Tc-99	1.20E-08	62.3	4.69E-10	4.69E-13	8.77E-15	105
Sr-90	4.98E-07	145	1.44E-16	1.44E-19	2.69E-21	649
Y-90	4.98E-07	145	1.44E-16	1.44E-19	2.69E-21	649
Th-232	6.53E-12	3740				
U-234	2.51E-08	3130	4.69E-10	4.69E-13	8.76E-15	8220
U-235	2.81E-10	3130	5.33E-12	5.33E-15	9.96E-17	8220
U-236	2.03E-09	3130	3.84E-11	3.84E-14	7.17E-16	8220
U-238	1.24E-09	3130	2.34E-11	2.34E-14	4.38E-16	8220
Np-237	2.06E-11	2130	7.87E-13	7.87E-16	1.47E-17	3560
Pu-238	4.87E-12	1350				
Pu-239	1.35E-08	3740				
Pu-242	1.25E-11	3740				
Am-241	7.82E-10	1700	4.15E-18	4.15E-21	7.76E-23	8630
Am-243	8.47E-12	3740				

Table 3-3 Peak Concentrations - Alternative 5 - Normal Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.86E-10	146				
H-3	2.79E-05	118				
I-129	1.03E-11	239				
Se-79	1.74E-10	539				
Tc-99	6.07E-09	145				
Sr-90	2.01E-08	244				
Y-90	2.01E-08	244				
Th-232	1.54E-09	6890				
U-234	8.96E-07	5030	3.25E-08	3.25E-11	6.08E-13	10500
U-235	5.14E-08	6190				
U-236	1.12E-07	2150				
U-238	2.57E-06	6190	9.47E-08	9.47E-11	1.77E-12	10500
Np-237	1.05E-11	2330				
Pu-238	7.86E-14	1600				
Pu-239	3.73E-07	6080				
Pu-242	6.92E-12	6890				
Am-241	2.40E-10	1970				
Am-243	4.09E-12	4050				

Table 3-4 Peak Concentrations - Alternative 6 - Normal Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	2.08E-11	151	1.02E-11	1.02E-14	1.91E-16	181
H-3	2.81E-06	112	2.23E-07	2.23E-10	4.17E-12	144
I-129	1.15E-12	267	5.67E-13	5.67E-16	1.06E-17	379
Se-79	1.95E-11	703	9.53E-12	9.53E-15	1.78E-16	1650
Tc-99	6.81E-10	151	3.36E-10	3.36E-13	6.28E-15	213
Th-232	1.57E-10	10900				
U-234	9.93E-08	7060	2.96E-08	2.96E-11	5.53E-13	13200
U-235	5.72E-09	7060	1.73E-09	1.73E-12	3.24E-14	13200
U-236	9.52E-09	4710	1.38E-09	1.38E-12	2.57E-14	12300
U-238	2.86E-07	7060	8.67E-08	8.67E-11	1.62E-12	13200
Np-237	1.18E-12	3050	5.78E-13	5.78E-16	1.08E-17	5960
Pu-239	3.35E-08	10800				
Pu-242	7.00E-13	10900				
Am-241	1.01E-14	6830				
Am-243	2.50E-13	10200				

Table 3-5 Peak Concentrations - Alternative 1 - Low Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.25E-10	30.1	1.62E-11	1.62E-14	3.03E-16	53.1
H-3	4.20E-09	24.4	1.92E-10	1.92E-13	3.58E-15	40.1
I-129	3.36E-12	132	4.44E-13	4.44E-16	8.29E-18	179
Rb-87	2.35E-16	2730	3.24E-17	3.24E-20	6.06E-22	3350
Se-79	7.42E-12	1380	1.02E-12	1.02E-15	1.90E-17	1700
Tc-99	4.13E-09	24.4	5.62E-10	5.62E-13	1.05E-14	47.7
Np-237	1.15E-13	5430	1.59E-14	1.59E-17	2.97E-19	6640

Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	7.95E-09	32.6	2.21E-10	2.21E-13	4.13E-15	55.9
H-3	2.31E-07	26.1	2.25E-09	2.25E-12	4.20E-14	42.4
I-129	2.09E-10	144	5.89E-12	5.89E-15	1.10E-16	190
Rb-87	1.46E-14	2950	4.31E-16	4.31E-19	8.05E-21	3560
Se-79	4.42E-10	1470	1.30E-11	1.30E-14	2.42E-16	1810
Tc-99	2.65E-07	27.4	7.49E-09	7.49E-12	1.40E-13	50.4
Np-237	7.15E-12	5860	2.10E-13	2.10E-16	3.93E-18	7060

High Activity Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	3.63E-10	57.1	1.41E-11	1.41E-14	2.64E-16	91.8
H-3	6.13E-03	37.7	6.58E-05	6.58E-08	1.23E-09	55.4
I-129	2.00E-11	171	7.82E-13	7.82E-16	1.46E-17	295
Rb-87	2.17E-14	3020	8.51E-16	8.51E-19	1.59E-20	3490
Se-79	3.40E-10	709	1.32E-11	1.32E-14	2.46E-16	1410
Tc-99	1.20E-08	64.6	4.69E-10	4.69E-13	8.77E-15	102
Sr-90	1.16E-16	1060				
Y-90	1.16E-16	1060				
U-234	2.47E-08	7480				
U-235	2.80E-10	7480				
U-236	2.02E-09	7480				
U-238	1.23E-09	7480				
Np-237	2.05E-11	3270	7.87E-13	7.87E-16	1.47E-17	4750

Table 3-6 Peak Concentrations - Alternative 3 - Low Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.11E-10	53.5	1.54E-11	1.54E-14	2.88E-16	75.1
H-3	1.37E-09	39.2	6.69E-11	6.69E-14	1.25E-15	57.7
I-129	2.68E-12	223	3.98E-13	3.98E-16	7.43E-18	262
Rb-87	1.89E-16	4360	2.89E-17	2.89E-20	5.39E-22	4980
Se-79	5.81E-12	2220	8.89E-13	8.89E-16	1.66E-17	2530
Tc-99	3.85E-09	45.9	5.35E-10	5.35E-13	1.00E-14	67.1
Np-237	9.35E-14	8620	1.43E-14	1.43E-17	2.67E-19	9860

Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	7.56E-11	304	1.86E-12	1.86E-15	3.48E-17	333
H-3	2.67E-14	223	1.99E-16	1.99E-19	3.71E-21	241
I-129	4.30E-12	975	1.06E-13	1.06E-16	1.98E-18	1040
Se-79	6.72E-11	8190	1.65E-12	1.65E-15	3.08E-17	8630
Tc-99	2.51E-09	273	6.21E-11	6.21E-14	1.16E-15	300

High Activity Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
Rb-87	2.17E-14	3020	8.51E-16	8.51E-19	1.59E-20	3490
Se-79	3.40E-10	709	1.32E-11	1.32E-14	2.46E-16	1410
Tc-99	1.20E-08	646	4.69E-10	4.69E-13	8.77E-15	102
Sr-90	1.16E-16	1060				
Y-90	1.16E-16	1060				
U-234	2.47E-08	7480				
U-235	2.80E-10	7480				
U-236	2.02E-09	7480				
U-238	1.23E-09	7480				
Np-237	2.05E-11	3270	7.87E-13	7.87E-16	1.47E-17	4750

Table 3-7 Peak Concentrations - Alternative 5 - Low Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	1.82E-10	304	8.24E-12	8.24E-15	1.54E-16	333
H-3	9.11E-08	219	1.14E-09	1.14E-12	2.13E-14	238
I-129	1.03E-11	975	4.66E-13	4.66E-16	8.70E-18	1040
Se-79	1.61E-10	8180	7.23E-12	7.23E-15	1.35E-16	8690
Tc-99	6.07E-09	272	2.75E-10	2.75E-13	5.14E-15	299

Table 3-8 Peak Concentrations - Alternative 6 - Low Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mCi/L)	Peak (year)	Wetlands (mCi/L)	Upper Three Runs Creek (mCi/L)	Savannah River (mCi/L)	Peak (year)
C-14	4.86E-11	879	9.37E-12	9.37E-15	1.75E-16	904
H-3	5.43E-20	691	3.17E-21	3.17E-24	5.93E-26	710
I-129	2.94E-12	4760	5.67E-13	5.67E-16	1.06E-17	4830
Tc-99	1.73E-09	858	3.36E-10	3.36E-13	6.27E-15	885

to plateau values at each receptor location - the well, creek, and river - but usually at times greater than 1000 years after closure and sometimes well beyond 10,000 years. Depending on the radionuclide-specific leach times, these plateaus in which the concentrations are almost constant may last for hundreds of years to tens of thousands of years. As the half-lives of most of these alpha emitters are also well in excess of 10,000 years the process of decay has little overall impact on peak concentrations and hence the doses. Two exceptions are plutonium-238 and plutonium-241 with half-lives of 88 and 13 years, respectively. The short halflives combined with the large sorption coefficient for plutonium reduce the concentrations of these isotopes to very low levels at the distant receptor locations.

The uranium isotopes and plutonium-239 are important in the case of the boundary well. These two radionuclides are considered further in the section on impacts at the boundary well, in a brief discussion on solubility controls and leach rates. While exhibiting a degree of mobility in the environment, neptunium-237 is not abundant enough in the inventory to present a problem.

3.2.2 Peak Doses via the Groundwater Pathways

The peak individual 50 year whole-body dose commitments arising from the usage of boundary well water and Savannah River water are given in Tables 3-9 through 3-16 for the alternatives 1,3,5 and 6. Both normal and reduced infiltration cases are given. These dose commitments were calculated via PATHRAE using the methodologies outlined in Appendices B and C. The times of peak doses correspond to the peak in concentrations.

3.3 Post Operations Impacts

3.3.1 Criteria

The impacts of radionuclides are developed in terms of the USEPA 4 mrem annual dose limit for drinking water[2] and the Department of Energy's Interim Derived Concentration Guides (DCG's) for effluent streams[3]. The USEPA dose limit is applied to both the boundary well and the Savannah River. The concentration guides are applied to the surface waters only.

The DCG's are based on a 100 mrem/yr dose limit for a member of the offsite public. Two points regarding this limit are worth noting. First, the limit is a whole body dose equivalent though it is expressed in mrem/yr, i.e., it has the units of a rate. Yet the DCG's are calculated using ICRP30[4] based ingestion 50 year committed effective dose equivalent factors (mrem/Ci), and the result should be a 50 year dose commitment (mrem). There is, however, an assumption that all of the 50 year committed dose is delivered in the same year that intake occurs. In reality the actual delivery of the dose in time to the exposed individual will vary with radiological and biological halflives of the radionuclides. The second point is that the limit is based on a scenario entailing the annual ingestion of 730 liters of contaminated drinking water and no other contaminated food stuffs. The PATHRAE scenarios incorporate a more complete human diet of plant, meat and dairy foodstuffs and assume only 370 liters of contaminated water are ingested per year.

Table 3-9 Peak Doses - Alternative 1 - Normal Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.83E-04	-13.8	2.32E-08	24.4
Co-60	4.91E-20	325		
H-3	1.51E-03	-14.3	9.31E-10	12.0
I-129	1.07E-03	-3.4	2.44E-09	68.7
Ni-63	9.15E-13	3450		
Rb-87	2.23E-09	259	6.09E-14	1230
Se-79	1.08E-04	122	4.28E-10	631
Tc-99	4.65E-03	-14.3	1.26E-08	22.6
Sr-90	1.67E-02	281	5.04E-16	795
Y-90	1.29E-03	281	3.88E-17	795
Th-232	4.08E-01	5460		
U-234	5.37E+01	2180	7.89E-05	9670
U-235	3.01E+00	2180	4.52E-06	9670
U-236	8.87E+00	2180	1.34E-05	9670
U-238	1.38E+02	2180	2.08E-04	9670
Np-237	5.30E-03	533	8.94E-09	2440
Pu-238	7.71E-14	3430		
Pu-239	1.42E+01	5460		
Pu-242	3.83E-06	5460		
Am-241	4.52E-05	3770		
Am-243	1.32E-05	5460		

Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.18E-02	-13.4	3.16E-07	24.8
Co-60	3.23E-18	367		
H-3	9.25E-02	-13.9	1.22E-08	12.4
I-129	6.63E-02	-2.2	3.23E-08	69.9
Ni-63	4.07E-12	3870		
Rb-87	1.39E-07	280	8.12E-13	1250
Se-79	6.42E-03	133	5.45E-09	642
Tc-99	2.90E-01	-13.9	1.68E-07	23
Sr-90	4.79E-01	315	3.08E-15	830
Y-90	3.68E-02	315	2.37E-16	830
Th-232	8.43E-04	5880		
U-234	9.27E-05	2350	2.91E-11	9840
U-235	1.67E-05	2350	5.34E-12	9840
U-236	7.05E-03	2350	2.26E-09	9840
U-238	1.65E-05	2350	5.28E-12	9840
Np-237	3.77E-01	576	1.18E-07	2480
Pu-238	2.54E-12	3860		
Pu-239	7.70E+00	5880		
Pu-242	2.42E-04	5880		
Am-241	1.55E-03	4190		
Am-243	7.91E-04	5880		

Table 3-9 (continued)

High Activity Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	4.59E-04	46.9	1.79E-08	81.6
Co-60	5.54E-06	144		
H-3	4.53E+02	31.9	9.15E-05	49.7
I-129	3.97E-03	144	3.32E-09	268
Ni-63	1.95E-02	1370		
Rb-87	8.24E-08	2150	1.11E-12	2930
Se-79	2.01E-03	419	3.86E-09	1160
Tc-99	1.14E-02	62.3	9.52E-09	105
Sr-90	3.19E+01	145	2.45E-13	649
Y-90	2.45E+00	145	1.88E-14	649
Th-232	8.51E-03	3740		
U-234	3.11E+00	3130	1.12E-06	8220
U-235	3.35E-02	3130	1.22E-08	8220
U-236	2.42E-01	3130	8.80E-08	8220
U-238	1.36E-01	3130	4.95E-08	8220
Np-237	3.74E-01	2130	3.06E-07	3560
Pu-238	8.65E-04	1350		
Pu-239	2.71E+00	3740		
Pu-242	2.40E-03	3740		
Am-241	8.76E-01	1700	3.81E-13	8630
Am-243	9.49E-03	3740		

Table 3-10 Peak Doses - Alternative 3 - Normal Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.71E-04	-10.5	2.32E-08	26.8
H-3	1.19E-03	-11.3	7.97E-10	14.8
I-129	9.89E-04	6.5	2.44E-09	79.4
Ni-63	6.19E-21	6400		
Rb-87	1.97E-09	429	6.07E-14	1420
Se-79	9.42E-05	209	4.26E-10	712
Tc-99	4.33E-03	-11.3	1.26E-08	24.8
Sr-90	4.13E-05	519	1.31E-18	1030
Y-90	3.18E-06	519	1.01E-19	1030
Th-232	3.58E-01	8800		
U-234	4.71E+01	3510		
U-235	2.65E+00	3510		
U-236	7.84E+00	3510		
U-238	1.22E+02	3510		
Np-237	4.70E-03	867	8.92E-09	2790
Pu-239	1.16E+01	8800		
Pu-242	3.35E-06	8800		
Am-241	4.22E-07	6720		
Am-243	8.51E-06	8790		

Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	3.95E-05	-10.5	2.40E-09	26.8
Co-60	2.23E-12	-10.5		
H-3	3.24E-07	-11.3	6.14E-14	14.8
I-129	3.46E-04	6.5	4.51E-10	79.4
Ni-63	3.50E-06	6400		
Rb-87	7.18E-09	429	1.51E-13	1420
Se-79	1.74E-04	209	5.20E-10	712
Tc-99	9.70E-04	-11.3	1.26E-09	24.8
Sr-90	1.50E-01	519	7.25E-16	1030
Y-90	1.15E-02	519	5.58E-17	1030
Th-232	7.29E-04	8800		
U-234	3.60E-05	3510		
U-235	6.52E-06	3510		
U-236	2.76E-03	3510		
U-238	6.46E-06	3510		
Np-237	3.30E-02	867	4.32E-08	2790
Pu-238	7.98E-05	867		
Pu-239	6.59E+00	8800		
Pu-242	2.09E-04	8800		
Am-241	2.83E-02	6720		
Am-243	6.81E-04	8790		

Table 3-10 (continued)

High Activity Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
Co-60	5.54E-06	144		
Ni-63	1.95E-02	1370		
Rb-87	8.24E-08	2150	1.11E-12	2930
Se-79	2.01E-03	419	3.86E-09	1160
Tc-99	1.14E-02	62.3	9.52E-09	105
Sr-90	3.19E+01	145	2.45E-13	649
Y-90	2.45E+00	145	1.88E-14	649
Th-232	8.51E-03	3740		
U-234	3.11E+00	3130	1.12E-06	8220
U-235	3.35E-02	3130	1.22E-08	8220
U-236	2.42E-01	3130	8.80E-08	8220
U-238	1.36E-01	3130	4.95E-08	8220
Np-237	3.74E-01	2130	3.06E-07	3560
Pu-238	8.65E-04	1350		
Pu-239	2.71E+00	3740		
Pu-242	2.40E-03	3740		
Am-241	8.76E-01	1700	3.81E-13	8630
Am-243	9.49E-03	3740		

Table 3-11 Peak Doses - Alternative 5 - Normal Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	2.35E-04	146		
H-3	1.49E+00	118		
I-129	2.05E-03	239		
Se-79	1.02E-03	539		
Tc-99	5.77E-03	145		
Sr-90	1.29E+00	244		
Y-90	9.91E-02	244		
Th-232	2.01E+00	6890		
U-234	1.11E+02	5030	7.76E-05	10500
U-235	6.13E+00	6190		
U-236	1.34E+01	2150		
U-238	2.82E+02	6190	2.00E-04	10500
Np-237	2.19E-01	2330		
Pu-238	1.40E-05	1600		
Pu-239	7.50E+01	6080		
Pu-242	1.33E-03	6890		
Am-241	2.69E-01	1970		
Am-243	4.58E-03	4050		

Table 3-12 Peak Doses - Alternative 6 - Normal Infiltration

Low Level and Intermediate Level Waste

Radio nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	2.63E-05	151	1.30E-08	181
H-3	1.50E-01	112	2.24E-07	144
I-129	2.28E-04	267	2.41E-09	379
Se-79	1.15E-04	703	2.78E-09	1650
Tc-99	6.47E-04	151	6.82E-09	213
Th-232	2.05E-01	10900		
U-234	1.23E+01	7060	7.06E-05	13200
U-235	6.82E-01	7060	3.98E-06	13200
U-236	1.14E+00	4710	3.15E-06	12300
U-238	3.14E+01	7060	1.83E-04	13200
Np-237	2.14E-02	3050	2.25E-07	5960
Pu-239	6.73E+00	10800		
Pu-242	1.34E-04	10900		
Am-241	1.13E-05	6830		
Am-243	2.80E-04	10200		

Table 3-13 Peak Doses - Alternative 1 - Low Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.58E-04	30.1	2.06E-08	53.1
H-3	2.24E-04	24.4	1.93E-10	40.1
I-129	6.67E-04	132	1.89E-09	179
Rb-87	8.93E-10	2730	4.24E-14	3350
Se-79	4.37E-05	1380	2.97E-10	1700
Tc-99	3.93E-03	24.4	1.14E-08	47.7
Np-237	2.09E-03	5430	6.19E-09	6640

Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.01E-02	32.6	2.80E-07	55.9
H-3	1.23E-02	26.1	2.26E-09	42.4
I-129	4.15E-02	144	2.50E-08	190
Rb-87	5.55E-08	2950	5.64E-13	3560
Se-79	2.60E-03	1470	3.78E-09	1810
Tc-99	2.52E-01	27.4	1.52E-07	50.4
Np-237	1.30E-01	5860	8.19E-08	7060

High Activity Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	4.59E-04	57.1	1.79E-08	91.8
H-3	3.28E+02	37.7	6.62E-05	55.4
I-129	3.97E-03	171	3.32E-09	295
Rb-87	8.24E-08	3020	1.11E-12	3490
Se-79	2.00E-03	709	3.84E-09	1410
Tc-99	1.14E-02	64.6	9.52E-09	102
Sr-90	7.43E-09	1060		
Y-90	5.72E-10	1060		
U-234	3.06E+00	7480		
U-235	3.34E-02	7480		
U-236	2.41E-01	7480		
U-238	1.35E-01	7480		
Np-237	3.72E-01	3270	3.06E-07	4750

Table 3-14 Peak Doses - Alternative 3 - Low Infiltration

Low Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	1.40E-04	53.5	1.96E-08	75.1
H-3	7.32E-05	39.2	6.73E-11	57.7
I-129	5.32E-04	223	1.69E-09	262
Rb-87	7.18E-10	4360	3.77E-14	4980
Se-79	3.42E-05	2220	2.59E-10	2530
Tc-99	3.66E-03	45.9	1.09E-08	67.1
Np-237	1.70E-03	8620	5.57E-09	9860

Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	9.57E-05	304	2.36E-09	333
H-3	1.43E-09	223	2.00E-16	241
I-129	8.54E-04	975	4.51E-10	1040
Se-79	3.96E-04	8190	4.81E-10	8630
Tc-99	2.39E-03	273	1.26E-09	300

High Activity Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
Rb-87	8.24E-08	3020	1.11E-12	3490
Se-79	2.00E-03	709	3.84E-09	1410
Tc-99	1.14E-02	64.6	9.52E-09	102
Sr-90	7.43E-09	1060		
Y-90	5.72E-10	1060		
U-234	3.06E+00	7480		
U-235	3.34E-02	7480		
U-236	2.41E-01	7480		
U-238	1.35E-01	7480		
Np-237	3.72E-01	3270	3.06E-07	4750

Table 3-15 Peak Doses - Alternative 5 - Low Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	2.30E-04	304	1.05E-08	333
H-3	4.08E-03	219	1.15E-09	238
I-129	2.05E-03	975	1.98E-09	1040
Se-79	9.48E-04	8180	2.11E-09	8690
Tc-99	5.77E-03	272	5.58E-09	299

Table 3-16 Peak Doses - Alternative 6 - Low Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	6.15E-05	879	1.19E-08	904
H-3	2.90E-15	691	3.19E-21	710
I-129	5.84E-04	4760	2.41E-09	4830
Tc-99	1.64E-03	858	6.80E-09	885

Table 3-16 Peak Doses - Alternative 6 - Low Infiltration

Low Level and Intermediate Level Waste

Radio-nuclide	Boundary Well (mrem)	Peak (year)	Savannah River (mrem)	Peak (year)
C-14	6.15E-05	879	1.19E-08	904
H-3	2.90E-15	691	3.19E-21	710
I-129	5.84E-04	4760	2.41E-09	4830
Tc-99	1.64E-03	858	6.80E-09	885

3.3.2 The Boundary Well or Maximum Individual

It is evident from the peak dose and peak concentration tables that the boundary well pathway dominates among all of the pathways considered. Indeed none of the other pathways - surface waters, the intruder food pathway, or direct gamma - produce discernible impacts. In the boundary well case there are six radionuclides which are of concern. The radionuclides are tritium, the four uranium isotopes, and plutonium-239. A dose commitment summary focusing on the impacts of these species only is presented in Table 3-17. In alternative 1, all six species result in significant doses relative to the 4 mrem dose limit.

The tritium dose is largest for alternative 1. However, it should be noted that the peak occurs well before the end of institution control. At the end of institutional control the tritium dose to the intruder will be an order of magnitude smaller than the peak value listed in Table 3.17. The impact of tritium on the boundary well can be ameliorated by one or more of the waste management practices proposed in alternatives 2, 3, 5, and 6. The exclusion of major tritium waste streams from the facilities, alternatives 2 and 3, entirely eliminates tritium as a significant source of exposure; whereas the imposition of a diffusion barrier as in alternatives 5 and 6 allows the tritium to decay before significant release to the environment occurs.

Because of the large source terms, the very long half-lives, and the lack of solubility controls in the initial calculations, significant concentrations were initially estimated for uranium-234, 235, 236, and 238 in the groundwater at the boundary well. The doses for uranium isotopes in Tables 3-9 through 3-16 reflect these concentrations as do the 'no sol.' doses in Table 3-17. Uranium chemistry is quite complex, and it is likely that some sort of solubility limits exist for uranium in the site environment. This solubility is a function of many factors such as the pH and the Eh of the groundwater, and the presence of chelating species; thus the solubility will vary from location to location, reflecting the variation of these parameters in the field. A solubility limit, if low relative to the release rate, can act as an upper bound on the annual release of uranium from the facilities. As a point of comparison the uranium groundwater transport calculations were repeated with a total uranium, i. e. summed over all isotopes, solubility limit of 100 ppb. This value is representative of what might be expected in the environment but has not been established as a SRP site value. The results obtained by imposing the solubility limit are included in Table 3-17 and show that the uranium doses have been significantly lowered. It is apparent that the solubility of uranium in the site groundwater environment may be a major controlling factor in the release of the uranium isotopes to the biosphere from the new LLW facility at SRP. Site-specific quantitative information in this regard could be very useful.

Another important factor, at least in the case of improved wasteforms, is rate of release of the uranium from the wasteform. In the base case and low infiltration calculations the release of every species from cement wasteforms was assumed to be the same as observed or estimated for the nitrate anion. Unpublished results from recent experimental studies at SRL on the release of uranium

Table 3.17 Summary Table of Boundary Well Doses

	Alternative 1		Alternative 2		Alternative 3		Alternative 5		Alternative 6	
	Normal (mrem)	Low (mrem)	Normal (mrem)	Low (mrem)	Normal (mrem)	Low (mrem)	Normal (mrem)	Low (mrem)	Normal (mrem)	Low (mrem)
Tritium	4.5E+02	3.3E+02	9.2E-02	1.2E-02	1.2E-03	7.3E-05	1.5E+00	4.9E-03	1.5E-01	-
Uranium (all) - no sol.	2.0E+02	7.8E+01*	2.0E+02	7.8E+01*	1.8E+02	6.3E+01*	4.1E+02	-	4.5E+01	-
Uranium (all) - sol.	5.5E+00	1.3E+00*	5.5E+00	1.3E+00*	5.5E+00	1.3E+00*	3.3E+00	-	5.4E+00	-
Plutonium-239 - no sol.	1.4E+01	2.0E+00*	1.4E+01	2.0E+00*	1.2E+01	2.0E+00*	7.5E+01	-	6.7E+00*	-
Plutonium-239 - sol.	1.8E-01	1.4E-02*	1.8E-01	1.4E-02*	1.8E-01	ND**	ND	ND	ND	ND

* Peak occurs after 10,000 years. Peaks designated '-' occur after 100,000 years.

** ND - not determined, but should be less than corresponding value for alternative 1.

from cement wasteforms shows that the loss of uranium from these wastes is approximately one one-tenth the value typically observed for nitrate. Doses associated with the uranium isotopes would be reduced correspondingly by this factor of ten. It should be noted, however, that the separate effects of an apparent lower diffusivity for uranium in the wasteform and environmentally imposed solubility controls are neither additive nor multiplicative - the latter still act merely as an upper bound to the release.

A solubility limit has also been applied to the plutonium isotopes, and the results are included in Table 3-17. The solubility used in the calculations was taken from reference 6. Though solubility controls potentially eliminate plutonium-239 as a species of concern, it is worth noting that even in the absence of solubility controls the highest projected dose attributed to this species is only 75 mrem.

3.3.3 Offsite Population

Application of both the four mrem/yr interim primary drinking water standard and the derived concentration guides suggests that there are no discernable radiological impacts on the individual offsite user of Savannah River water. There is, however, a small but finite collective risk to a large population, e.g., 100,000 people, using the water. This risk is quantified in section 3.4.

3.3.4 Food Grown on Site

The peak doses attributed to the ingestion of radionuclides via the intruder garden are given in Table 3-18. Individual radionuclide and total dose commitments are well below one mrem.

3.3.5 Ecological Impacts

3.3.5.1 Wetlands

The DOE derived concentration guides are not exceeded for any individual radionuclide or combination of radionuclides. This applies to all alternatives, normal and low infiltration.

3.3.5.2 Upper Three Runs Creek

The DOE derived concentration guides are not exceeded for any individual radionuclide or combination of radionuclides. This applies to all alternatives, normal and low infiltration.

3.3.5.3 Savannah River

The DOE derived concentration guides are not exceeded for any individual radionuclide or combination of radionuclides. This applies to all alternatives, normal and low infiltration.

Table 3.18 Doses at 80 Years via the Food Pathway*

	Normal	Low**
Alternative 1	1.9E-03 mrem	1.9E-03 mrem
Alternative 3	1.2E-04	1.2E-04
Alternative 5	1.4E-03	1.4E-03
Alternative 6	1.5E-05	1.5E-05

* 50 year dose commitment
** The intruder food dose is independent of infiltration.

3.4 Risks

Risks of premature cancer deaths have been estimated using a risk estimator of 2.85×10^{-4} effects per person rem. The results are summarized in Table 3-19 where the maximum risks or excess cancer deaths resulting from one year exposure to the peak concentration or uptake are presented for the individual using a boundary well; an offsite individual using Savannah River water; an offsite population of 100,000 using the Savannah River; and an intruder eating contaminated food grown on site.

3.5 Accidental Atmospheric Releases During Operations

Accident analyses were not undertaken as a part of this performance assessment. The siting, transportation, and operational aspects are not known well enough to allow a detailed analyses of normal and accidental operational exposures of workers at the facility. These analyses will have to be considered when more details become available.

Nevertheless, it is of interest to estimate the potential exposures (via inhalation - not cloud immersion) to the public offsite as a result of 1) a small fire and 2) waste container dropping accidents. As current practices generally entail the use of steel waste containers, only a small volume of waste (100 ft^3) is considered. [These calculations are for the purpose of demonstration and do not replace a full accident analysis.]

By applying the Gaussian plume model for a continuous point source[6], an estimate of the dose commitment at 5000 meters from a small fire lasting two hours has been made. The low-level, intermediate activity, and high activity inventories were examined in turn. As expected, the latter two inventories resulted in the greatest exposure. Under neutral atmospheric conditions the dose commitment at 5000 meters is on the order of 1 to 1000 mrem. The uncertainty associated with this number is large - on the order of decades -reflecting the rather complex problem of estimating the release at the source under a wide variety of conditions.

Using the results for the continuous plume a rough estimate of the inhalation exposure from a 'puff' due to a container dropping accident was also made. It is recognized that puff dispersion is fundamentally different from plume dispersion in that only fluctuations of the same scale as the puff are important. Larger scale fluctuations which are important in plumes tend to guide but not to disperse puffs. Nevertheless at the larger distances the plume and puff concentration are approximately equal. It then follows that the estimated dose commitment due to the container accident is also from 1 to 1000 mrem.

Table 3.19 Summary Table for Risks Arising from One Year Exposure to Peak Concentrations*

PATHWAY	Alternative 1		Alternative 2		Alternative 3		Alternative 5		Alternative 6	
	Normal	Low	Normal	Low	Normal	Low	Normal	Low	Normal	Low
Well-no sol.	1.3E-04	9.2E-05	5.7E-05	2.2E-05	5.1E-05	1.8E-05	1.2E-04	1.6E-09	1.3E-05	4.6E-10
Radionuclide	H-3	H-3	U	U	U	U	U	Tc-99	U	Tc-99
Well-sol.**	1.3E-04	9.2E-05	8.9E-06	3.7E-07	1.3E-04	9.2E-05	9.4E-07	9.7E-10	1.5E-06	4.6E-10
Radionuclide	H-3	H-3	SR-90	U	H-3	H-3	U	Tc-99	U	Tc-99
River-indiv.	8.5E-11	5.8E-11	8.5E-11	5.8E-11	8.5E-11	5.2E-11	8.5E-11	2.9E-15	7.5E-11	3.3E-15
Radionuclide (no sol.)	U	U	U	U	U	U	U	C-14	U	C-14
River-pop.	8.5E-06	5.8E-06	8.5E-06	5.8E-06	5.3E-06	5.2E-06	8.5E-06	2.9E-10	7.5E-06	3.3E-10
Radionuclide (no sol.)	U	U	U	U	U	U	U	C-14	U	C-14
Food-total (80 years)	5.4E-10	5.4E-10	5.4E-10	5.4E-10	3.4E-11	3.4E-11	4.0E-10	4.0E-10	4.3E-12	4.3E-12

* Excess deaths.

** Concurrent solubility controls on uranium and plutonium.

References for Chapter 3

1. G. B. Merrell, V. C. Rogers, and M. K. Bollenbacher, **The PATHRAE-RAD Performance Assessment Code for the Land Disposal of Radioactive Wastes**, Rogers and Associates Engineering Corp. Report RAE-8511-28 to E. I. du Pont de Nemours and Company, Savannah River Laboratory, August 1986, and

   A. A. Sutherland, B. C. Robertson, and M. K. Bollenbacher, **Performance Assessments of Alternatives for a New Low-Level Radioactive Waste Disposal Facility**, Report RAE-8515-2 (Draft) to E. I. du Pont de Nemours and Company, Savannah River Laboratory, August 1986.

2. U. S. Environmental Protection Agency, **National Interim Primary Drinking Water Standards**, EPA-570/9-76-003, 1977.

3. R. J. Stern, **Preparation of Annual Site Environmental Reports for Calendar Year 1985**, Memorandum, U. S. Department of Energy, 1985.

4. International Commission on Radiological Protection, **Limits for Intakes of Radionuclides by Workers, Parts 1 and 2**, ICRP Publication 30, Pergamon Press, 1979 (Part 1), 1980 (Part 2).

5. B. B. Looney, M. W. Grant, and C. M. King, **Estimation of Geochemical Parameters for Assessing Subsurface Transport at the Savannah River Plant**, DPST-85-904 (draft), July 1986.

6. D. H. Slade (Ed.), **Meteorology and Atomic Energy (1968)**, U. S. Atomic Energy Commission, July 1968.

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4. COST ESTIMATES FOR NEW LLRW STORAGE/DISPOSAL ALTERNATIVES

4.1 OBJECTIVE

This section provides long-term life cycle cost estimates for six of the operational alternatives described in Section 2.6 of this document.

The method used is to develop a general scope of work for site preparation that is used for all six alternatives, and to develop individual scopes of work for each of the six alternatives. The scopes of work are then used to make the cost estimates. Costs are developed for four different cycles in the operation: initial site preparation and construction of disposal/storage units over the twenty year period of site operation; operational costs consisting of personnel and material costs for a period of twenty years; a period for closure of the site; and finally, a one hundred year period of institutional control after closure for site maintenance and ground water monitoring. Thus, the total life cycle is 120 years.

4.2 COST CATEGORIES

Each of the six alternatives requires the following cost estimates:

- SITE PREPARATION AND FACILITY CONSTRUCTION

  The scope of work for site development includes grading an initial 125 acre site, landscaping, putting up fencing, building roads and aprons, and constructing sedimentation basins, railroads, and drainage structures.

  The scope also includes construction of storage and/or disposal facilities for the first two years of operation.

  The costs given below are developed for the site directly north of the present low level waste disposal area (Site G). Incremental costs for facilities at the other two top-rated sites -- Site B and Site L -- are $7,000,000 and $6,000,000 respectively.

  The scope includes construction of 9 more sets of two-year storage and/or disposal facilities for a total period of operation of twenty years.

  The construction estimates include the cost of containers and grout needed for all alternatives. All waste is assumed to be containerized and stabilized in all alternatives except Alternative 6, where untreated, uncontainerized waste is placed in above grade vaults.

disposal facility. About 100 cubic feet/year of deionizer vessels and berl saddles would be placed in the above ground storage building with the tritium, but with additional shielding.

4.3.3 Alternative 3: Combination of Facilities

About 880,000 cubic feet/year would be disposed of in an Above Grade Operation. About 50,000 cubic feet per year would be placed in Greater Confinement Disposal trenches or boreholes. Tritium waste, deionizers, and berl saddles would be stored as in Alternative 2.

4.3.4 Alternative 4: Engineered Storage of all Waste

About 620,000 cubic feet/year of low activity waste would be stored in an above ground building; about 320,000 cubic feet/year of intermediate activity waste would be stored in a below grade vault; and about 60,000 cubic feet/year of high activity waste would be stored in a separate below grade vault with greater shielding. The costs given do not include the ultimate disposal of the stored waste.

4.3.5 Alternative 5: Engineered Disposal of all Waste

About 314,000 cubic feet/year of higher activity waste would be disposed of in below grade vaults and grouted in place. About 620,000 cubic feet/year of low activity waste would be disposed of in above grade operations. One half of this would be placed on top of the below grade vaults, and the other half in another location. Tritium waste, deionizers, and berl saddles would be stored as in Alternative 2.

4.3.6 Alternative 6: Above Grade Vault Disposal of all Waste

One million cubic feet/year of untreated waste would be disposed of in above grade vaults and grouted in place.

4.4 COST ESTIMATES

Cost estimates have been made for the following actions: site preparation, storage and disposal facilities, twenty years of operation, closure by capping, site maintenance for 100 years of institutional control, and groundwater monitoring for the same period.

Table 4.1 summarizes the cost estimates for each of the six operational alternatives.

Table 4.1 also presents, under the heading "Initial Facility", the cost estimates for site preparation, construction of two years worth of disposal or storage facilities, and two years of operating costs. This provides an estimate of the start up costs for each alternative.

disposal facility. About 100 cubic feet/year of deionizer vessels and berl saddles would be placed in the above ground storage building with the tritium, but with additional shielding.

4.3.3 Alternative 3: Combination of Facilities

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Table 4.1 also presents, under the heading "Initial Facility", the cost estimates for site preparation, construction of two years worth of disposal or storage facilities, and two years of operating costs. This provides an estimate of the start up costs for each alternative.

TABLE 4.1

COST ESTIMATES FOR THE LLW STORAGE DISPOSAL ALTERNATIVES

(Costs are given in millions of constant 1985 dollars)

ALTERNATIVE	1	2	3	4	5	6
Construction	190	213	223	392	367	366
Operation	74	88	123	94	121	120
Closure	50	60	60	0	32	16
Maintenance	6	20	20	180	6	6
Monitoring	30	30	30	30	30	30
Total Cost	350	411	456	696	556	538
Initial Facility	29	27	26	42	40	41

TABLE 4.2

COSTS RELATIVE TO ALTERNATIVE 1

ALTERNATIVE	RELATIVE COSTS	
	TOTAL COST	INITIAL FACILITY
1. Current Operation at New Site	1.00	1.00
2. Near Surface Disposal with Exceptions	1.17	0.93
3. Combination of Facilities	1.30	0.90
4. Engineered Storage	1.99	1.45
5. Engineered Disposal	1.59	1.38
6. Vault Disposal	1.54	1.41

APPENDIX A. REGIONAL SETTING

A.1 REGIONAL GEOLOGY AND PHYSIOGRAPHY

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 (Figure A-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 3100 feet 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 River and the Congaree Rivers (Figure A-1), and slopes from an elevation of about 650 feet at the Fall Line to an elevation of about 250 feet. 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 feet.[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 Savannah River Plant.

Between the Savannah and 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 A-2). These creeks, which flow southwestward to join the Savannah River, commonly have assymmetrical valleys with the northwest side being of gentle topographic slope and the southwest side being steeper. It is inferred that the assymmetrical 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.

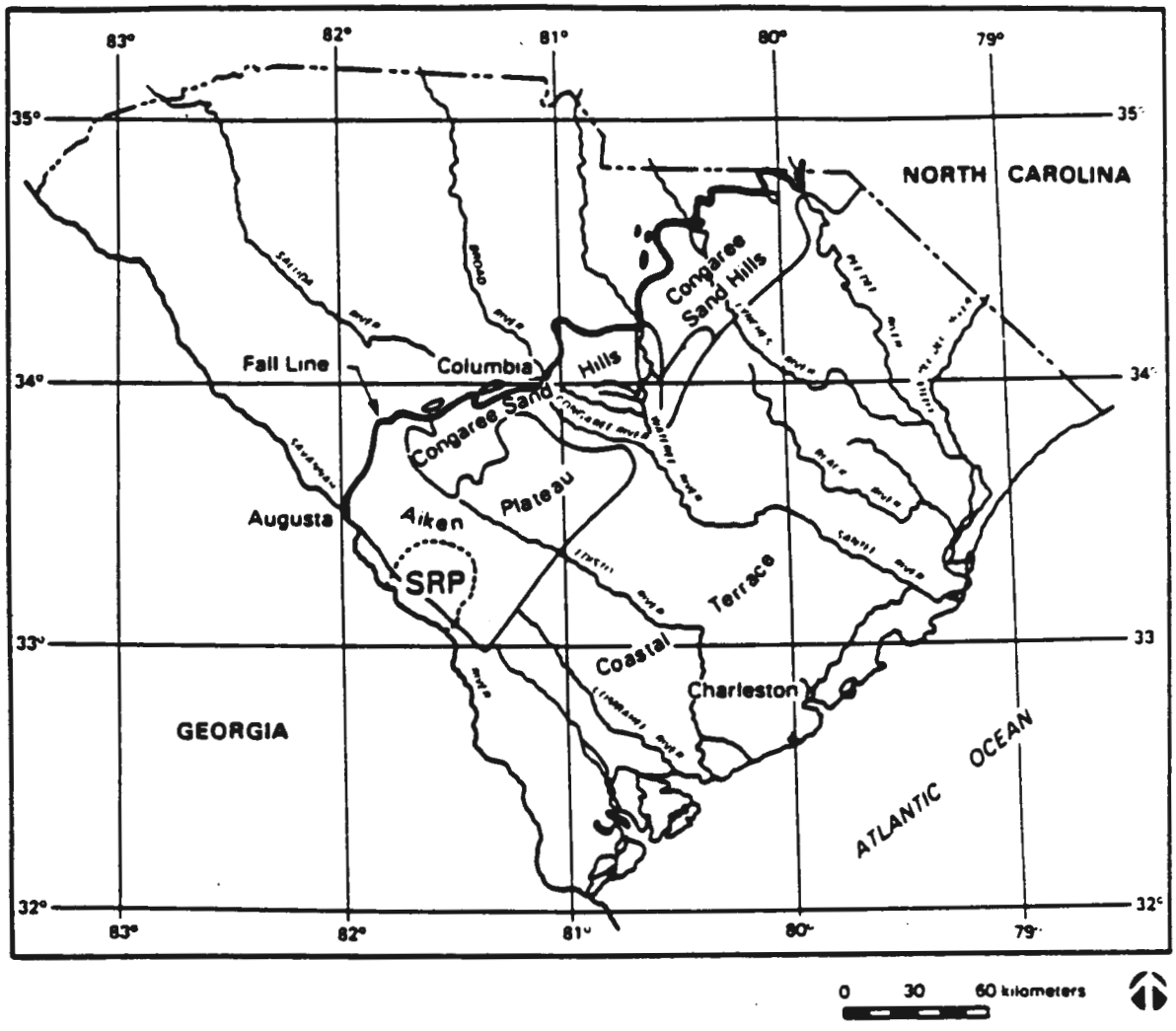


Figure A-1 Physiography of the Savannah River Region

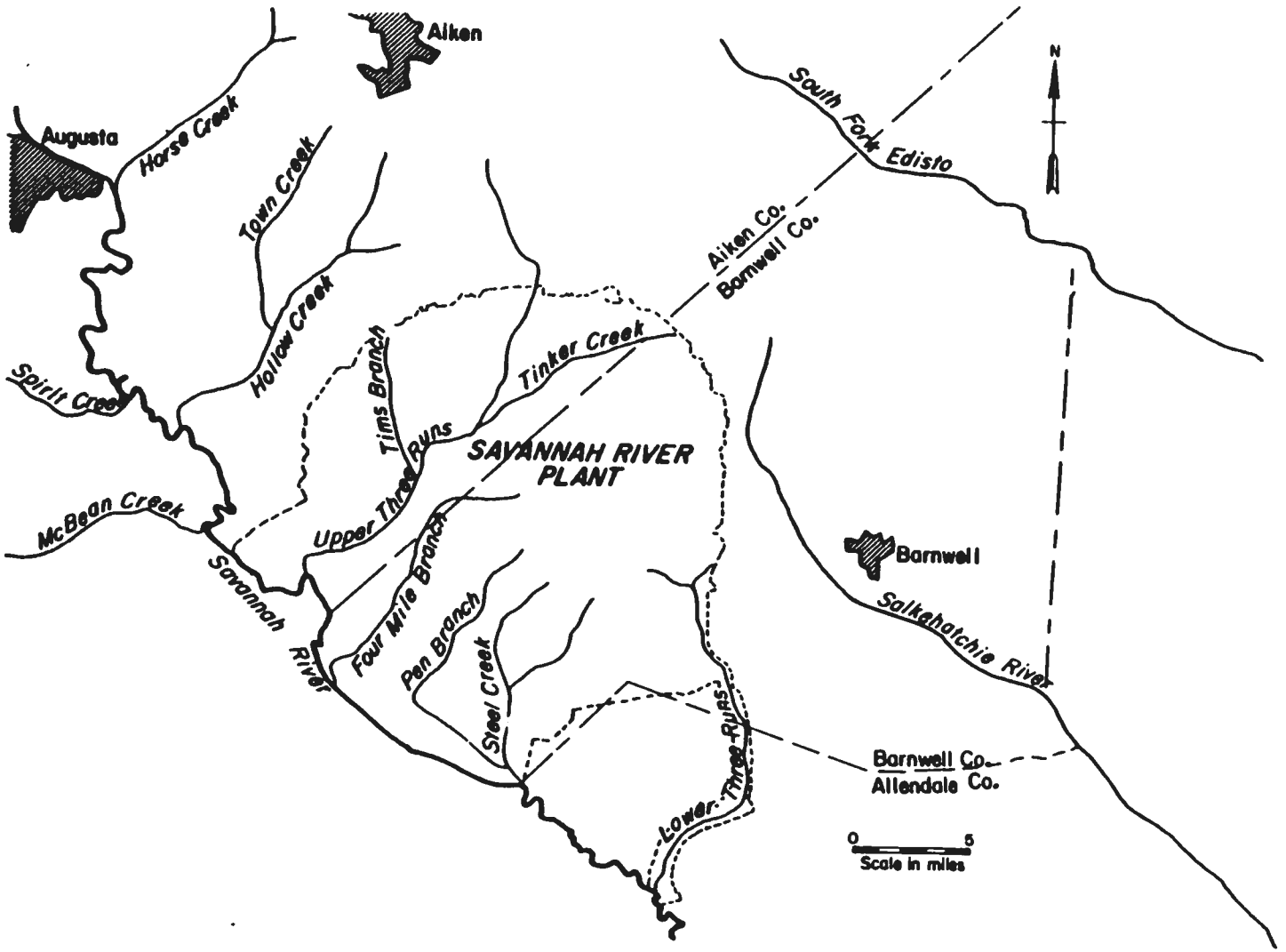


Figure A-2 Surface Hydraulic Features in the Vicinity of the Savannah River Plant

DPST-85-862

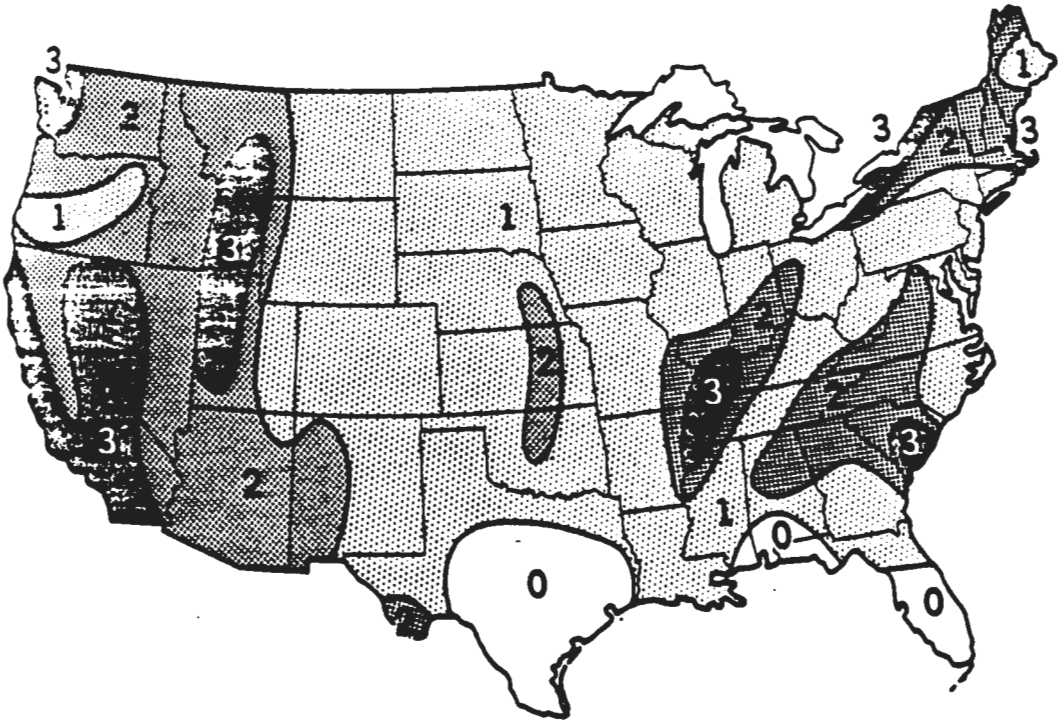
The sediments of the Atlantic Coastal Plain in South Carolina are stratified gravel, sand, clay, and limestone which dip gently seaward; although, there are local variations in dip and thickness due to locally variable depositional regimes. The base of the Coastal Plain sediments lies on the weathered surface of crystalline metamorphic rock that dips at about 36 feet 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 feet per mile to the southeast with some local variation. The Triassic basins beneath the Coastal Plain were created by tensional rifting and erosion of 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 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 as 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 feet of displacement at the base of the Coastal Plain decreasing to 40 feet 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 Company indicated that a fault of this magnitude does not exist and that a more conventional interpretation of the head relationships is satisfactory. Neither geophysical nor hydrologic work at the Savannah River Plant has indicated the existence of a fault of this magnitude.

The SRP site is located in an area of low-to-moderate seismic activity based on earthquake risk predictions by the U.S. Coast and Geodetic Survey[7] (Figure A-3). Prior to the Charleston earthquake of 1886, the only events of significance felt in the area were those associated with the New Madrid, Missouri, earthquakes of 1811-1812 (MM Intensity XI-XII). Only two earthquakes of MM Intensity VII of greater have occured within 200 miles of the site: 1) the MM Intensity X Charleston, South Carolina event of 1886, and 2) the MM Intensity VII-VIII Union County earthquake of 1931.[8,9] The epicenter of the Charleston earthquake was located some 90 miles from SRP and



ZONE 0 - No damage

Zone 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds; corresponds to Intensities V and VI of the modified Mercalli scale.

ZONE 2 - Moderate damage; corresponds to Intensity VII of the modified Mercalli scale.

ZONE 3 - Major damage; corresponds to Intensity VIII and higher of the modified Mercalli scale.

Figure A-3 Seismic Risk Map for Conterminous United States

the Union County event some 100 miles from SRP. Site intensities and accelerations resulting from these and other major earthquakes are listed on Table A-1.

A.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 like 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. The Savannah River Plant is totally on the Savannah River side of the ground water 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 ground water 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 ground water is most affected by small tributaries, deeper ground water by major tributaries, and deepest ground water only by the Savannah River itself. It is not unusual to have the deepest ground water moving at right angles or even in the opposite direction to the shallow ground water 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 feet below the surface. The depth to the water table is dependent 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 shallower 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 assymmetrical 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 ground water 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.

Table A-1 Site Intensities From Significant Earthquakes

Date*	Location	Latitude	Longitude	Intensity	Distance From Site (km)	Reported or Estimated Site Intensity	Estimated Site Acceleration (g)
1811-1812 (3 shocks)	New Madrid, MO	36.6	89.5	XI-XII	850	V-VI	0.05
Sept. 1, 1986	Charleston, SC	32.9	80.0	X	145	VI	0.07
Oct. 22, 1886	Charleston, SC	32.9	80.0	VII	155	III-IV	<0.02
June 12, 1912	Charleston, SC	33.0	80.2	VII	135	III-IV	<0.02
Aug. 1, 1920	Charleston, SC	33.1	80.2	VII	135	III-IV	<0.02
Nov. 22, 1974	Charleston, SC	33.9	80.1	VI	145	III-IV	<0.02
Jan. 1, 1913	Union Co., SC	34.7	81.7	VII-VIII	160	<IV	<0.02
May 31, 1897	Giles Co., VA	37.3	80.7	VIII	455	<III	<0.01
Nov. 2, 1875	Lincolnton, GA	33.8	82.5	VI	100	III-IV	<0.02
Aug. 2, 1974	Willington, SC	33.9	82.5	VI	105	IV	<0.02
Jan. 13, 1811	Burke Co., GA	33.2	62.2	V	55	III-IV	<0.02
Feb. 3, 1972	Bowman, SC	33.5	80.4	V	115	IV	<0.02

* Dates are based on Greenwich Mean Time.

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. Ground water 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 ground water (centuries), the water in the Coastal Plain sediments is low in dissolved solids. Most of the waters have a low pH (5.5) and are generally corrosive to metal surfaces.

A.2.1 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 pther 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 lithostratigraphic (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 hydrostraigraphic units used in this report (Table A-2) is modified from Siple.[3] Table A-2 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 ground water at SRP. Figure A-4 is a cross section through SRP from the Fall Line showing the relationship of the units discussed in Table A-2. Figure A-5 shows a tentative correlation of these units to stratigraphic terminology being described in current publications.[10,11,12] However, the thrust of much of the 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.

A.2.2 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 A-6 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.

A.2.2.1 Crystalline Metamorphic Rock

Near the center of SRP the crystalline metamorphic rock is buried beneath about 930 feet of unconsolidated-to-semiconsolidated Coastal Plain sediments.[13] The surface of the rock dips to the southeast at about 36 feet per mile, and the rock crops out at the Fall Line about 20 miles northwest of SRP.[3]

Table A-2 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).

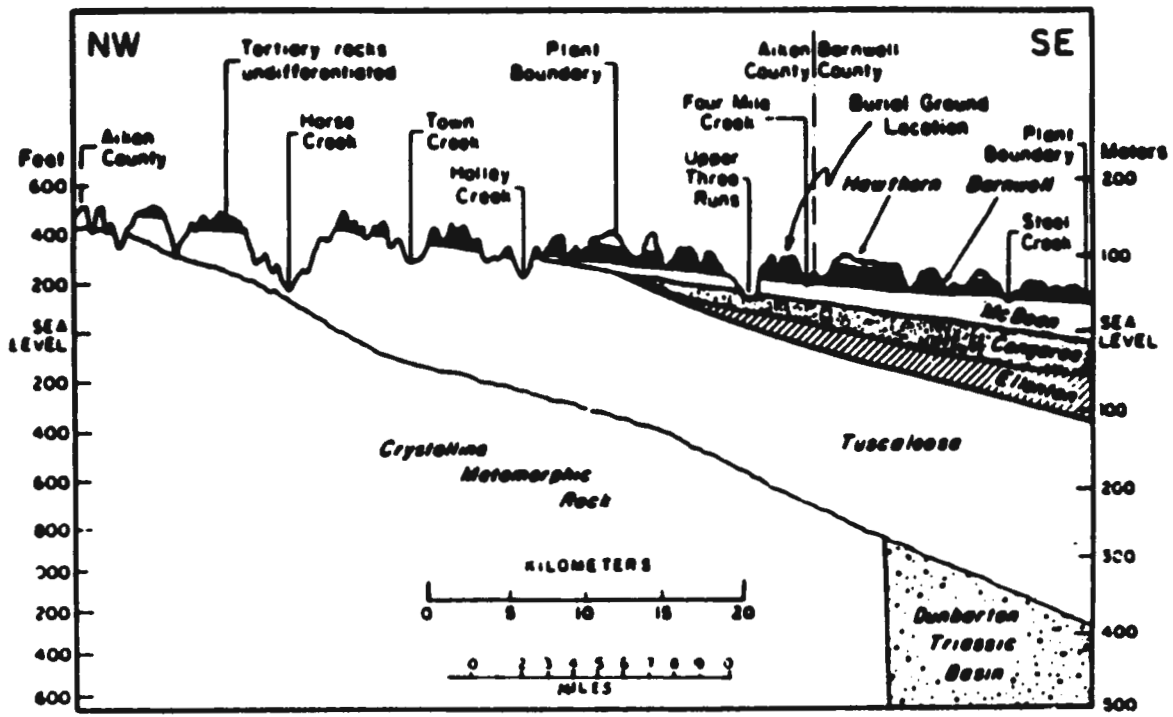


Figure A-4 Generalized NW to SE Geologic Profile Across the Savannah River Plant

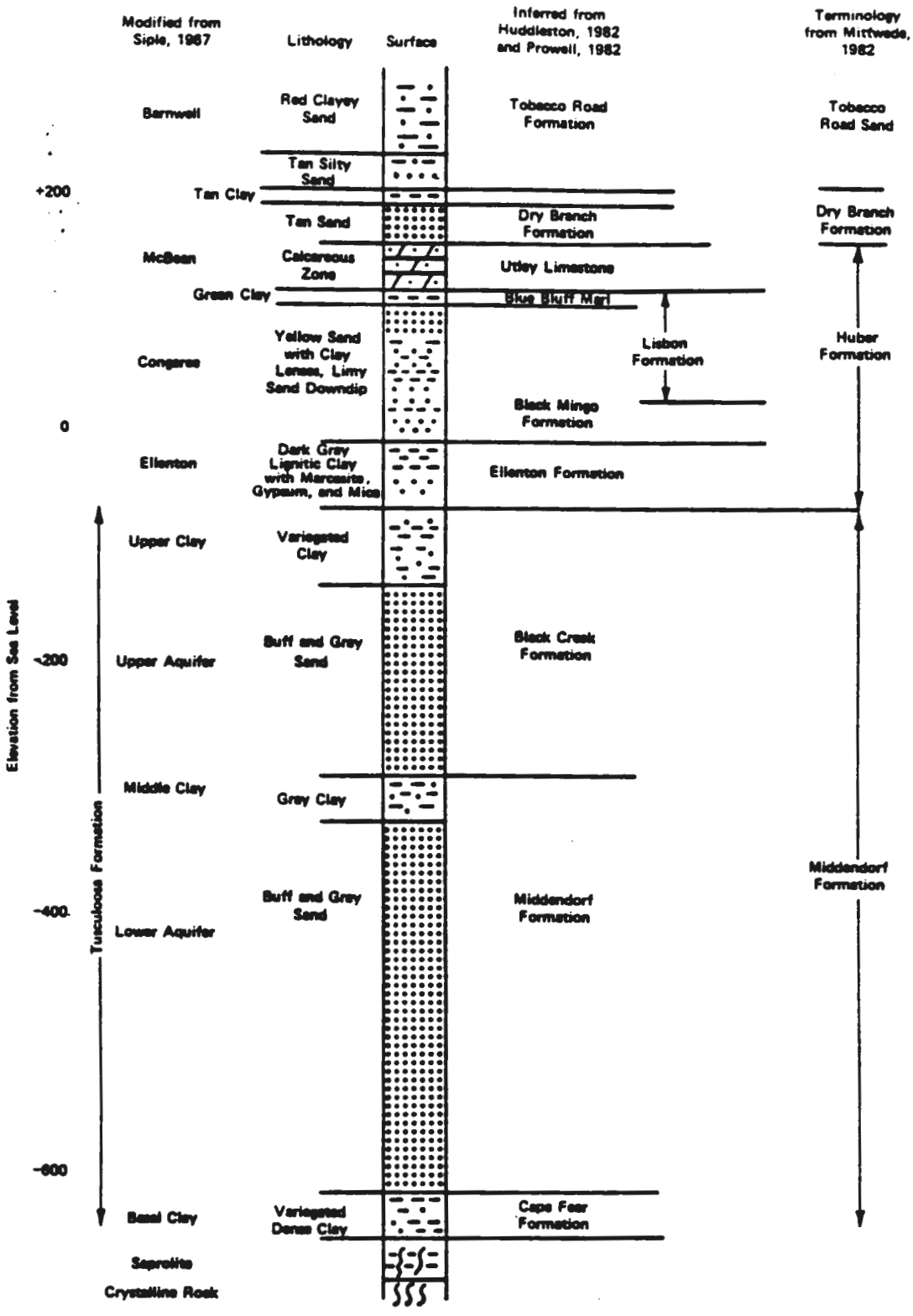


Figure A-5 Tentative Correlation of Stratigraphic Terminology of the Southwestern South Carolina Coastal Plain

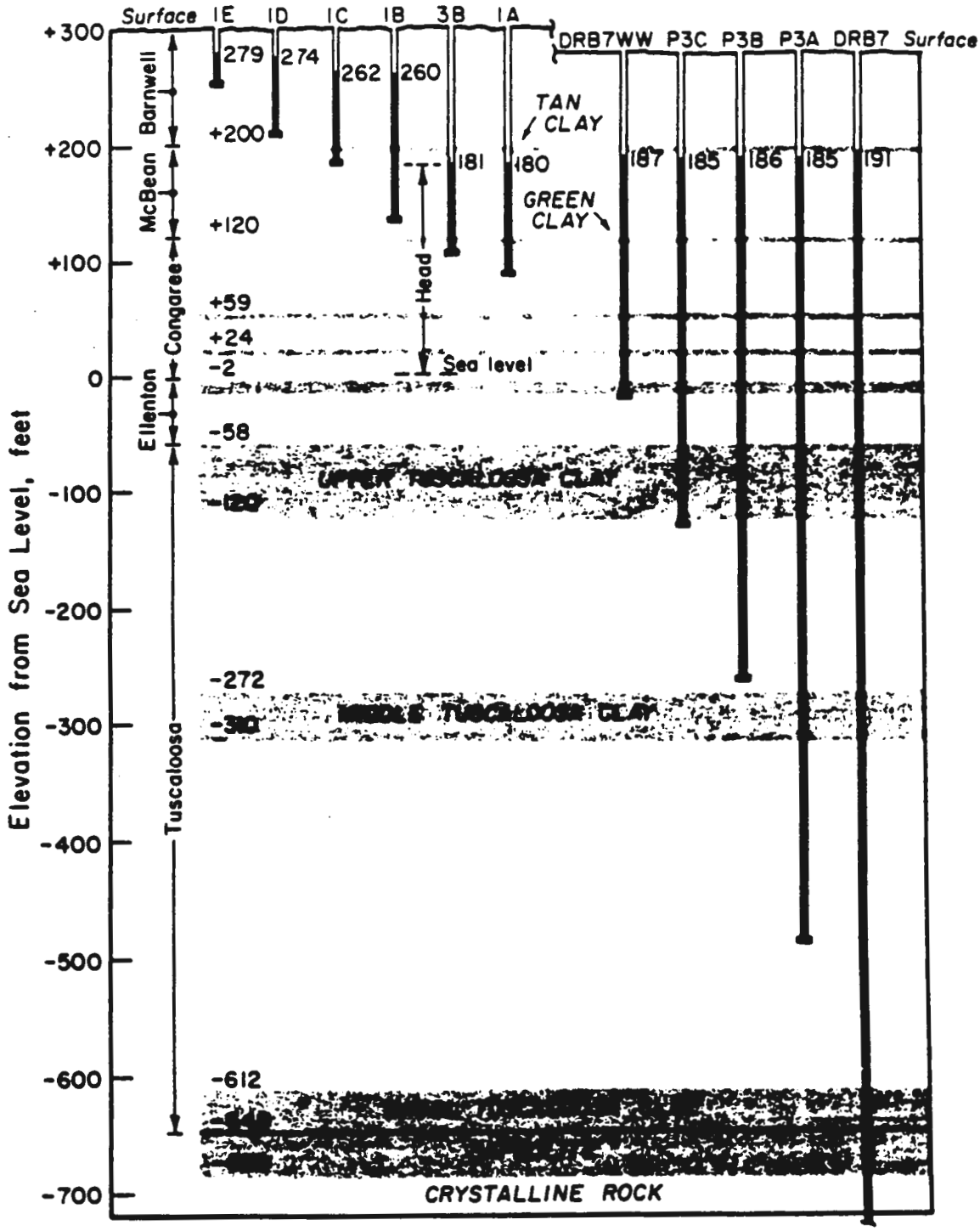


Figure A-6 Geology and Hydrologic Head in Groundwater Near the Center of the Savannah River Plant in 1972

Water injection and removal tests on packed-off sections of rock indicated that there are two types of fractures in the crystalline rock.[14] 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 definate 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.[15] Analysis of a two-well tracer test with tritium indicated a fracture porosity of 0.08% in a hydraulically transmissive fracture zone.[16] Laboratory analysis 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 A-6) at the top of the metalmorphic 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 usage.

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 A-3 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).

A.2.2.2 Triassic Sedimentary Rock

A basin of mudstone (the Dunbarton basin), formed in the Triassic Period, is buried within the metamorphic rock beneath about 1200 feet of Coastal Plain sediments (Figure A-4). The northwest boundary of the basin has been well defined by seismic traverses and by a well that penetrated 1,600 feet of Traissic rock and then passed into the crystalline metamorphic rock below.[17] 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 feet 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 feet 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,[17] 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 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.

Ground water occurs in the primary porosity of the Triassic clastic rock. However, the hydraulic conductivity of extremely low, and water movement is almost nonexistent.

The hydraulic conductivity of the Triassic sedimentary rock as determined from field tests[18] 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 A-3 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.

Table A-3 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	461	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

A.2.2.3 "Tuscaloosa" Formation

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 feet beneath SRP (Figure A-4). 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 feet 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 ground water. 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 A-4 and A-6). Near the center of the SRP site, the units of the "Tuscaloosa" Formation from top to bottom (Figure A-6) 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 feet thick, in which one or more clay lenses occur; (4) an aquifer unit of well-sorted medium-to-course 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.

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 A-4 for each area at SRP shown on Figure A-7.[19] The average of these 11 transmissivity values is 118,000 gpd/ft; the median is 110,000 gpd/ft.

Table A-4 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.

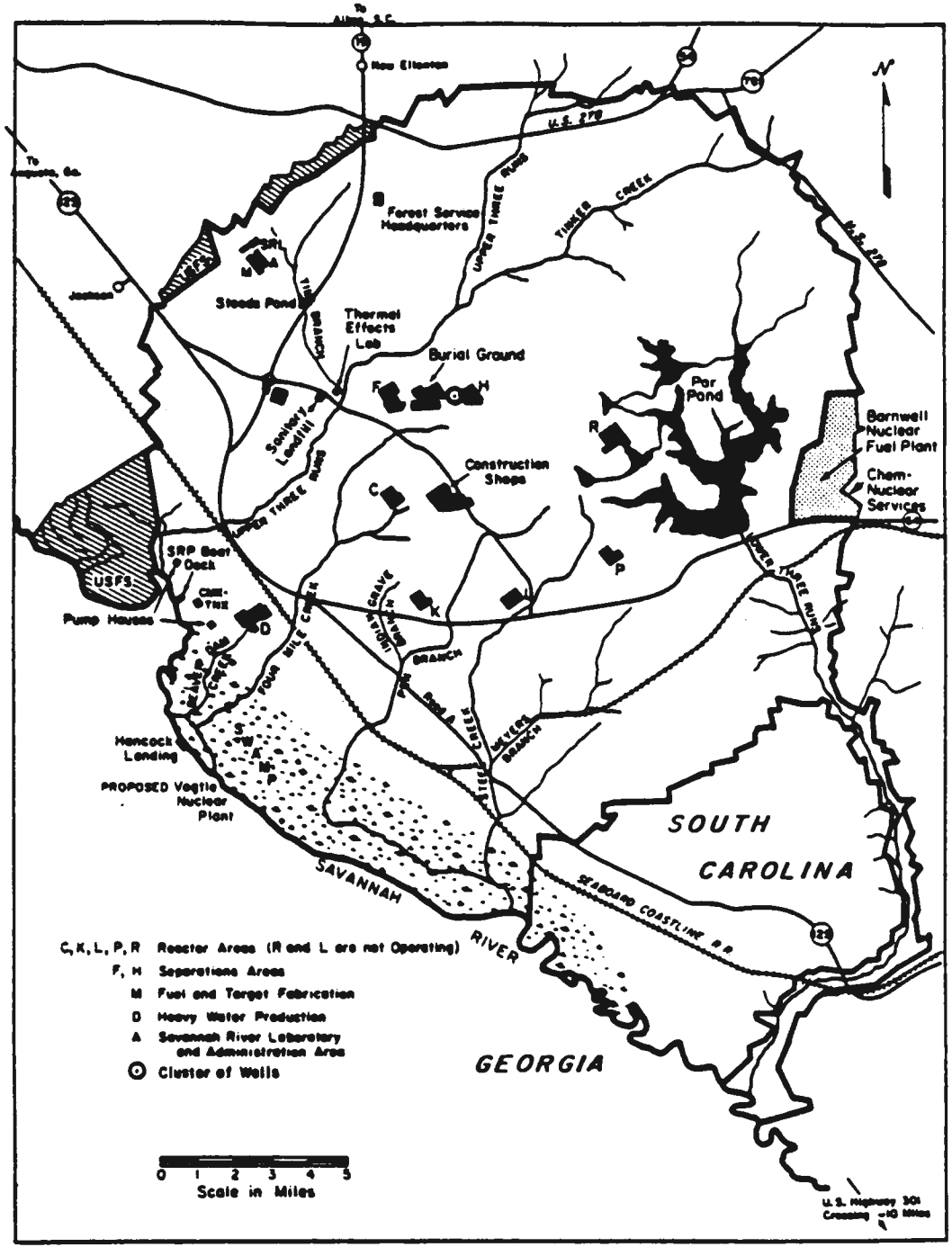


Figure A-7 Areas for Which the Transmissivity of the Tuscaloosa Formation is Given on Table 1.2-4 and the Location of the Cluster Wells Shown in Figure 1.2-6

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 A-8. Continuous hydrographs on selected wells (Figure A-9) 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 A-8. 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 independant piezometric maps of the "Tuscaloosa" aquifer have been published. The first of these (Figure A-10) was prepared by Faye and Prowell[20] based on data from 1945 to 1981. The general piezometric pattern presented on this 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 A-11) was prepared in a study for Georgia Power Co.[21] using only data from May to June 1982. This map also shows a ground water sink along the Savannah River. All of these maps indicate that ground water 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 A-12 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 are 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 in H Area in 1972 is shown in Figure A-6. The head in the "Tuscaloosa" is 5 to 6 feet above those in the Congaree; however, these particular "Tuscaloosa" observation

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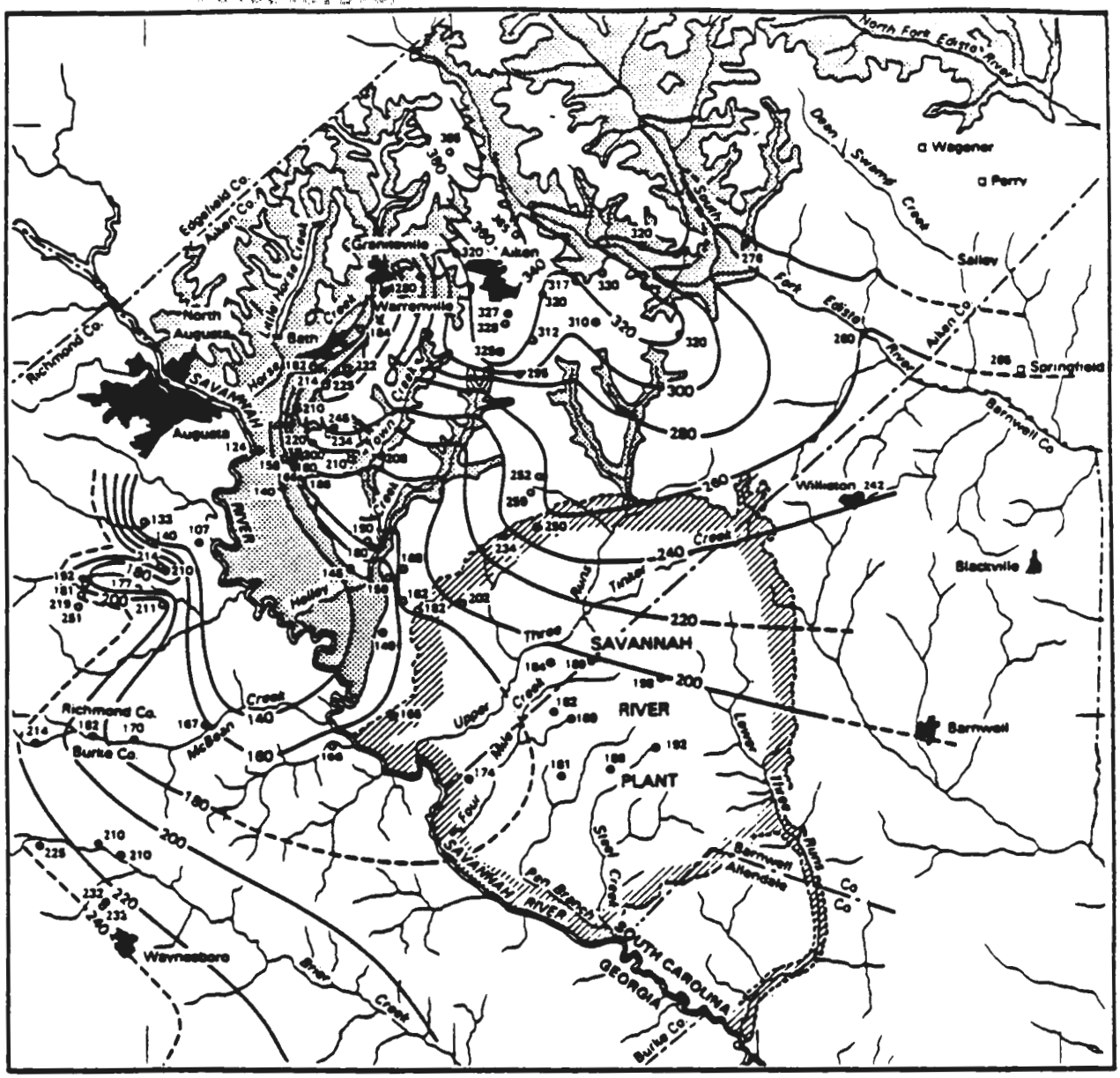

Figure A-8 Piezometric Surface and Outcrop Area of the Tuscaloosa Formation Reproduced from Siple[3]

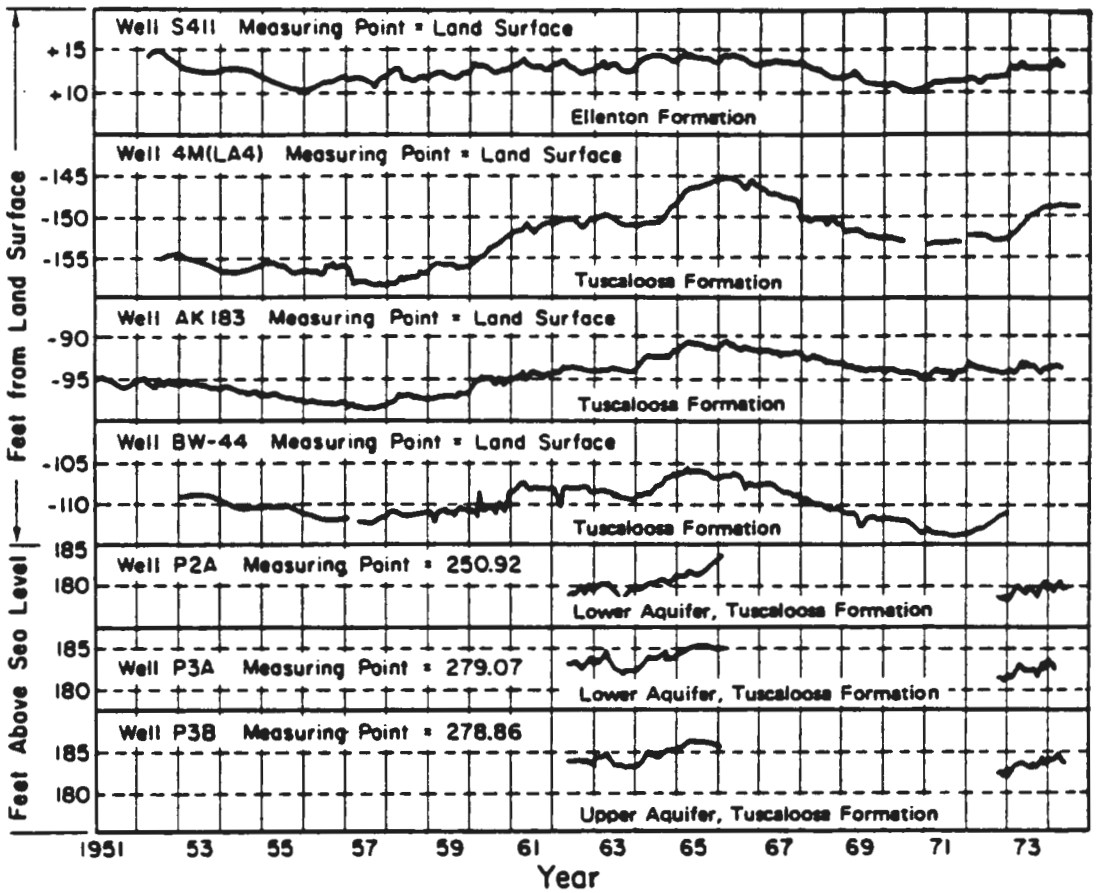

Figure A-9 Long-Term Hydrographs of Water Levels in the Tuscaloosa and Ellenton Formations

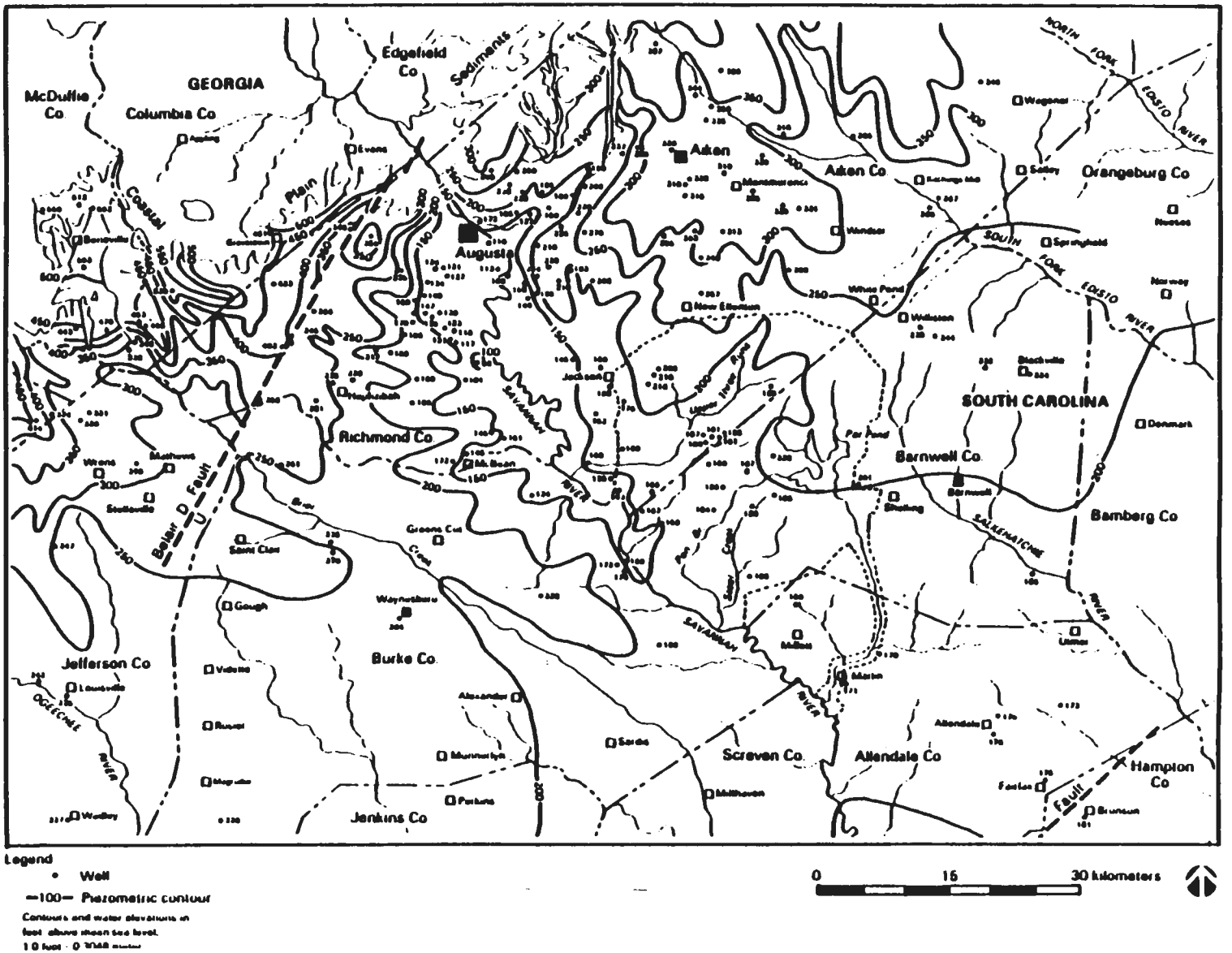

Figure A-10 Piezometric Surface of the Tuscaloosa Formation Reproduced from Faye and Prowell[20]

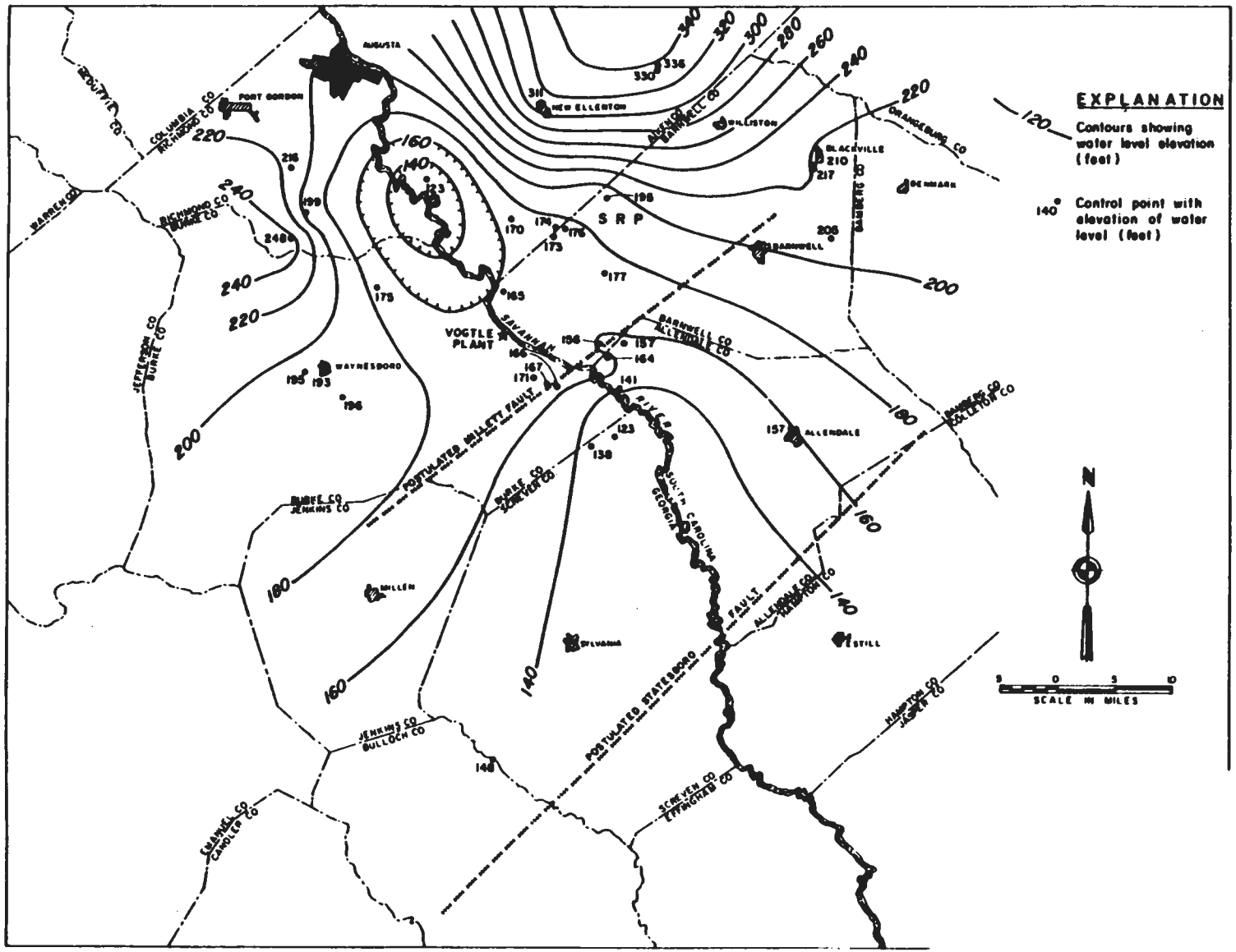

Figure A-11 Piezometric Surface of the Tuscaloosa Formation Reproduced from Georgia Power Company[21]

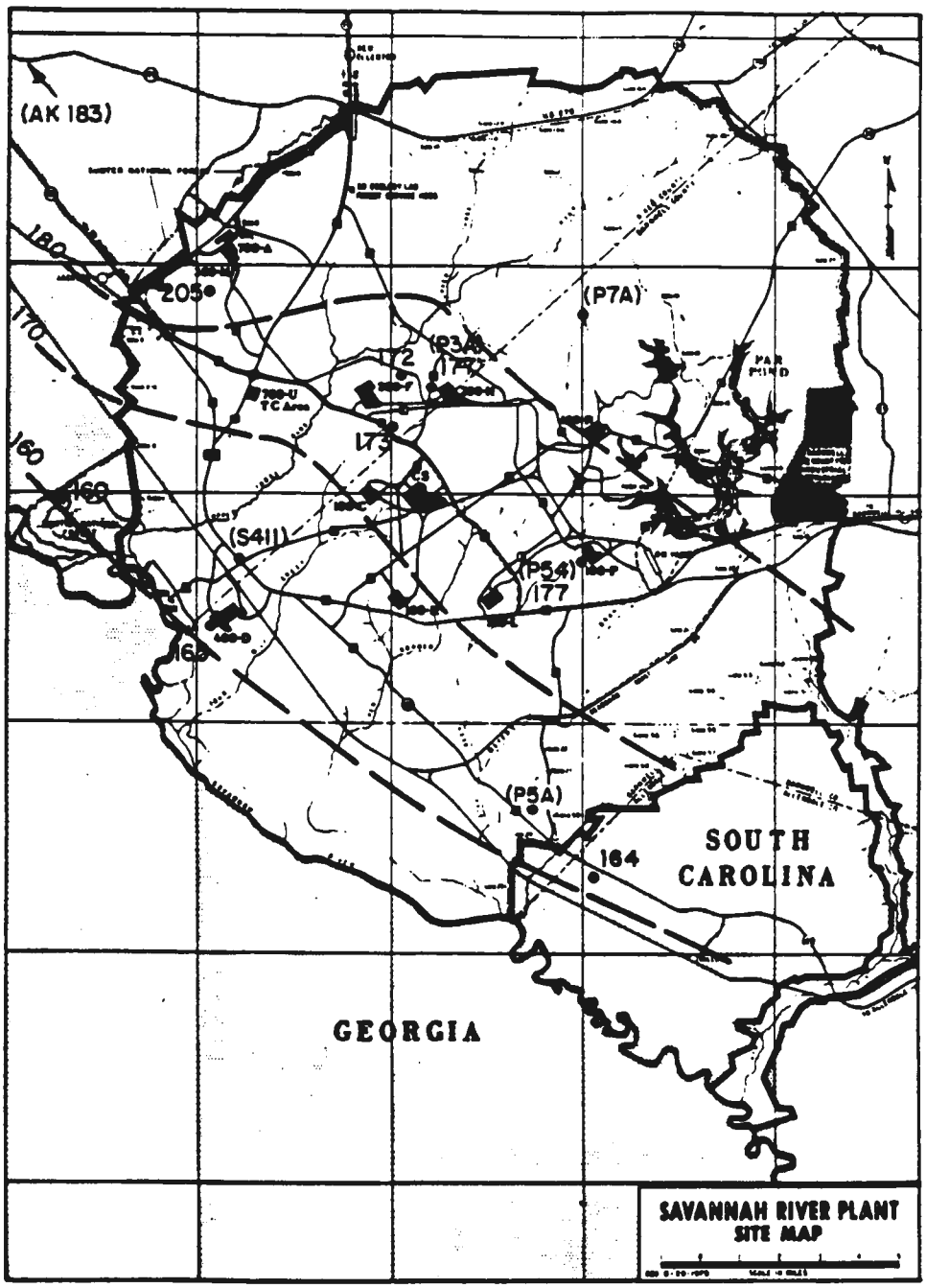

Figure A-12 Piezometric Surface of the Tuscaloosa Formation at SRP (May 11, 1982) and Locations of Tuscaloosa Wells (Parentheses) for Which Hydrographs and Given in Figure 1.2-9. Contours and Water Levels in Feet Above Mean Sea Level.)

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 A-6 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 A-6), showing that the "Tuscaloosa" and Ellenton Formations at SRP are separated from the Congaree Formation by a confining layer. Figure A-13 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 A-13 also shows that the water level in the deep "Tuscaloosa" aquifer is higher than that in the shallower "Tuscaloosa" aquifer by about 28 feet.

This difference means that care must be exercised in constructing a "Tuscaloosa" piezometric map. Each aquifer must be mapped separately. Figure A-12 is a map of the upper aquifer of the "Tuscaloosa" Formation. The water levels in P5A and P7A (both screened in the lower aquifer) are not shown, because they are 25 and 10 ft higher, respectively, than those of the upper aquifer at those locations.

Figure A-14 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 the ground water 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 constraints: 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".

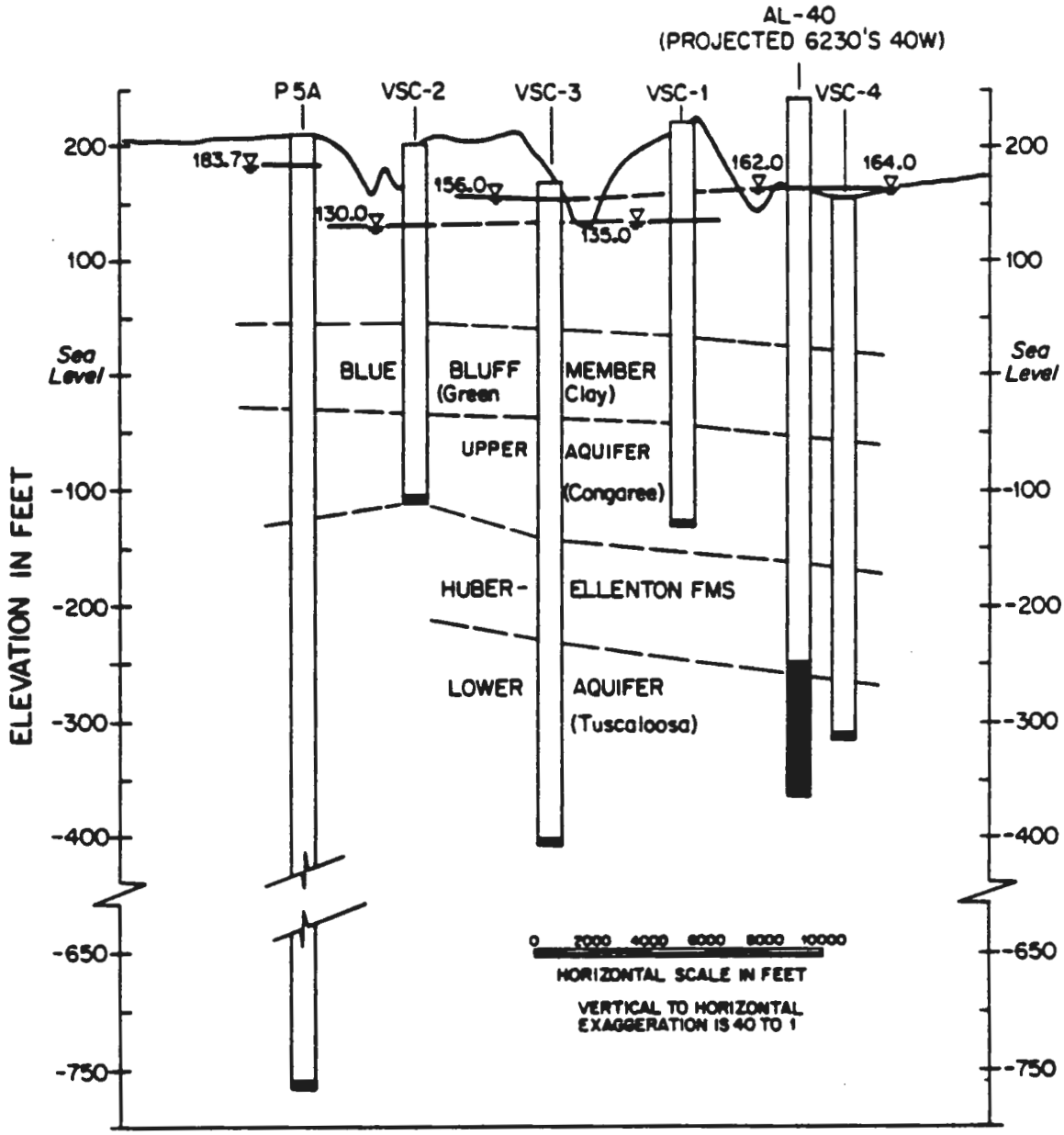

Figure A-13 Comparison of Water Levels in the Congaree Formation to Those in the Tuscaloosa Formation Figure 1.2-14 in the Southern Part of SRP.

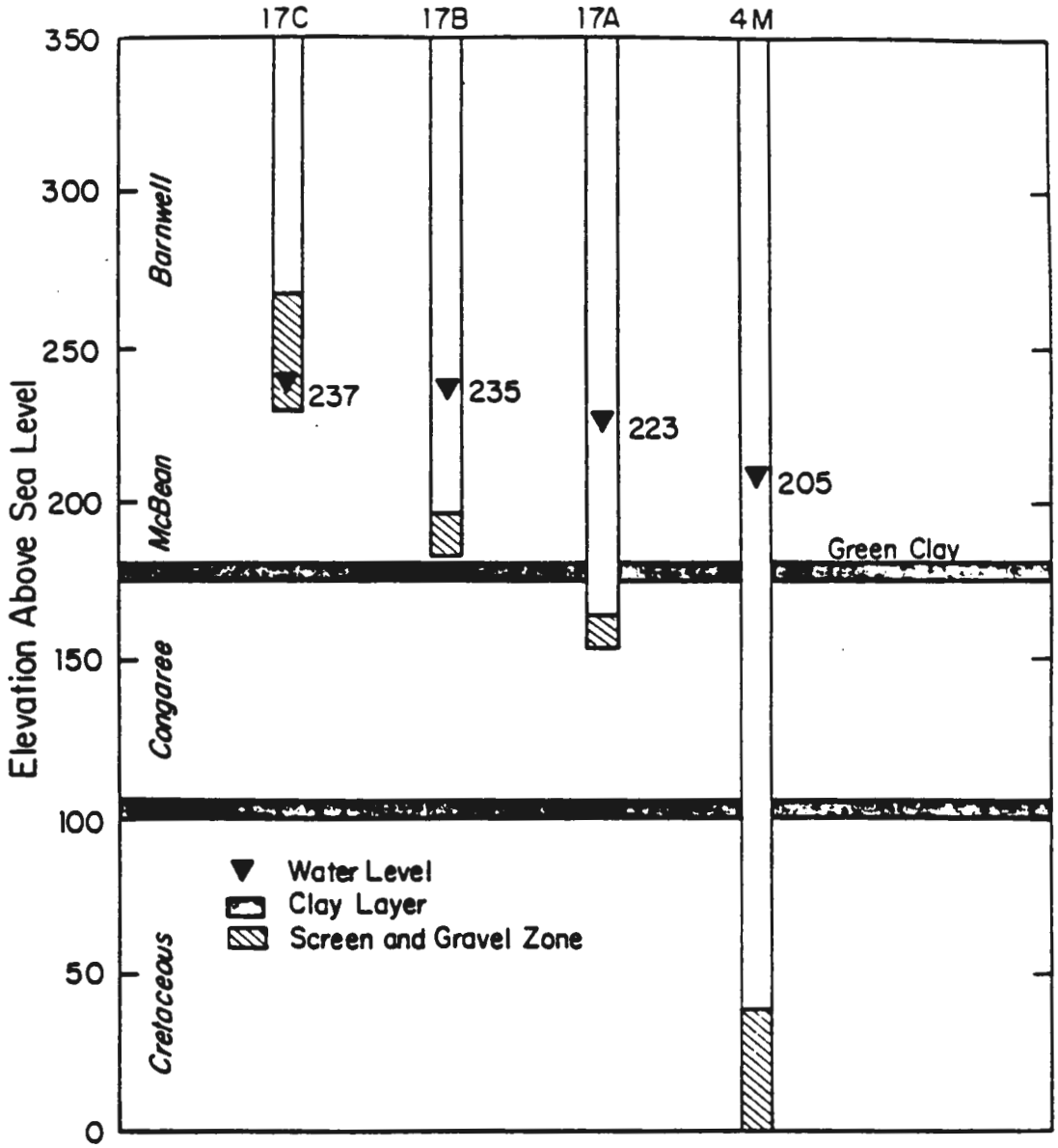

Figure A-14 Vertical Head Relationships Near M Area.

As shown in Figure A-9, 22 years of pumping 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 the development for industrial or irrigational use can be expected in the future.

Water Quality

Water from the "Tuscaloosa" Formation is low in dissolved solids (Table A-5). Specific analyses of water from the "Tuscaloosa" are given in Table A-6. Locations of the sampled wells are shown in Figure A-15. 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,[22] 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.

A.2.2.4 Ellenton Formation

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 overlian 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]

Table A-5 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 A-6 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
4/28/66	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	0.06	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	0.3	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.

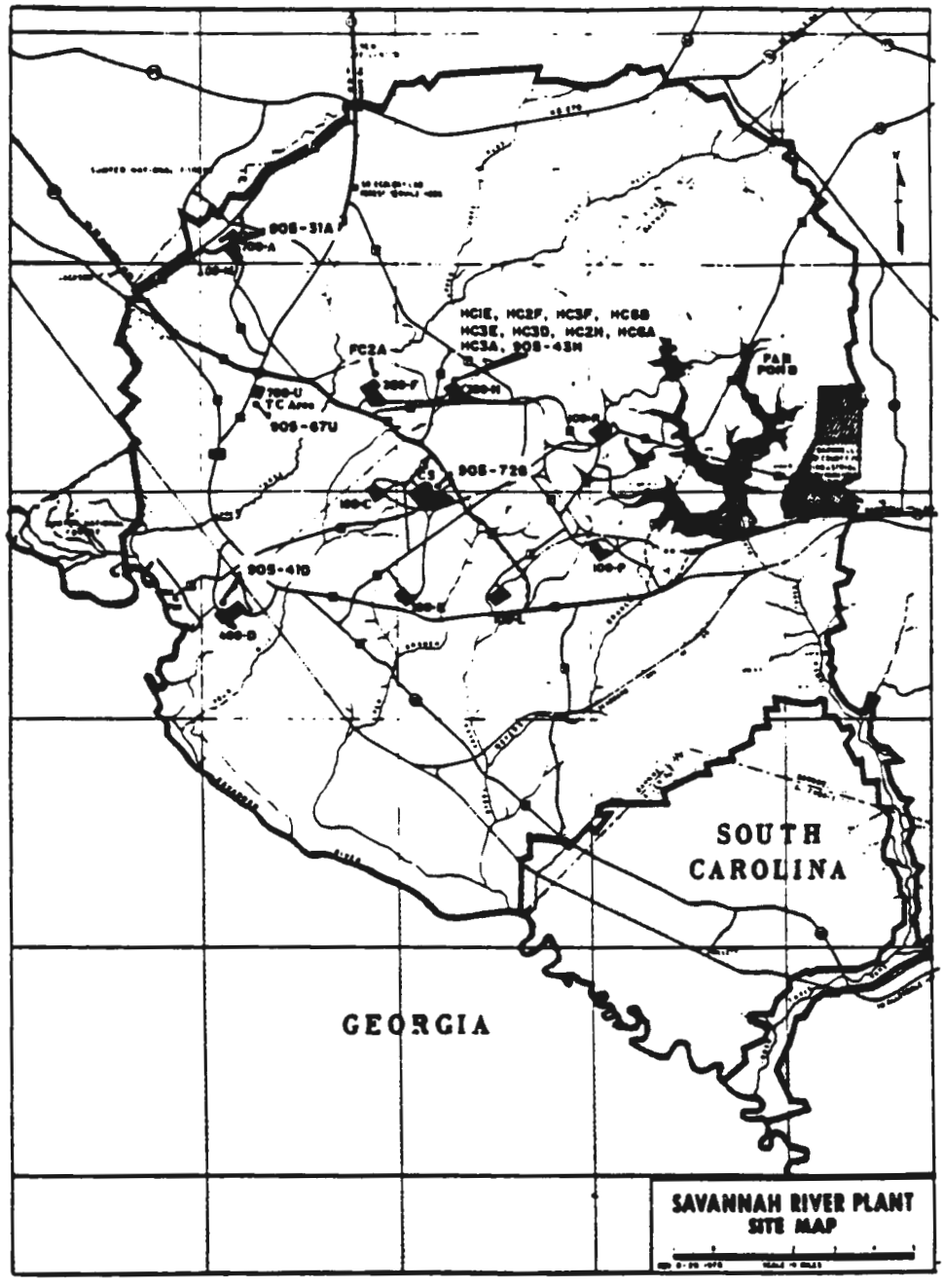

Figure A-15 Location of Wells Sampled for Chemical Analyses of Groundwater.

In many places in the vicinity of SRP, there is a thick clay at the top of the "Tuscaloosa" (Figure A-6) 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 water bearing zones within the two formations are not completely separated by an intervening confining bed.[3] Since ground water is free to move from one formation to 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 A-6 indicate that this is probably the case.

Hydrologic Characteristics

Some of the sand lenses on 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 A-6 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 A-6 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 A-6 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 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, 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.

Water Quality

A summary of chemical analyses of water from the Ellenton Formation os given in Table A-5. Its dissolved solids content is somewhat higher than that of water from the "Tuscaloosa", but it is still very low.

A.2.2.5 Congaree Formation

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.[23] 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.[24] In discussing geology and ground water at SRP, Siple used the term "McBean" both to include all deposits of Claiborne age and to include only the uppr 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.[23]

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.[23] 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.[24]

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 A-6), 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.[23] 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 on Calhoun County, SC, it consists of well to poorly sorted sand, fuller's earth, brittle 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 the 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 A-5). 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.[23] 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 calcareous 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.

Hydrologic Characteristics

Table A-7 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 A-8. The results of pumping tests, recovery tests, and slug tests on Tertiary units in the separations areas are shown in Figure A-16.

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 ground water 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 A-6 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 A-17).

Table A-7 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 TBC	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 A-8 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).

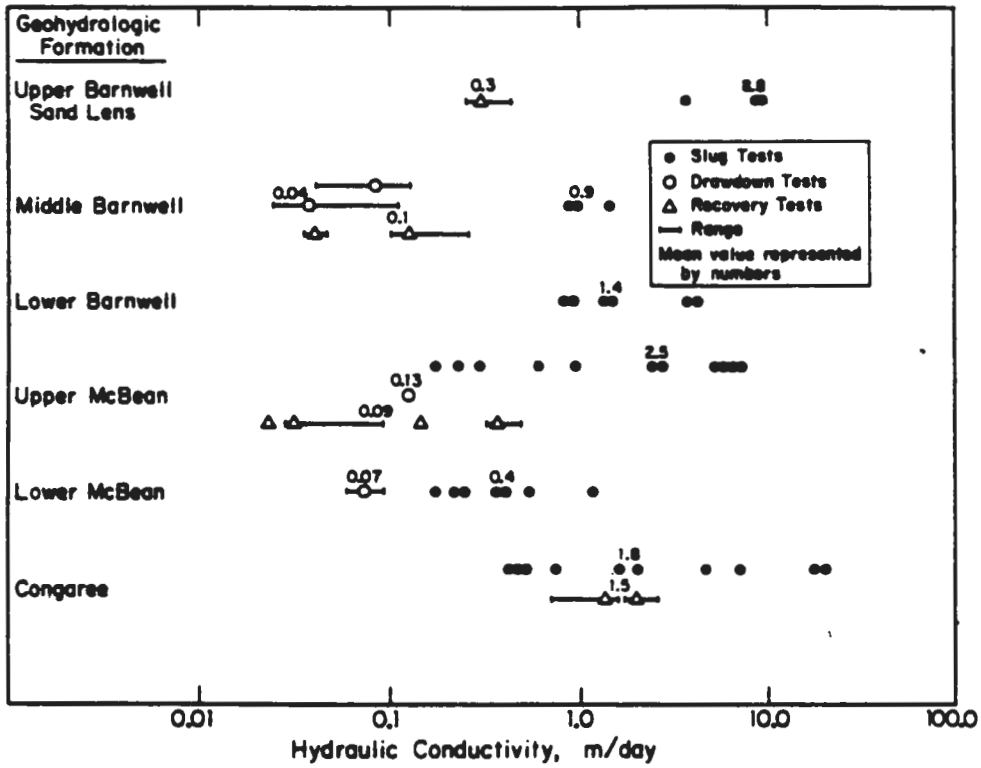

Figure A-16 Hydraulic Conductivity Values from Selected Hydrostratigraphic Units Near the Center of SRP.

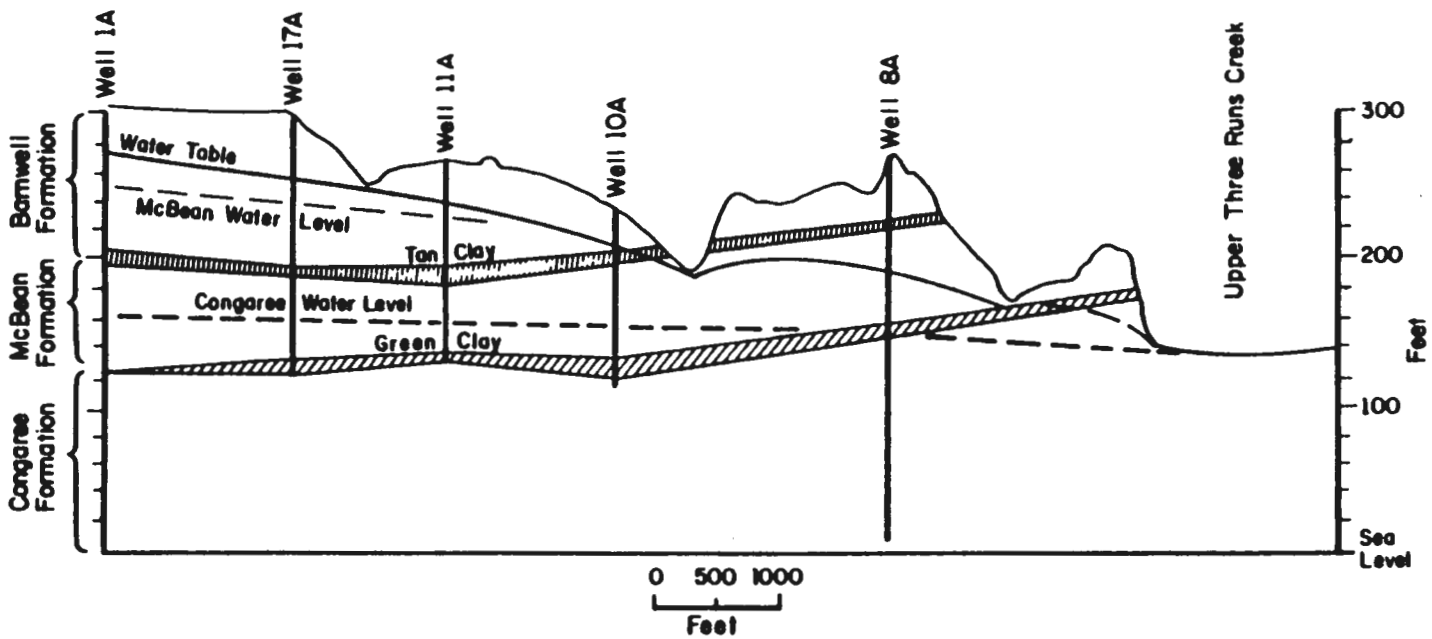

Figure A-17 Geohydrologic Section in Central Part of SRP.

The fluctuations of water levels in the Congaree Formation and their relationship to those in other hydrostratigraphic units are shown in Figure A-18.

The spatial variation of water levels in the Congaree Formation in the separations areas is shown in Figure A-19. 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 A-20 shows a regional piezometric map for the Congaree even though the control is not as good.

As shown in Figure A-20 the water levels in the Congaree Formation are significantly drawn down by the ground water 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 incision of the formation by Upper Three Runs Creek. The first by Faye and Prowell[20] is shown in Figure A-21. The second prepared by Georgia Power Co.[21] is shown in Figure A-22.

The vertical head relationships of the Congaree to the units above and below are shown in Figures A-6, A-17, and A-18. 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 A-19) ranges from about 0.003 to 0.005 ft/ft. Using a hydraulic conductivity, K, of 4.9 ft/day (Table A-8) and an effective porosity, n_e, of 20%, the flow velocity would be

$$V = \frac{IK}{n_e} = \frac{365 \text{ days/yr} \times 0.005 \text{ ft/ft} \times 4.9 \text{ ft/day}}{0.20} = 44 \text{ ft/yr}$$

The natural discharge areas for the Congaree Formation at SRP are the swamps and marshes along Upper Three Runs Creek and the Savannah River Valley. Although springs do occur, most of the discharge occurs along the valley bottoms in swamps, making it difficult to measure.

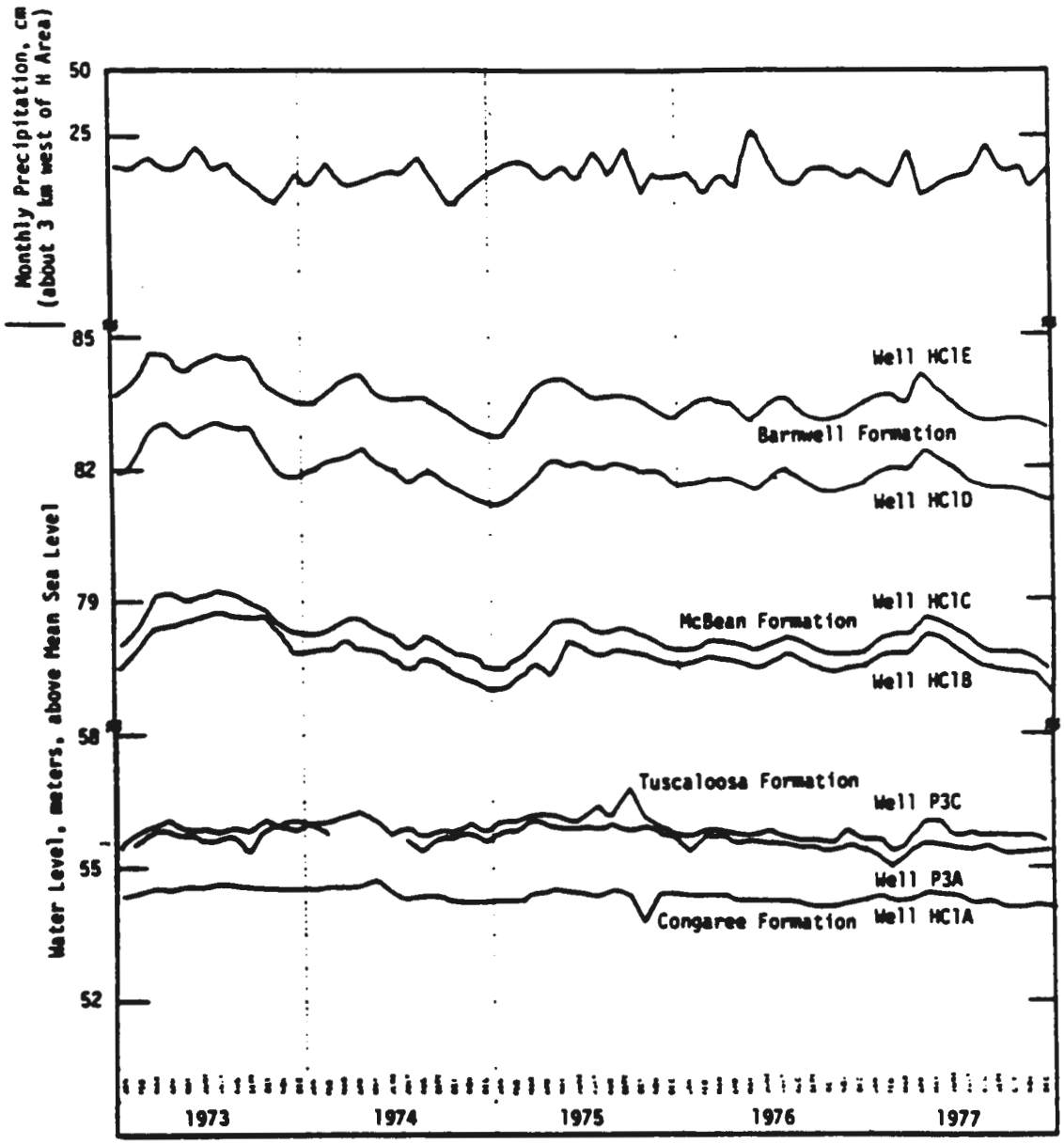

Figure A-18 Hydrographs of Selected Wells and Monthly Precipitation.

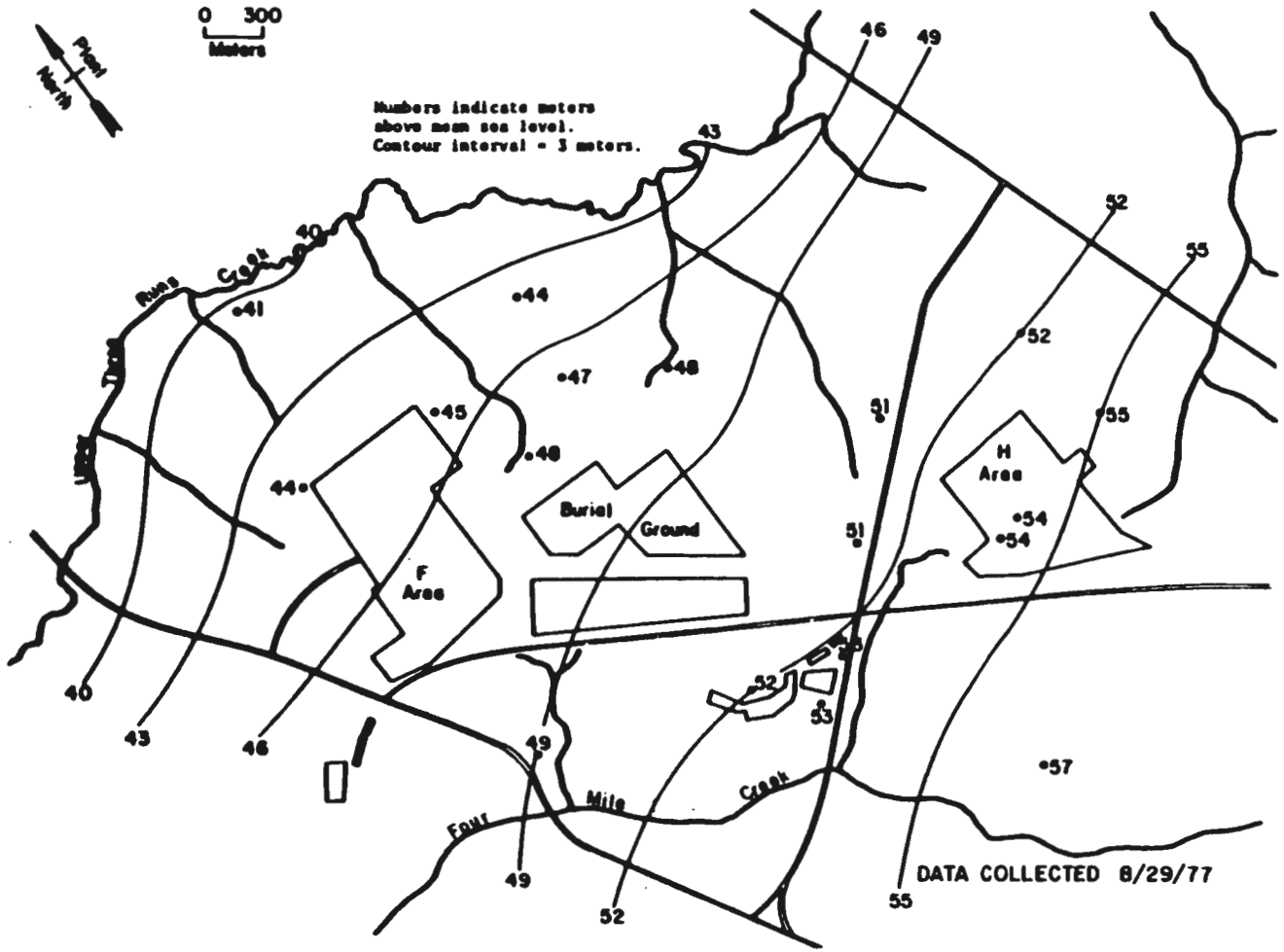

Figure A-19 Piezometric Map of the Upper Part of the Congaree Formation in the Separations Areas at SRP.

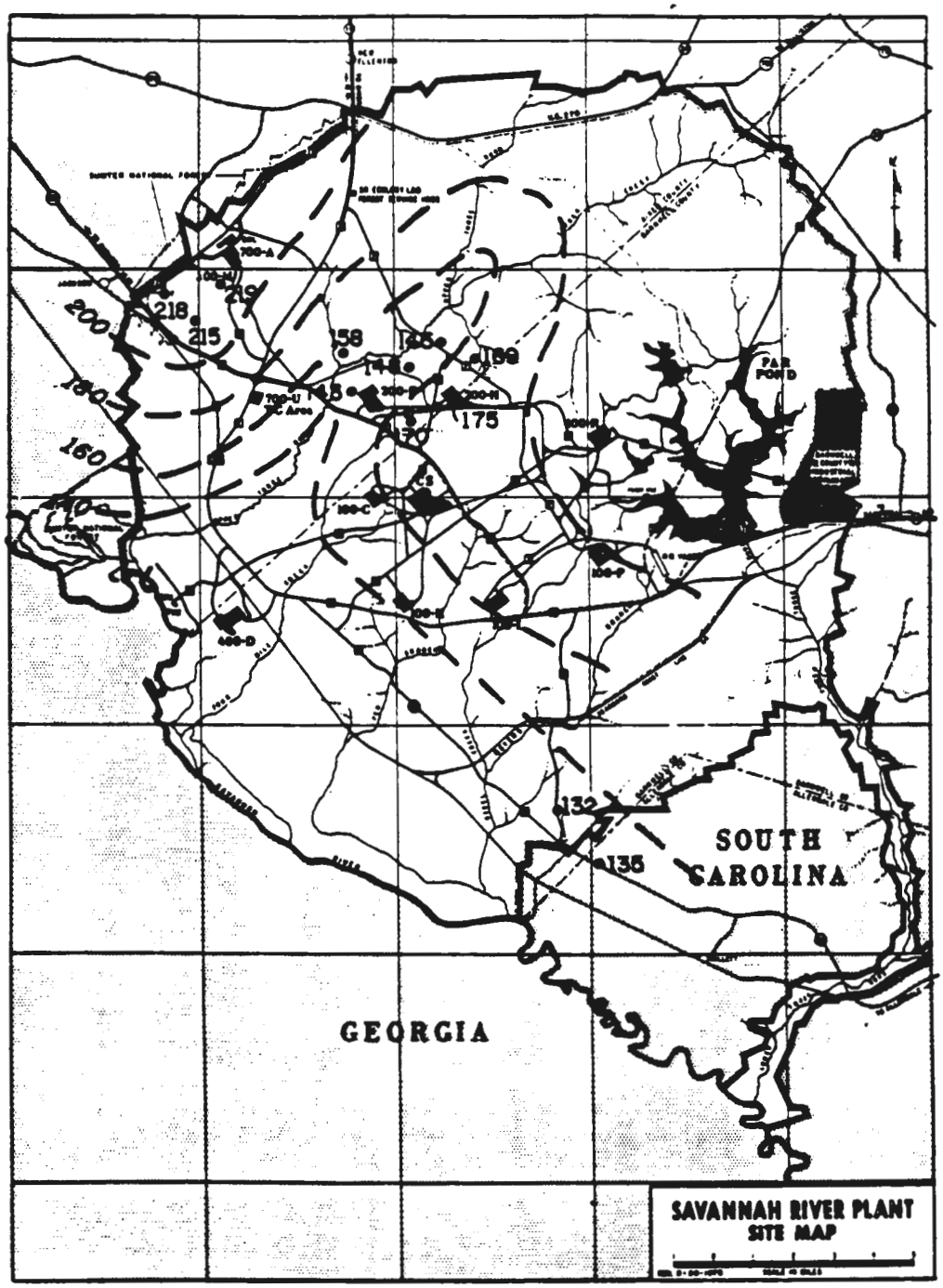

Figure A-20 Piezometric Map of the Congaree Formation (May 11, 1982) at SRP. (Contours and Water Levels in Feet Above Mean Sea Level.)

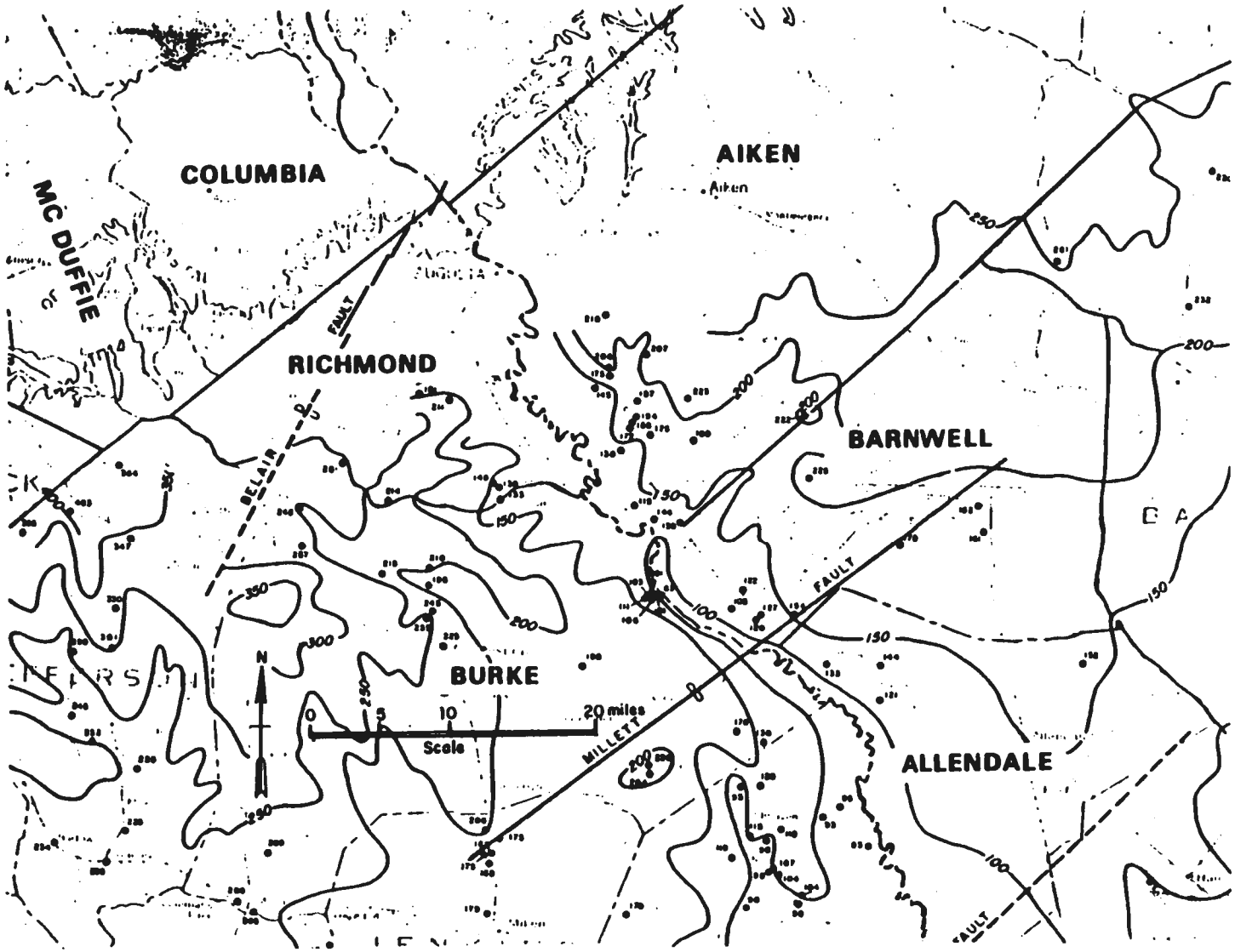

Figure A-21 Piezometric Surface of the Congaree Formation Reproduced from Faye and Prowell[20].

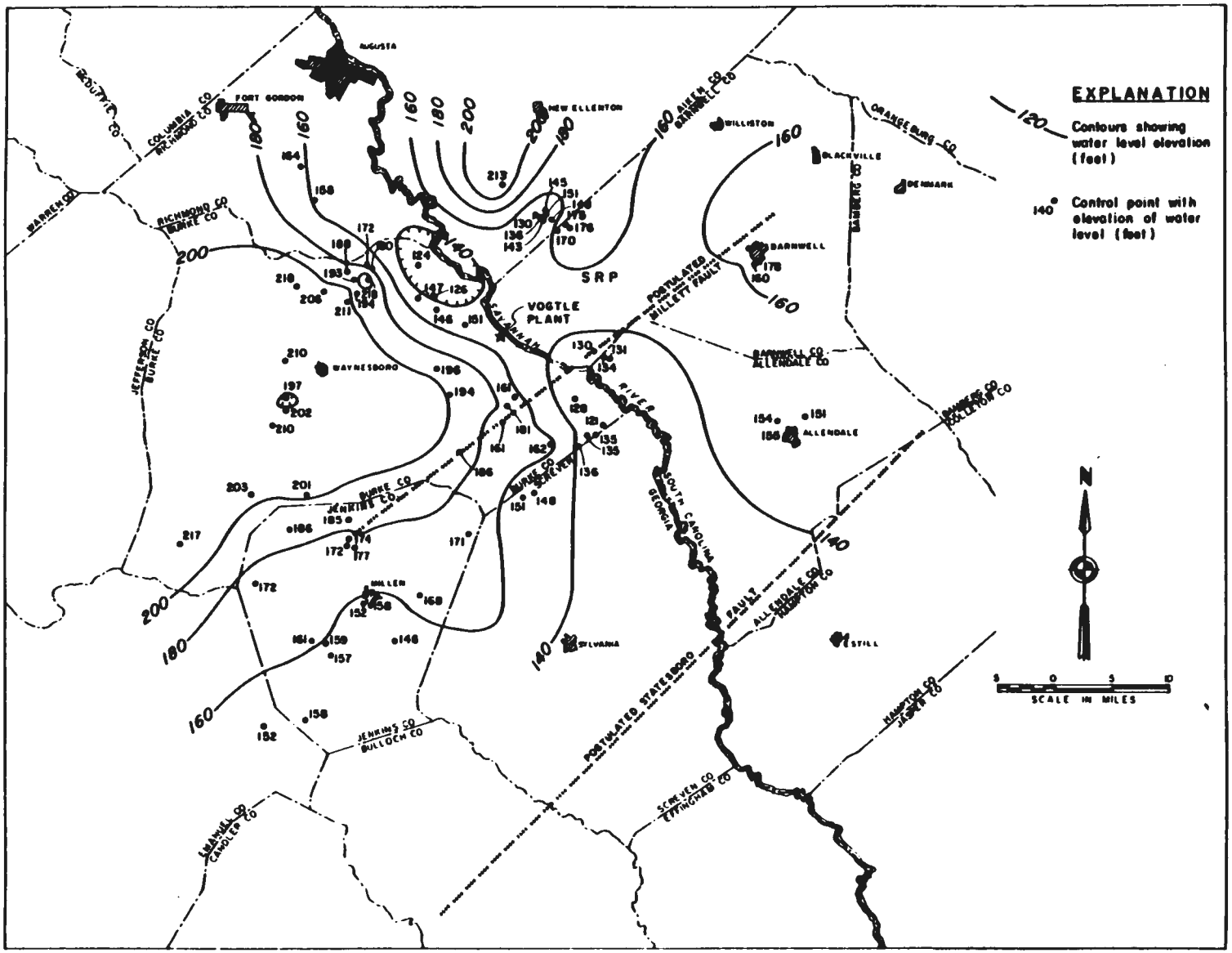

Figure A-22 Piezometric Surface of the Congaree Formation Reproduced from Georgia Power Company.[21]

On a regional basis, the dissecting creeks divide the ground water in the Congaree Formation into discrete subunits. Depending on the depth of dissection, ground water 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 A-20 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 A-7 to the value of about 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 that the total quantity pumped from the "Tuscaloosa" Formation.

Water Quality

Ranges and medians of chemical analyses of water from deposits of Eocene age are given in Table A-5 as reported by Siple.[3] These analyses are grouped into those from Eocene limestone, which would be primarily for water from the McBean Formation, and those of water from Eocene sand, which would include the Barnwell, McBean, and Congaree Formations.

The analyses of water from 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 A-6. 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.

A.2.2.6 McBean Formation

Hydrostratigraphy

As previously discussed, the term McBean Formation was originally 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,[23] 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.[27] 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.

Ground water 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 increases, well yields are moderate.

As with the Congaree Formation, creeks on the region dissect the McBean Formation, and divide the hydrogeologic unit into separate 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, ground water that enters the McBean Formation in the separations areas cannot migrate to other subunits of the McBEan.

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Hydrologic Characteristics

The median hydraulic conductivity of the upper sand of the McBean Formaiton is 3.2 gpd/ft^2 and that of the calcareous zone is about half that of the upper sand (Table A-8). Figure A-16 shows the median and range of hydraulic conductivity as measured in the field by slug tests, recovery tests, and drawdown tests.

Figure A-23 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 ground water 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 A-8 and Figure A-16). 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. Aparently 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 the upper sand unit and in the calcareous zone are shown in Figures A-6 and A-18. 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 A-24 shows the piezometric surface of the upper part of the McBean Formation in the separation areas. This map indicates lateral flow in the upper part of the McBean Formaiton toward Upper Three Runs Creek to the north and toward Four Mile Creek to the south. Because the hydraulic connection between the upper sandy zone and the calcareous zone, Figure A-24 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 A-6).

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

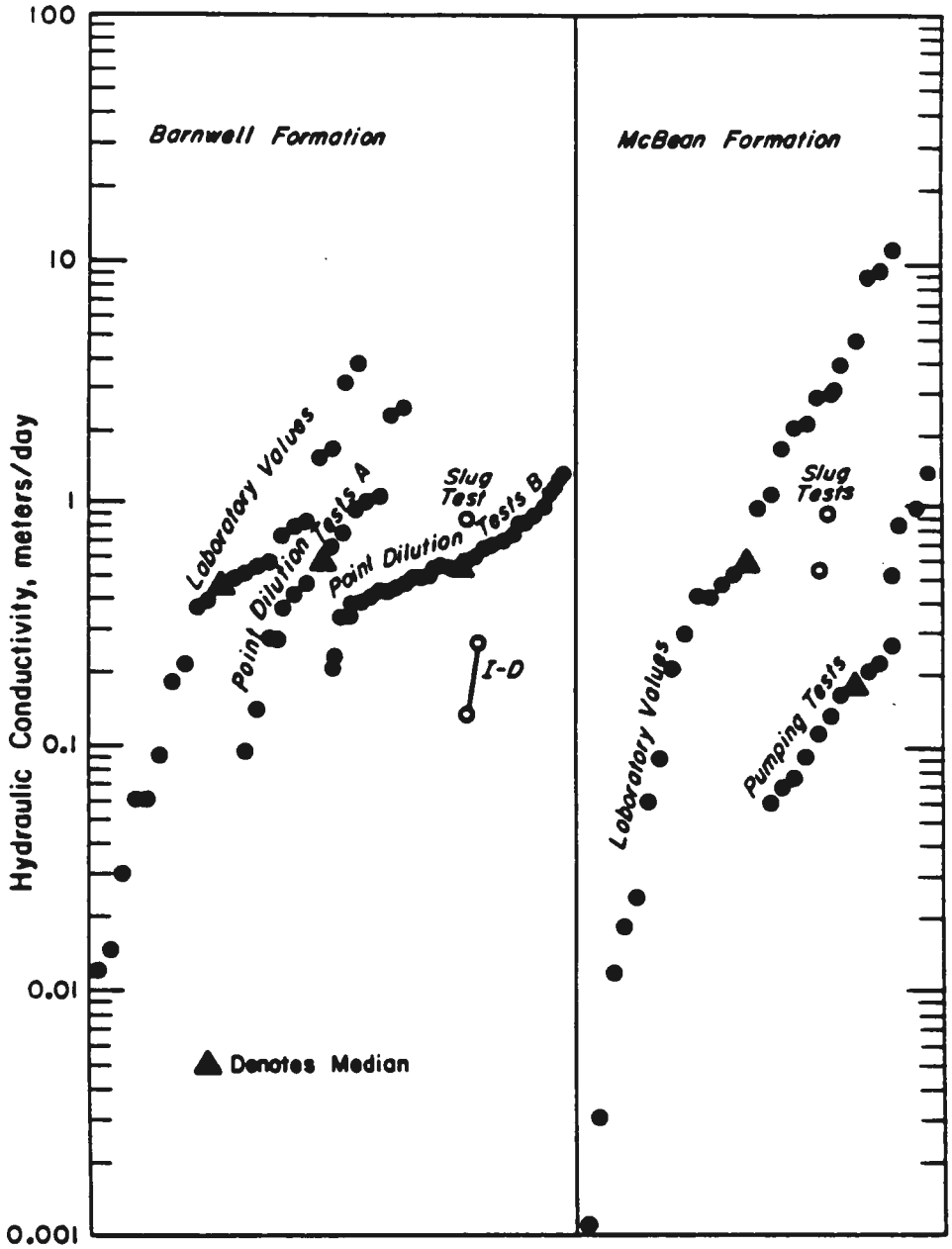

Figure A-23 Horizontal Hydraulic Conductivities of the Barnwell and McBean Formations in the Separations Areas at SRP.

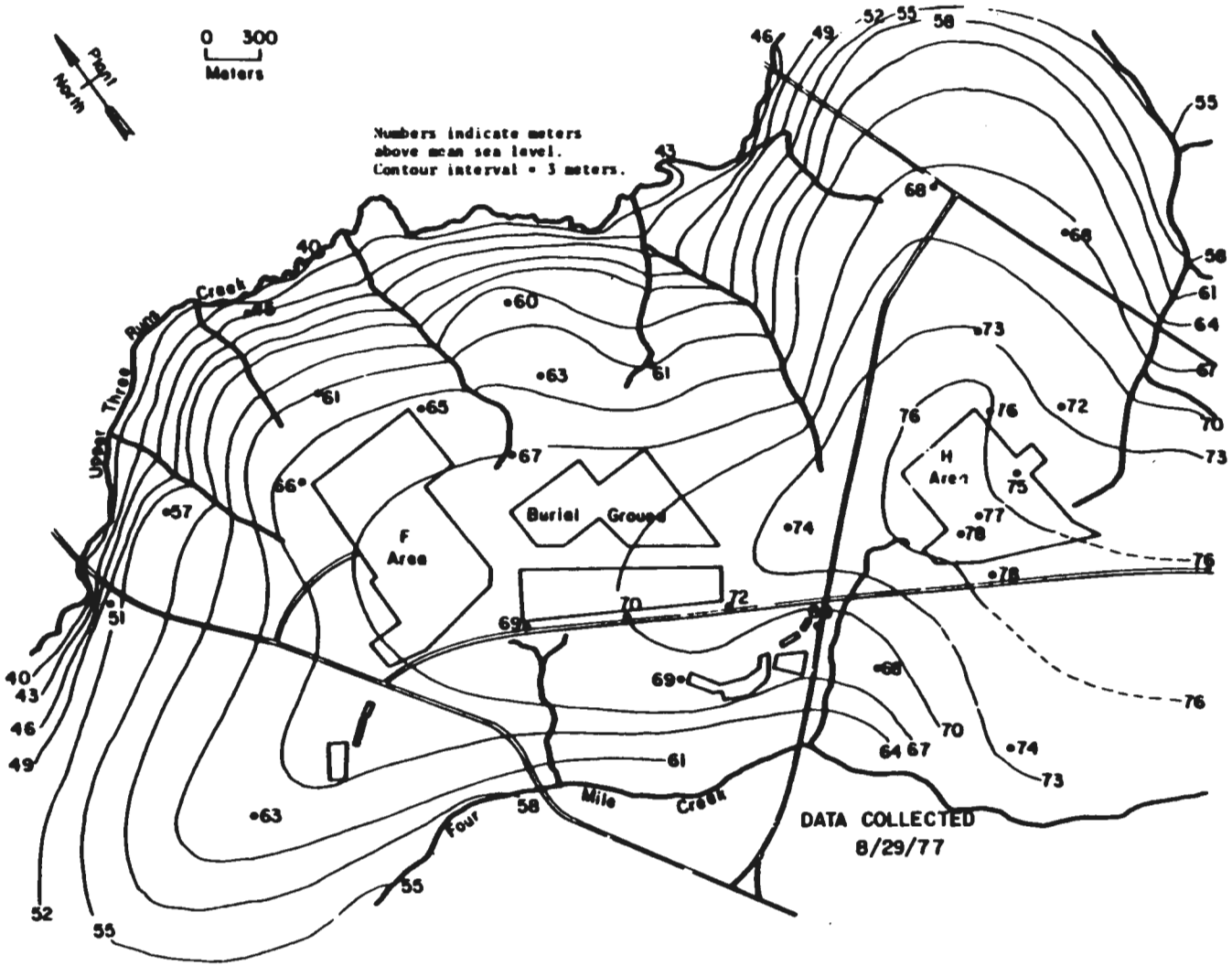

Figure A-24 Piezometric Surface of the Upper Part of the McBean Formation in the Separations Areas at SRP.

differential between the Barnwell and the McBean Formations is only about 12 ft (Figure A-6) 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 A-8) 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 A-24), the average horizontal velocity of calculated to be:

$$V = \frac{IK}{n_e} = \frac{365 \text{ days/yr} \times 0.017 \text{ ft/ft} \times 0.4 \text{ ft/day}}{0.20} = 12.4 \text{ ft/yr}$$

Assuming the same gradient as for the Upper McBean, the regional ground water velocity in the calcareous zone is calculated to be:

$$V = \frac{IK}{n_e} = \frac{365 \text{ days/yr} \times 0.017 \text{ ft/ft} \times 0.23 \text{ ft/day}}{0.20} = 7.1 \text{ ft/yr}$$

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 on 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.

Water Quality

Samples of water from Eocene sand and Eocene limestone probably include some water from both the upper sand unit and the calcareous subunits of the McBean Formation. The median and range of chemical analyses are listed in Table A-5. 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 A-6. 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 os generally less than 5.

A.2.2.7 Barnwell Formation

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 at 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 ground water 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 unit 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.

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 A-23. The median conductivity was 1.0 gpd/ft^2 for the clayey sand unit (Table A-8 and Figure A-16). Although no pumping tests were made on the silty sand unit (Table A-8), 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 hese levels to those in the formations below, are shown in Figures A-6 and A-17. The variations of water levels in the Barnwell over a period of five years are shown in Figure A-18. 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 A-17). A map of the elevation of the water table is shown in Figure A-25. 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 ground water flow towards them.

Figures A-6 and A-17 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 of 1.0 gpd/ft^2 (Table A-8) and an effective porosity of 20%, the velocity through Barnwell material is calculated to be:

$$V = \frac{IK}{n_e} = \frac{365 \text{ days/yr} \times 0.018 \text{ ft/ft} \times 0.13 \text{ ft/day}}{0.20} = 4.3 \text{ ft/yr}$$

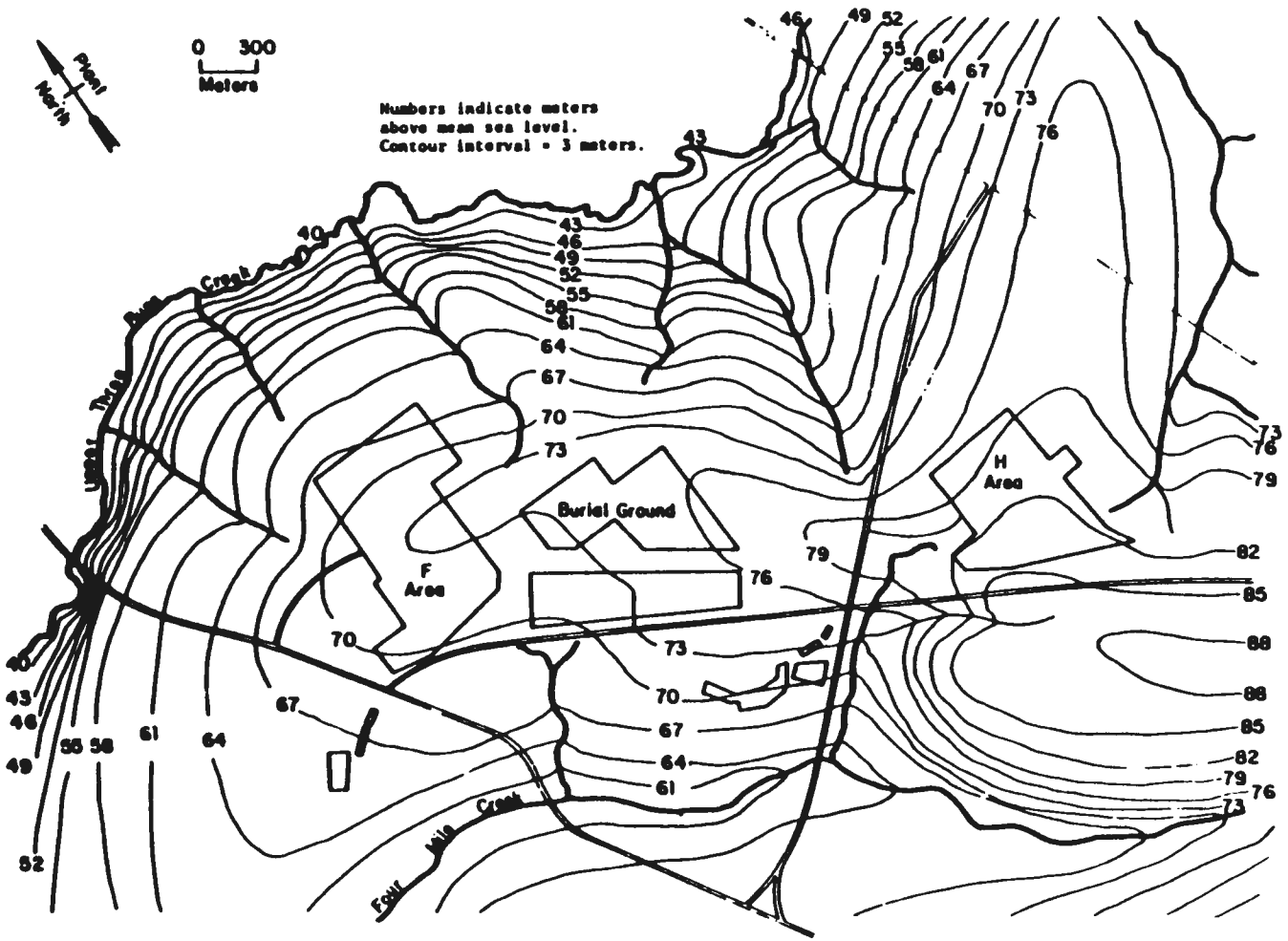

Figure A-25 Average Elevation of the Water Table in the Separations Areas at SRP During 1968.

If a sand lens with a hydraulic conductivity of 7.4 gpd/ft^2 (Table A-8) 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 fy/yr.

Natural discharge from the water table, which is predominatly 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 A-25.

The Barnwell Formation supplies water for domestic purposes on 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.

Water Quality

Five analyses of water from the Barnwell Formation in the separations areas are given in Table A-6. 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 formation in the area.

A.2.2.8 Hawthorn Formation

Hydrostratigraphy

The Hawthorn Formation crops out over a 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 on 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 shal+ resembling 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 koalinitic 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.

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 predominatly 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 os 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]

Water Quality

No water samples from the unsaturated zone have been analyzed.

A.2.2.9 Surficial Formations

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 ground water for wells. Nevertheless, they are fairly permeable, and are capable of storing and transmitting water. Their presence therefore enhances recharge to underlying formations.

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.

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 ground water development except along the larger streams where infiltration galleries might be possible.

A.2.3 Hydrologic Interrelationships at SRP

Although a number of hydrologic interrelationships among the various hydrologic units at SRP have been discussed in the previous section describing the hydrostratigraphic units, the purpose of this section is to summarize and amplify these relationships.

Precipitation at the Savannah River Plant averages about 48 inches per year with a maximum of 73.5 inches in 1965 and a minimum of 28.8 in 1954. Although there may be both spatial and temporal variations in the fraction of this precipitation that recharges the ground water, the overall average is about 30%, or 15 inches per year. This average will vary due to variations on 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 unstaurated zone at a rate of 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.[29] 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 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 A-6 shows the head relationship of the various hydrostratigraphic units in H Area, and Figure A-17 shows how these relationships change towards Upper Three Runs Creek. The water table in H Area is high because the "Tan Clay" inhibits the downward movement of water and the low 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 horizontal and vertical components. The water recharging this formation through the "Tan Clay" is the nominal surface recharge (15 inches per year) minus the amount of water that is removed from the Barnwell Formation by lateral flow. The discharge points for the McBean Formation are more distant from their respective ground water 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 level in the Congaree much lower than those above, as shown in Figures A-6 and A-17. The discharge areas for the Congaree are the valleys of the Savannah River and Upper Three Runs Creek. Even though the 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 A-6) 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 the SRP (Figure A-8). Water is discharged from the "Tuscaloosa" upward into the overlying sediments in the Savannah River Valley. This relationship is shown on Figure A-26 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 A-13 shows the vertical head relationships between the Congaree water level and higher "Tuscaloosa" water 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 A-14. 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

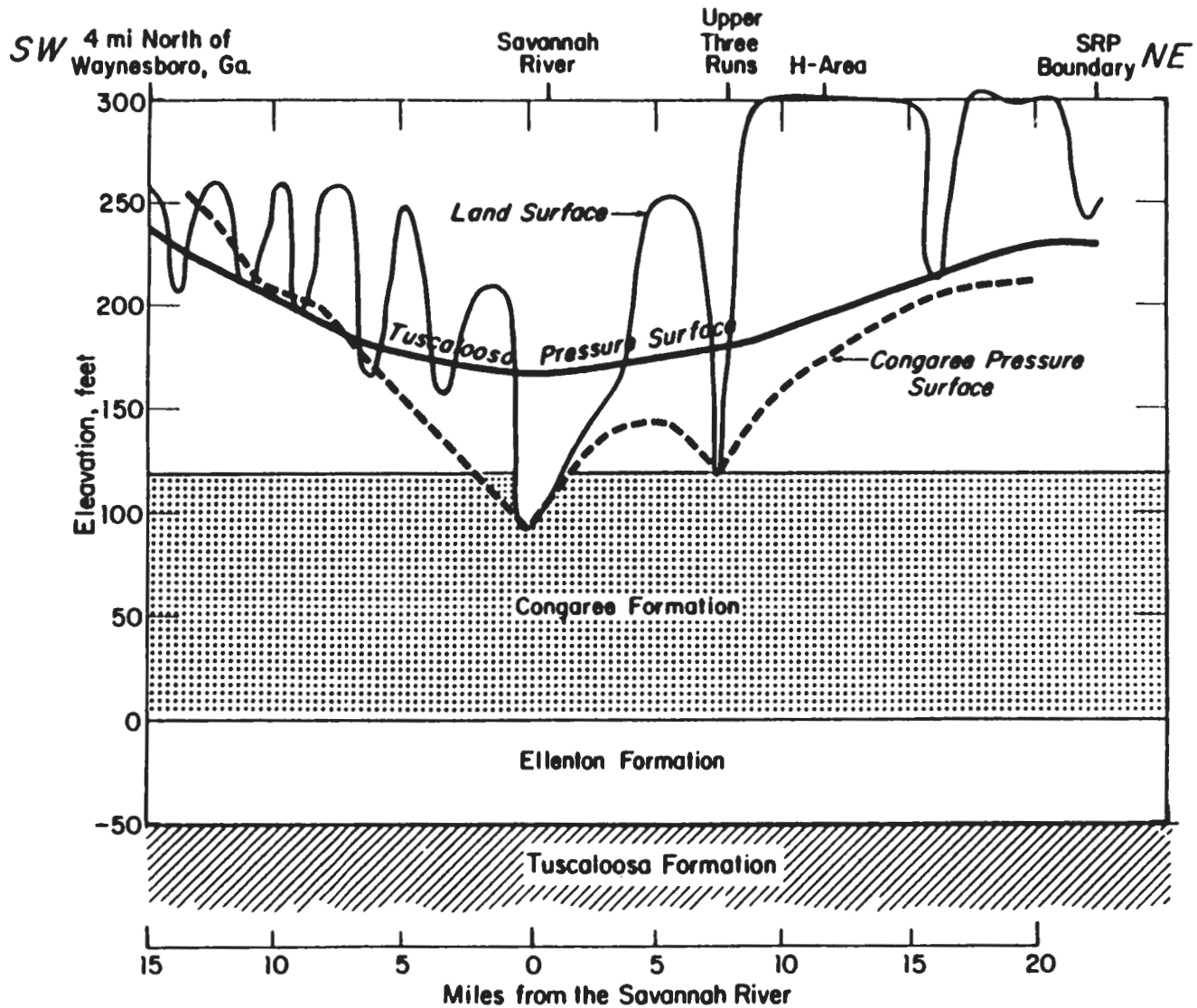

Figure A-26 Hydrologic Section Perpendicular to the Savannah River Through H Area.[3,20]

Tertiary sediments. Thus, 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 A-27).

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 A-4. 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 head reversal between the Congaree and the "Tuscaloosa" Formations and areas where there is not, may be obtained by constructing a map showing the difference between the "Tuscaloosa" piezometric map (Figure A-12) and the Congaree piezometric map (Figure A-20). This head difference map (Figure A-28) shows that the head in the "Tuscaloosa" is higher than the head in the Congaree in a broad area within about 4 miles 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 surface for which the control is somewhat sparse. Thus it should not be used to predict detailed head relationships, but only to indicate directions of expected vertical gradient in general areas.

A.3 DEMOGRAPHY

All of the candidate site are located within a few miles of the Defense Waste Processing Facility (DWPF). Therefore, the population data developed for the DWPF can be applied to the new radioactive waste disposal/storage facility with only minor adjustments.[30]

In 1970, there were 21 urban centers with populations of more than 2500 persons within a 50-mile radius of SRP (Table A-9). Augusta, Georgia, is the only urban center in that radius with more than 25,000 persons. Four centers had populations between 10,000 and 25,000.

A.3.1 Estimation of Population Distribution

Population data were developed for geographical divisions formed by subdividing the 50-mile radius circle of the SRP site into 22.5 degree compass-sector segments as shown on Figure A-29. The 1970 population distribution by compass sector segments is given in

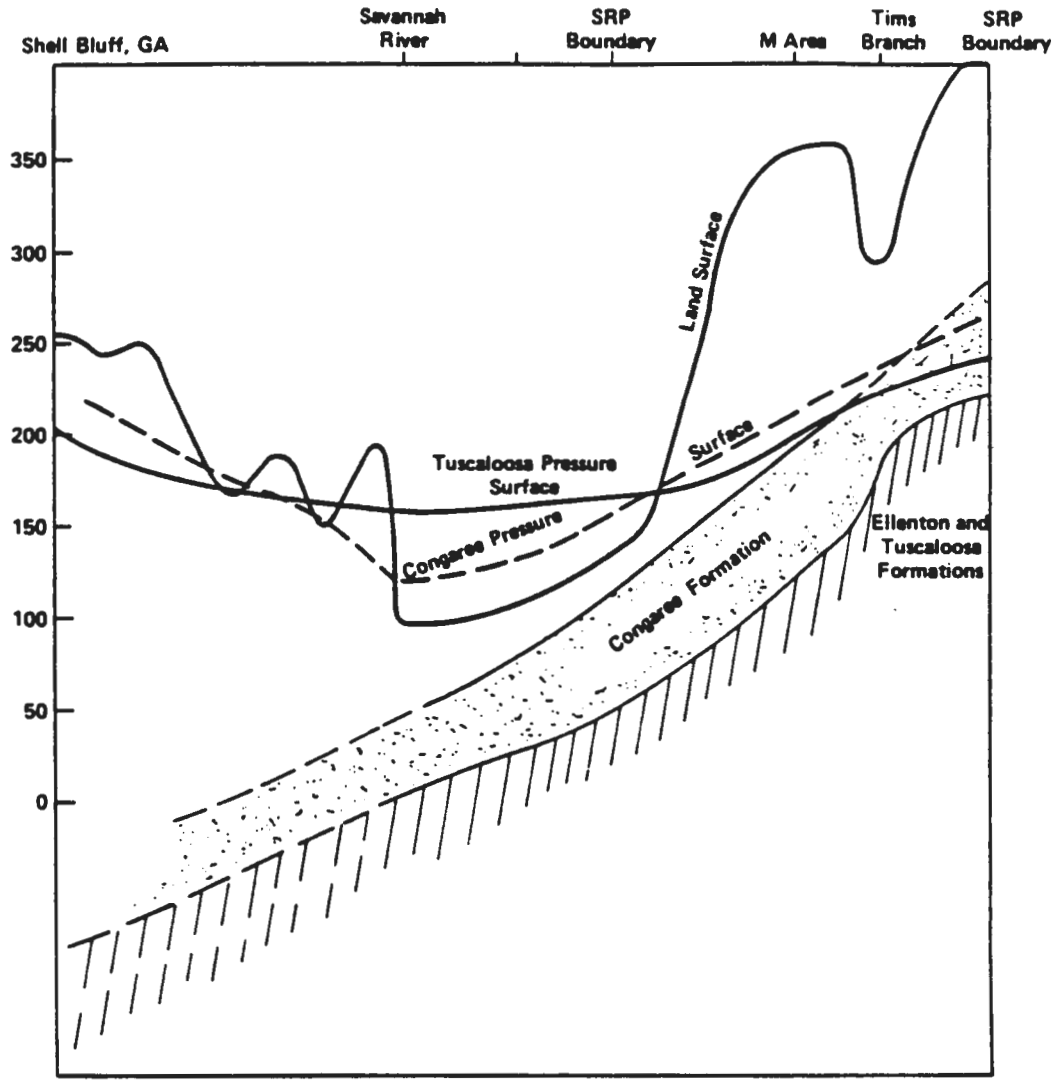

Figure A-27 Hydrologic Section Perdendicular to the Savannah River Through M Area.[3,20]

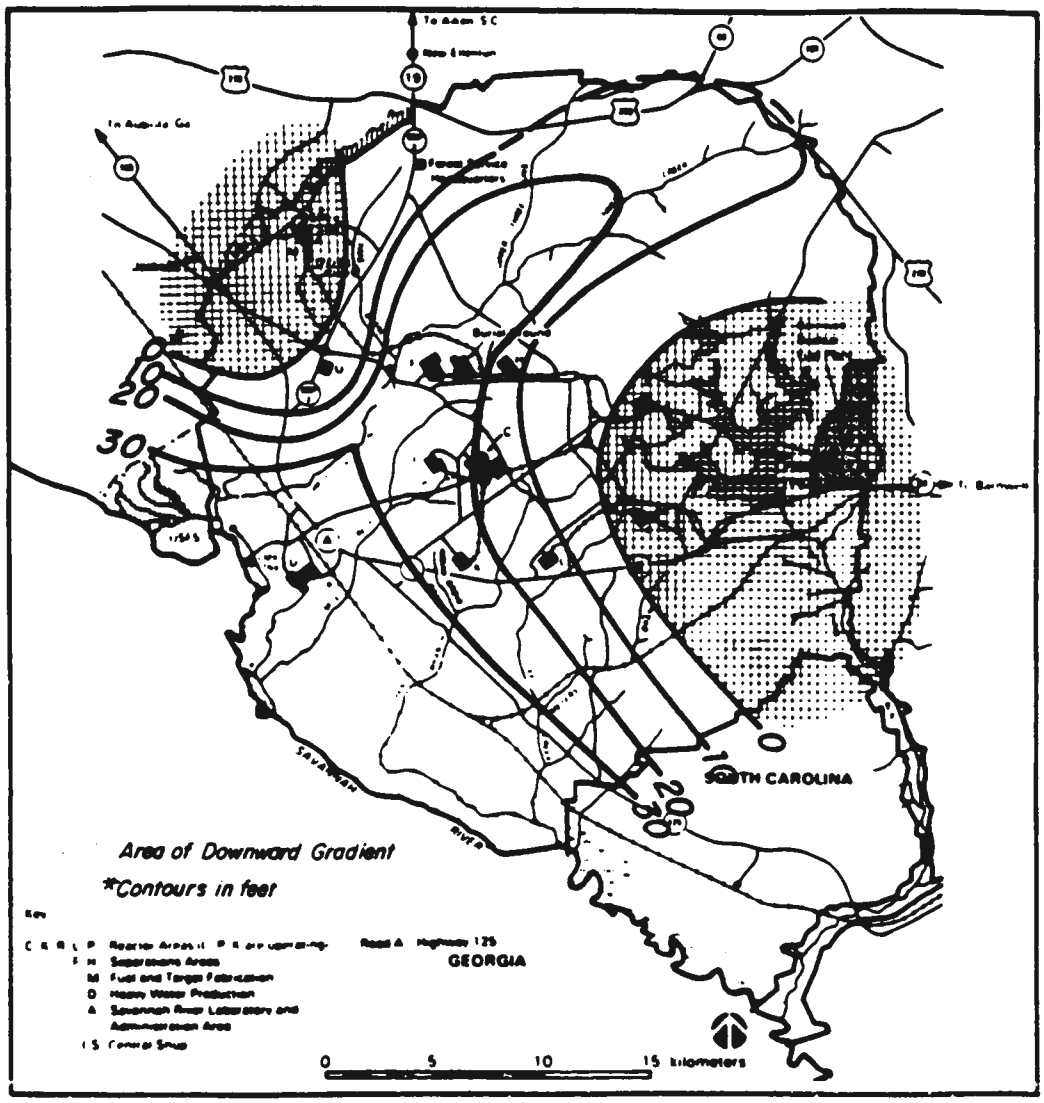

Figure A-28 Head Difference Between the Tuscaloosa and Congaree Formations at SRP.

Table A-9 1970 Urban Centers (Population Greater than 2500) Within 50 Miles of SRP

Urban Center	County & State		Distance, Miles*	Sector	Population
Augusta**	Richmond	GA	20	WNW	59,864
Fort Gordon†	Richmond	GA	28	WNW	15,589
Aiken	Aiken	SC	16	NNW	13,436
Orangeburg	Orangeburg	SC	44	ENE	13,252
North Augusta	Aiken	SC	20	NW	12,883
Waynesboro	Burke	GA	25	WSW	5,530
Barnwell	Barnwell	SC	16	ESE	4,439
Batesburg	Lexington	SC	42	N	4,036
Millen	Jenkins	GA	37	SSW	3,713
Allendale	Allendale	SC	27	SE	3,620
Denmark	Bamberg	SC	28	E	3,406
Bamberg	Bamberg	SC	34	E	3,406
Sylvania	Screven	GA	37	S	3,199
Grovetown	Columbia	GA	33	WNW	3,169
Hampton	Hampton	SC	42	SE	2,845
Edgefield	Edgefield	SC	37	NNW	2,750
Louisville	Jefferson	GA	48	WSW	2,691
West Aiken††	Aiken	SC	20	NNW	2,689
Williston	Barnwell	SC	14	ENE	2,594
Johnston	Edgefield	SC	38	NNW	2,552
New Ellenton	Aiken	SC	8.3	NNW	2,546

* Approximate distance from the center of SRP to the nearest edge of urban center.

** Central city of an urbanized area (Augusta, GA-SC; population 148,953).

† U.S. Military reservation.

†† Unincorporated community.

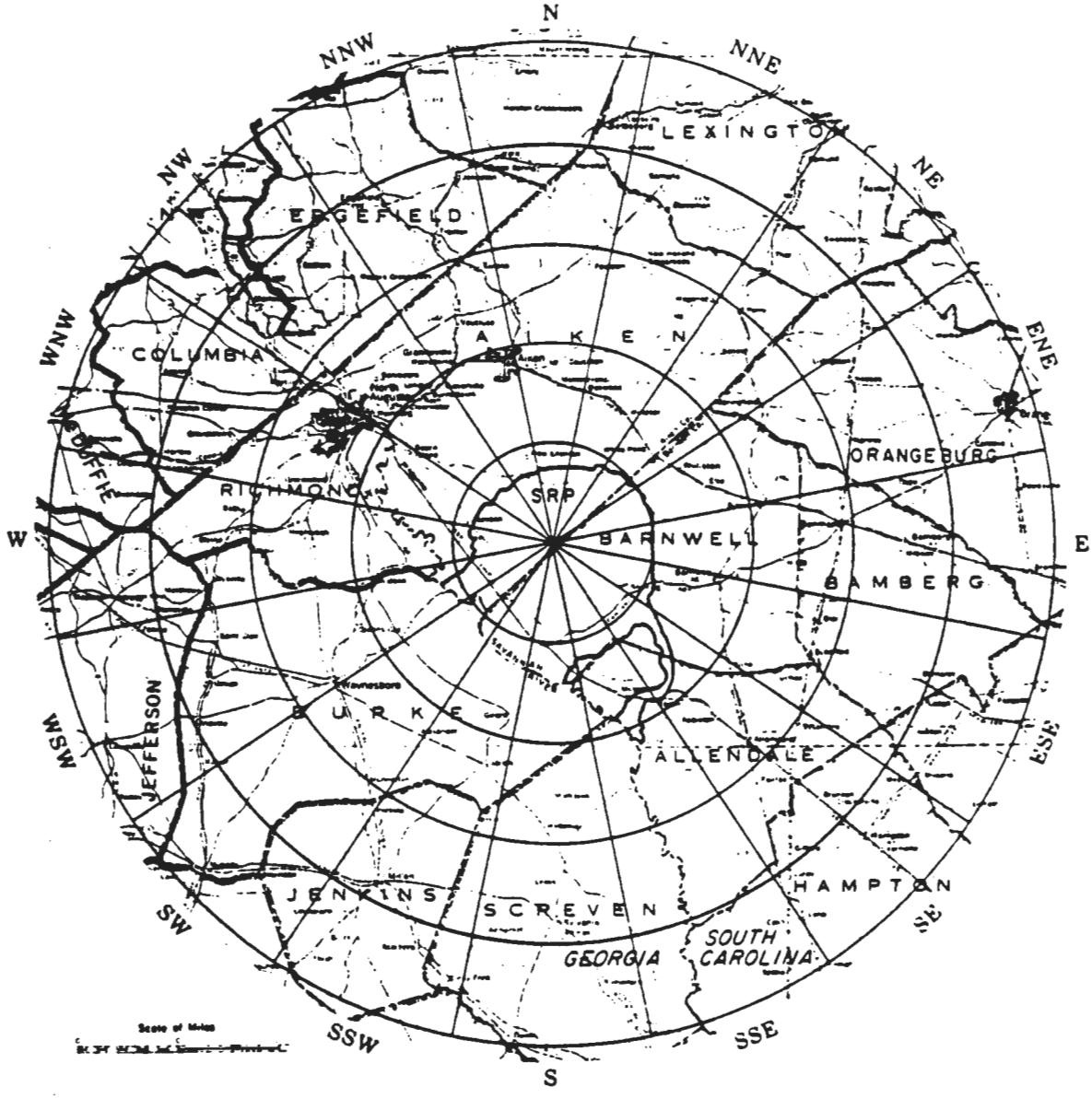

Figure A-29 Fifty-Mile Vicinity of SRP Site.

Table A-10. Projected distributions for 1980 through 2020 are given in Tables A-11 through A-15. The source of the basic data and the method used to develop population data for 1970 and to project population data are described in References 30-34.

A.3.2 Residential Population

The residential population within 50 miles of the site was estimated to be 553,000 in 1980. More than 50% of the population is in the Augusta, Georgia - South Carolina Standard Metropolitan Statistical Area (SMSA) which includes Richmond and Columbia Counties, Georgia, and Aiken County, South Carolina.

Between 1980 and 2020, the residential population is projected to increase from 553,000 to 845,000 (153%). The cities of Aiken and North Augusta, South Carolina are expected to become major urban centers with populations over 25,000. No other major urban centers are expected to develop in this period.

The estimated distribution of age groups in the 50-mile population is shown in Table A-16 for each of the decennial years (1980-2020).[34] The percent distribution projected remains fairly constant during the period.

SRP is closed to the public except for permitted transients. The residential population cannot get closer than about five miles from the new radioactive waste disposal/storage facility.

A.3.3 Industrial Population

The industrial population within ten miles of candidate sites consists almost entirely of the SRP work force (approximately 9180 daily transients). The Alvin W. Vogtle Nuclear Plant currently has 3420 construction workers and another 300 people make up the work force at Chem-Nuclear Systems, Inc. Table A-17 shows the industrial population with ten miles of the candidate sites as of April, 1981 (see Figure A-30 for locations). These workers are on the plantsite about 36 hours per week with approximately 80% of them working Monday through Friday from about 8:00 a.m. until 4 p.m.[30]

The SRP work force is expected to increase by up to 5000 additional construction personnel from about 1983 through 1989 because of construction of the DWPF. Therefore, in the mid-1980's, the SRP work force could be near 12,600, decreasing to 8500 in the mid-1990's. The work force at Vogtle is expected to increase to over 5000 by the end of 1985. The work force at Chem-Nuclear Systems, Inc. is assumed to remain at its present level in the 1980's.

Table A-10 1970 Population Distribution Within Fifty Miles of the Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	25214	0	823	3076	4037	4923	12355
NNE	11161	0	39	614	1631	2168	6709
NE	14318	0	162	710	3081	4797	5568
ENE	44348	0	18	4695	3572	5494	30569
E	21159	0	0	2230	8043	4193	6693
ESE	13607	0	0	4038	3399	2973	3197
SE	17165	0	0	315	5041	4159	7650
SSE	5932	0	0	552	863	432	4085
S	11528	0	0	878	1322	6044	3284
SSW	10600	0	0	217	2047	5714	2622
SW	8284	0	0	479	3420	1907	2478
WSW	12734	0	0	392	4939	1576	5827
W	17940	0	241	1383	5362	2301	8653
WNW	173798	0	2225	3131	130159	31734	6549
NW	49644	0	617	8404	35527	3487	1609
NNW	46837	0	2309	22327	9407	9510	3284
Total	484,269	0	6434	53,441	221,850	91,412	111,132

Table A-11 Projected 1980 Population Distribution Within Fifty Miles of Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	28200	0	950	3550	4650	5500	13500
NNE	15000	0	44	710	1900	2800	9500
NE	17300	0	185	790	3400	5700	7200
ENE	45700	0	18	4800	3650	5700	31500
E	21700	0	0	2300	8200	4250	6900
ESE	13900	0	0	4150	3500	3000	3250
SE	17000	0	0	325	5200	4150	7300
SSE	5690	0	0	560	850	425	3850
S	10800	0	0	850	1250	5600	3050
SSW	10300	0	0	205	1950	5500	2600
SW	7900	0	0	450	3200	1800	2450
WSW	12400	0	0	380	4650	1500	5800
W	19700	0	275	1650	6300	2550	8900
WNW	219000	0	2550	3750	159000	44500	8700
NW	56400	0	710	9700	40500	3750	1700
NNW	52900	0	2650	26000	11000	9800	3400
Total	553,000	0	7400	61,000	260,000	107,000	120,000

Table A-12 Projected 1990 Population Distribution Within Fifty Miles of Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	31200	0	1050	3900	5100	6100	15000
NNE	17700	0	49	780	2100	3250	11500
NE	19500	0	200	870	3700	6400	8300
ENE	48100	0	19	5100	3900	6000	33000
E	23000	0	0	2450	8700	4500	7300
ESE	14600	0	0	4350	3700	3200	3350
SE	17700	0	0	340	5500	4300	7500
SSE	5860	0	0	590	880	440	3950
S	10800	0	0	830	1200	5600	3100
SSW	9800	0	0	200	1850	5200	2550
SW	7530	0	0	430	3000	1700	2400
WSW	12100	0	0	375	4350	1450	5900
W	21100	0	305	1850	6800	2700	9400
WNW	249000	0	2850	4100	175000	56000	11000
NW	62900	0	780	11000	45000	4200	1900
NNW	58100	0	2950	28500	12000	11000	3650
Total	609,000	0	8300	66,000	283,000	123,000	130,000

Table A-13 Projected 2000 Population Distribution Within Fifty Miles of Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	34900	0	1200	4450	5900	6800	16500
NNE	21200	0	56	890	2350	3900	14000
NE	22700	0	225	970	4150	7400	9900
ENE	51500	0	20	5400	4100	6400	35500
E	24200	0	0	2550	9100	4800	7700
ESE	15300	0	0	4600	3900	3350	3450
SE	18500	0	0	360	5800	4500	7800
SSE	6020	0	0	610	910	450	4050
S	10900	0	0	860	1250	5600	3150
SSW	10400	0	0	210	1900	5500	2750
SW	7840	0	0	440	3100	1800	2500
WSW	12500	0	0	395	4500	1450	6100
W	22800	0	350	2050	7500	2950	9900
WNW	285000	0	3200	4600	197000	67000	12500
NW	71000	0	890	12500	51000	4600	2000
NNW	64800	0	3350	32500	13500	11500	3900
Total	679,000	0	9300	74,000	316,000	138,000	142,000

Table A-14 Projected 2010 Population Distribution Within Fifty Miles of Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	38700	0	1350	5100	6700	7500	18000
NNE	24900	0	63	1050	2700	4500	16500
NE	25900	0	255	1100	4650	8300	11500
ENE	55000	0	21	5700	4350	6900	38000
E	25700	0	0	2700	9600	5100	8300
ESE	16000	0	0	4850	4050	3500	3550
SE	19100	0	0	375	6000	4650	8000
SSE	6260	0	0	640	950	470	4200
S	11400	0	0	910	1300	5800	3300
SSW	10600	0	0	220	2000	5500	2850
SW	8220	0	0	470	3300	1850	2600
WSW	13100	0	0	425	4800	1550	6300
W	24900	0	395	2300	8400	3250	10500
WNW	325000	0	3650	5200	221000	80000	15000
NW	79200	0	1050	14000	57000	5000	2150
NNW	71900	0	3800	37000	15000	12000	4100
Total	756,000	0	11,000	83,000	352,000	156,000	155,000

Table A-15 Projected 2020 Population Distribution Within Fifty Miles of the Site

Total Population by Sector		Miles from SRP Site 0-5	5-10	10-20	20-30	30-40	40-50
N	42900	0	1550	5800	7600	8400	19500
NNE	28500	0	72	1150	3050	5200	19000
NE	29200	0	285	1250	5200	9400	13000
ENE	58700	0	23	6100	4650	7400	40500
E	27600	0	0	2900	10500	5400	8800
ESE	16900	0	0	5200	4350	3700	3650
SE	20100	0	0	405	6500	4950	8200
SSE	6940	0	0	690	1000	495	4300
S	11500	0	0	970	1300	5800	3400
SSW	10800	0	0	235	2050	5500	2950
SW	8650	0	0	495	3500	1950	2700
WSW	13800	0	0	460	5100	1650	6500
W	27400	0	450	2550	9300	3550	11500
WNW	372000	0	4150	5800	248000	96000	18000
NW	90100	0	1150	16000	65000	5600	2350
NNW	80800	0	4350	42000	17000	13000	4400
Total	845000	0	12,500	93,000	395,000	178,000	169,000

Table A-16 Relative Distribution of Age Groups in Fifty-Mile Population

Year	Percent of Population: Infants and Children, 0 to 11 years	Teenagers, 11 to 17 years	Adults, 17 years and older
1980	18.6	11.1	70.3
1990	22.7	9.0	68.3
2000	20.8	11.8	67.4
2010	20.9	10.5	68.6
2020	21.9	10.9	67.2
Average, 1990 to 2020*	21.3	10.8	67.9

* Thirty-year population-weighted average, assuming population changes linearly between decennial years (Tables 2.2-4 through 2.2-7).

Table A-17 Industrial Population Within Ten Miles of Central SRP.

Operating Area at U.S. Department of Energy, Savannah River Plant	Daily Transients**	Distance from L Area Miles	Direction
A, M, SREL***	3025	11.2	NNW
H	1350	5.5	N
F	1290	6.2	NNW
D	480	6.9	W
Central Shops	450	3.2	NNW
C	400	4.1	NW
P	385	2.8	ENE
K	340	2.3	W
CMX-TNX	245	8.4	W
L	235	-	-
TC-1, U	105	8.2	NW
Railroad Yard	35	4.3	ENE
Forest Service****	25	11.2	NNW
Burial Ground	10	5.8	NNW
General†	805	-	-
Total	9180		
Vogtle††	3420	9.6	WSW
Allied-General Nuclear Services Barnwell Nuclear Fuel Plant	350	9.0	ENE
Chem-Nuclear System, Inc.†††	110	9.5	ENE

* Data as of April 1981 except as noted.

** Personnel nominally at work 8 hours per day, 5 days per week.

*** Outside the ten-mile radius but included because of the large population.

**** Headquarters is outside the ten-mile radius, but workers are included because employees work inside the ten-mile radius a large portion of the time.

† Includes (1) permanent employees and co-ops who work at various SRP locations
(2) about 95 daily visitors
(3) an estimated calendar year average of 175 subcontractor employees cutting and removing timber who nominally work a 4-day week.

†† As of January 1981.

††† As of January 1980.

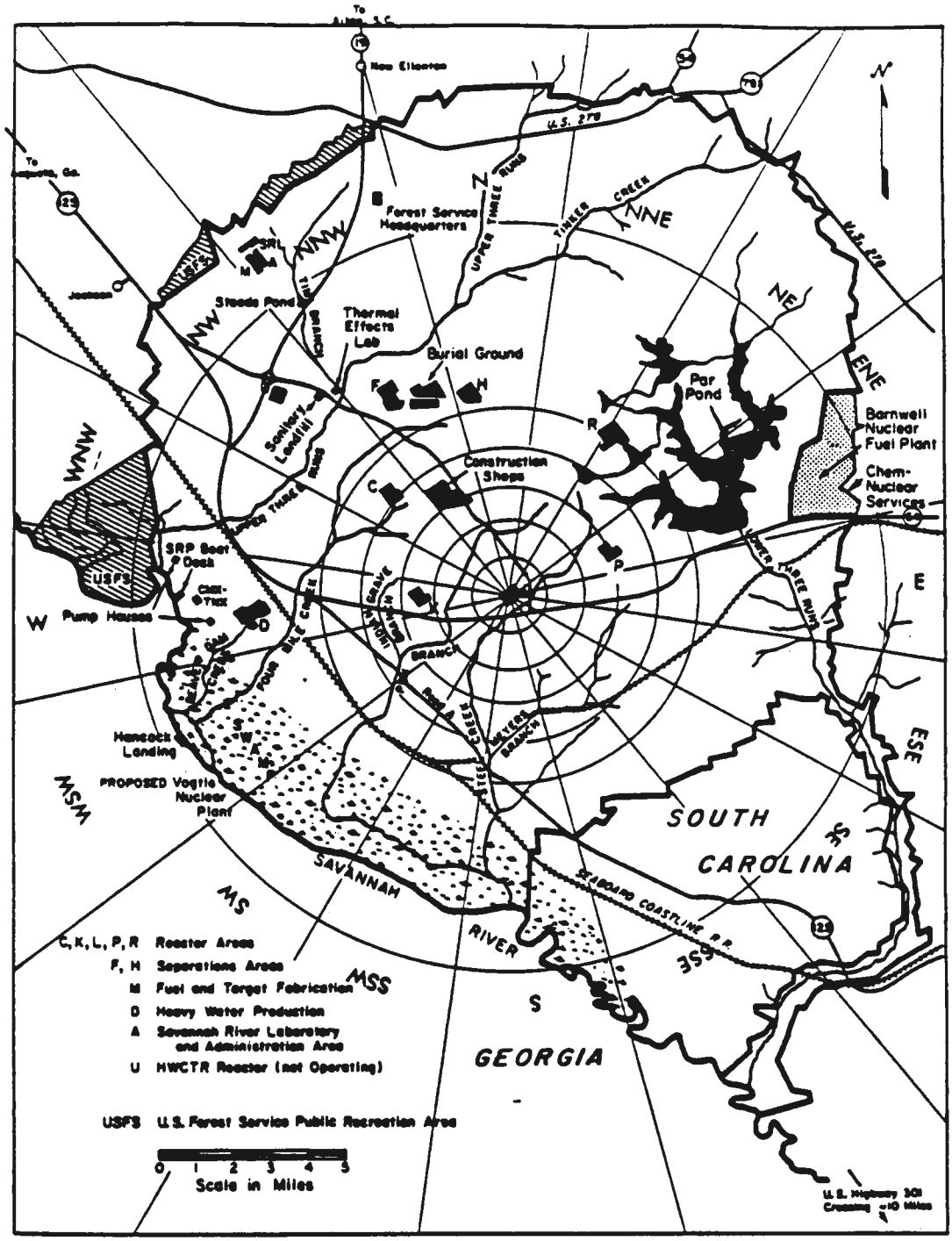

Figure A-30 Ten-Mile Vicinity of L Area.

A.3.4 Recreation and Transient Population

Recreational hunting and camping account for about 10,000 visitor-days within a 15-mile radius of of thecandidate sites. Travellers crossing SRP on U.S. Route 278 and S.C. Route 125 and on the Seaboard Coast Line Railroad add about 20,800 person-days to the 10-mile transient population.

There are no schools, military reservations, hospitals, prisons, or airports within the 10-mile radius.

A.4 LAND USE

A.4.1 SRP Land Use

The SRP industrial and support facilities use less than 5% of the 192,000 acres of SRP. An additional 200 acres will be used by the DWPF. About 900 acres are reserved for research sites and/or natural areas, while reservoirs and ponds occupy another 3000 acres. The remainder of SRP is managed by the U.S. Forest Service under a cooperative agreement with the department of Energy (DOE). As of 1980, over 107 million pine seedlings had been planted, and 48 million board-feet of timber and over 636,000 cords of pulp wood had been harvested.

The candidate sites are is located neart the geographic center of SRP and will occupy about 200 - 300 acres.

A.4.2 Other Nearby Land Use

Two nuclear facilities are either under construction or in use adjacent to SRP (Figure A-31). The Alvin W. Vogtle Nuclear Plant is being constructed by the Georgia Power Company on the Savannah River southwest of SRP. Chem-Nuclear Systems, Inc. operates a low-level radioactive waste disposal facility east of SRP. Carolina Metals, Inc. operates a plant at a site east of SRP.

Other industrial, commercial, and agricultural activities in the counties surrounding SRP have been described previously.[1]

A.5 WATER USES

A.5.1 Surface Water

The Savannah River forms the boundary between Georgia and South Carolina (Figure A-31). Upstream of SRP the river supplies water for Augusta, Georgia and North Augusta, South Carolina. It also receives treated waste water from these cities and Horse Creek Valley (Aiken County, South Carolina).[35,36] It also, until recently, provided a channel for barge traffic between Savannah, Georgia and Augusta, Georgia.

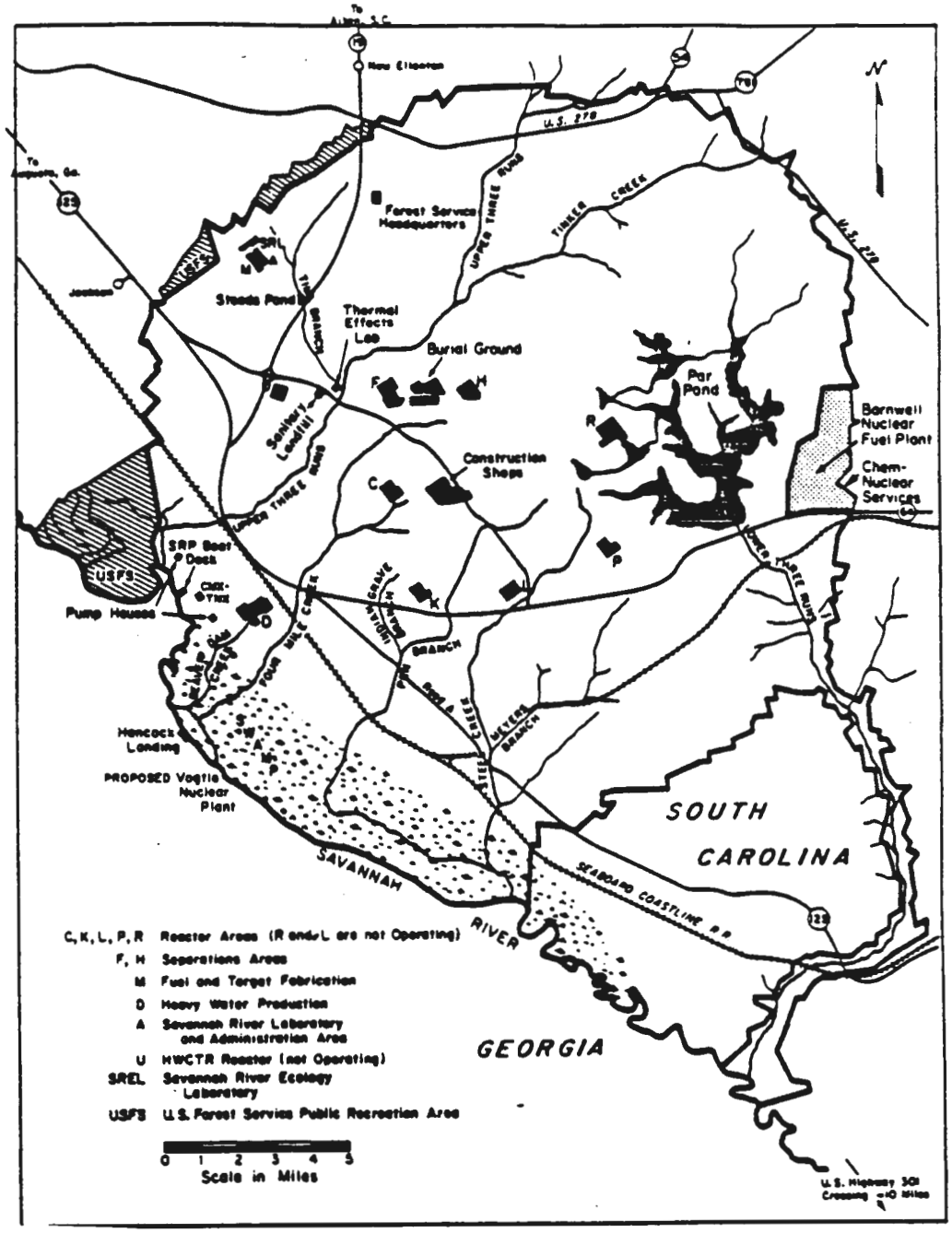

Figure A-31 The Savannah River Plant Site.

At SRP, the river supplies water for cooling the production reactors and for use in the coal-fired power plants.[8,30] SRP effluents and waste water are discharged into the tributaries which flow across the SRP site to the Savannah River.

A.5.1.1 Domestic Use

Downstream from SRP, the Beaufort-Jasper Water Authority in South Carolina withdraws about 5.2 million gallons per day to supply domestic water for a population of about 51,000 (Table A-18). The Cherokee Hill Water Treatment Plant at Port Wentworth, Georgia, withdraws about 45 million gallons per day from the river to supply a business-industrial complex near Savannah which has an estimated consumer population of about 20,000 (Table A-19).

A.5.1.2 Fisheries

Commercial fisheries in South Carolina and Georgia are important to the economy of the coastal regions of both states. Fishermen in the two states earned about 29 million dollars in 1978.[1] Shad, shrimp, blue crabs and oysters are the most important cash species. Table A-20 lists the species and catches of fish from the Savannah River for 1970-1979. Table A-21 lists the total weight of shellfish caught in the Savannah River and its environs near the Atlantic Coast for the years 1972-1979. Figures A-32 through A-34 summarize the commercial catches of American shad for South Carolina, Georgia, and the Savannah River.

A.5.1.3 Miscellaneous Use

Recreational uses if the Savannah River are mostly upstream of SRP near Augusta or downstream of SRP near the coast. Recreational activities include sport fishing and limited water contact activities such as swimming or skiing. No uses of the Savannah River for irrigation have been identified in either South Carolina of Georgia.[1] A recent aerial survey of land for one mile on each side of the Savannah River downstream from SRP showed that about 100 beef cattle have free access to the river.

A.5.1.4 Savannah River Plant

The Savannah River Plant is a major user of surface water from the Savannah River presently with the capacity to remove 3.6 million cubic meters of water a day (1470 cfs, 41.6m^3 per second) (Table A-22). This water is used primarily for cooling C and K Reactors and to provide makeup cooling water for Par Pond and P Reactor.

Under the worst conditions, the removal of the full 41.6 m^3 per second would consume about 25% of the usual minimum flow of 170 m^3 per second (6100 cfs) at SRP.[38] During 1974-1976, the maximum fraction of river discharge which was withdrawn for cooling water was 12%. The average amount withdrawn for the same period was about 7% of the average river discharge.

Table A-18 Beaufort - Jasper Water Authority

Water Treatment Capacity: 8 million gal/day
Average use: 5.2 million gal/day

South Carolina population served:

Group	Population
Beaufort-Port Royal	18,000
Navy Installations	23,000
Rural Areas	10,000
Total	51,000

Year	Million gal/day	Month in 1980	Million gal/day
1970	4.45	January	4.65
1971	4.41	February	4.43
1972	4.83	March	4.53
1973	5.57	April	4.38
1974	4.73	May	4.83
1975	4.66	June	6.19
1976	4.50	July	6.24
1977	4.85	August	6.10
1978	4.74	September	6.74
1979	4.99	October	5.32
1980	5.25	November	4.99
		December	4.42

Table A-19 Use of Water from Cherokee Hill Water Treatment Plant

Water Treatment Capacity: 45 million gal/day

Customers (Primarily Industrial)	Million gal/day
Continental Can Corp. (paper plant)	8.9
Union Camp (paper plant)	13.1
American Cyanamid	6.2
Kaiser Agricultural Chemical Co.	1.3
Savannah Electric Co.	0.11
American Oil Co.	0.10
Georgia Port Authority*	0.072
Coca Cola Bottling Co.**	0.043
Royal Crown Cola Bottling Co.**	0.011
Atlantic Creosoting Co.	0.041
Savannah Sugar Refinery	0.79
Continental Roofing Co.	0.022
Johns Mansville Co.	0.022
Chevron Oil Co.	0.022
Koppers Co.	0.015
Hubson Battery Mfg. Co.	0.003
St. Regis Paper Co.	0.00028
Allied Chem. Co. - Indust. Chem. Div.	0.00017
Total	30.8

Estimated Number of Customers	Persons
Industrial Workers	1,000
Seamen (effective man-year users)	2,000*
Beverages (effective man-year users)	17,000**
Total	20,000

* Fresh water for ships entering Savannah Harbor. Assumes 1% of water delivered is consumed by crewmen.

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

Table A-20 Commercial Catches of Fish from the Savannah River

Species	Combined Catches in Georgia and South Carolina, lb									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Carp	-	551	555	3,314	1,300	2,200	300	1,000	300	800
Catfish	1,200	347	489	1,142	1,600	4,000	2,300	2,300	800	2,300
Drum, Black	-	-	-	-	-	500	600	-	-	-
Drum, Red	-	-	-	-	100	0	400	1,100	300	-
Hickory Shad	700	846	641	1,598	200	500	200	300	400	200
Sea Trout (Spotted)	-	-	-	714	500	2,500	1,800	400	400	
American Shad	96,100	56,367	56,082	74,761	57,900	45,000	19,000	45,900	120,000	127,000
Sturgeon	1,600	50	4,337	1,215	300	100	800	1,900	1,000	500
Suckers	-	-	-	-	-	-	200	-	-	-
Eels, Common	-	-	-	-	-	200	-	100	-	100
Mullet	-	-	-	-	-	500	-	200	-	-
Striped Bass	1,800	1,621	2,234	2,361	-	-	-	-	-	-

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Table A-21 Commercial Catches of Shellfish from Coastal Environs of the Savannah River

Year	Shellfish Catch, lb*			
	Clams	Blue Crabs	Oysters	Shrimp
1972	-	924,800**	3,200*	255,600*
1973	1,900**	1,199,200**	6,300*	489,700*
1974	-	2,760,300††	15,000††	2,516,600††
1975	-	38,000†	7,600††	2,788,400††
1976	-	-	-	-
1977	-	140,000†	42,000††	1,380,700††
1978	4,100†	150,000†	-	1,612,600††
1979	1,000†	231,000†	20,000†	-

* References 1 and 9.
** Wassaw Sound plus Ossabaw Sound.
† Savannah River landings.
†† Northern District, Georgia.

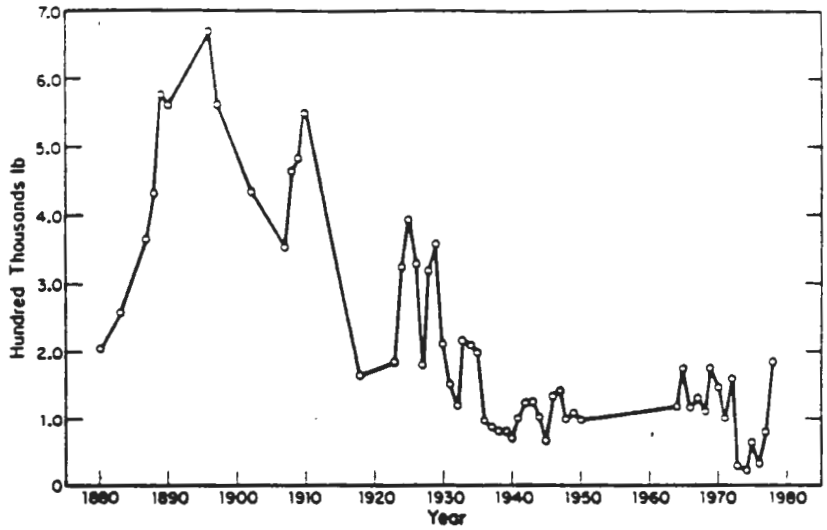

Figure A-32 American Shad Catches from the State of South Carolina, 1880 - 1980.

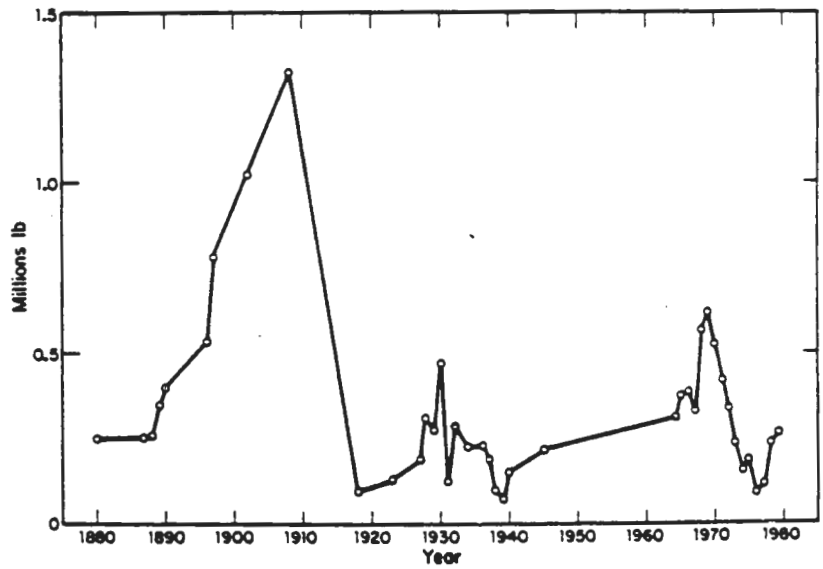

Figure A-33 American Shad Catches from the State of Georgia, 1880 - 1980.

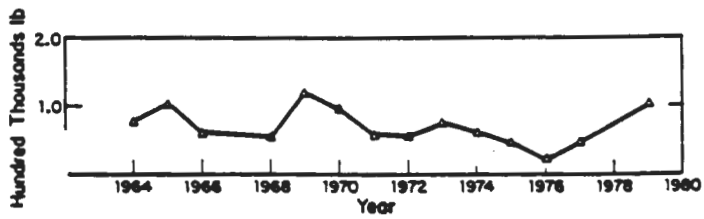

Figure A-34 American Shad Catches from the Savannah River, 1964 - 1979.

Table A-22 Present Savannah River Pumping Station Capacities

Pumping Station	No. of Pumps	Rated Pump Capacity, gal/min	Maximum Sustained Capacity m^3/sec	Maximum Sustained Capacity $m^3 \times 10^6$/day
1G	8*	32,500	16.4	1.4
3G	10	32,500	20.5	1.8
5G	6	12,500	4.7	0.4
		Total SRP capacity	41.6	3.6

* Two additional pumps will be placed in service before L-Reactor startup.

Figure A-35 shows the total maximum possible flow pumped from the river and the total reactor cooling water flow from 1954-1980. At present, C and K Reactors wach receive about 400 cfs cooling water flow from the river. Par Pond receives about 20 cfs to compensate for seepage and evaporation. After river water is used to cool C and K Reactors, it is discharged to Four Mile Creek and Pen Branch, respectively, which flow to the Savannah River.

A.5.2 Ground Water

A.5.2.1 Industrial Use of Ground Water

The most heavily used hydrological formation for industrial water supplies in the SRP area is the "Tuscaloosa" Formation. Ground water from the formation is used by SRP, J. M. Huber Corporation, Augusta Sand & Gravel Company, and the Sandoz Company in Allendale County (Table A-23).[30] Municipal usage is shown in Table A-24.[30]

In the future, additional water will be withdrawn from the "Tuscaloosa" Formation at and near SRP by the DWPF and the Alvin W. Vogtle Nuclear Plant in Georgia.

The maximum yield of the "Tuscaloosa" Formation in the southeast is estimated to be 19 x 10^6 m^3 per day without depleting the approximately 21-billion-acre feet of water in storage.[39] Hydrographs of the region show no effects from past and present withdrawals at SRP.[1] Future needs are apparently within the capacity of the "Tuscaloosa" Formation.[3,4,39-42]

A.5.2.2 Miscellaneous Use of Ground Water

Numerous small communities, mobile home parks, state parks, and small commercial interests use ground water near SRP. The wells are usually equipped with pumps which have capacities of .04 to 0.23 m^3 per minute and do not reach the "Tuscaloosa" Formation.

A.6 METEOROLOGY

Meteorological data needed to characterize atmospheric dispersion are wind speed and direction, horizontal and vertical wind direction variability, vertical termperature profiles, and vertical mixed depth. The data applicable to SRP are collected at primary sources at SRP and at Bush Field, Augusta, Georgia (Figure A-36). Wind measurements area made ar seven 61-meter meteorological towers at SRP and at the 335-meter WJBF-TV tower located near Beech Island, about 15 miles (25 kilometers) northwest of the center of SRP; temperature data are also collected at the WJBF tower.

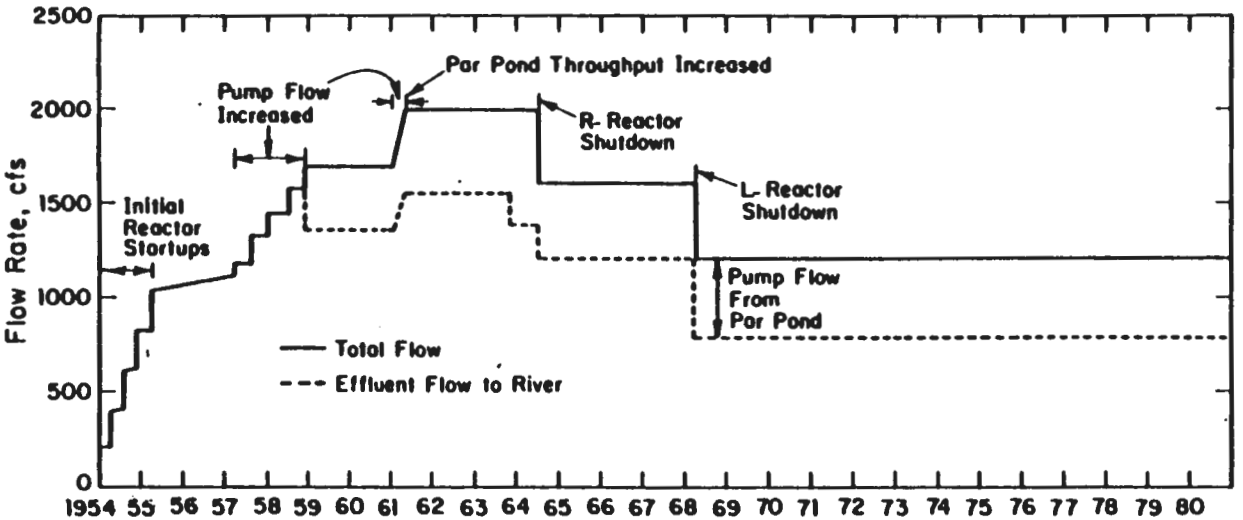

Figure A-35 Total Reactor Cooling Water Flow, 1954 - 1980.

Table A-23 Industrial Ground Water Use from the Tuscaloosa Formation at and in the Vicinity of SRP

User	Average Daily Use, m^3/day
Aiken County	
SRP A-Area	6,100
F-Area	6,800
H-Area	5,600
U-Area	19
Central Shops	4,100*
CMX-TNX	400*
Classification Yard	400*
U.S. Forest Service	**
Graniteville Co.	**
J. M. Huber Co.	8,400
Augusta Sand and Gravel	3,600
Cyprus Mines Corp.	1,400
Florida Steel Corp.	75
Valchem	400
Allendale County	
Sandoz Co., Inc.	11,000
Barnwell County	
E. T. Barwick, Inc.	950
Projected	
DWPF	4,000
Barnwell NFP	15,000†
A. W. Vogtle NPS	11,000†

* Pump capacity.
** Not available.
† Projected future pumpage.

Table A-24 Municipal Ground Water Use in the Vicinity of SRP

User	Average Daily Use, m^3/day	Water-Bearing Formation
Aiken County		
City of Aiken	7,600	Tuscaloosa
Town of Jackson	660	Tuscaloosa
Town of New Ellenton	1,100	Tuscaloosa
Town of Langley	490	Tuscaloosa
College Acres	250	Tuscaloosa
Bath Water District	1,200	Tuscaloosa
Beech Island	1,100	Tuscaloosa
Talatha	150	Tuscaloosa
Breezy Hill	880	Tuscaloosa
Burnettown	570	Tuscaloosa
Montmorenci	1,600	Tuscaloosa
Warrenville	550	
Johnstown	1,100	Tuscaloosa
Howlandville	380	Tuscaloosa
Gloverville	550	
Belvedere	1,400	Tuscaloosa
Barnwell County		
Barnwell	15,000	Congaree
Williston	2,700	McBean Tuscaloosa
Blackville	1,100	Tuscaloosa
Hilda	35	McBean
Elko	380	McBean
Burke County, Ga.		
Girard	75	Tuscaloosa

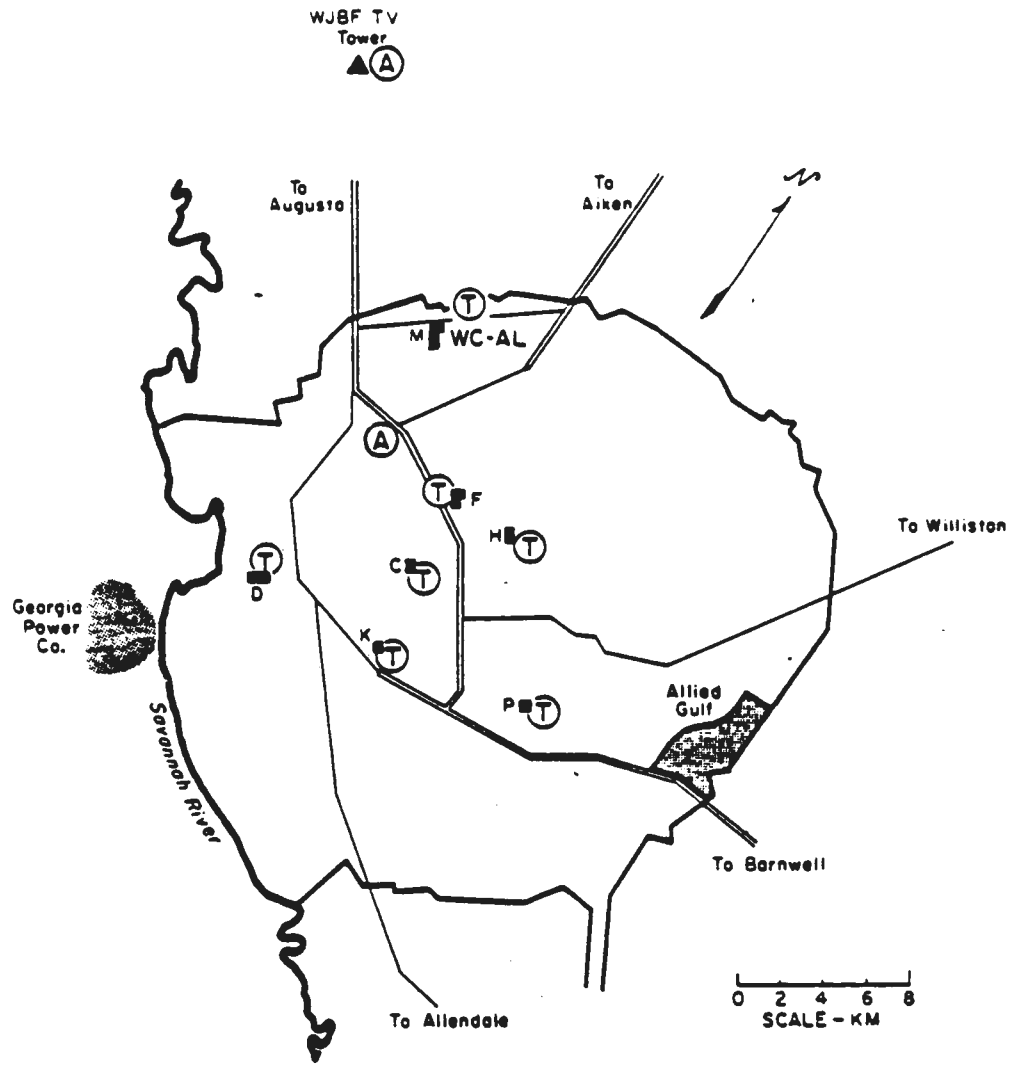

Figure A-36 SRP Site Map; T denotes 61 m tower; A Denotes Acoustic Sounder; WC-AL is the Weather Center Analysis Laboratory.

The closest National Weather Service Station is at Bush Field, west of SRP. Surface measurements at Bush Field are supplemented by a standard instrument shelter located in A Area at SRP, which records the following:

- Maximum and minimum temperatures
- Daily rainfall (also monitored at seven additional location at SRP)
- Continuous measurements of temperature, relative humidity, and pressure

A.6.1 Climatology

The climate in the SRP area is temperate with long summers and mild winters. The Blue Ridge Mountains to the north and northwest protect the area from the more severe winters occurring in the Tennessee Valley. The absence of extremes in temperature and precipitation prevents frost wedging, rapid erosion, and excessive drying of sediments. In general, weather changes proceed at a slow, uniform rate because of the moderate climate. A condensed description of the climate is given in Table A-25.[8,30,43]

A.6.2 Temperature and Humidity

The average annual SRP temperature is 64 ^{o}F with an average daily variation of 22 ^{o}F. Temperature averages and extremes at SRP from 1961 to 1076 are shown in Table A-26, and a summary of temperatures at SRP from 1961 to 1972 is shown in Figure A-37.

The SRP humidity at maximum and minimum temperatures is given in Table A-27 for 1964 to 1978. The average daily humidity is about 66%; the minimum is 43%, and the average maximum is 90%.[30]

A.6.3 Precipitation

The average annual rainfall at SRP was about 47.5 inches from 1952 through 1978. The greatest rainfall occurs in March, and the least occurs in November (Table A-28). Snowfall and freezing rain occur infrequently during the winter.

A.6.4 Wind and Dispersion Characteristics

Wind data are obtained from two locations in the vicinity of SRP, the National Weather Service at Bush Field in Augusta, Georgia, and an instrumented television tower near Beech Island about 15 miles (25 kilometers) from the center of SRP (Figure A-36). Some differences in the data are expected because of differences in topography and the difference in heights of the instruments at Bush Field (130 feet above msl) and at the television tower (380 feet above msl).

Table A-25 SRP Climate

Season	Features
Spring (March-May)	Pleasant temperatures with an occasional cold snap; infrequent tornadoes; infrequent hail; rainfall 27% of annual total.
Summer (June-September)	Humid, frequent thunderstorms, 6-8 days with temperatures of 97°F or higher; rainfall 30% of annual total.
Fall (October-November)	Cool mornings with warm afternoons; about 50-60 thunderstorms per year; infrequent hail, rainfall 18% of annual total.
Winter (December-February)	Mild, about 30% of days with minimum temperatures below freezing; occasional snowfall with short periods of coverage (3 days average); rainfall 25% of annual total.

Table A-26 Average and Extreme Temperatures at SRP, 1961 through 1976

Month	Average Daily Temperature, °F			Extreme Monthly Temperature, °F	
	Maximum	Minimum	Monthly	Maximum	Minimum
January	56	36	46	86	4
February	59	37	48	81	14
March	68	44	56	90	22
April	77	53	65	95	33
May	83	61	72	99	41
June	89	67	78	105	49
July	91	70	81	102	58
August	90	70	80	104	56
September	85	64	75	100	41
October	77	54	66	92	28
November	67	43	55	89	18
December	59	39	49	82	16

Average annual temperature = 64°F.

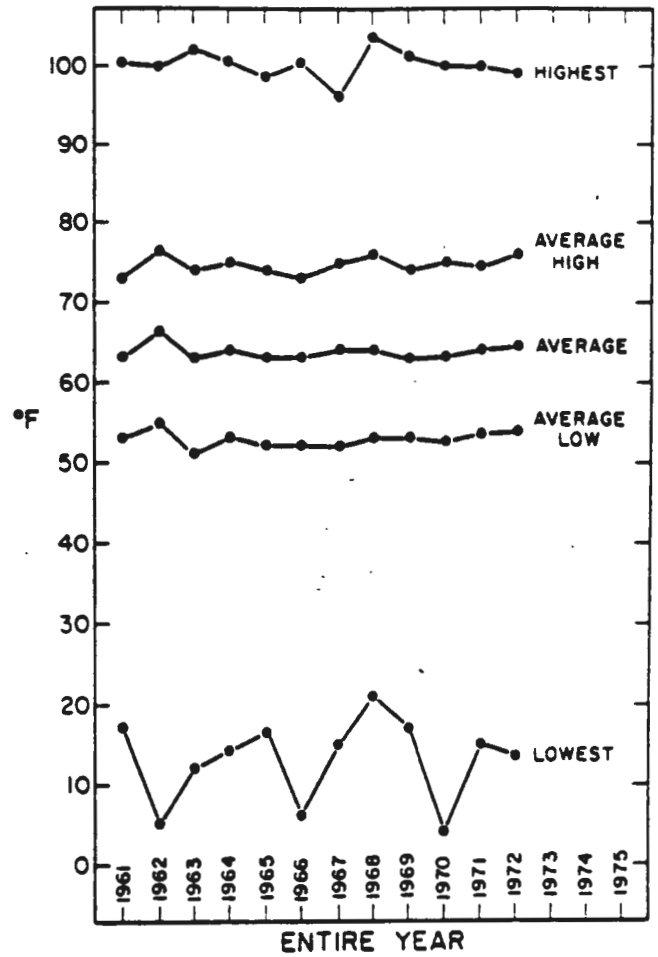

Figure A-37 Summary of Temperatures at SRP from 1961 to 1972.

Table A-27 Relative Humidity at SRP, 1964-1978

Month	Relative Humidity, % Minimum	Maximum
January	50	81
February	43	80
March	38	83
April	35	87
May	39	92
June	41	95
July	45	97
August	46	98
September	44	96
October	41	92
November	42	89
December	49	85
Average	43	90

Table A-28 SRP Precipitation by Month and Year, 1952-1983
(Inches/Period, 773-12A)

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	5.63	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	8.67	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	3.88	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	

There are also surface effects with respect to measured wind velocity. The velocity generally increases as a logarithmic function of height near the ground. Variations in atmospheric stability can cause departures from the logarithmic function.

A.6.5 Wind Speed

The average hourly wind velocity for Augusta, Georgia, was 6.4 mph (measured at a height of 20 feet) for the years 1950 to 1955. The wind frequency distribution for each quarter during the same period is shown in Figure A-38. Poor dispersion conditions (calms and wind speeds below 3 mph) occur about one-third of the time, usually during late evening and early morning hours.

The frequency of wind speed as a function of height in the television tower near SRP is shown in Table A-29. These data show that at 120 feet (37 meters) above ground level, wind speeds of less than four mph (two meters per second) occur 15% of the time with frequency decreasing with elevation. This speed-to-height ratio is much less than indicated for Augusta, Georgia, because of the more sensitive instruments on the television tower and greater height from the ground.

A.6.6 Wind Direction

Wind direction near SRP is shown in Figure A-39 as the percent of time the wind was blowing from different directions.[30] The data represented in Figure A-39 are valid for an elevation of 200 feet (61 meters) which is the height of the major SRP stacks. These data were interpolated from data of 120, 300, and 450 feet obtained from the television tower near SRP for 1976 and 1977. During that period, winds blew mostly from the west and southwest.

Table A-30 shows the prevailing wind direction, by month, based on a nine-year record at Augusta, Georgia. The prevailing wind shifts direction as much as 180 $^{\circ}$ from day to day (Table A-31) with an average shift of 42 $^{\circ}$ to 83 $^{\circ}$. Hourly observations show that the wind shifted from hour to hour during 1957.[44]

A.6.7 Wind Persistence

Wind persistence is the length of time that the wind blows from one direction within a given azimuthal angle. The probability of wind persistence at SRP (1966-1968) for elevations of 300 and 800 feet and several angular widths are shown in Figures A-40 and A-41.[45] At the 300-foot elevation, the probability of wind persistence for a ten-hour period is 0.07, 0.125, and 0.23 for a 22.5, 30, and 45° sector width, respectively (Figure A-40). Results are similar at 800 feet (Figure A-41).

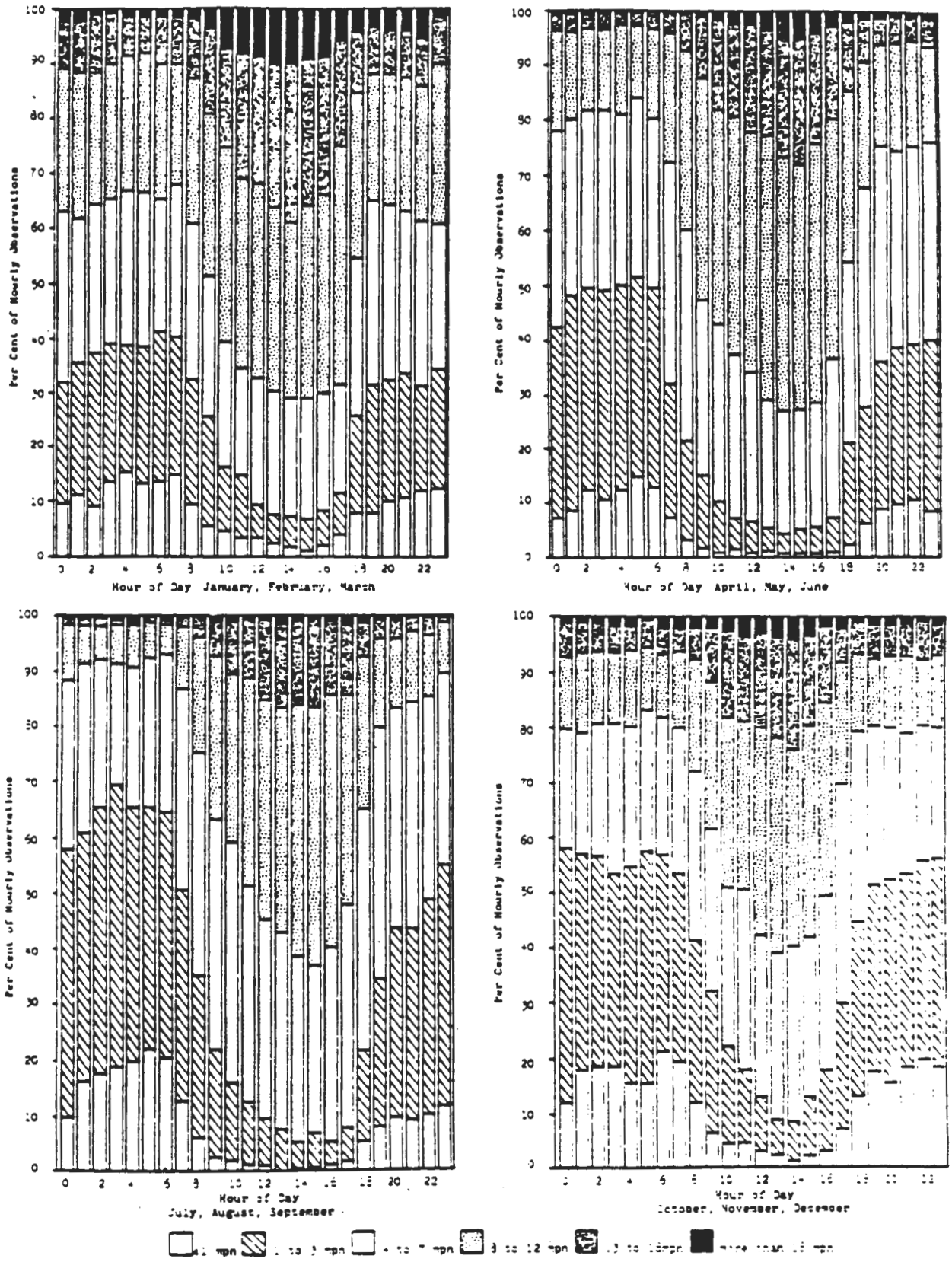

Figure A-38 Wind Frequency Distribution at Bush Field, Augusta, Georgia (1950-1955).

Table A-29 Frequency of Wind Speed at Various Elevations (2 Years Data from March 1966 to March 1968)

Wind Speed, m/sec	Frequency at each Elevation, in feet*						Fraction at each elevation, in feet						Accum Fraction by Speed and Elevation, in feet					
	1000	800	600	450	300	120	1000	800	600	450	300	120	1000	800	600	450	300	120
0 to 1	3054	4350	4530	7133	6655	11744	0.02	0.02	0.02	0.03	0.03	0.05	0.02	0.02	0.02	0.03	0.03	0.05
1 to 2	6634	9543	10370	9998	15345	26109	0.04	0.04	0.04	0.05	0.06	0.11	0.06	0.06	0.06	0.08	0.09	0.15
2 to 3	13042	18581	19837	18369	28575	47555	0.09	0.07	0.08	0.09	0.11	0.19	0.15	0.13	0.14	0.16	0.20	0.35
3 to 4	15266	24017	24782	22720	34373	56300	0.10	0.10	0.10	0.11	0.13	0.23	0.25	0.23	0.24	0.27	0.33	0.58
4 to 5	16158	25349	26490	23719	36510	46297	0.11	0.10	0.11	0.11	0.14	0.19	0.35	0.33	0.34	0.38	0.47	0.77
5 to 6	16207	26908	27726	26357	38747	29049	0.11	0.11	0.11	0.12	0.15	0.12	0.46	0.43	0.45	0.50	0.62	0.89
6 to 7	14218	23231	25474	24042	32190	12576	0.09	0.09	0.10	0.11	0.13	0.05	0.56	0.53	0.56	0.61	0.75	0.94
7 to 8	11780	21237	23311	21944	26761	6569	0.08	0.08	0.09	0.10	0.10	0.03	0.63	0.61	0.65	0.72	0.85	0.97
8 to 9	11222	20311	21970	20856	19411	3901	0.07	0.08	0.09	0.10	0.08	0.02	0.71	0.69	0.74	0.81	0.93	0.98
9 to 10	9836	17342	18055	15841	9688	2012	0.06	0.07	0.07	0.07	0.04	0.01	0.77	0.76	0.81	0.89	0.97	0.99
10 to 11	9738	16560	17454	12095	4526	1189	0.06	0.07	0.07	0.06	0.02	0.00	0.84	0.83	0.88	0.94	0.98	0.99
11 to 12	7463	13545	12417	6457	1963	585	0.05	0.05	0.05	0.03	0.01	0.00	0.89	0.88	0.93	0.97	0.99	1.00
12 to 13	5611	10098	8377	3321	992	318	0.04	0.04	0.03	0.02	0.00	0.00	0.92	0.92	0.96	0.99	1.00	1.00
13 to 14	4508	8055	5350	1522	615	165	0.03	0.03	0.02	0.01	0.00	0.00	0.95	0.95	0.98	0.99	1.00	1.00
14 to 15	3006	5093	2548	571	289	86	0.02	0.02	0.01	0.00	0.00	0.00	0.97	0.97	0.99	1.00	1.00	1.00
15 to 16	1940	3240	1194	281	144	41	0.01	0.01	0.00	0.00	0.00	0.00	0.98	0.99	1.00	1.00	1.00	1.00
16 to 17	1118	1826	539	150	82	13	0.01	0.01	0.00	0.00	0.00	0.00	0.99	0.99	1.00	1.00	1.00	1.00
17 to 18	610	879	181	51	43	11	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
18 to 19	316	338	76	32	18	5	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
19 to 20	172	144	36	10	5	1	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Over 20	120	111	41	46	52	65	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Totals	152019	250758	250758	215525	256984	244591												

* Number of records in this survey = 257292. Data from instrumented TV tower near SRP.

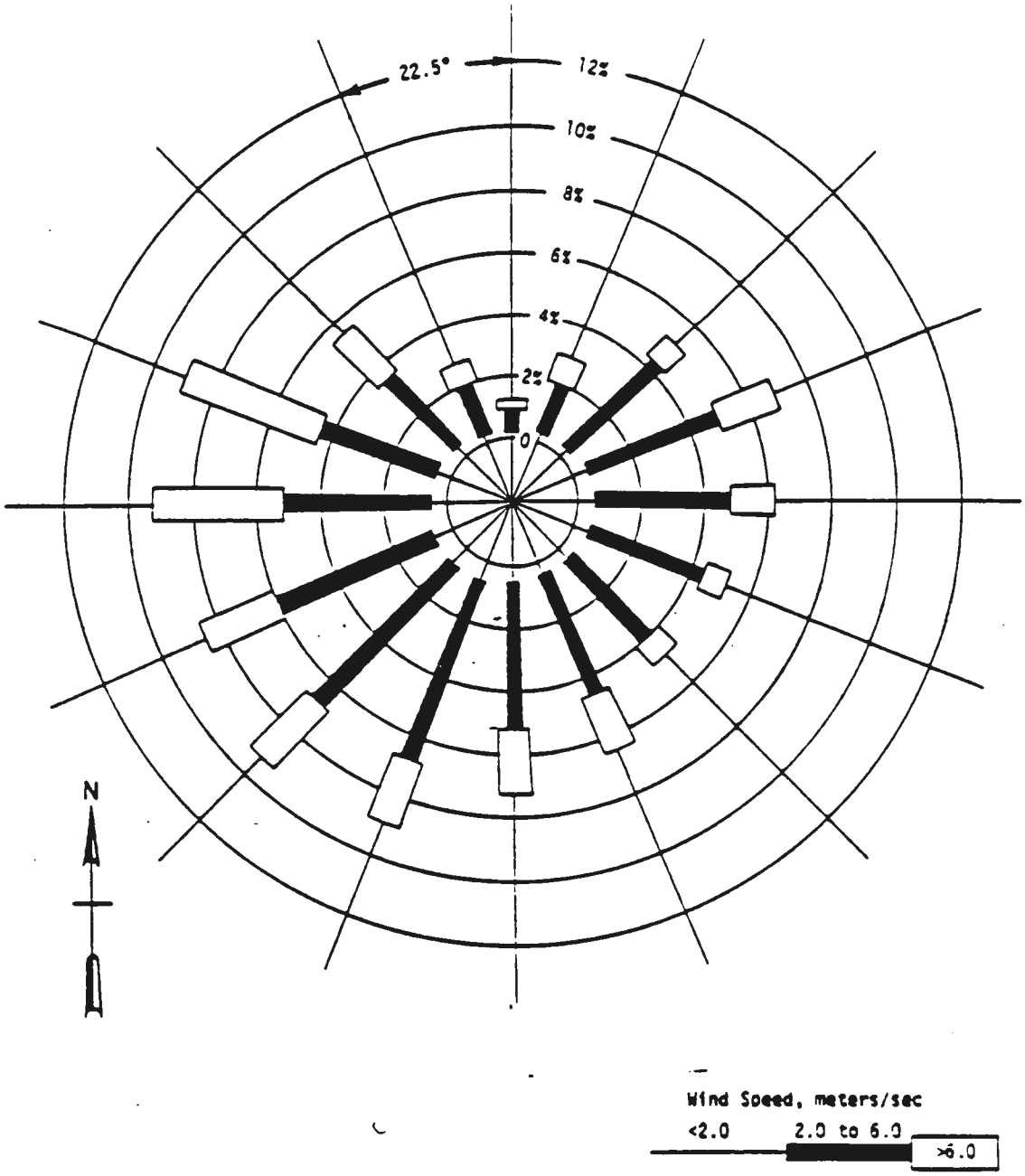

Figure A-39 Wind Direction Near SRP From 1976 to 1977.

Table A-30 Prevailing Wind Direction at Augusta, Georgia

Month	Prevailing Wind*	Time at Given Direction, %
January	Northwest	26
February	Northwest	26
March	Northwest	25
April	Northwest	19
May	Northwest	17
June	South	21
July	South	26
August	South	23
September	East	20
October	Northwest	21
November	Northwest	28
December	Northwest	22

* Direction from which wind blows.

Table A-31 Daily Shift of Prevailing Wind Direction in Augusta (1957)

	Shift, Degrees*											
Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	NNW	SSW	W	ESE	E	NE	NW	SW	NW	NE	NW	W
2	15	150	30	120	30	75	90	75	180	0	90	45
3	0	120	165	105	75	0	90	0	105	15	105	15
4	165	0	0	0	0	30	45	60	15	60	15	90
5	120	180	0	45	0	135	135	165	75	0	0	15
6	180	45	0	90	90	15	180	0	30	45	90	135
7	180	45	75	60	165	30	135	90	0	0	90	0
8	135	120	150	0	120	30	60	135	45	60	0	0
9	75	90	30	105	150	180	15	135	15	0	165	135
10	30	15	15	75	15	45	165	75	30	45	60	45
11	180	135	165	120	0	135	0	75	15	105	60	30
12	15	30	120	150	75	0	30	105	15	15	15	30
13	135	75	60	30	75	150	90	150	0	45	0	90
14	30	15	30	105	15	120	0	120	0	30	90	60
15	165	180	90	0	60	75	120	45	30	120	45	30
16	45	180	90	75	0	45	30	105	0	0	60	0
17	60	0	45	0	90	135	105	0	30	45	30	135
18	0	180	180	0	60	180	45	75	180	135	60	0
19	150	180	135	15	120	135	30	15	60	30	120	45
20	135	105	30	15	90	30	90	30	60	15	30	60
21	15	0	30	30	105	15	15	60	30	15	120	150
22	180	15	0	0	0	0	45	0	60	30	150	60
23	120	75	165	0	0	15	45	15	165	60	15	30
24	135	165	75	0	105	30	0	45	90	0	90	0
25	0	0	180	15	105	0	165	135	135	120	180	90
26	0	60	15	15	45	90	15	90	45	60	135	150
27	180	30	75	30	60	90	15	75	90	15	60	0
28	0	90	30	0	165	60	15	120	0	0	105	180
29	0	-	45	15	15	60	45	30	45	45	45	120
30	90	-	45	15	0	30	150	120	0	60	90	30
31	105	-	150	-	15	-	150	90	-	150	-	30
Average	83	81	74	42	62	67	71	75	54	45	73	60

* The change was taken as the smaller angular rotation from the previous day's prevailing wind. The actual change could be greater than indicated if the shift occurred through the larger angular rotation.

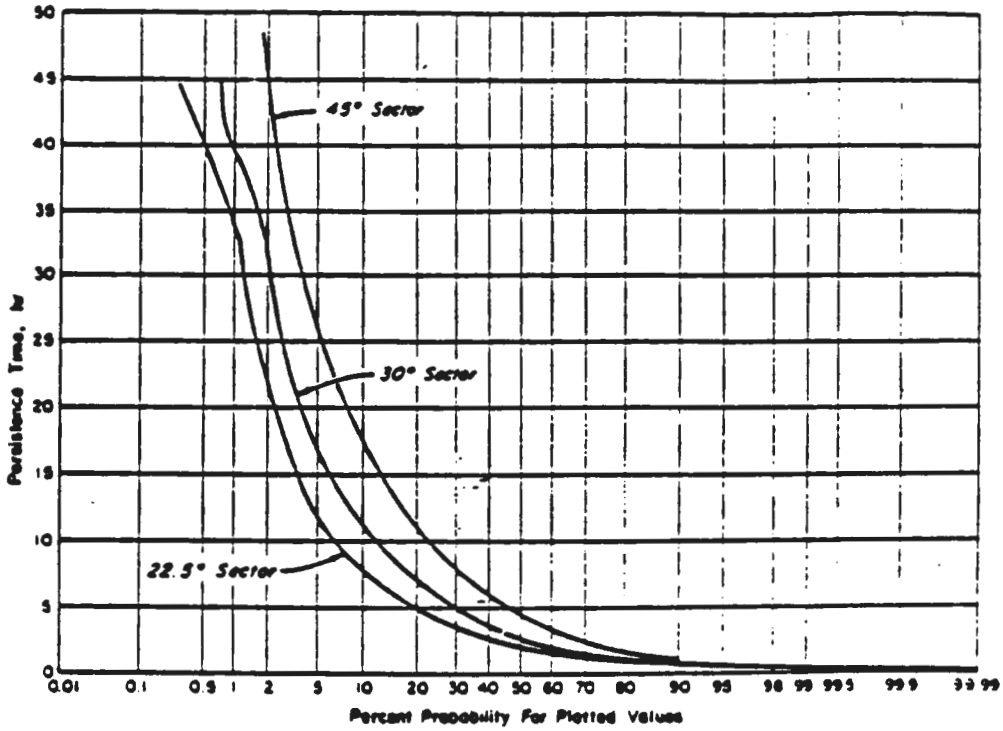

Figure A-40 Probability of Wind Persistence at 300-Foot Elevation at SRP.

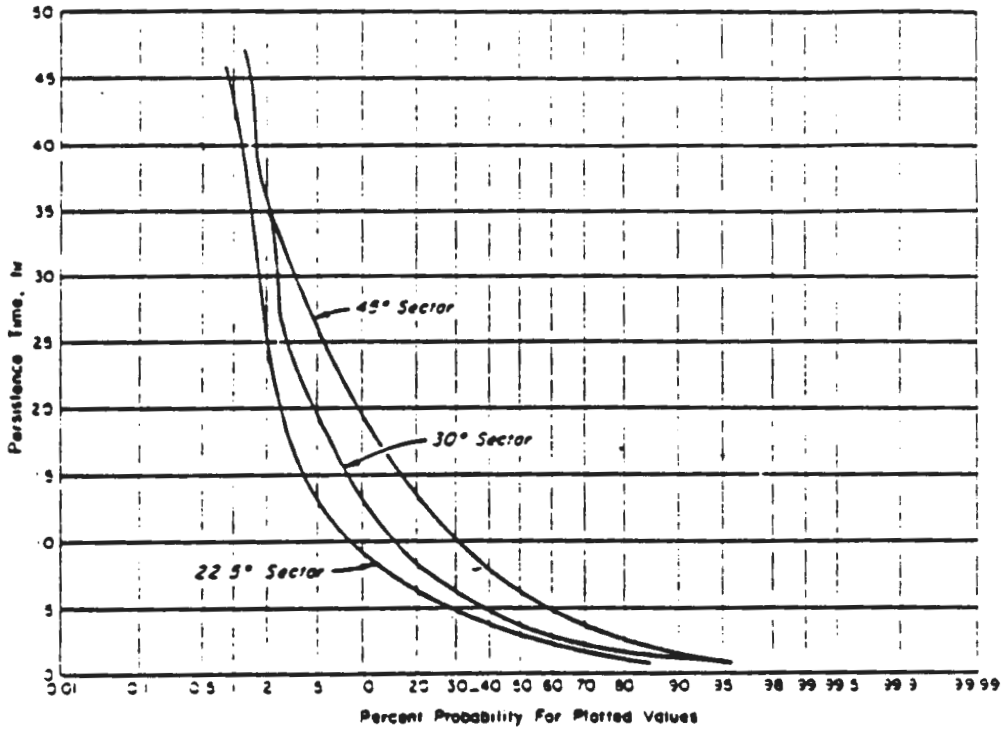

Figure A-41 Probability of Wind Persistence at 800-Foot Elevation at SRP.

The wind persistence for the most populated sector (Sector 14) is shown in Figure A-42 in hours versus probability of occurrence at 300 amd 800 feet. The probability at the 300-foot elevation for a ten-hour period in this sector is only 0.025.

A.6.8 Severe Weather

A.6.8.1 Thunderstorms

The average number of thunderstorm days at Augusta from 1951 through 1977 varied from a minimum of one from October through January to a maximum of 13 in July. The summer thunderstorms occur mainly during late afternoon and evening hours.

A.6.8.2 Tornadoes

Occasional tornadoes are to be expected in the SRP area. Weather Bureau records show that 278 tornadoes occurred in Georgia, and 154 occurred in South Carolina from 1916 through 1958.[46] More recent data show that South Carolina has an average of about ten tornadoes per year.[47,48] Most tornadoes occur from March through June and travel in a southwest-to northeast direction.

Georgia and South Carolina may have extreme tornadoes with maximum wind speeds up to 260 mph. During the history of SRP, no production facility has suffered significant tornado damage. In two instances, light damage has occurred, such as window breakage and tree breakage. Other tornado funnels have been sighted in unpopulated areas of SRP, but investigations revealed no damage.

Tornado risks have been calculated for the local region surrounding the SRP site. The probability of exceeding threshold windspeeds in one year versus windspeed is shown in Figure A-43.[49]

A.6.8.3 Hurricanes

Hurricanes that affected South Carolina occurred predominantly in August and September.[50] The occurrence of a hurricane along the Coastal region does not mean that SRP will be subjected to winds of hurricane force (>75 mph). Winds diminish as the storms pass overland, and SRP is about 100 miles inland. Winds of 75 mph have been measured only once at the SRP site during its history, when Hurricane Gracie passed nearby on September 29, 1959.

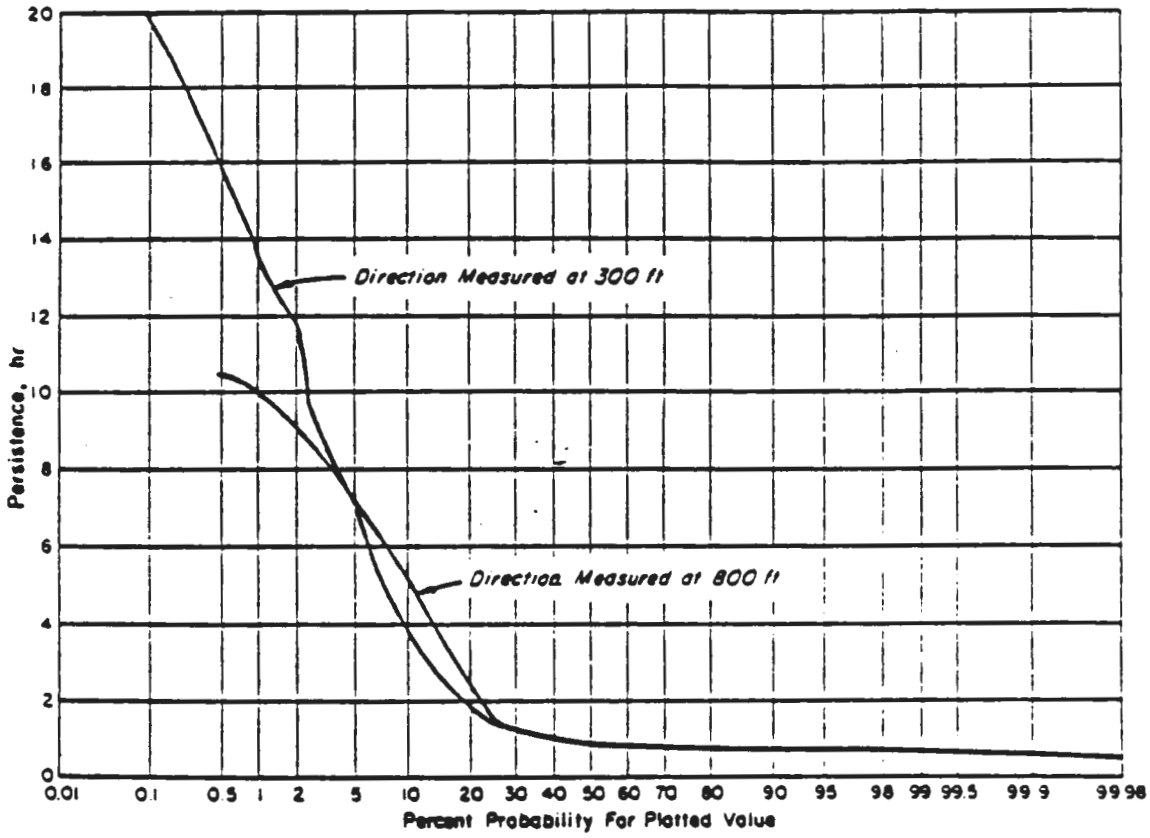

Figure A-42 Percent Probability versus Wind Persistence Between SRP and Augusta, Georgia (22.5° Sector).

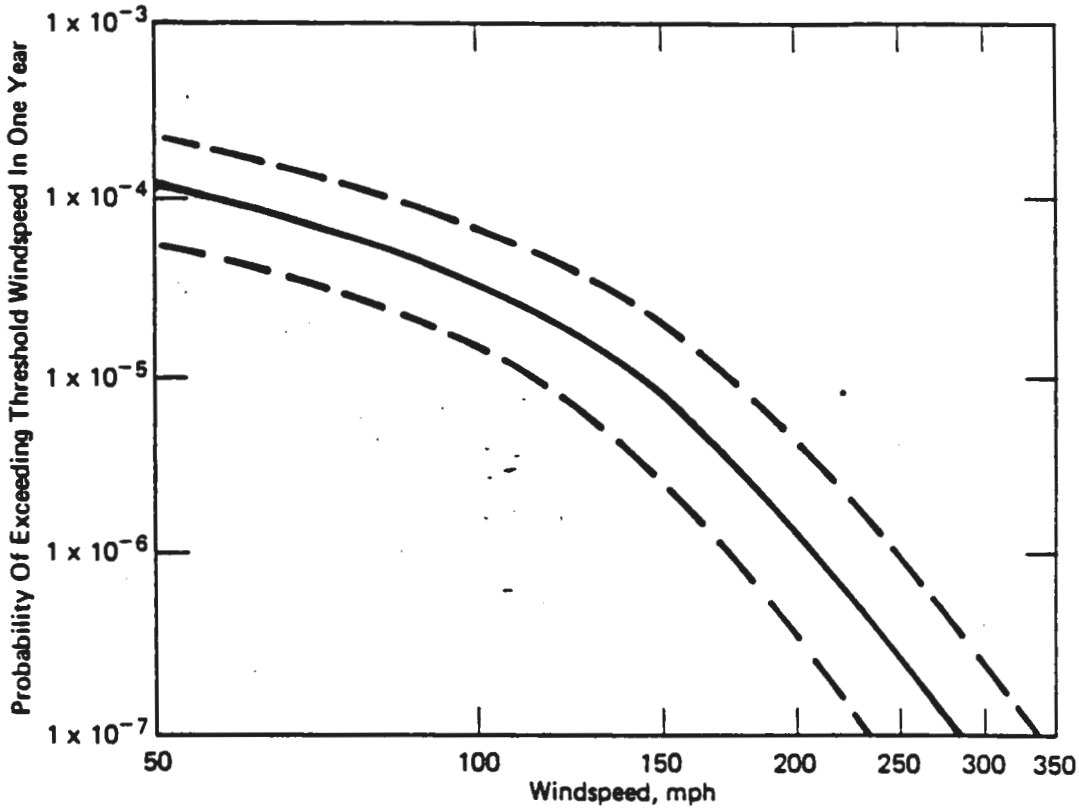

Figure A-43 Tornado Risk Model with 95 Percent Confidence Limits.

A.7 ECOLOGY

A.7.1 Terrestrial Ecology

A.7.1.1 Upland Ecology of SRP

SRP is located on the Upper Coastal Plain of South Carolina. Two distinct physiographic subregions are present on SRP: the Pleistocene Coastal Terraces (below 270 feet in elevation) and the Aiken Plateau (above 270 feet in elevation), Figure A-44. The lowest terrace, the Wicomico, is the present floodplain of the Savannah River. The floodplain is largely covered by a dense swamp forest, which also extends along the floodplains of the major tributaries of SRP. The higher terraces, the Sunderland and Brandywine, have a level to gently rolling topography. The Aiken Plateau is hilly and dissected by small streams with scrub-oak-longleaf pine forest along the ridges.

At the time of Government acquisition, about 67% of the land area of SRP was forested, and 33% was in croplands and pastures. Cotton and corn were the chief crops. After acquisition, abandoned homesites and farms entered ecologocal succesional stages. Abandoned fields passed through a herbaceous stage into perennial grasses and gradually became more wooded, mostly with pine. The invasion of pine into the abandoned fields was accelerated by an extensive planting program by the U.S. Forest Service. By 1962, nearly all of the fields had been planted and many of the early plantations consisted of closed stands of trees 20 to 30 feet high. Today, 90% of SRP is covered by forests.

Upland game and fur-bearing mammals and small nongame birds are common on SRP. These include whitetail deer, gray and fox squirrel, cottontail rabbit, raccoom, red and gray fox, opossum, and bobcat. Smaller nongame animals such as mice, rat, voles, moles, and shrews are found also. The populations of many species of mammals increased rapidly after SRP was closed to the public. In 1965, organized deer hunts began on SRP with about 1300 deer taken annually since 1972.

A.7.2 Aquatic Ecology

A.7.2.1 Introduction

The aquatic systems most likely to be impacted by the the startup of a new radioactive waste disposal/storage facility are the Savannah River, Upper Three Runs Creek, and their adjacent floodplains (Figure A-45).

The Savannah River has its headwaters in the mountains of North Carolina, South Carolina, and Georgia. Two large reservoirs - Clarks Hill Reservoir and Hartwell Reservoir - upstream of SRP have stabilized the river flow and have influenced the biological and water quality of the Savannah River in the vicinity of SRP. Suspended sediment load has been reduced, and backwater and

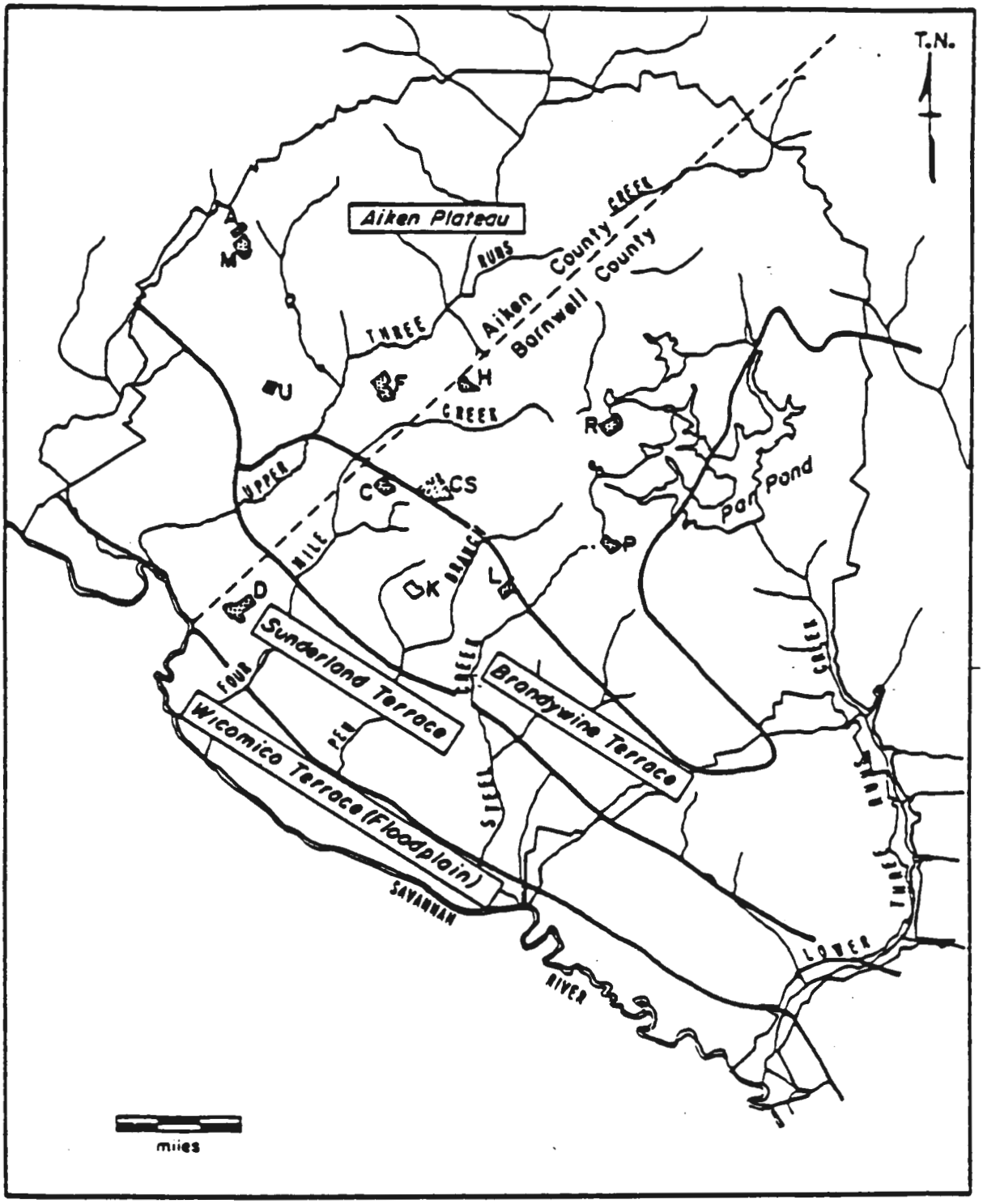

Figure A-44 Coastal Terraces on the Savannah River Plant.

floodplain areas are flooded less frequently and for shorter durations.

The Savannah River has been subjected to other alterations on the last 30 years. Channel dredging was conducted in the 1950's, and both municipal and industrial waste water treatment has improved upstream of SRP in the last ten to fifteen years. The main use of water by SRP since operations began in the early 1950's has been for cooling of a coal-fired power plant and the five nuclear production reactors via streams on SRP to the Savannah River.

The main streams on SRP which drain to the Savannah River are Upper Three Runs Creek, Beaverdam Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek (Figure 1.1-2). All of these streams except Upper Three Runs Creek have been influenced by reactor cooling water discharges. These discharges, 10 to 20 times the natural stream flows, cause the streams to overflow their original banks along much of their length. The original swamp bottomland forests have been eliminated along much of Four Mile Creek, Pen Branch, and Steel Creek.

Those sections of the Savannah River swamp bottomland which receive heated effluents have been modified, because of thermal loading, flooding, and increased movement of silt. About one square mile of bottomland hardwoods has been killed by reactor cooling water effluents (Figure A-46). Slight-to-moderate damage has occurred in another 6.5 square miles.[51,52]

A.7.2.2 Savannah River

The most complete biological data on the Savannah River are contained in a series of reports prepared by the Academy of Natural Sciences of Philadelphia (ANSP).[53-65] These surveys have been conducted on a regular basis since 1951. The first survey was made by sampling selected river stations during all four seasons. In subsequent years, the practice has been to conduct cursory surveys annually and more complete surveys every three to five years. Table A-32 is an inventory of the surveys and the season during which the survey was conducted. Water quality data for the Savannah River are summarized in Tables A-33 and A-34.

Biological components included in each ANSP survey include algae and diatoms, protozoa, macroinvertebrates, fishes, and bacteria (occasionally), plus some water quality and physical measurements. Emphasis was placed on obtaining as complete an inventory of species as possible at each station and on taxonomic identification. Initially, five stations were sampled by the ANSP. Stations were located on the Savannah River in a reach extending upstream and downstream from SRP. Detailed description of the sampling stations are provided in each ANSP report and their present location are shown in Figure A-47.

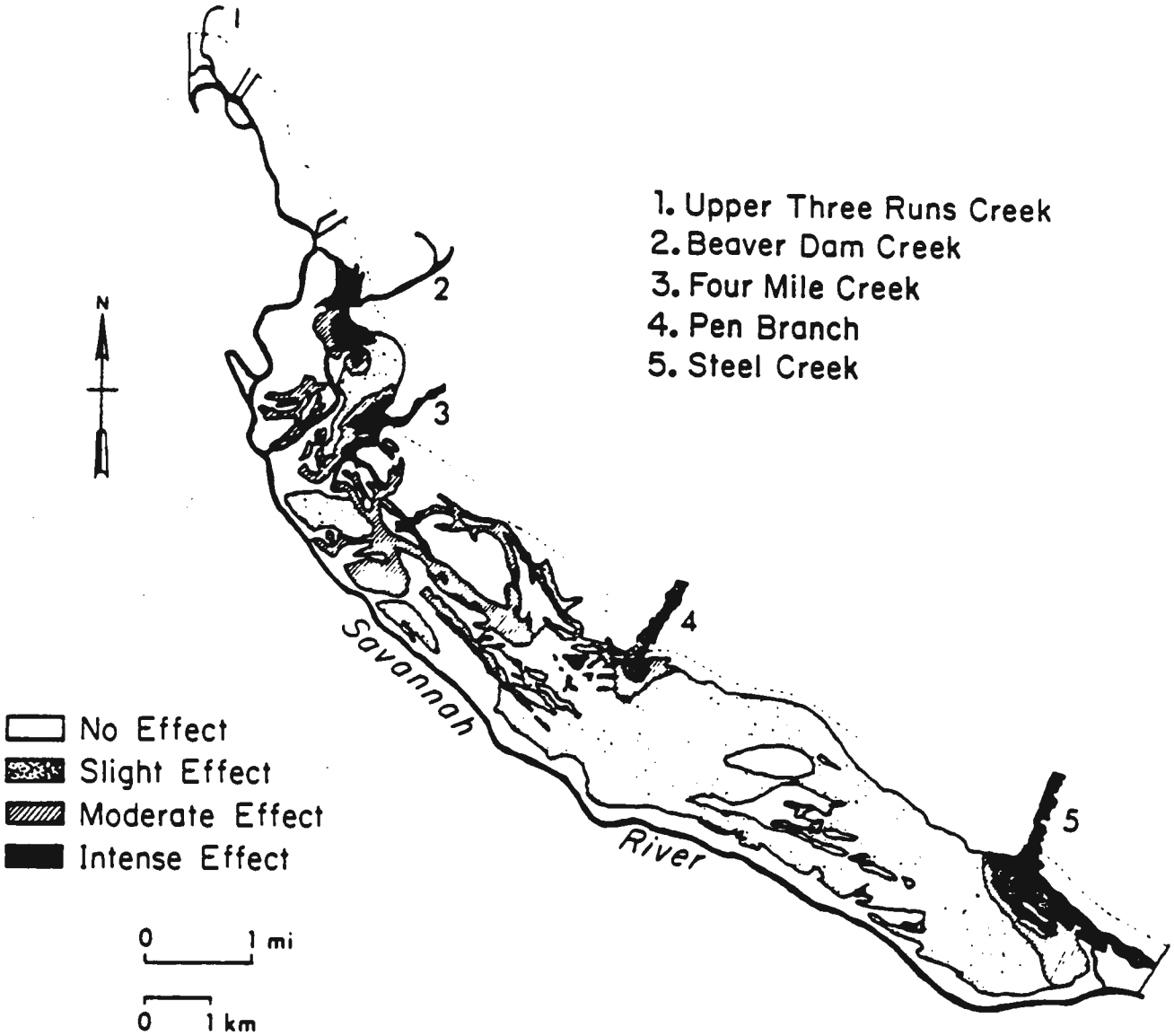

Figure A-46 Thermal Effects on Bottomland Hardwoods.

Table A-32 Academy of Natural Sciences Aquatic Collections Reported, 1951-1977

Sampling Year	Sampling Stations by Quarter*																							
	1				2				3				4				5				6			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1951-1952	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1955-1956		x	x			x	x			x	x			x	x			x	x			x	x	
1960		x	x							x	x			x	x			x	x			x	x	
1965		x	x							x	x			x	x			x	x			x	x	
1968		x	x							x	x			x	x			x	x			x	x	
1972		x	x							x	x			x	x			x	x			x	x	
1976			x								x				x				x				x	

* First Quarter - Jan. 1 - Mar. 31.
Second Quarter - Apr. 1 - June 30.
Third Quarter - July 1 - Sept. 30.
Fourth Quarter - Oct. 1 - Dec. 31.

Table A-33 Water Quality Monitoring Data for the Savannah River Above SRP for 1973-1980

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December
Temperature	°C	11.2 (7.0-14)	9.3 (6-12)	10.5 (7-14.5)	13.6 (11-17)	17.5 (15-19.5)	20.5 (17-24)	22.7 (19-25)	24.6 (22.5-26)	24.7 (23.0-25.6)	23.1 (22-24)	19.4 (17-23)	15.0 (10-16)
pH	pH	(6.21-7.0)	(6.4-7.2)	(6.4-7.1)	(5.9-7.0)	(6.5-6.9)	(5.34-7.0)	(5.9-7.1)	(6.1-7.4)	(6.4-7.6)	(6.5-7.1)	(6.6-7.3)	(6.3-7.2)
Dissolved Oxygen	mg/ℓ	11.0 (10.4-12.2)	11.5 (10.8-12.4)	11.3 (10.2-12.3)	10.5 (9.7-11.08)	9.7 (9.3-10.14)	9.1 (8.5-9.6)	8.66 (7.7-9.35)	8.43 (8.2-8.74)	8.21 (6.32-8.7)	8.52 (7.4-9.12)	9.29 (8.7-9.7)	10.01 (9.0-11.3)
Alkalinity ($CaCO_3$)	mg/ℓ	14.3 (10.6-16.0)	13.9 (7.0-19.1)	12.5 (6.7-18)	11.6 (0.70-18.7)	12.1 (7.0-15.7)	12.4 (5-22.8)	13.0 (11.2-18)	12.8 (7.0-18)	13.4 (3.1-18.5)	17.0 (6.0-29)	16.5 (11.4-25.7)	16.6 (0.55-25.7)
Hardness	mg/ℓ	18.5 (12.0-51.0)	14.2 (9.1-20.2)	12.1 (9.4-17.2)	16.3 (7.2-29)	16.0 (12-24.6)	16.2 (10.1-42.3)	17.3 (10-37.3)	17.2 (8.0-39.7)	13.1 (6.2-35)	18.9 (8.0-36)	28.4 (10-86)	15.7 (6-38)
Conductivity	µmhos	63 (37-90)	50.9 (8.5-69)	58.7 (43-77)	59.6 (47-82)	57.3 (41-88)	58.8 (49-80)	65.3 (50-79)	68.7 (49-77)	69.5 (53-83)	71.5 (51-92)	66.1 (50-78)	66.8 (42-81)
Suspended Solids	mg/ℓ	9.3 (1-22)	24.4 (10-44)	28.7 (5.0-115)	30.6 (4.0-74)	22.0 (10-40.9)	16.5 (5.0-28)	14.4 (3.0-25)	<15.1 (<1-33)	15.5 (5.5-40)	14.3 (2.0-53)	21.6 (5.0-90)	14.6 (3.0-31)
Volatile Solids	mg/ℓ	21.7 (14-29)	24.3 (11-59)	23.0 (16-27)	<19.4 (<1-27)	19.8 (3-31)	24.9 (16-31)	22.4 (2.0-30)	19.3 (7.0-31)	23.9 (16-35)	32.4 (12-95)	21.9 (1-34)	26.9 (16-49)
Total Dissolved Solids	mg/ℓ	38.7 (29-54)	43.6 (11-79)	41.6 (31-50)	37.2 (18-52)	40.3 (18.6-71)	47.1 (31-61)	43.5 (9-61)	38.4 (20-57)	43.9 (22-52)	56.0 (39-115)	47.1 (23-62)	50.6 (3.5-114)
Fixed Residue	mg/ℓ	16.6 (3-27)	<19.4 (<1-31)	18.2 (7.4-34)	18.0 (8.0-31)	20.5 (0-41)	2.2 (16-30)	20.9 (7.0-38)	19.3 (3.0-44)	19.8 (5.5-26)	23.8 (20-30)	24.9 (10-38)	29.1 (11-79)
BOD	mg/ℓ	<3.1 (<1-12)	<3.2 (<1-12)	<1.7 (<1-4.0)	<1.0 (<1-1.0)	<1.5 (<1-2.5)	<1.6 (<1-4.0)	<1.72 (<1-3.0)	<1.61 (<1-4.0)	<1.46 (0.5-3.7)	<1.56 (<1-2.0)	1.69 (1-2)	1.52 (0.67-2.0)
Lignin	mg/ℓ	<1 (<1-1.2)	<2.0 (<1-5.5)	<1.4 (<1-2.9)	<1.7 (<1-4.2)	<1.5 (<1-3.2)	<3.1 (<1-17)	<3.3 (<1-19)	<1.95 (<1-8.5)	<1.18 (<1-19)	<2.56 (<1-11)	<2.79 (<1-15)	<3.41 (<1-19)
Chloride (Cl)	mg/ℓ	4.0 (3.0-5.5)	7.03 (2.4-9.0)	4.69 (3.0-6.8)	3.62 (1.5-7.0)	3.71 (2.5-5.0)	5.43 (3.2-10)	6.46 (4.4-8.8)	5.66 (3.2-8.1)	6.11 (4.8-8.0)	5.21 (3.5-7.5)	5.90 (4.4-7.6)	6.94 (1.8-11.2)

Table A-33 (Continued)

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December
		<0.12	<0.03	<0.06	<0.02	<0.03	<0.03	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite (NO_2-N)	mg/l	(<0.02-0.4)	(<0.02-0.07)	(<0.02-0.3)	(<0.02-0.04)	(0.01-0.08)	(<0.02-.05)	(<0.02-0.09)	(<0.02-0.19)	(<0.02-<0.1)	(<0.02-0.19)	(<0.02-0.21)	(<0.02-0.2)
		<0.54	<0.43	0.99	0.48	<0.35	0.42	0.46	0.66	0.72	0.90	1.03	<0.90
Nitrate (NO_3-N)	mg/l	(<0.02-1.1)	(<0.02-0.8)	(0.16-3.8)	(0.02-0.9)	(<0.02-0.8)	(.06-0.8)	(0.2-1.3)	(0.27-1.6)	(0.05-2.5)	(0.2-3.1)	(0.4-3.8)	(<0.02-4.0)
		4.6	5.2	4.14	<4.4	<4.0	6.75	<4.94	<5.20	<4.69	5.38	5.35	4.66
Sulfate (SO_4-S)	mg/l	(3.25-6.9)	(3.8-6.4)	(2.9-7.1)	(<2-6.4)	(<2-6.9)	(3.0-6.6)	(<2-6.3)	(<2-6.1)	(<2-7.8)	(4.3-6.8)	(4.1-8.1)	(2.5-6.2)
		<1	<1	<1	<1	<1	<1.2	<1	<1	<1	<1	<1	<1
Sulfide (S)	mg/l	(<1-1.3)					(<.1-5.9)	(<0.1-3.6)	(<0.1-<1)	(<0.1-1.0)	(0.1-<1)	(<0.1-<1)	(<0.1-1)
		<1.1	<0.19	<0.19	<0.34	<0.44	<0.33	<0.5	<0.35	<0.13	<1.36	<0.21	<0.19
Total Phosphate (PO_4-P)	mg/l	(<0.02-3.6)	(<0.02-0.4)	(<0.02-0.6)	(<0.02-0.6)	(<0.02-1.0)	(<0.02-0.6)	(<0.02-0.5)	(<0.02-1.1)	(<0.02-0.3)	(<0.02-4.7)	(<0.02-0.46)	(<0.02-1.0)
		<0.5	<0.5	<1.4	<1.2	<0.95	<0.82	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Aluminum (Al)	mg/l		(<0.5-1.0)	(<0.5-5.0)	(<0.5-1.3)	(<0.5-2.0)	(<0.5-3.0)						(<0.5-69)
		<.10	<0.1	<0.23	<0.1	<0.1	<0.1	<0.17	<0.1	<0.1	<0.1	<0.1	0.1
Ammonia (NH_3)	mg/l	(<.10-.10)	(<0.1-0.1)	(<0.1-0.9)	(<0.1-0.2)	(<0.1-1.5)	(<0.1-0.3)	(<0.1-0.6)	(<0.1-0.1)	(<0.1-0.12)	(<0.1-0.1)	(<0.1-0.3)	(<0.1-0.1)
		2.1	1.74	1.81	1.88	1.94	1.73	<1.88	2.16	2.09	2.31	2.19	2.08
Calcium (Ca)	mg/l	(1.4-2.75)	(1.1-2.3)	(1.4-2.5)	(1.6-2.6)	(1.2-4.0)	(.15-4.0)	(<0.1-4.0)	(1.5-2.8)	(1.3-2.8)	(1.6-2.9)	(1.2-3.4)	(1.7-2.3)
		6.1	6.2	5.6	6.0	5.5	6.8	7.78	7.28	7.23	7.56	7.61	7.38
Sodium (Na)	mg/l	(4.3-7.7)	(4.0-12.5)	(3.5-7.5)	(4.1-8.4)	(2.5-8.7)	(2.9-9.2)	(4.4-11)	(5.2-9.85)	(5.9-9.3)	(4.9-10.4)	(6.65-9.7)	(4.4-11)
		<0.24	<0.24	<0.53	<0.69	<0.61	<0.69	<0.31	<0.17	<0.12	<0.28	<0.19	<0.12
Total Iron (Fe)	mg/l	(<0.1-0.7)	(<0.1-0.5)	(<0.1-2.0)	(<0.1-1.7)	(<0.1-1.5)	(<0.1-2.0)	(<0.1-0.5)	(<0.1-0.4)	(<0.1-0.2)	(<0.1-1.2)	(<0.1-0.5)	(<0.1-0.1)

Table A-34 Water Quality Monitoring Data for the Savannah River Below SRP for 1973-1980

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December
Temperature	°C	11.0 (7.0-16.5)	9.32 (5.6-13)	10.8 (7.3-16)	16.6 (11.75-19)	18.3 (15-20.5)	21.2 (18-24)	23.1 (20.25-25.5)	25.2 (23-26)	26.9 (23.0-26.6)	23.3 (21-25)	19.2 (17-23)	15.1 (11-18)
pH	pH	11.1 (6.36-7.3)	11.2 (6.35-6.95)	11.2 (6.5-7.0)	10.6 (5.51-7.0)	9.68 (6.0-6.8)	8.86 (5.8-6.9)	8.62 (5.48-7.0)	8.31 (6.35-7.0)	8.10 (6.35-7.0)	8.60 (6.0-7.09)	9.23 (6.4-6.8)	9.98 (6.4-7.01)
Dissolved Oxygen	mg/ℓ	11.2 (10.4-12.2)	11.2 (10.1-12.6)	11.2 (10-12)	10.6 (9.4-11)	9.68 (8.5-10.7)	8.86 (7.0-9.45)	8.62 (6.7-8.88)	8.31 (8.0-8.66)	8.10 (6.2-8.6)	8.60 (8.3-9.0)	9.23 (8.6-9.7)	9.98 (8.4-11.1)
Alkalinity ($CaCO_3$)	mg/ℓ	14.2 (10.2-21)	12.8 (8.7-16.8)	13.3 (9.0-17)	13.4 (0.8-19.9)	13.0 (9.0-17)	12.7 (5.1-19.5)	12.2 (3.1-16)	13.9 (12-17)	14.3 (7.8-18.8)	16.8 (5.0-38)	13.4 (0.8-26.9)	14.8 (0.55-2.1)
Hardness	mg/ℓ	17.1 (12-28)	13.2 (9.1-16.5)	16.7 (9.6-18)	14.5 (7.2-27.2)	16.6 (10-20.2)	17.8 (8.1-38.3)	17.0 (11-35.3)	16.4 (6.0-34.3)	13.7 (6.0-26)	20.5 (8.1-68)	28.2 (9.1-78)	14.4 (8.1-30)
Conductivity	umhos	66.1 (41-89)	60.4 (39-89)	59.6 (46-80)	64.0 (48-84)	58.9 (42-77)	57.9 (41-76)	58.0 (31-77)	66.9 (54-86)	69.2 (54-98)	72.0 (62-102)	65.6 (50-81)	67.9 (41-80)
Suspended Solids	mg/ℓ	<8.64 (<1-22.5)	13.9 (6.0-28)	22.6 (3.0-86)	31.4 (9.0-59)	17.9 (10-20.2)	15.0 (2-27)	15.7 (8.0-22)	20.0 (15.5-38)	17.8 (2.0-45)	19.0 (1.0-87)	9.43 (<1-16)	<9.96 (<1-27)
Volatile Solids	mg/ℓ	26.0 (16-38)	19.4 (10-31)	20.3 (15-26)	24.1 (14-28)	20.1 (5.0-30)	23.9 (16-32)	26.2 (4.0-40.7)	17.6 (6.0-26)	25.7 (19-32)	33.3 (<1-90)	17.7 (5.0-22)	26.4 (11-55)
Total Dissolved Solids	mg/ℓ	62.6 (29-67)	36.0 (17-60)	39.3 (21-55)	38.9 (14-57)	40.7 (7.0-76)	45.9 (27-51)	44.5 (14-63)	43.8 (31-61)	47.4 (39-52.5)	59.4 (42-120)	44.2 (27-56)	51.6 (36-110)
Fixed Residue	mg/ℓ	20.6 (13-30)	17.3 (2.0-29)	25.8 (2.0-40)	<15.1 (<1-30)	20.3 (2.0-51)	24.6 (6.0-36)	18.3 (10-26)	30.4 (8.0-67)	22.0 (16.5-34)	28.6 (7.0-53)	27.4 (11-38)	28.7 (1.0-65)
COD	mg/ℓ	<3.0 (<1-12)	<1.33 (<1-2.0)	<2.0 (<1-4.0)	<1.67 (<1-3.0)	<1.88 (<1-4.0)	<1.26 (<1-3.0)						
BOD	mg/ℓ	<1.03 (<1-1.1)	<1.67 (<1-4.6)	<1.36 (<1-1.9)	<1.41 (<1-2.3)	<1.45 (<1-2.8)	<2.96 (<1-15)	1.79 (1.0-4.0)	<1.51 (<1-3.0)	<1.01 (<1-1.5)	<1.25 (<1-2.0)	<1.71 (1.0-3.0)	<1.68 (<1-4)
Lignin	mg/ℓ	5.09 (3.1-8.8)	4.10 (2.4-8.0)	4.40 (3.0-5.6)	4.01 (2.5-7.0)	4.04 (2.8-5.2)	5.68 (3.0-10)	<3.08 (<1-17)	<2.69 (<1-16)	<1.17 (<1-2.0)	<2.10 (<1-7.0)	<3.0 (<1-16)	<1.13 (<1-17)

Table A-34 (Continued)

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December
Chloride (Cl)	mg/l	5.09 (3.1-8.8)	4.10 (2.4-8.0)	4.40 (3.0-5.6)	4.01 (2.5-7.0)	4.04 (2.8-5.2)	5.68 (3.0-10)	5.19 (3.8-7.5)	5.22 (2.9-7.5)	6.06 (4.1-7.4)	5.66 (3.0-8.1)	5.65 (4.4-8.0)	7.06 (1.1-9.5)
Nitrite (NO_2-N)	mg/l	<0.05 (<.02-0.14)	<0.04 (<.02-0.08)	<0.02 (<.02-0.06)	<0.03 (<.02-0.1)	<0.03 (<.02-0.03)	<0.03 (<.02-.07)	<0.03 (<.02-0.09)	<0.03 (<.02-0.07)	<0.04 (<.02-<0.1)	<0.03 (<.02-<0.1)	<0.03 (<.02-0.1)	0.08 (<.02-0.3)
Nitrate (NO_3-N)	mg/l	<0.57 (<0.02-1.1)	<0.45 (<0.02-0.8)	0.91 (0.2-2.3)	<0.39 (<0.02-0.9)	<0.39 (<0.02-1.0)	0.42 (.05-0.6)	0.37 (0.07-1.1)	1.63 (0.2-8.715)	0.92 (0.05-2.5)	0.83 (0.11-3.1)	0.90 (0.4-1.4)	0.91 (<0.02-4.0)
Sulfate (SO_4-S)	mg/l	4.22 (3.0-6.4)	5.61 (2.3-10.6)	5.49 (3.5-9.4)	4.33 (<2-6.8)	4.59 (2.0-6.6)	4.26 (<2-7.4)	4.90 (<2-11)	3.84 (<2-5.3)	4.64 (<2-7.6)	5.32 (3.6-6.8)	4.61 (3.35-6.8)	4.92 (2.8-6.7)
Sulfide (S)	mg/l	<1	<1	<1	<1	<1	<1.6 (<1-8.3)	<1	<1	<1	<1	<1	<1
Total Phosphate (PO_4-P)	mg/l	<0.64 (<0.02-2.7)	<0.14 (<0.02-0.4)	<1.38 (<0.02-8.3)	<0.20 (<0.02-0.4)	<0.38 (<0.02-0.9)	<0.26 (<0.02-0.4)	<0.43 (<0.02-1.5)	<0.30 (<0.02-1.0)	<0.09 (<0.02-0.375)	<1.45 (<0.02-5.0)	<0.33 (<0.02-0.6)	0.40 (<0.02-0.7)
Aluminum (Al)	mg/l		<0.5 (<0.5-2.6)	<0.80 (<0.5-3.6)	<1.13 (<0.5-2.8)	<0.91 (<0.5-2.8)	<0.88 (<0.5-2.0)	<0.69 (<0.5-2.0)	<0.5	<0.5	<0.5	<0.5	<0.5
Ammonia (NH_4)	mg/l	<0.1	<0.16 (<0.1-0.5)	<0.21 (<0.1-0.9)	<0.11 (<0.1-0.15)	<0.1	<0.11 (<0.1-0.3)	<0.11 (<0.1-0.2)	<0.1	<0.1 (<0.1-0.12)	<0.1	<0.14 (<0.1-0.3)	<0.1
Calcium (Ca)	mg/l	2.11 (1.7-2.8)	1.93 (1.3-2.6)	2.09 (1.6-2.9)	2.13 (1.9-2.6)	2.03 (1.3-3.0)	2.09 (1.6-3.0)	<1.95 (<0.1-3.0)	2.32 (1.6-3.0)	2.28 (1.4-2.85)	2.42 (1.8-3.1)	2.08 (1.6-3.8)	2.16 (1.9-3.3)
Sodium (Na)	mg/l	6.23 (4.9-8.2)	6.17 (4.3-12)	5.89 (3.7-8.0)	5.78 (3.2-7.7)	5.6 (3.6-7.6)	6.7 (2.9-11)	7.04 (5.4-10.8)	6.64 (5.5-7.65)	7.13 (5.4-9.8)	7.10 (4.2-9.8)	6.73 (6.1-7.6)	7.31 (4.9-12)
Total Iron (Fe)	mg/l	<0.33 (<0.1-0.6)	<0.33 (<0.1-1.0)	<0.49 (<0.1-1.8)	<0.62 (<0.1-1.7)	<0.52 (<0.1-1.5)	<0.44 (<0.1-1.5)	<0.29 (<0.1-0.75)	<0.19 (<0.1-0.45)	<0.125 (<0.1-0.2)	<0.29 (<0.1-1.3)	<0.20 (<0.1-0.5)	<0.15 (<0.1-0.4)

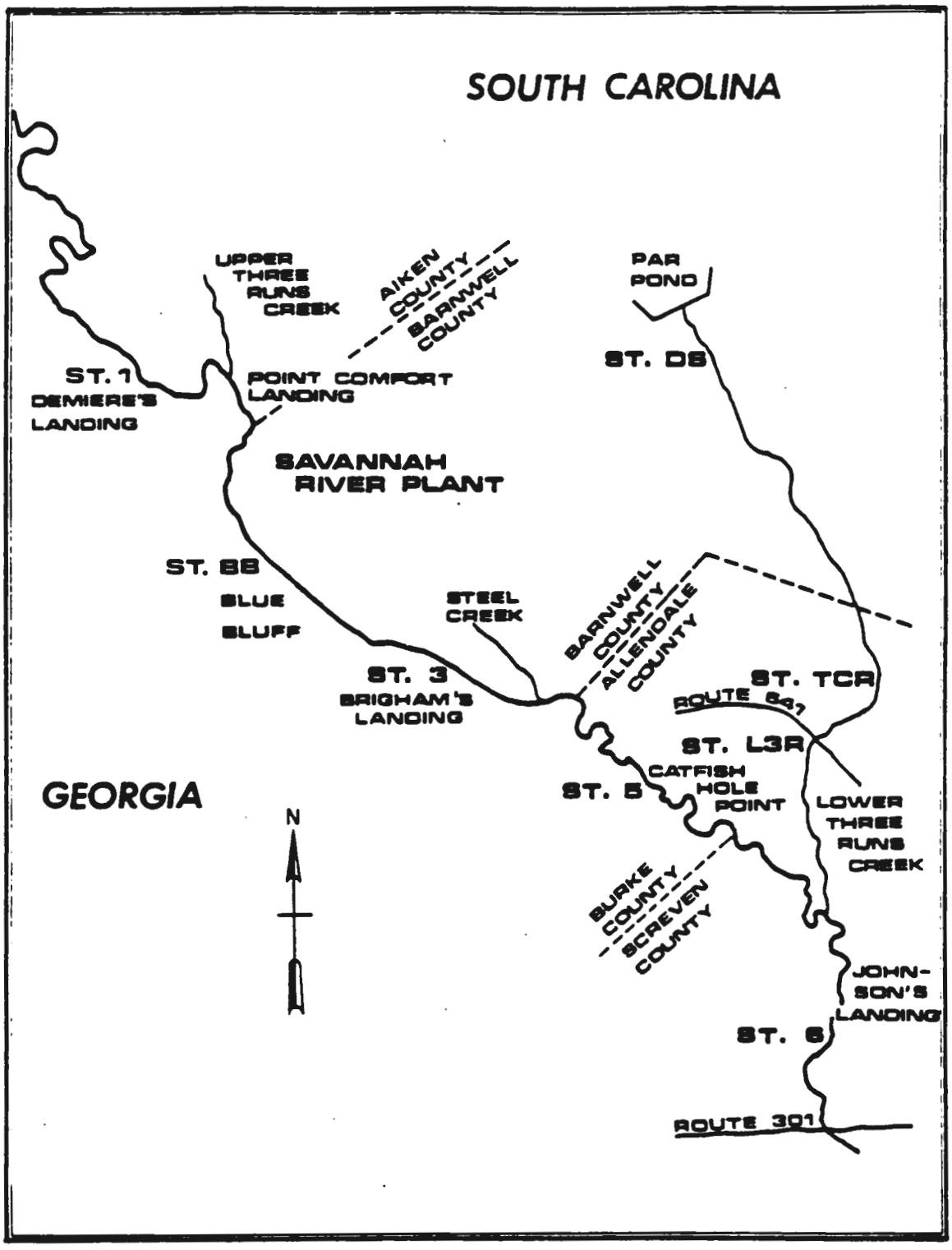

Figure A-47 Survey Stations on the Savannah River.

A.7.2.3 Primary Producers

Algae, macrophytes (aquatic vascular plants), and detritus serve as the base of the food web in aquatic environments. In rivers such as the Savannah River, attached algae (periphyton) assume a greater role in food production than floating algae (phytoplankton). Much of the phytoplankton of the Savannah River consist of detached periphytic forms as well as free-floating forms that are discharged from the Clarks Hill Reservior and from tributaries and backwater areas entering the river. The number of species of algae represented in ANSP collections are presented in Figure A-48. Diatoms have been the dominant group in most years. Blue-greens are the second most common group, particularly in the more upstream stations which are influenced by more organic waste discharged from Augusta and Horse Creek Valley. The most diverse algal flora consistently occurs during the summer, coincident with lower flow and less turbid water.

The distribution of macrophytes along the Savannah River is spotty. Larger concentrations are found in areas of less current, in oxbows, behind sand bars, and around spur dikes.

A.7.2.4 Consumers

A.7.2.4.1 Macroinvertebrates

Macroinvertebrates typically include aquatic insects and other invertebrates. These groups occupy similar habitats; that is, they are associated with the substrate; they are relatively stationary except as movement may occur with downstream drift; and they are subject to inpact from similar factors. Functionally, they are diverse and fulfill the niches of preditors, grazers, filter feeders and, in the case of insects, are not confined to the water for their life cycle. The Savannah River supports a diverse benthic (bottom-dwelling) fauna in the vicinity of the SRP. Most of the suitable habitat is associated with areas of shallow water with silted substrate or in the quieter backwaters. The river bottom consists primarily of shifting sand that does not provide optimum habitat for benthic invertebrates.

The number of aquatic macroinvertebrates represented by ANSP collections are shown in Figure A-49. There is a dominant pattern evident in the figure, which began in the mid-fifties. The greatest number of species collected in a single sampling year was in the initial year of the study (1951-1952). Immediately thereafter, the number of species collected at each station declined to less than half that of the initial year. Apparent recovery from this decline did not occur intil the early sixties. Complete recovery has not taken place even after 25 years. The reduction in the number of species during the 1950's has been attributed to dredging in the river which had been initiated by 1955. Stabilization of river discharge and elimination of habitat through reduction in flooding of backwater areas may have also contributed to the decline. The groups most affected were Baetid and Heptagenid mayflies, Perlid

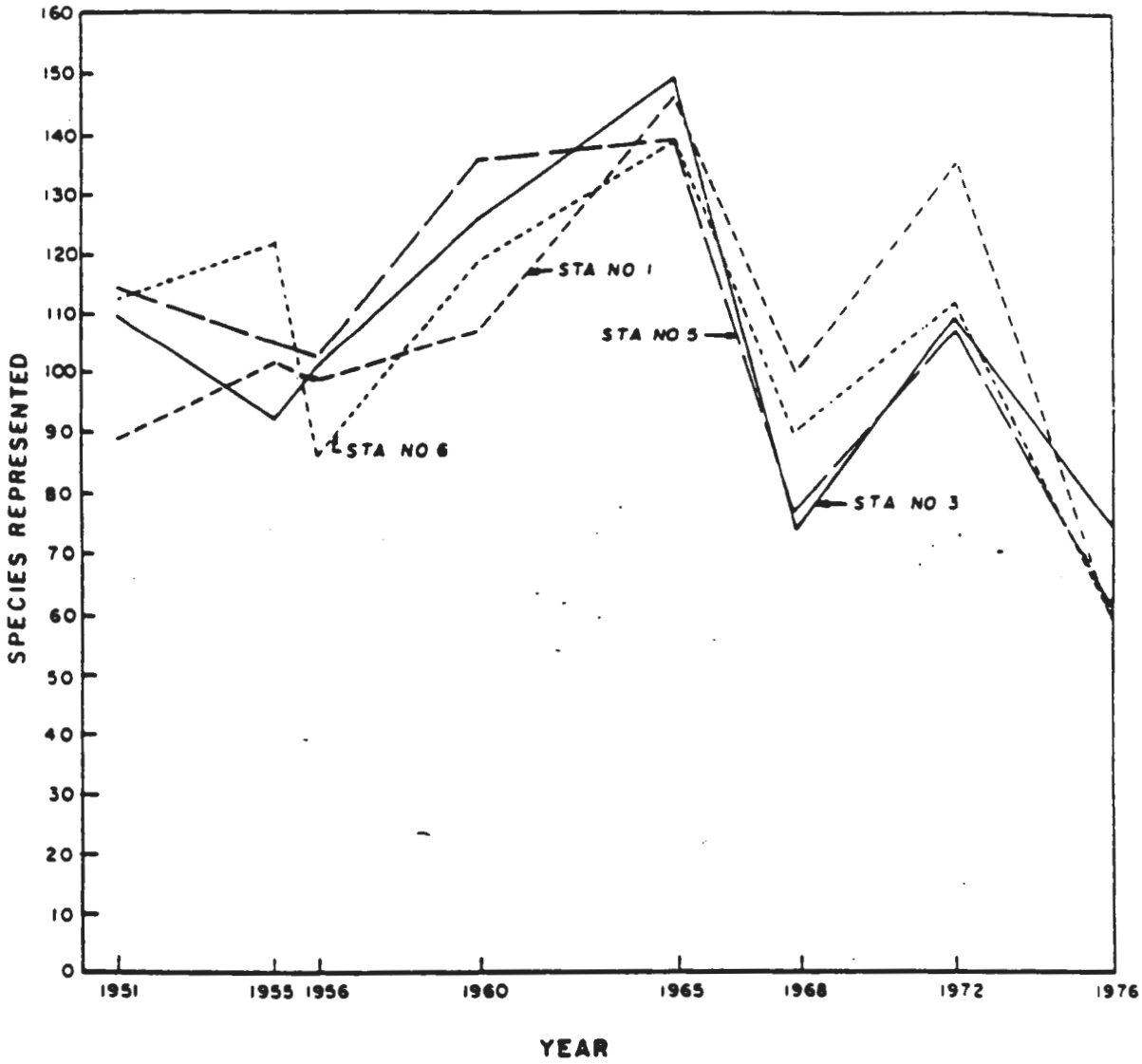

Figure A-48 Species of Algae Represented in ANSP Collections in the Savannah River.

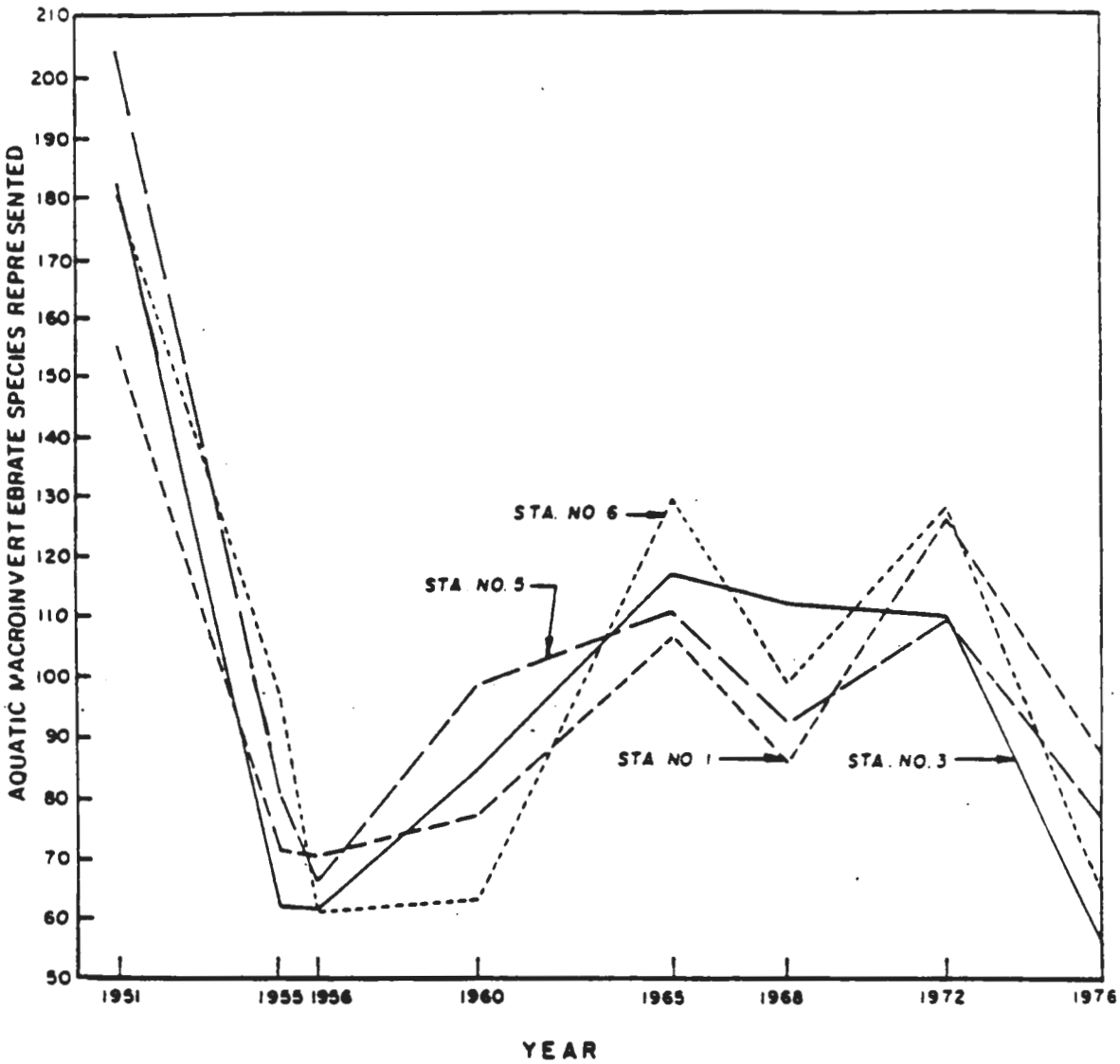

Figure A-49 Aquatic Macroinvertebrates Represented by ANSP Collections in the Savannah River.

stoneflies, dragonflies, Hemipterans, Dystiscid and Gyninid beetles, and the Chironomids. The most dramatic reduction among the noninsect fauna occurred in the Crustacea, the Oligochaete worms, and the pelecypods. These groups are sensitive to siltation and substrate instability. Pulmonate gastropods were also less abundant, but were able to survive by attachment to areas of riprap placed in the river prior to 1951 for channel stability.[66]

Of the insect fauna, beetles comprised the largest number of species when all ANSP surveys are considered. Mayflies and dragonflies were represented by the largest number of species among the earlier surveys. Following the decline in species in the 1955 through 1960 period, the Diptera (flies) have been represented by the most species, indicating a general decline in environmental quality.[66]

A.7.2.4.2 Fish

Streams of the southeastern Atlantic Coastal Plain are noted for their diverse fish fauna. Dahlberg and Scott reported 102 species from the Savannah River drainage basin.[67] The most complete surveys of the Savannah River include those initiated by the ANSP in 1951 and that of McFarlane and others in 1976-1977 in which they reported 64 species in the environ of the Savannah River near SRP.[38] Numbers of fish species represented in the ANSP collections are shown in Figure A-50

Looking at the number of species in the ANSP collections for 1951-1976, data from all the Savannah River sampling stations follow a similar pattern. An increase in the number of species collected during the second sampling period (1955-1956) is apparent. The increase can be explained on the basis of revised methodology (i.e., incorporating rotenone toxification) into the collection procedure. Since 1960, the number of species has gradually declined and become more variable from station to station and from one sampling year to the next. The decline in species numbers in collections after 1960 may be attributable to substrate removal and disturbance related to dredging between 1955 and 1960.[66]

A.7.2.4.3 Fish Species of Special Concern

McFarlane summarized much of the impact of SRP operations on fishes of the Savannah River.[38] Fish listed as of special concern included the shortnose sturgeon (Acipenser brevirostrum), the American shad (Alosa sapidissima), the blueback herring (A. aestivalis), the striped bass (Morome saxatilis), the channel catfish (Ictalurus punctatus), and the American eel (Anguilla rostrata). Of these, the American shad, the blueback herringm and the striped bass are anadromous; that is, migrating from saltwater to freshwater for spawning. The American eel is catadromous; that is, migrating from freshwater to saltwater for spawning. The only significant comercial species are the American shad and channel catfish (Section A.3.1.2). These are exploited to a limited degree

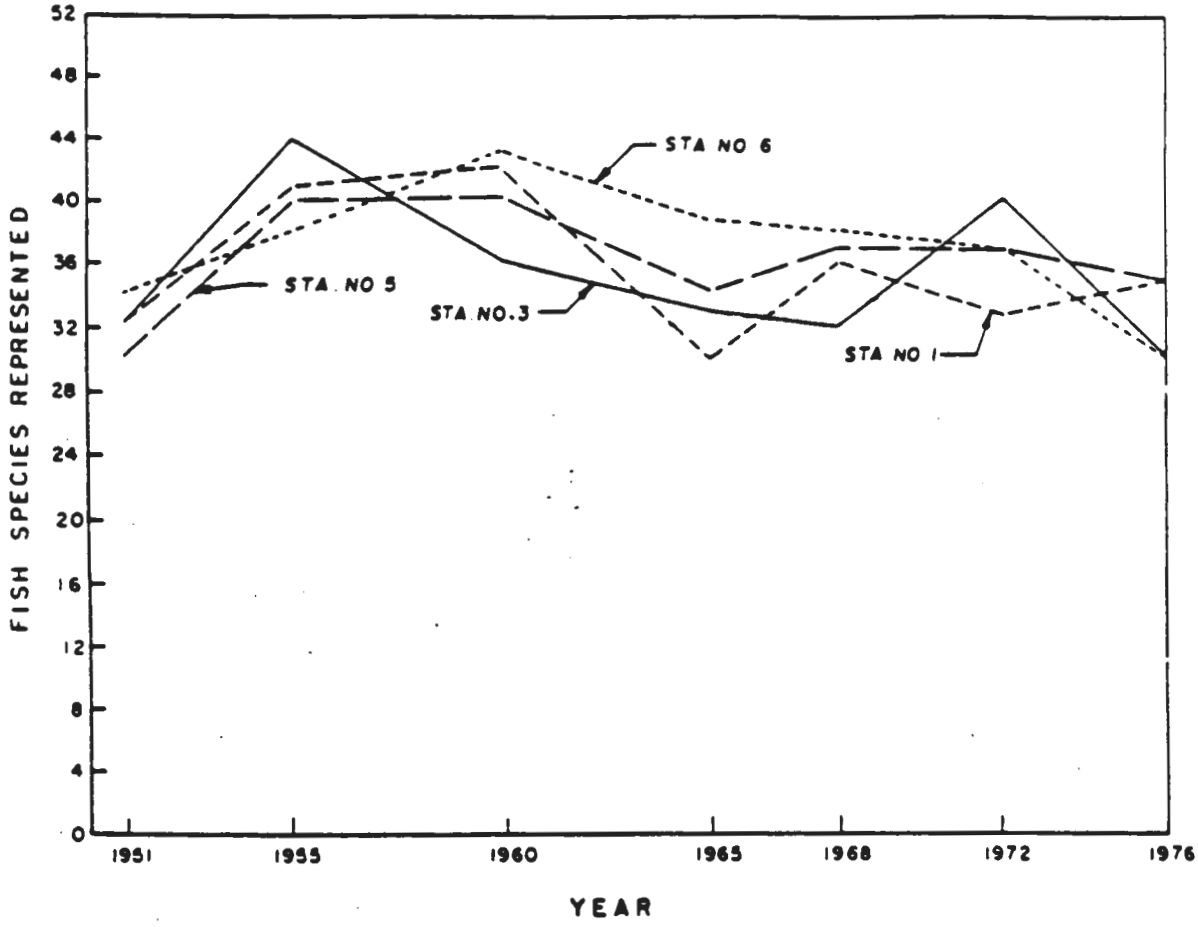

Figure A-50 Fish Species Represented in the ANSP Collections in the Savannah River.

by local fishermen. Sport fishermen are the principal consumers of other river fishes, principally bass, sunfishes, crappie, and catfish. Striped bass are popular in the Augusta area.

- Shortnose Sturgeon

  The shortnose sturgeon is the only endangered species of fish known from the Savannah River.[68] It is restricted to the tidewaters and has not been reported near the SRP.

- American Shad

  This anadromous species ascends the Savannah River in early spring spawning above or near the SRP (Table A-35). The semi-bouyant eggs are carried downstream past SRP and can become entrained on intake facilities. Few shad larvae appear to hatch near SRP. Juveniles migrate back up the river and are attracted to the SRP intake canals; however, they are only rarely impinged.[38] A few adults, typically emaciated, are impinged late in the spawning season. Thus, the impact of SRP upon the American shad is limited to entrainment of shad eggs for about a three-month period.[38]

- Blueback Herring

  This forage fish in the Savannah River has no direct commercial or sport fishing value and is essentially unexploited. It ascends the river to spawn in late spring in adjacent floodplain areas (Table A-35). The eggs are adhesive and are not subject to entrainment, bur larval fish, upon hatching, move into the main river channel and can become entrained by SRP intake structures. Juvenile fish are typically not impinged.[38]

- Striped Bass

  The striped bass has unique spawning habits in the Savannah River.[69] Some individuals spend most of the year in upstream waters and migrate downstream for spawning (Table A-35). The Little Back River near the coast is the most important spawning area for striped bass in the Savannah River. Juveniles and adults migrate back upstream and congregate near the dams upstreams from SRP as well as potentially use the nonthermal creeks of SRP such as Upper Three Runs Creek during the summer months. Impingement and entrainment have not been reported for this species at SRP.[38]

A.8 RADIOLOGICAL CHARACTERISTICS OF THE ENVIRONMENT

Natural radiation contributes about 48% of the annual dose of 194 mrem which an average member of the population receives within 50 miles of SRP. Medical exposure accounts for 47% of the annual dose and the combines doses from weapons test fallout, consumer and industrial products, and air travel account for about 5% of the dose. Releases of radioactivity to the environment from SRP accounts for less than 0.1% of the dose.

Table A-35 Fish of Interest to SRP*

Life History	Shad	Blueback Herring	Striped Bass
Spawning			
Location(s)	Savannah River and Steel Creek	Savannah River and Steel Creek	Savannah River - Upper Tidal Reaches
Month(s)	Early January - Late April	March - Late April	Late March - May
Time	Afternoon - Midnight	Afternoon - Night	Late Afternoon
Frequency	Once per year	Once per year	Once per year
Repeat Spawner	Not in South	Yes (17-78%)	Yes
Water temperature	12-20°C	About 20°C	15.5-19.5°C
Water Velocity	Main Channel 0-3 ft/sec	Off Main river Channel and in River Swamps	Main Channel 0-3 ft/sec
Water Type	Tidal Fresh Water	Fresh Water	Tidal Fresh Water
Eggs			
Size	1.27 mm	1.2 mm	1.28-1.36 mm
Fecundity	$6x10^4$ - $6x10^5$	$4.6x10^4$ - $3.5x10^5$	$1x10^4$ - $5x10^6$
Adhesive	No (demersal)	Yes (demersal)	No (demersal)
Movements	By Current	Adhesive	By Current
Incubation	2-3 days (17°C)	2 days (22°C)	2 days (20°C)
Larvae			
Size	9-10 mm	3.5 mm	2.5 mm
Transformation	4-5 weeks	3-4 weeks	3-4 weeks
Juveniles			
First Summer	Natal River	Natal River	Natal River
Migration	To Sea in Autumn	To Sea in Autumn	Remain in River
Size	About 30 mm	About 30 mm	About 10-12 cm
Adults			
Mature	3-6 years	3-6 years	2-6 years
Weight	2-4 pounds	0.5-0.8 pound	Up to 30 pounds
Length	457-483 mm	277-289 mm	15-57 cm

* Sources:

G. Wrich, N. Chipley, J. W. McCord, I. Cupka, J. L. Enusis, Jr., and R. K. Mahood. Development of Fishery Management Plans for Selected Anadromous Fishes in South Carolina and Georgia. Number 14, Marine Resources Department, South Carolina Wildlife and Marine Resources Department, Marine Resources Division, Office of Conservation, Management and Marketing, Charleston, SC; Number 31, Coastal Resources Division, Georgia Department of Natural Resources, Georgia Department of Natural Resources, Coastal Resources Division, Brunswick, GA.

D. H. Bennett and R. W. McFarland. The Fishes of the Savannah River Plant. National Environmental Research Park, Savannah River Ecology Laboratory, E. I. du Pont de Nemours and Co., Aiken, SC (NERP Report, to be published).

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A.8.1 Natural Background Radiation

A.8.1.1 Cosmic Radiation

The contribution of cosmic radiation to natural background dose varies with both latitude and altitude. Sea-level dise rates range from 30 mrem per year in Florida to 45 mrem per year in Alaska; the exposure rate increases to 200 mrem per year at an altityde of 8000 feet.[70] The average unshielded radiation dose rate in Georgia and South Carolina is 40 mrem per year.[71] SRP and the surrounding area lie between latitudes 33°N and 34°N and with an altitude variation between sea level and roughly 1000 feet (305 meters). It has been estimated that the total unshielded dose equivalent from cosmic radiation in the vicinity of SRP (50 mile radius) is 35 mrem per year, of which 29 mrem per year is from the ionizing component and 6 mrem per year is from neutrons.[8] Shielding by buildings and the body reduces cosmic radiation dose to about 32 mrem per year, a 10% reduction.

A.8.1.2 Terrestrial Gamma Radiation

Terrestrial gamma radiation (external to the human body) is attributed primarily to gamma-emmiting radionuclides in the natural radioactive series derived from uranium and thorium, with some additional contribution from potassium-40. Variation is the distribution of these natural radioactive materials with geologic formations and their inclusion in materials of construction commonly used in urban areas leads to a wide variation with location. The average unshielded external dose rates from this source of exposure are 60 mrem per year and 70 mrem per year in Georgia and South Carolina, respectively. Within 50 miles of SRP, measured external gamma dose rates range from 6 to 385 mrem per year.[8] A value of 55 mrem per year represents the average unshielded external terrestrial background in the vicinity of SRP. Shielding by buildings and the body reduces this terrestrial radiation dose to about 33 mrem per year, a 40% reduction.

A.8.1.3 Natural Radiation in the Human Body

Internal radiation from natural sources arises primarily from potassium-40, daughters of radium-226, carbon 14, and rubidium-87. No estimate of variation with location is made because the widespread distribution of fertilizers and food and population mobility has an averaging effect for these long-lived radionuclides that produce the internal dose. It is estimated that the average internal radiation exposure in the United States from natural radioactivity is 28 mrem per year[72]

A.8.2 Medical Radiation

Medical radiation is the largest source of population exposure to man-made radiation in the United States. Based on a nationwide survey[73] made in 1970, the Bureau of Radiological Health of the Food and Drug Administration estimated the 65% of the people in the United States were exposed to medical and dental x-rays that year. Based on this survey, the average dose to an individual when prorated over the entire population was 77.3 mrem per year. In addition, radio-pharmaceuticals administered to patients for diagnostic and therapeutic purposes account for an average annual dose of 13.6 mrem when prorated over the population. To these patient doses must be added the radiation dose to medical and dental personnel (occupational exposure), which amounts to 0.36 mrem per year when prorated of the total population. Thus, the average medical radiation dose in the U.S. population is about 91 mrem per year.

A.8.3 Weapons Test Fallout

Fallout from nuclear weapons tests is a source of radioactivity in the environment. The large-scale atmospheric tests conducted by the Unites States and the Soviet Union in 1961 and 1962 introduced radioactive materials into the stratosphere which were later distributed worldwide. A small amount of radioactivity from these tests continues to be deposited. The more recent Chinese and French tests have been sufficient to maintain a relatively constant rate of fallout deposition. The current and past fallout contributed to human exposure through:

- External radiation from radioactive material on the earth's surface
- Internal radiation from inhalation of airborne fallout
- Internal radiation from injestion of food and water contaminated by fallout

Cesium-137 deposited from past nuclear weapons tests is the major source of long-lived external gamma radiation from fallout. Short-lived radionuclides also contribute significantly to external radiation within a few years of major tests but currently contribute little to the dose. The current dose rate from external gamma radiation is estimated to be about 0.9 mrem per year.[71]

Most doses from inhalation of fallout are received in the year after exposure. However, doses from strontium-90 and plutonium-239 will be received over a lifetime because of the long residence time of these radionuclides in the body. Tha annual dose from inhaled fallout radioactivity was estimated to be only 0.04 mrem per year in 1969[71] and is currently even lower.

Injestion of radioactivity of fallout origin in food and water is the largest source of radiation exposure. It is estimated that this source of exposure was 3.7 mrem per year in 1980, consisting of 0.6 mrem from carbon-14, 0.4 mrem from cesium-137, and 2.7 mrem from strontium-90.

The average annual total body dose in 1980 from fallout from nuclear weapons tests is estimated to be 4.6 mrem (0.9 from external gamma and 3.7 from injested radioactivity).

A.8.4 Consumer and Industrial Products

A variety of consumer and industrial products yield ionizing radiation or contain radioactive materials and therefore cause radiation exposure to the general population. Some of these sources are television sets, luminous dial watches, airport x-ray inspection systems, dental prosthesis, smoke detectors, cardiac pacemakers, tobacco products, fossil fuels, and building materials. The estimated whole body dose for the U.S. population from these sources is four to five mrem per year.[72] About 3/4 of this is from external exposure to naturally occurring radionuclides in building materials.

A.8.5 Cosmic Radiation Dose to Airline Passengers

Persons who travel by aircraft receive addition exposure from cosmic radiation because at high altitude the atmosphere provides less shielding from this source of radiation. The average annual airline passenger dose is 2.8 mrem, which when prorated over the entire U.S. population amounts to an average dose rate of 0.5 mrem per year.[72]

A.8.6 Nuclear Facilities Other Than SRP

The growth of nuclear industry and facilities in the southern United States has been rapid, most of it occurring in the 1970's. Figure A-51 shows the location of facilities either operating or licensed to operate in 1981. The low-level burial site shown at Maxey Flats, Kentucky was shut down in 1977. Figure A-51 shows 24 power reactors. Not shown are 34 power reactors under construction and 4 reactors being planned. When all of these operating, there will be 61 power reactors in the southern U.S. Typically, the average radiation dose to individuals within 50 miles of a nuclear facility is quite low as shown in Table A-36.[74] The radiation doses shown in this table are population-weighted averages for the entire 50-mile radius around the nuclear facilities.

The only nuclear facility operating within 50 miles of the SRP (during the operating history of SRP) is a low-level waste burial site operated by Chem-Nuclear Systems, Inc., near the east SRP boundary. This facility, which started operation in 1971, releases essentially no radioactivity to the environment[75] and population dose from normal operations is nil. The 50-mile radius population

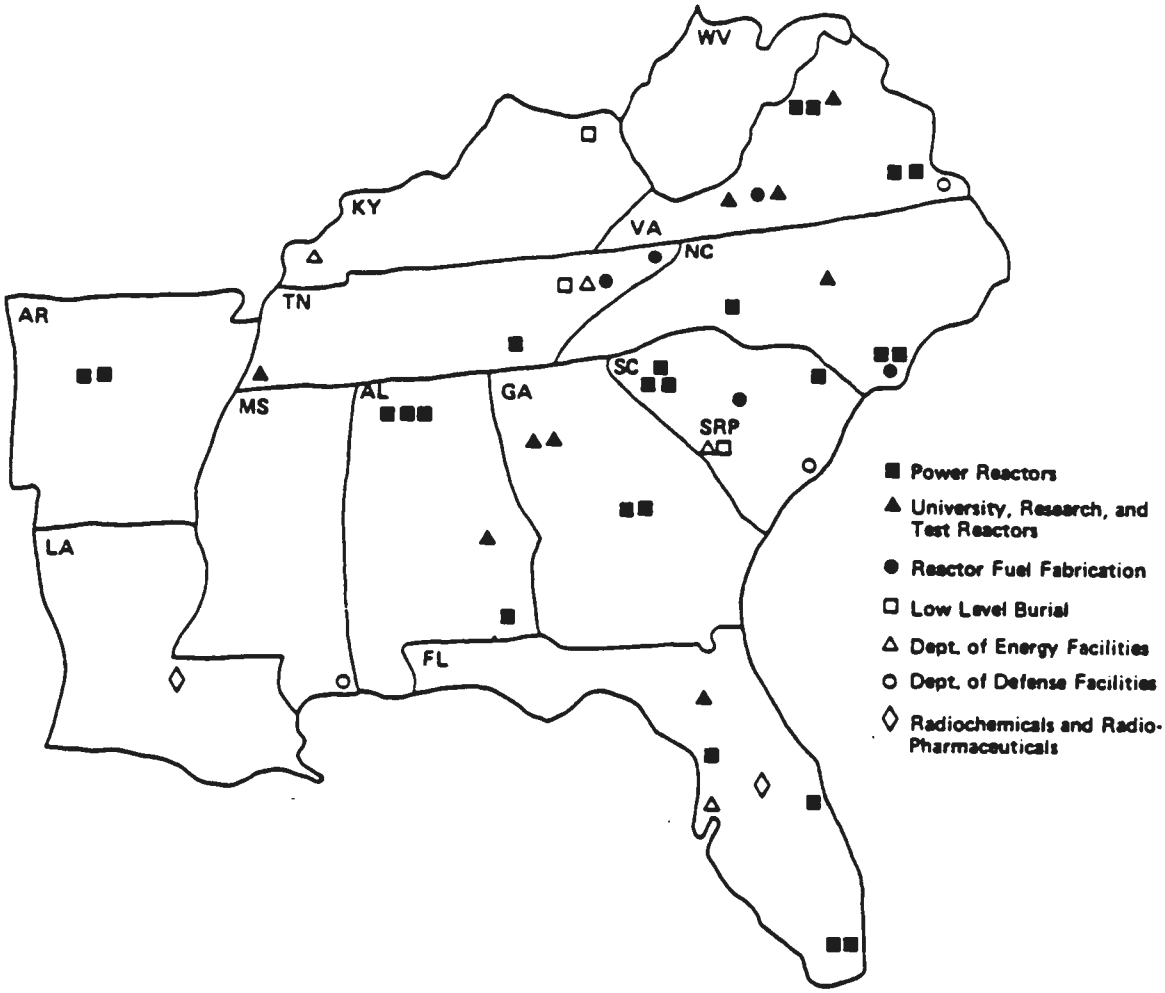

Figure A-51 Nuclear Facilities in the Southern United States - October 1980.

Table A-36 Average Dose Rates to 50-Mile Radius Population from Nuclear Facilities[74]

Facility	Dose to Average Individual, mrem/yr
Power reactors	
boiling water reactor (BWR)	0.0033
pressurized water reactor (PWR)	0.0021
Nonpower reactors	
test reactors	0.00044
research reactors	0.00021
university reactors	0.00097
Reactor fuel fabrication	0.000036
Low-level burial	0.012
DOE facilities - Oak Ridge, TN	0.0068

9516585.0241

receives an unmeasurable external radiation dose from transportation of low-level radioactive waste to the burial site.

A.8.7 Savannah River Plant

Construction of the Savannah River Plant started in February 1951, with completion of most of the major facilities by July 1955.[43] Releases of radioactive material to the environment from current operation (1978-1980) cause an average dose of about 0.1 mrem per year of operation to the 50-mile radius population and to downstream consumers of Savannah River water.[76-79]

A.8.8 Summary of Major Sources of Population Exposure

A summary of the major sources of exposure for the population with 50 miles of SRP and to the river water consuming population in Beaufort and Jasper Counties, South Carolina, and in Port Wentworth, Georgia, is presented in Table A-37. Natural background radiation and medical exposure account for about 48% and 47%, respectively, of the annual average dose of 194 mrem. Weapons test fallout, consumer and industrial products, and air travel combine to account for about 5% of the dose. Releases of radioactivity to the environment from SRP accounts for only about 0.1% of the dose.

Table A-37 Major Sources of Radiation Exposure in the Vicinity of SRP

Source of Exposure	Dose to Average Individual, mrem per year of exposure	Percent of Exposure
Natural Background Radiation		
Cosmic Radiation	32	
External Terrestrial Gamma	33.0	
Internal	28.0	
Natural Background Total	93	47.9
Medical Radiation		
Diagnostic X-Rays	77.3	
Radiopharmaceuticals	13.6	
Medical and Dental Personnel	0.4	
Medical Total	91.3	47.1
Weapons Test Fallout	4.6	2.4
Consumer and Industrial Products	4.5	2.4
Air Travel	0.5	0.3
Nuclear Facilities (other than SRP)	nil	-
Savannah River Plant - Environmental Radioactivity (1980)	0.2	0.1
Grand Total	194	

9515386.0242

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APPENDIX B. ENVIRONMENTAL PATHWAYS MODELS

The equations used to estimate environmental concentrations and doses for each of the transport/exposure pathways considered in this analysis are presented in this appendix. The presentation is brief with very little development of concepts. A more detailed discussion may be found in Reference 1.

B.1 Groundwater and Surface Water

Human and environmental exposure from groundwater pathways all involve release of the contaminants from the facility, movement downward through the unsaturated zone, and movement through the aquifer to an access location where uptake occurs. Differences in the groundwater pathways considered are manifested only in the different access locations and uptake scenarios. From a calculational point-of-view these differences are reflected primarily in dilution factors and, in the case of dose estimation, uptake factors.

B.1.1 General Considerations

For pathways involving the transport of a contaminant through an aquifer the concentration at the access location is given by

$$C(t) = \lambda_L Q_o \exp(-\lambda\,(t_c + t_v + t))\ \frac{1}{N} \sum_{j=o}^{N-1} (F_j(t_j) - F_j(t_j - 1/\lambda_L))\ /q_w \qquad \text{(B-1)}$$

where

Q_o = inventory at closure

$F_j(t_j) = 0.5\ U(t_j)[\mathrm{erfc}(z-) + \exp(d_j)\mathrm{erfc}(z+)]$

$U(t_j)$ = unit step function

$z\pm = \sqrt{d_j}\left(1 \pm t_j/Rt_{wj}\right)/2\sqrt{t_j/Rt_{wj}}$

q_w = dilution volume

$dj = [x + \frac{L}{N}(0.5 + j)]/a_L$

x = distance from near the edge of the facility to the access location

L = length of the facility in the direction of groundwater flow (m)

a_L = longitudinal dispersivity (m)

$t_j = t + t_{op}(1 - j/N) - t_c - t_v$ (yr)

t_{op} = operational lifetime of the facility (yr)

t_c = container lifetime (yr)

t_v = vertical transport time, Rx_a/v (yr)

$t_{wj} = [x + \frac{L}{N}(0.5 + j)]/v_a$

R = retardation factor of contaminant in the soil

v_a = linear groundwater velocity in the saturated zone (m/yr)

x_a = distance from the bottom of the facility to the water table (m)

v = average vertical water velocity in the unsaturated zone (m/yr)

λ = radioactive decay constant of the contaminant (yr^{-1})

λ_L = leach fraction (yr^{-1}).

This expression is an extension of the one-dimensional transport problem for a point source with a band release into a semi-infinite column.[2] Though radioactive decay has been incorporated into the solution, nondecaying species are easily handled by setting the decay constant equal to zero. The extensions to Burkholder's work[2] which have been implemented in equation B-1 are, 1) consideration of a distributed source, i.e., an area source, 2) emplacement of the wastes uniformly throughout the operations phase, 3) the optional use of a container life, and 4) transport via plug flow through the unsaturated zone.

The dose, or more specifically the annual equivalent whole body dose commitment[3] which results from using contaminated water at an access location is given by

$$D(t) = C(t) \cdot U\ (DF)_{ing} \qquad \text{(B-2)}$$

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Supplemental Table
Universal Transverse Mercator Coordinates
Archaeological Sites Associated with Alternative Waste Sites - SRP

Waste Site Designation	Archaeological Site	U.T.M. Easting	U.T.M. Northing	Zone
G	38AK155	437500	3683960	17
G	38AK279	438460	3684100	17
G	38AK280	440020	3684700	17
G	38AK281	438840	3684200	17
G	38AK338	438380	3684030	17
L	38AK424	435800	3682000	17
L	38AK425	436400	3682350	17
Y(III)	38AK428	439720	3685500	17
Y(III)	38AK429	439820	3685740	17
Y(III)	38AK430	439840	3686100	17
Y(III)	38AK431	440520	3686000	17
Y(III)	38AK432	440580	3685480	17
Y(III)	38AK433	440020	3685300	17

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implementing a viable cultural resource management plan for the Savannah River Plant.

However, because these sites lack either sufficient content, integrity of deposits, and/or there are similar sites preserved nearby, they have little potential for yielding additional information that would enhance our understanding of the history and prehistory of the region. Consequently, none of these thirteen sites are considered significant and eligible for the National Register of Historic Places. Therefore, we conclude that: 1) there will be no effect on the archaeological resources through the development of any of the alternative waste storage/disposal areas, and 2) no further archaeological work is recommended within these areas. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for the development of any of the alternative waste storage/disposal facilities.

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al. 1978) contain comparable temporal components and occur in similar physiographic settings; thus, minimizing the research potential of 38AK428.

For the above reasons, the authors recommend that: 1) 38AK428, 38AK429, 38AK430, 38AK431, 38AK432, and 38AK433 are not eligible for nomination to the National Register of Historic Places because of their disturbed contexts and/or their limited potential to provide additional information about the past human occupations in the region, and 2) that no further archaeological consideration of these sites and Parcel Y (III) is warranted. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for these six sites and for the development of this alternative waste storage/disposal facility.

Summary and Conclusions

An intensive archaeological survey with subsurface testing was conducted at each of the six alternative waste storage/disposal facilities (Parcels B, G, L, P, Q, and Y (III)). No archaeological sites were previously recorded for Parcels B, P, and Q, nor were any discovered in these parcels during the course of the present survey.

Through previous research and the present survey, a total of thirteen archaeological sites have been recorded and tested within the confines of Parcels G (38AK155, 38AK279, 38AK280, 38AK281, and 38AK338), L (38AK424, and 38AK425), and Y (III) (38AK428, 38AK429, 38AK430, 38AK431, 38AK432, and 38AK433). These sites have provided locational and artifact assemblage data that will, when incorporated with other survey and excavation data, ultimately be useful for modeling variability in prehistoric and historic cultural systems; the elucidation of which is important not only for a broad understanding of these human populations, but also for deriving and

to the historic period occupation of the region, especially in view of the documentation of numerous, similar sites on the Savannah River Plant.

For the above reasons, the authors recommend that: 1) 38AK424 and 38AK425 are not eligible for nomination to the National Register of Historic Places because of their disturbed contexts and/or their limited potential to provide additional information about the past human occupations in the region, and 2) that no further archaeological consideration of these sites and Parcel L is warranted. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for these two sites and for the development of this alternative waste storage/disposal facility.

Parcel Y (III)

Six prehistoric archaeological sites (38AK428, 38AK429, 38AK430, 38AK431, 38AK432, and 38AK433) are recorded for this parcel. Four of these sites (38AK429, 38AK430, 38AK431, and 38AK432) contain subsurface deposits with integrity, but their low artifact density, low artifact assemblage diversity, and our inability to recover temporally diagnostic artifacts at the survey and testing level employed, indicate that these sites have little potential for providing new, signigicant data of relevance to the model presented in Chapter III and to our general understanding of the prehistory of the region. One site (38AK433) consisted of an isolated surface find (thinning flake - not temporally diagnostic) in a disturbed context.

In contrast, site 38AK428 has intact deposits that contain a moderate artifact density and artifact assemblage diversity, which is atypical of the upland, sandhills environment. However, nearby sites 38AK34 and 38AK224 (reported in Hanson et

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and 38AK280 indicate that all, or portions, of these two sites may represent secondary deposition and, hence, highly disturbed contexts. In contrast, prehistoric site 38AK338 contains subsurface deposits with integrity, but the low artifact density and artifact assemblage diversity indicate that this site has little potential for providing new, significant data of relevance to the model presented in Chapter III and to our general understanding of the prehistory of the region.

For the above reasons, the authors recommend that: 1) 38AK155, 38AK279, 38AK280, 38AK281 and 38AK338 are not eligible for nomination to the National Register of Historic Places because of their disturbed contexts and/or their limited potential to provide additional information about the past human occupations in the region, and 2) that no further archaeological consideration of these sites and Parcel G is warranted. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for these five sites and for the development of this alternative waste storage/disposal facility.

Parcel L

Two prehistoric/historic archaeological sites (38AK424 and 38AK425) are recorded for this parcel. Site 38AK425 occurs exclusively in a surface context in a high, upland area characterized by erosion. In contrast, 38AK424 contains subsurface deposits with integrity, but the low prehistoric artifact density and artifact assemblage diversity indicate that the prehistoric component of this site has little potential for providing new, significant data of relevance to the model presented in Chapter III and to our general understanding of the prehistory of the region. Similarly, the 20th Century component of 38AK424 (represented by the surface and subsurface remains of a tenant homestead) has little potential to provide new, significant information of relevance

Chapter VI

ARCHAEOLOGICAL RECOMMENDATIONS

Introduction

The intensive archaeological survey and testing of the six alternative waste storage/disposal facilities (survey parcels) resulted in the examination of thirteen archaeological sites. Each site was examined for the explicit purpose of establishing the presence of significant archaeological information in light of the eligibility criteria for nomination to the National Register of Historic Places. Further, information relative to the determination of potential effects was derived for each site location. This section summarizes the research results and presents recommended determinations of eligibility and considerations of effects with specific reference to the alternative waste storage/disposal facilities (survey parcels). As with the previous chapter, the archaeological sites are discussed by survey parcel.

Parcels B, P and Q

No archaeological sites were previously recorded for these parcels, nor were any discovered during the course of the present survey. Consequently, it is recommended that no additional archaeological work be conducted within these areas. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for the development of any of these alternative waste storage/disposal facilities.

Parcel G

Five prehistoric/historic archaeological sites (38AK155, 38AK279, 38AK280, 38AK281 and 38AK338) are recorded for this parcel. Four of these sites (38AK155, 38AK279, 38AK280 and 38AK281) occur primarily or exclusively in a surface context in high, upland areas characterized by erosion. In addition, the historic components at 38AK279

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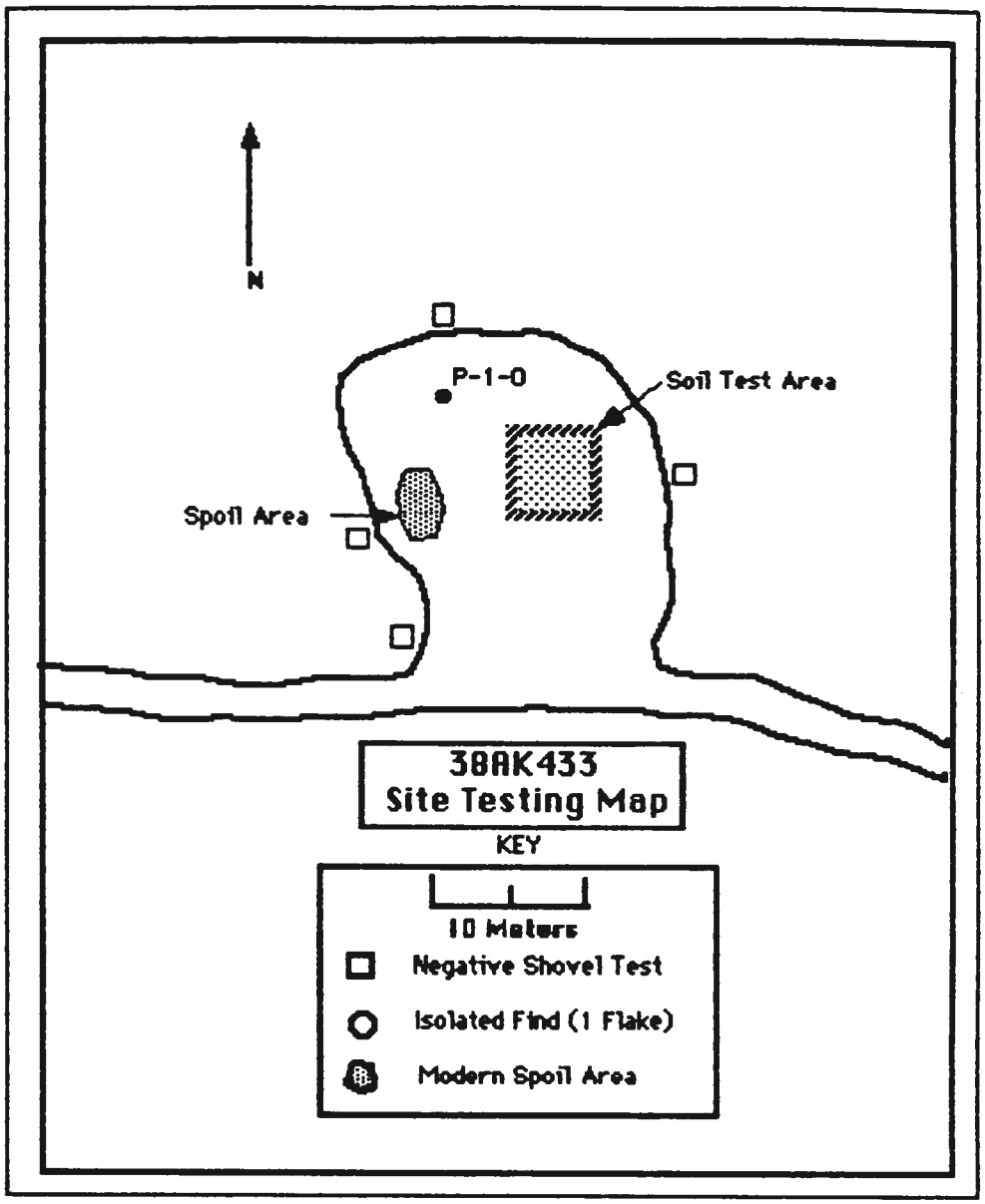

Figure 19: Site testing map of 38AK433

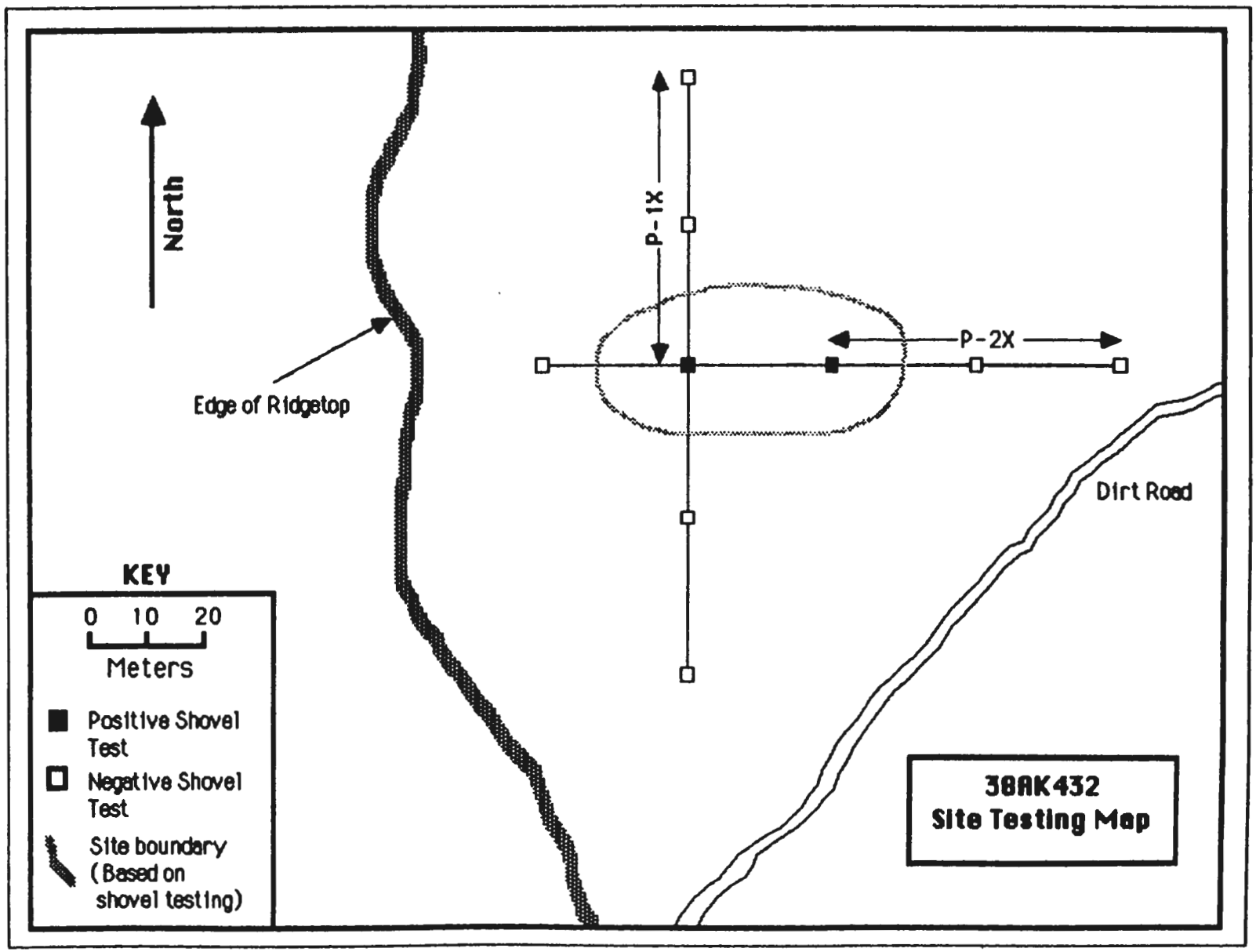

Figure 18: Site testing map of 38AK432.

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Figure 17: Site photograph, 38AK432

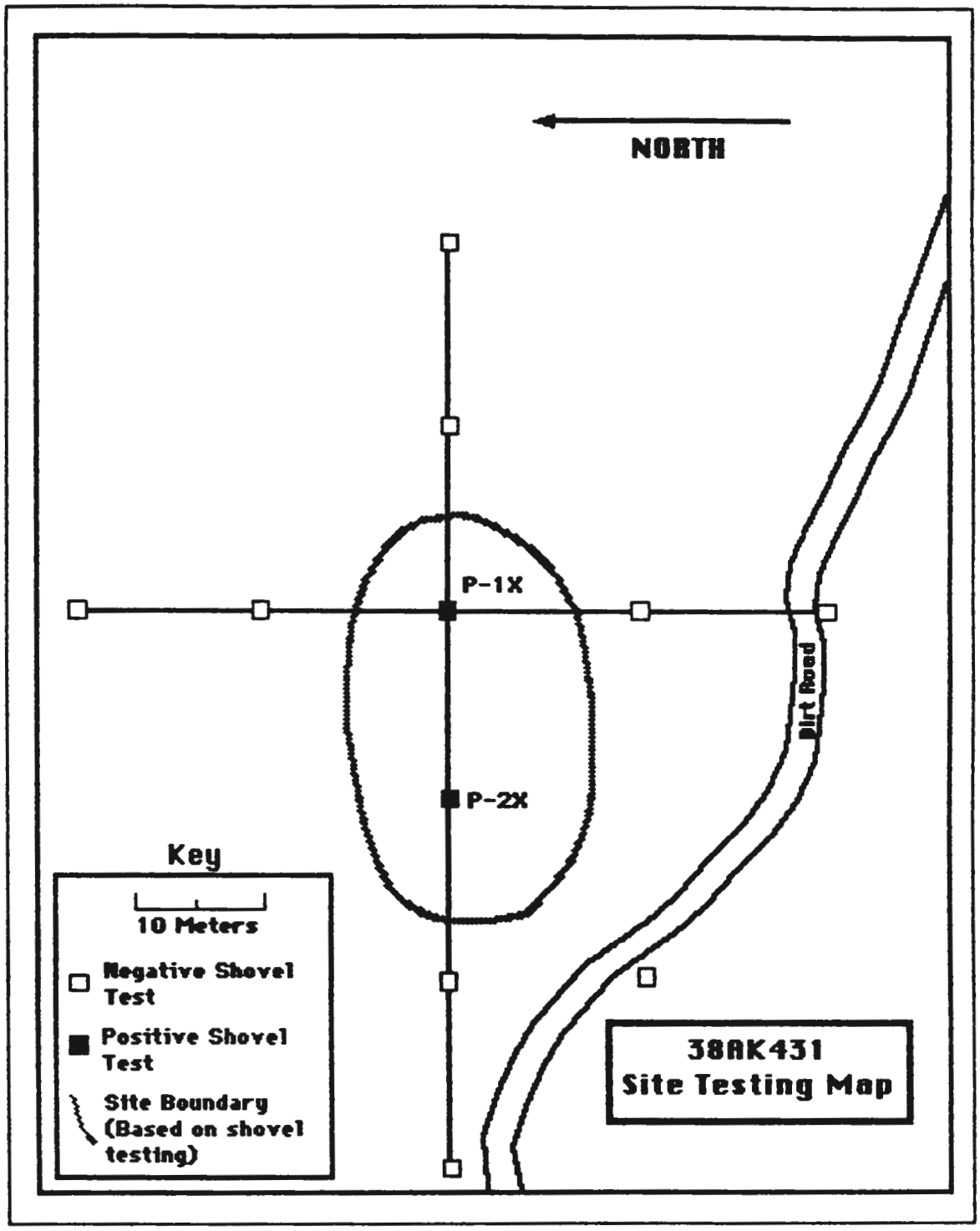

Figure 16: Site testing Map of 38AK431.

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Figure 15: Site photograph, 38AK431

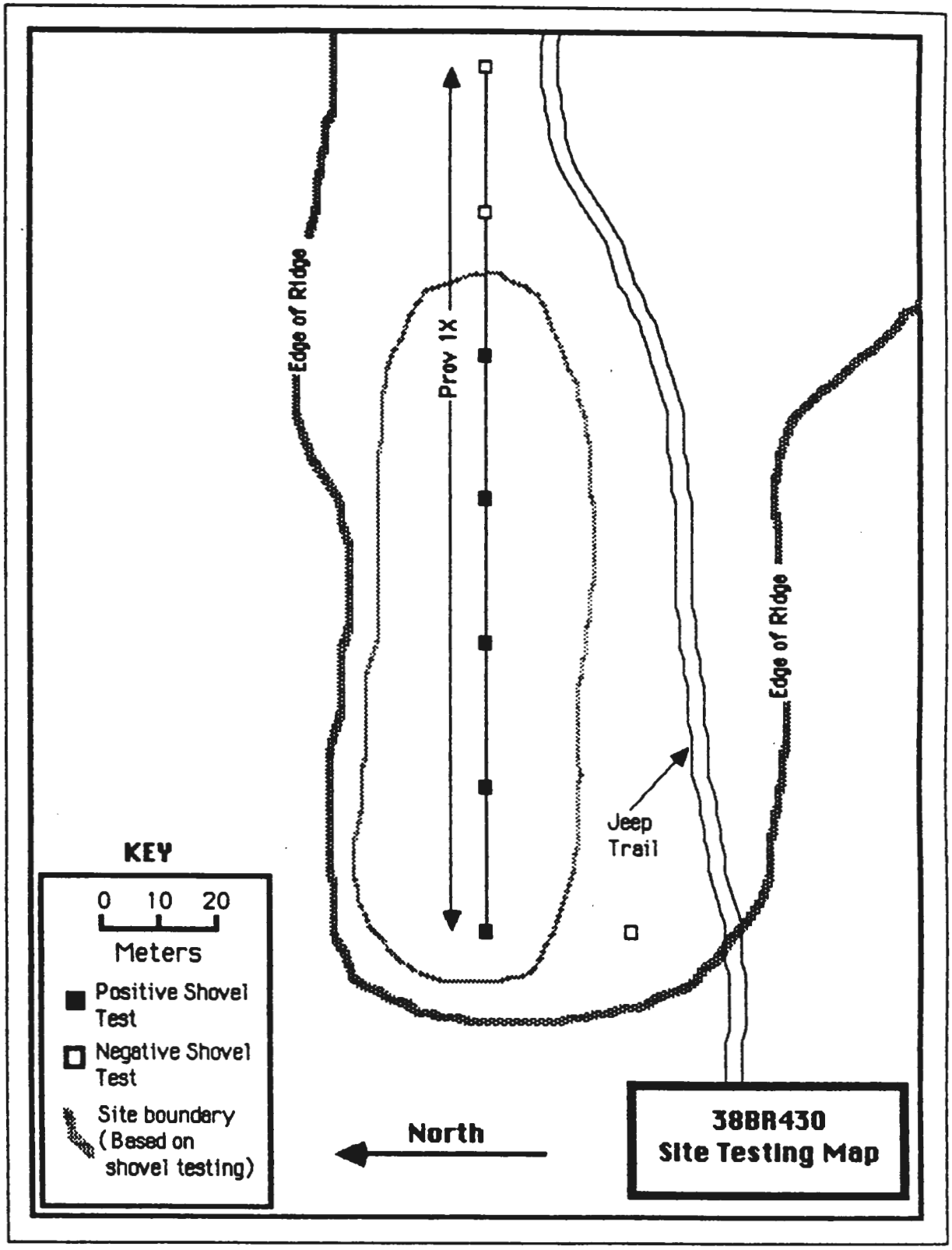

Figure 14: Site Testing Map of 38AK430.

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Figure 13: Site photograph, 38AK430

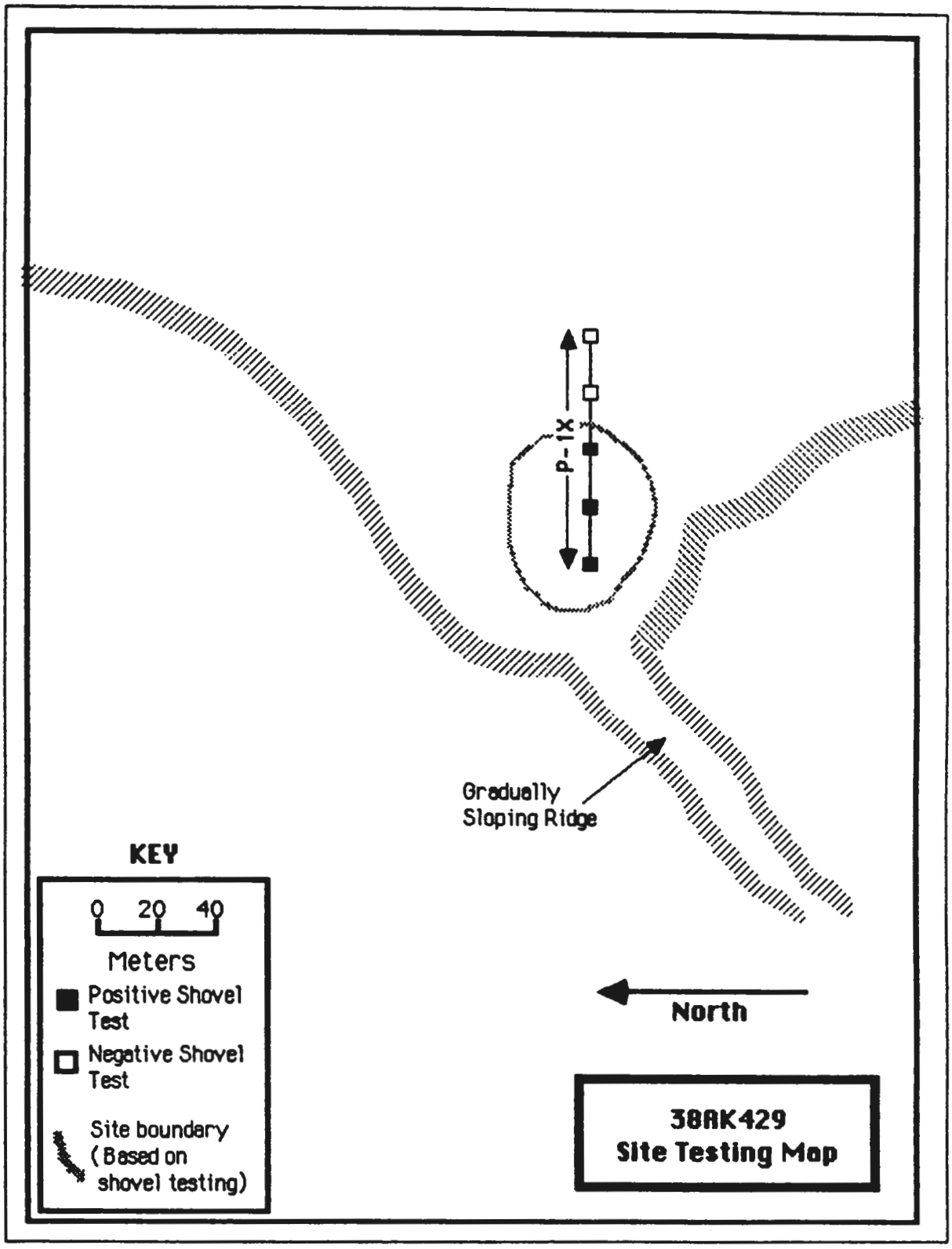

Figure 12: Site testing map of 38AK429.

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Figure 11: Site photograph, 38AK429

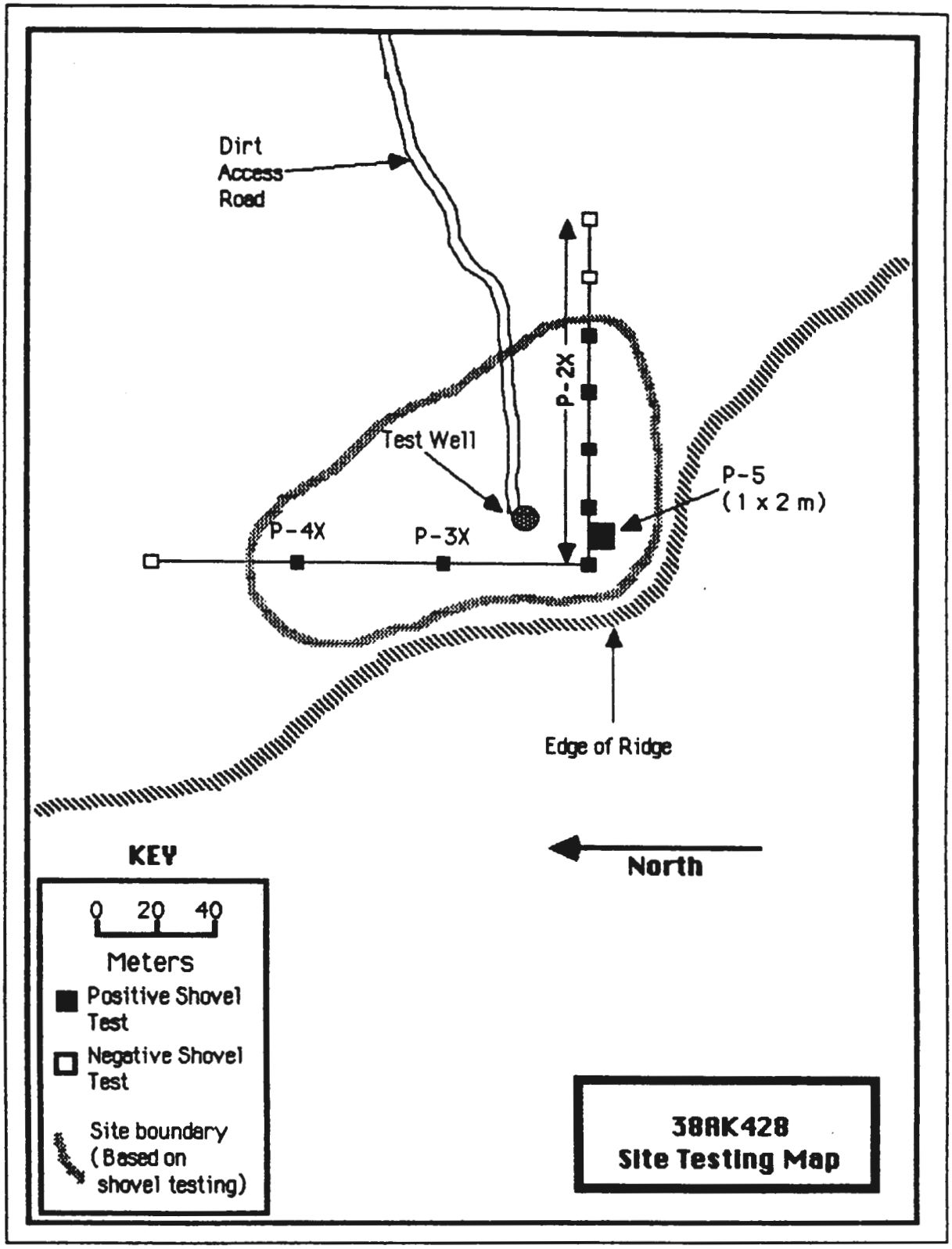

Figure 10: Site testing map of 38AK428.

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Figure 9: Site photograph, 38AK428

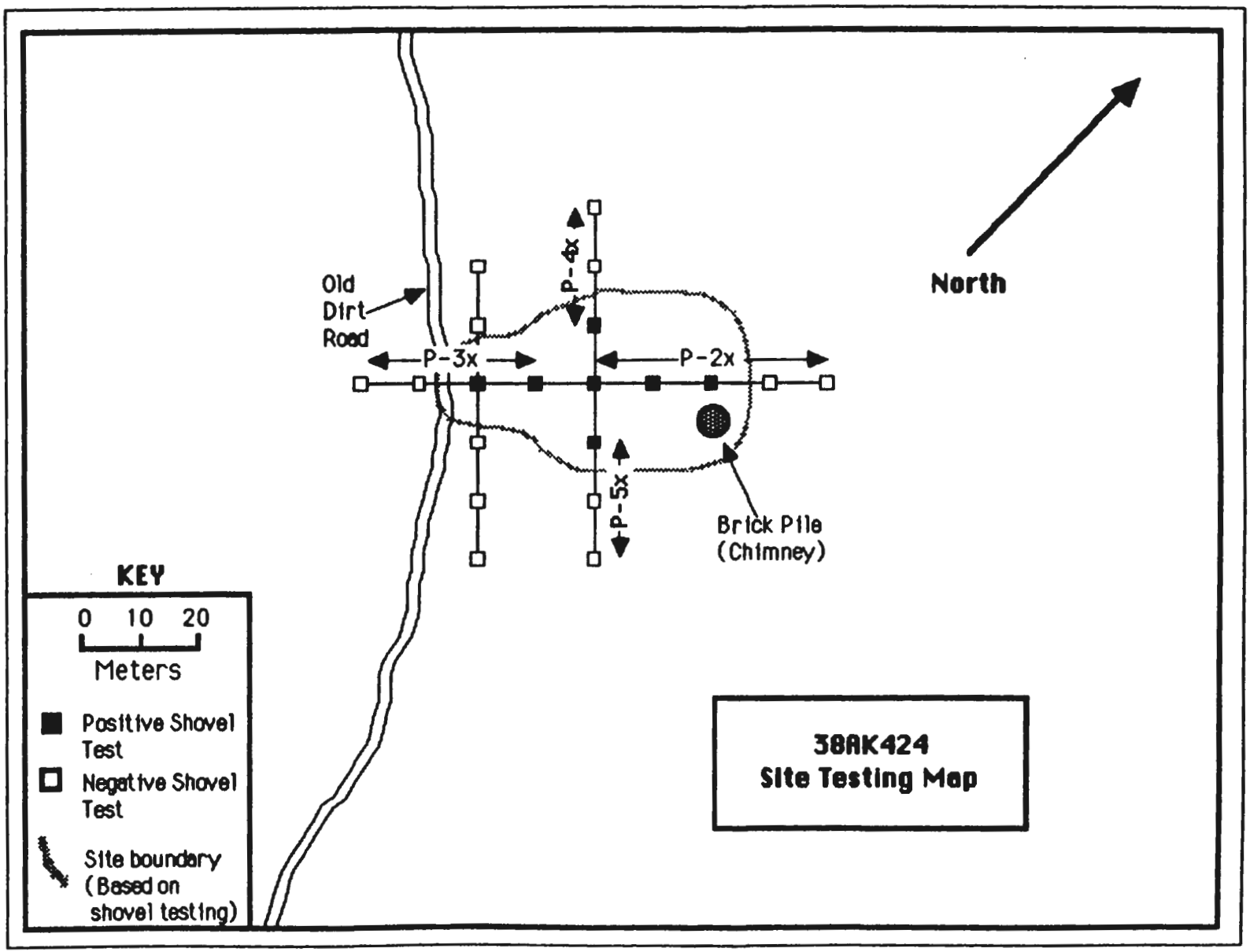

Figure 8: Site testing map of 38AK424.

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Figure 7: Site photograph, 38AK424

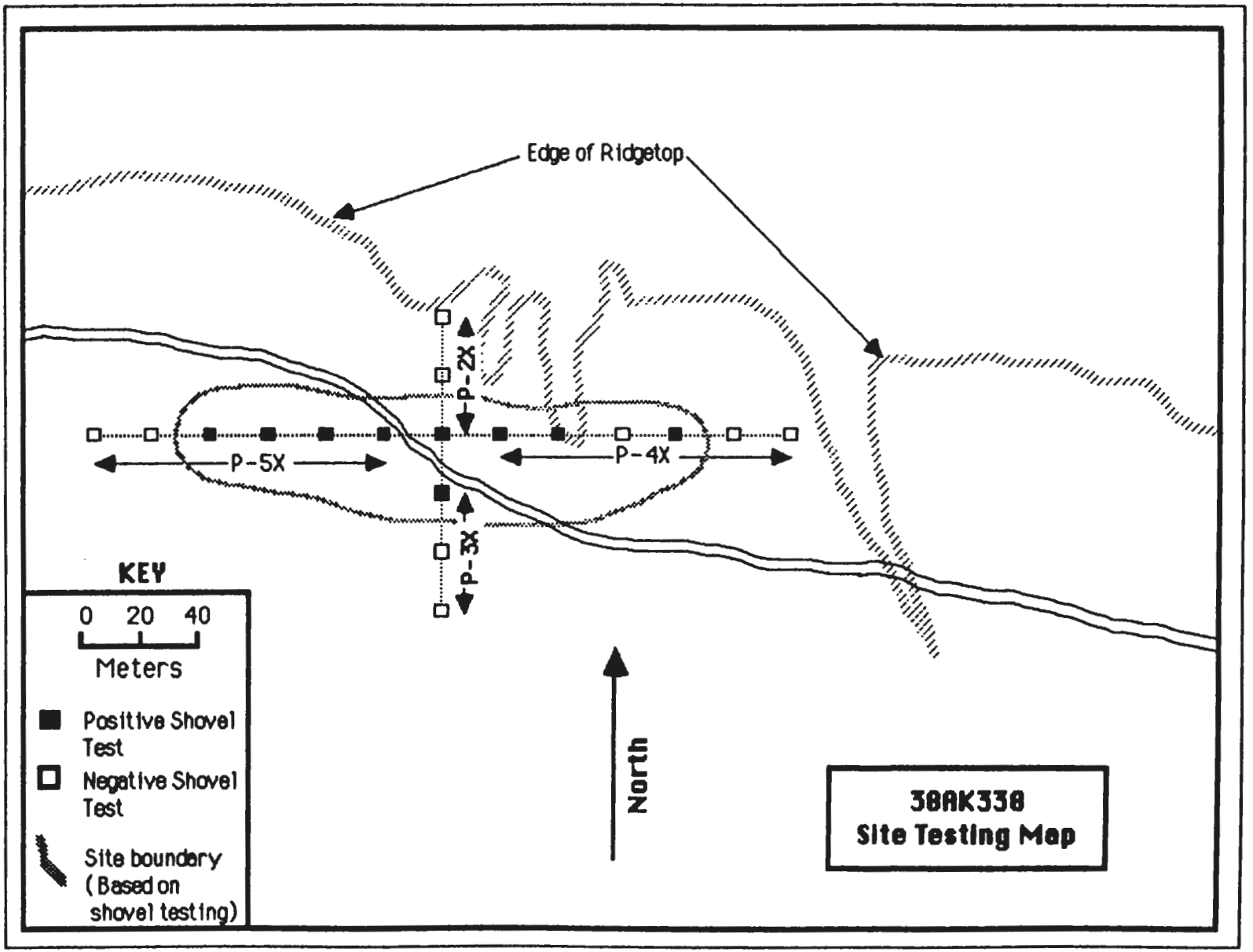

Figure 6: Site testing map of 38AK338.

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Figure 5: Site photograph 38AK338

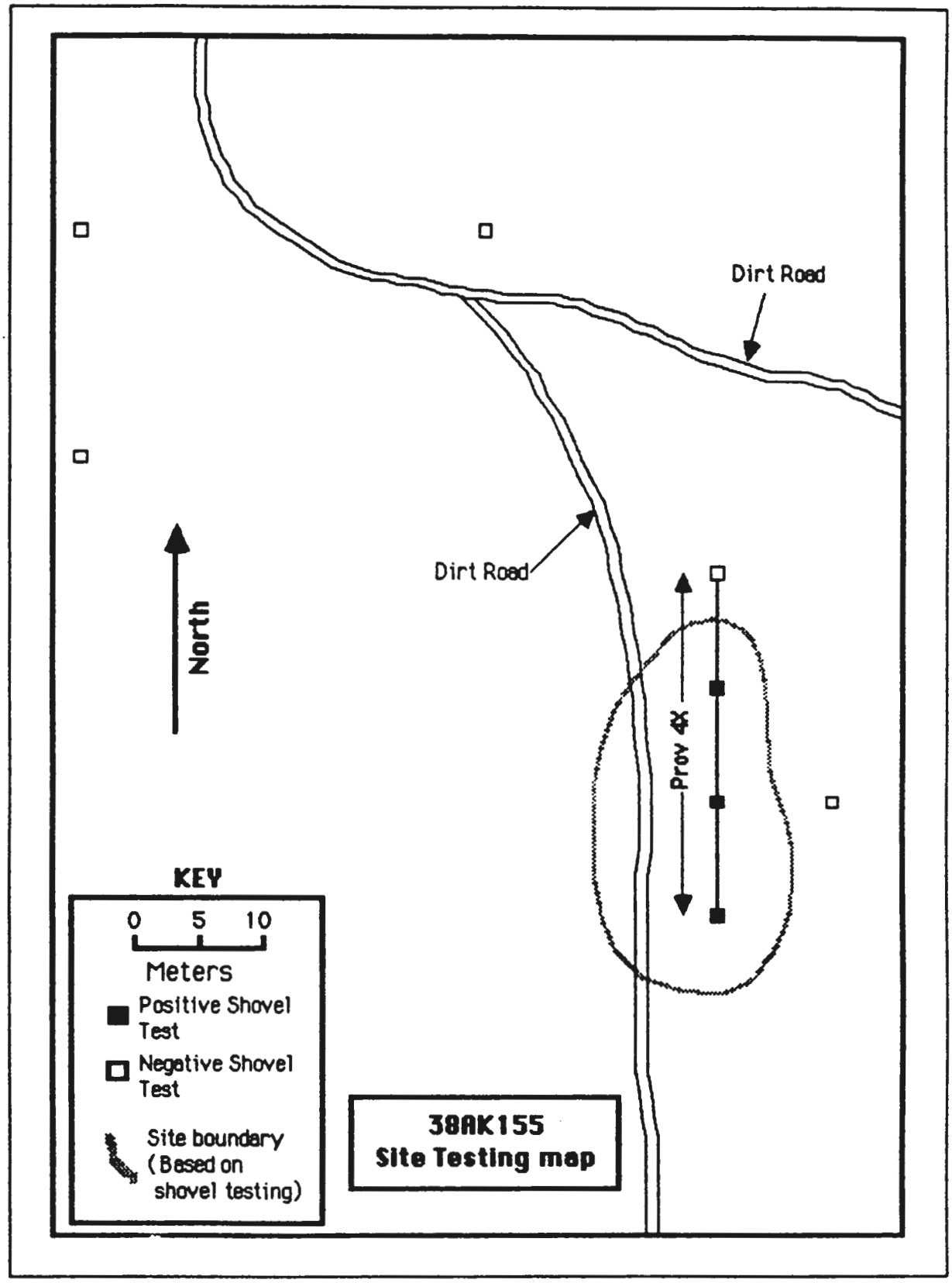

Figure 4: Site Testing Map of 38AK155.

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Figure 3: Site photograph, 38AK155

Table 6
Historic Sites within the Proposed Waste Management Areas:
Artifact Assemblage Inventory

Site Number	38AK279	38AK280	38AK424	38AK424	38AK424	38AK424	38AK424
Provenience	1-0	1-0	1-0	2-X	3-X	4-X	5-X
CERAMICS							
Pearlware	2	2					
Finger Painted Pearlware		2					
Shell-edge Pearlware		1					
Whiteware	3	2	5			1	
Decorated Whiteware	2	1	2				
Alkaline Glaze	1	2					
Albany Slipware				2			
Red-brown Slipware	1						
Porcelain			3				
OTHER MATERIAL							
Modern Glass	2		8	4			1
Glass Bead					1		
Pipe Stem	1						
Cut Nails				2	1		
Wire Nails				3			
Brick/Mortar (grams)	0.8		810.8	46	82.4	16.1	

Table 5a: Prehistoric Sites within the Proposed Waste Management Areas: Ceramic Assemblage Inventory

SITE NUMBER	PROV-LEVEL	FIBER TEMPERED	SAND TEMPERED								TOTAL CERAMIC ARTIFACTS
		Plain	Plain	Parallel Simple Stamped	Crossed Simple Stamped	Linear Check/ S. S.	Bold Cord Marked	Fine Cord Marked	Fine Crossed Cord	Eroded	
38AK155	1-0								1		1
38AK155	2-0										0
38AK155	3-0		2					1			3
38AK155	4-X							1			1
38AK279	1-0		1	3				1		1	6
38AK280	1-0		6	3					8	7	24
38AK281	1-0								1		1
38AK338	1-0			2							2
38AK338	4-X		1								1
38AK338	5-X		3								3
38AK424	3-X	2									2
38AK425	1-0				3	1					4
38AK428	1-0							1			1
38AK428	2-X						1	5		1	7
38AK428	5-A		1					2		1	4
38AK428	5-B						5	2	2		9
38AK428	5-C			2			1			1	4
38AK428	5-D									1	1

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TABLE 5: Prehistoric Sites within the Proposed Waste Management Areas: Artifact Assemblage Inventory

SITE NUMBER	PROV-LEVEL	Debitage	Fire Cracked Rock	Hafted Bifaces	Other Bifaces	Utilized Flakes	Other Tools	RAW MATERIALS				TOTAL LITHICS	TOTAL CERAMICS	BONE	TOTAL ARTIFACTS
								CPC	TAC	QTZ	OTH				
38AK428	5-F	5						5				5			5
38AK428	5-G	7			1		1 (GS)	8			1	9			9
38AK429	1-X	11						11				11			11
38AK430	1-X	6						5			1	6			6
38AK431	1-X	1						1				1			1
38AK431	2-X	1						1				1			1
38AK431	3-X	1							1			1			1
38AK432	1-X	1						1				1			1
38AK432	2-X	1						1				1			1
38AK433	1-0	1						1				1			1

KEY

CPC = Coastal Plain Chert	SR = Savannah River
TAC = Thermally Altered CPC	ST = Small Triangular
QTZ = Quartz	HS = Hammerstone
OTH = Other Lithic Material	STE = Steatite
MM = Morrow Mountain	GS = Ground Stone

TABLE 5: Prehistoric Sites within the Proposed Waste Management Areas: Artifact Assemblage Inventory

SITE NUMBER	PROV-LEVEL	Debitage	Fire Cracked Rock	Hafted Bifaces	Other Bifaces	Utilized Flakes	Other Tools	RAW MATERIALS				TOTAL LITHICS	TOTAL CERAMICS	BONE	TOTAL ARTIFACTS
								CPC	TAC	QTZ	OTH				
38AK155	1-0	1		1 (MM)				1		1		2	1		3
38AK155	2-0	9		2 (ST)				5	6			11			11
38AK155	3-0	7	1	1 (ST)			1 (HS)	2	6	2		10	3		13
38AK155	4-X	3						1	2			3	1		4
38AK279	1-0	10		1				11				11	6		17
38AK279	2-0	1							1			1			1
38AK280	1-0	12		2 (1-SR)		1		15				15	24		39
38AK281	1-0	37						27	9		1	37	1		38
38AK281	2-0				1			1				1			1
38AK338	1-0	5		1	1			2	5			7	2		9
38AK338	2-X	2						1	1			2			2
38AK338	3-X	3						3				3			3
38AK338	4-X	2						1	1			2	1		3
38AK338	5-X	4							4			4	3		7
38AK424	2-X	1						1				1			1
38AK424	3-X												2		2
38AK425	1-0	1						1				1	4		5
38AK428	1-0												1		1
38AK428	2-X	18						13	1	1	3	18	7		25
38AK428	3-X	4						2		2		4			4
38AK428	4-X	6						6				6			6
38AK428	5-A	3						2	1			3	4	1	7
38AK428	5-B	8						8				8	9	1	17
38AK428	5-C	16					1 (STE)	11	3		3	17	4	2	21
38AK428	5-D	29						21	8			29	1		30
38AK428	5-E	10			1			9	2			11			11

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Table 4: Prehistoric and Historic Sites within the Proposed Waste Management Areas: Site Locational Data and Culture-Historical Affiliation

Potential Waste Site Designation	Site Number	Site Size (meters)	Site Depth (cm)	Landform	Elevation (feet)	Aspect	Slope %	Rank of Nearest Stream	Drainage System	Distance to Water (meters)	On-Site Soil Type	Culture-Historical Affiliation(s)
G	38AK155	15 x 35	40	Ridgetop	250	SW	2	2	UTR	160	MIXED	LW, MA
G	38AK279	75 x 75	0	Ridge Slope	250	NW	2	1	UTR	110	Vaucluse & Blaney	LW, MW, EW, 19th & 20th C.
G	38AK280	75 x 75	0	Ridge Nose	260	NE	2	2	UTR	900	Vaucluse & Blaney	LW, MW, EW, LA 19th C.
G	38AK281	1 x 1	0	Ridge Slope	260	NE	1	1	UTR	300	Vaucluse & Blaney	LW
G	38AK338	30 x 90	65	Ridge Nose	240	NE	1	1	UTR	35	Americus	MW, EW
L	38AK424	30 x 40	40	Terrace	240	SE	1	1	UTR	350	Orangeburg & Red Bay	Ceramic LA, 20th C.
L	38AK425	20 x 20	0	Ridgetop	260	W	1	1	UTR	160	Orangeburg & Red Bay	MW
Y (III)	38AK428	60 x 140	85	Ridge Nose	250	W	3	4	UTR	666	Fuquay & Wagram	LW, MW, Archaic?,
Y (III)	38AK429	40 x 70	70	Ridge Nose	250	W	3	4	UTR	600	Fuquay & Wagram	Lithic
Y (III)	38AK430	30 x 120	60	Ridge Nose	225	W	5	4	UTR	333	Gunter Sand	Lithic
Y (III)	38AK431	25 x 50	55	Ridge Nose	260	N	2	3	UTR	400	Gunter Sand	Lithic
Y (III)	38AK432	25 x 50	60	Ridge Nose	260	N	2	3	UTR	530	Gunter Sand	Lithic
Y (III)	38AK433	1 x 1	0	Ridgetop	270	W	1	4	UTR	1000	Fuquay & Wagram	Lithic

KEY:

N = North	UTR = Upper Three Runs Creek
NE = Northeast	LW = Late Woodland
NW = Northwest	MW = Middle Woodland
W = West	EW = Early Woodland
SE = Southeast	LA = Late Archaic
SW = Southwest	Lithic = Prehistoric Lithic

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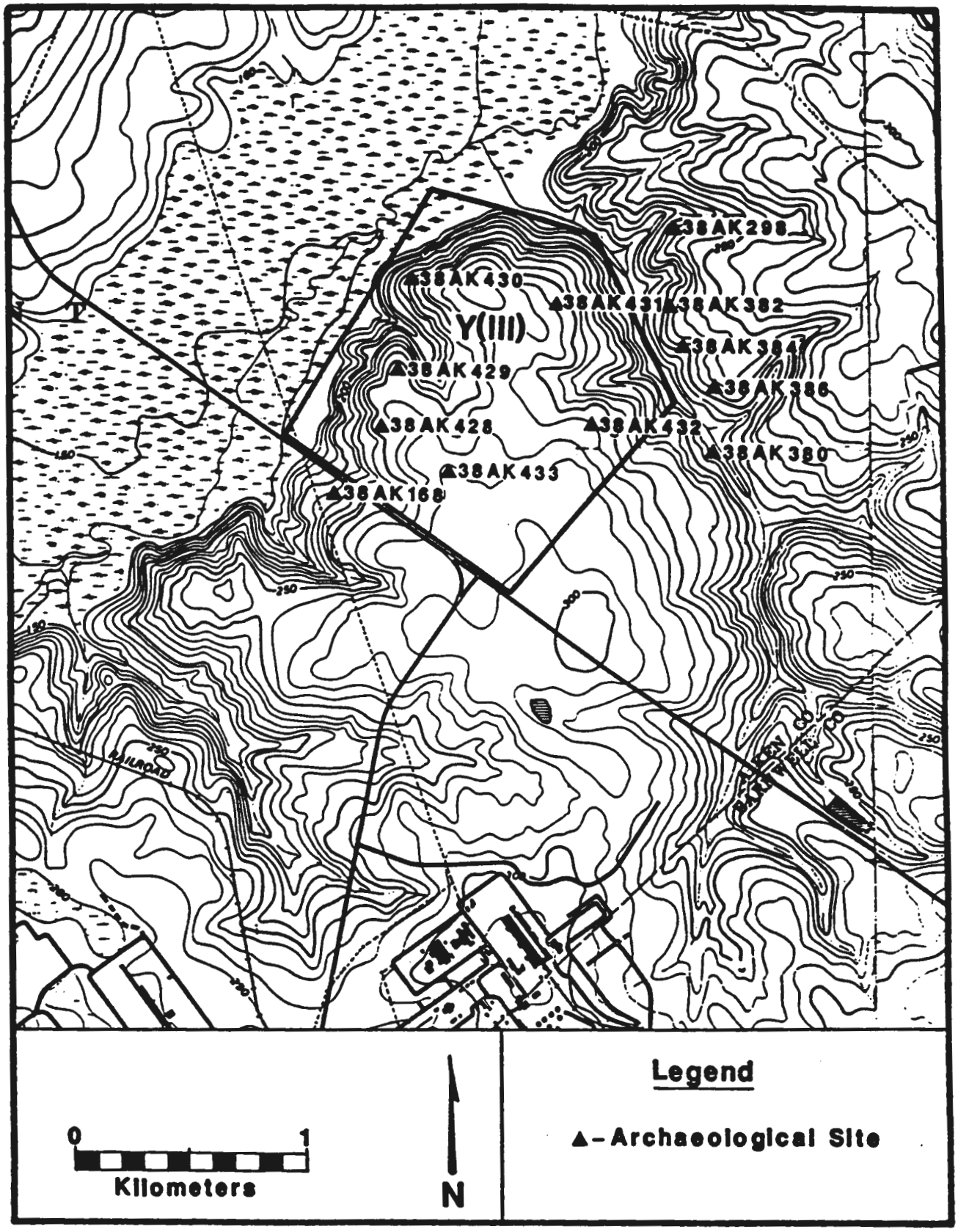

Figure 2 (e): Location of archaeological sites within and adjacent to proposed waste manageme... area Y (III).

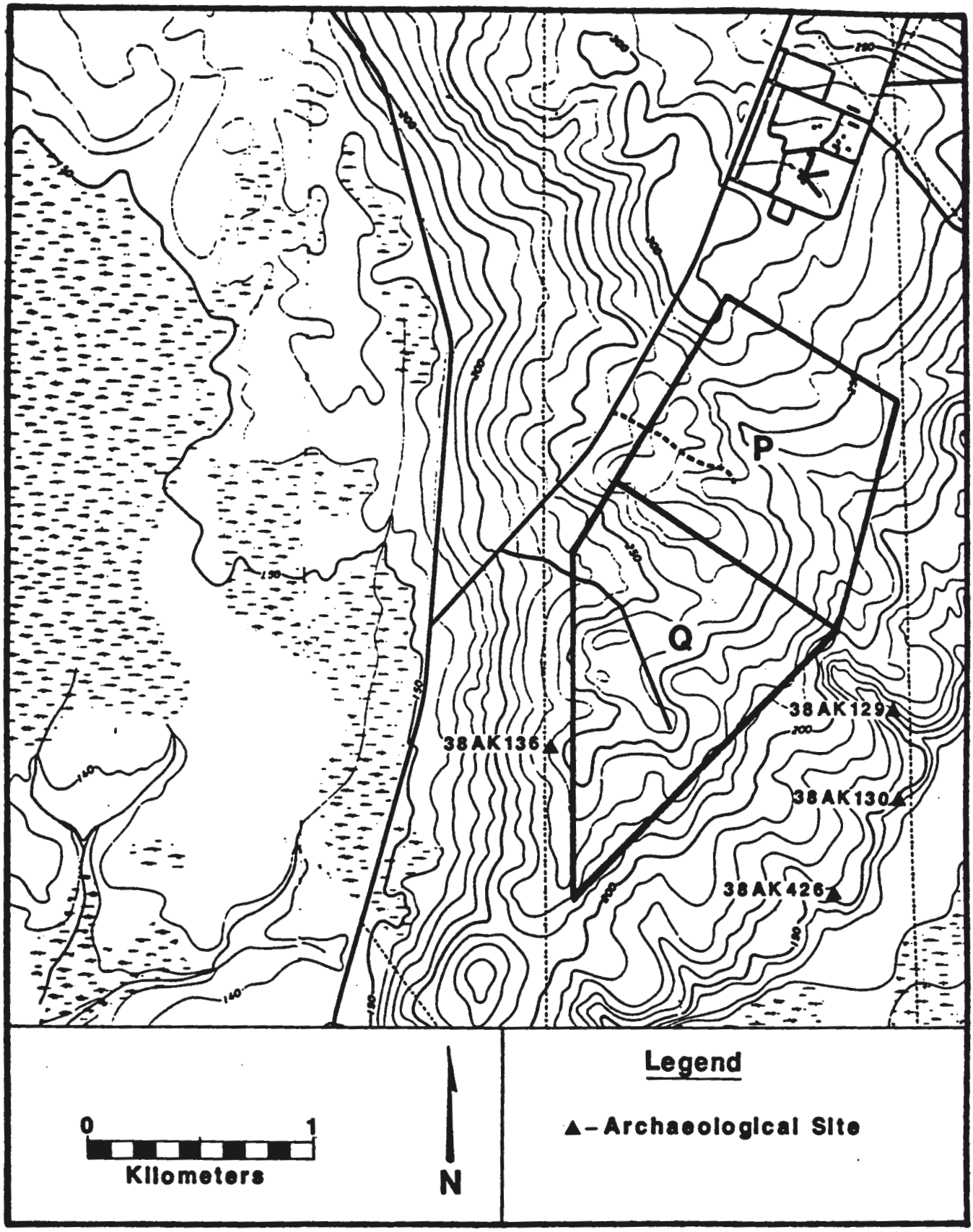

Figure 2 (d): Location of archaeological sites within and adjacent to proposed waste management areas P and Q.

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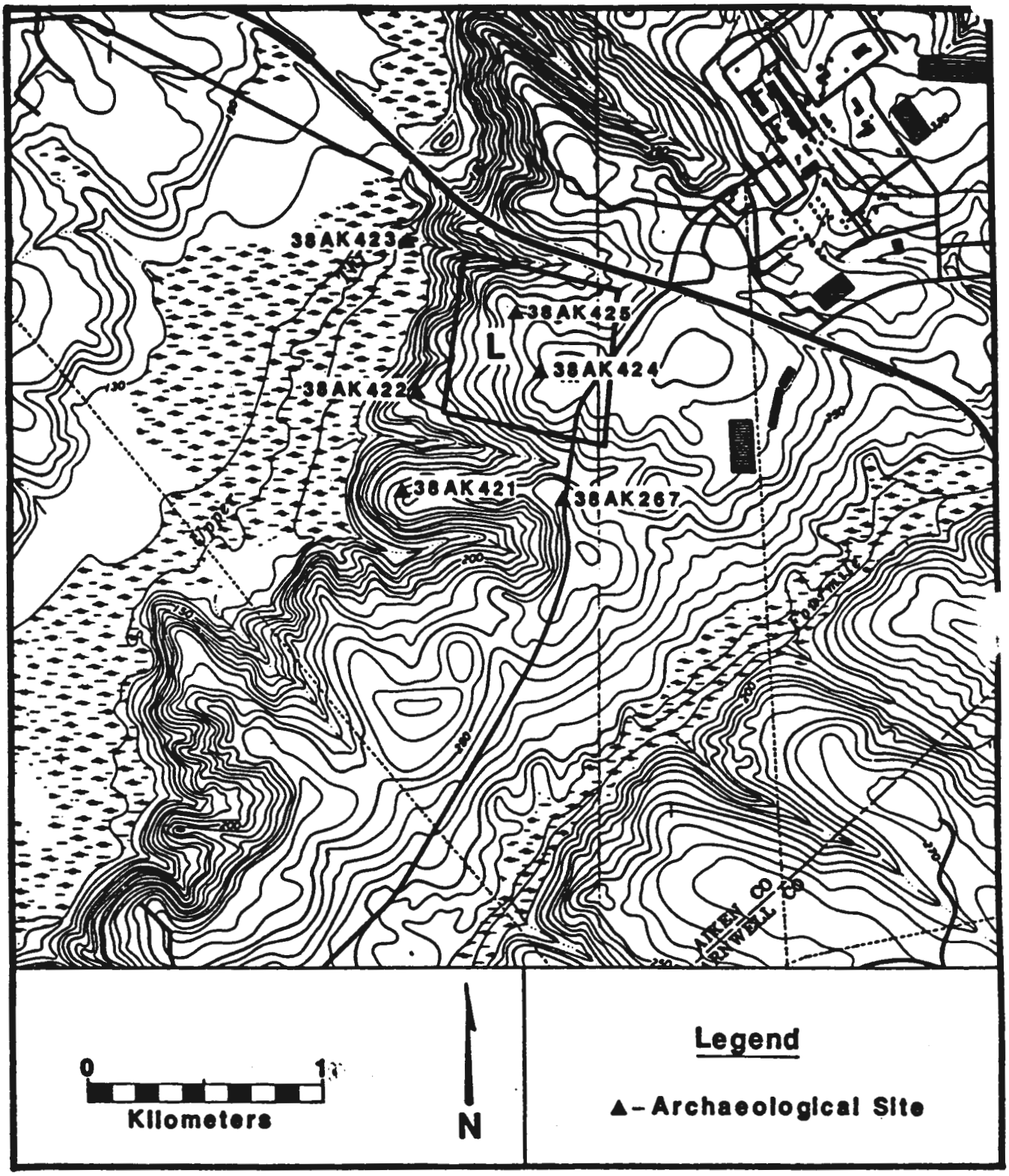

Figure 2 (c): Location of archaeological sites within and adjacent to proposed waste management area L.

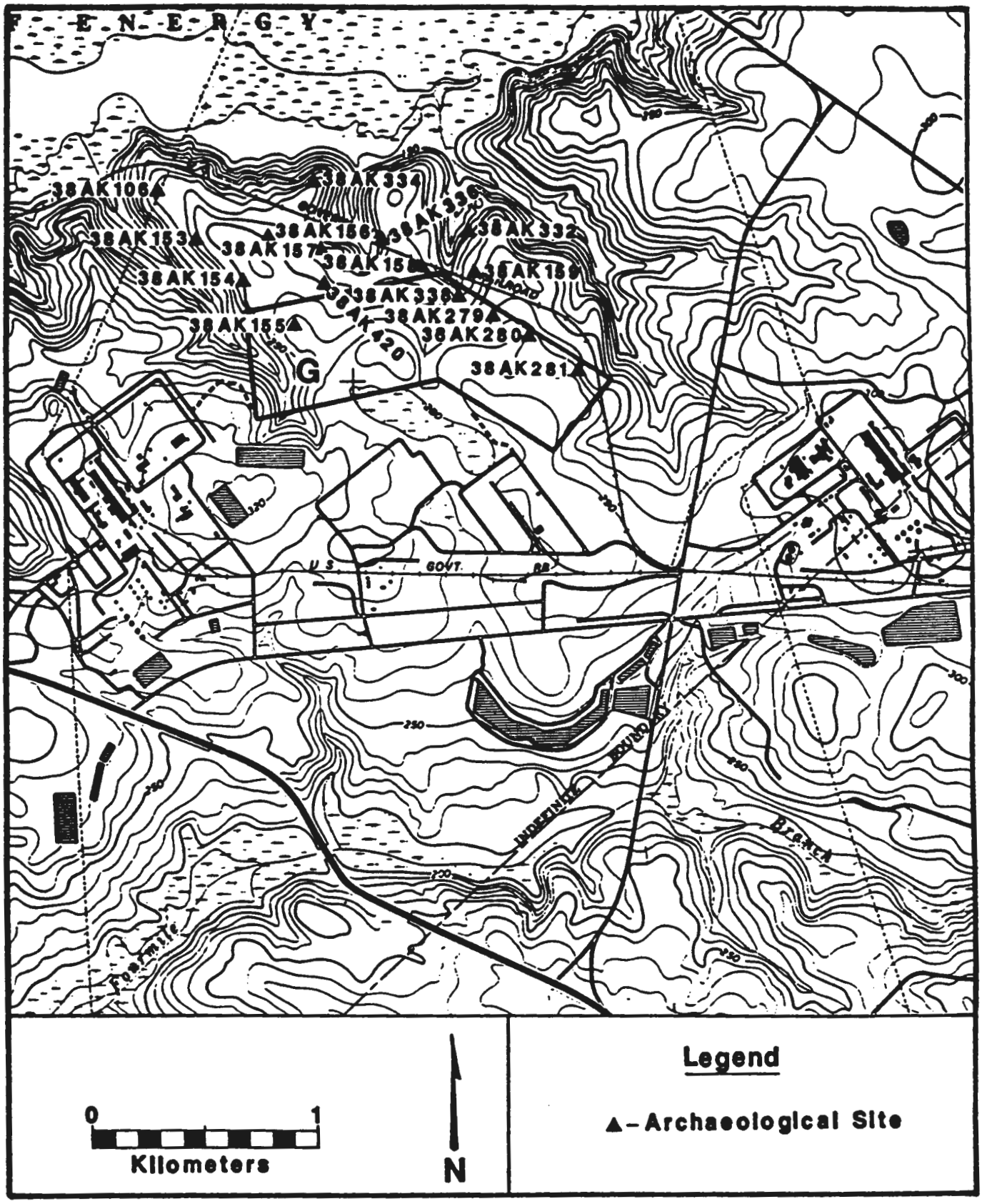

Figure 2 (b): Location of archaeological sites within and adjacent to proposed waste management area G.

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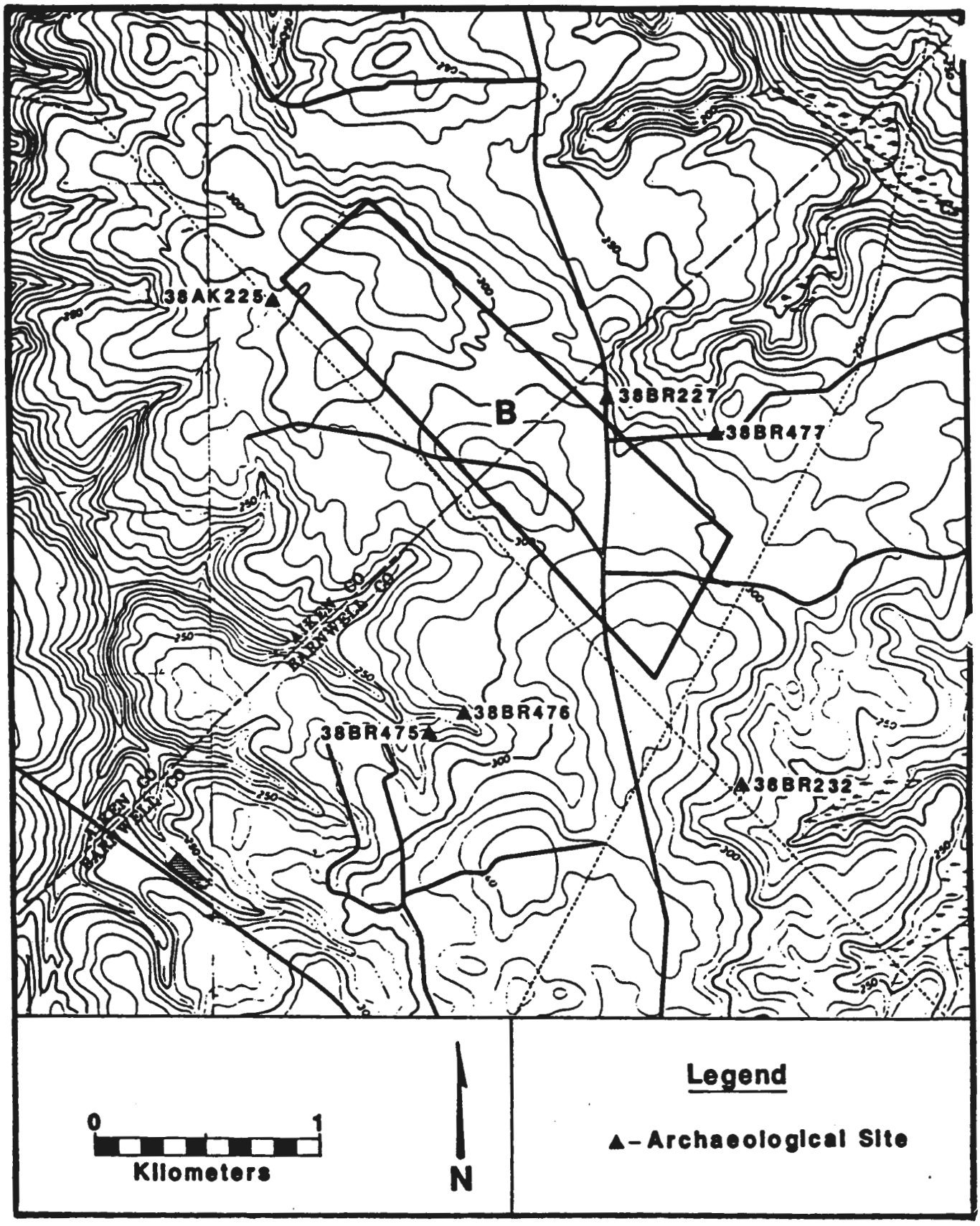

Figure 2 (a): Location of archaeological sites within and adjacent to proposed waste management area B.

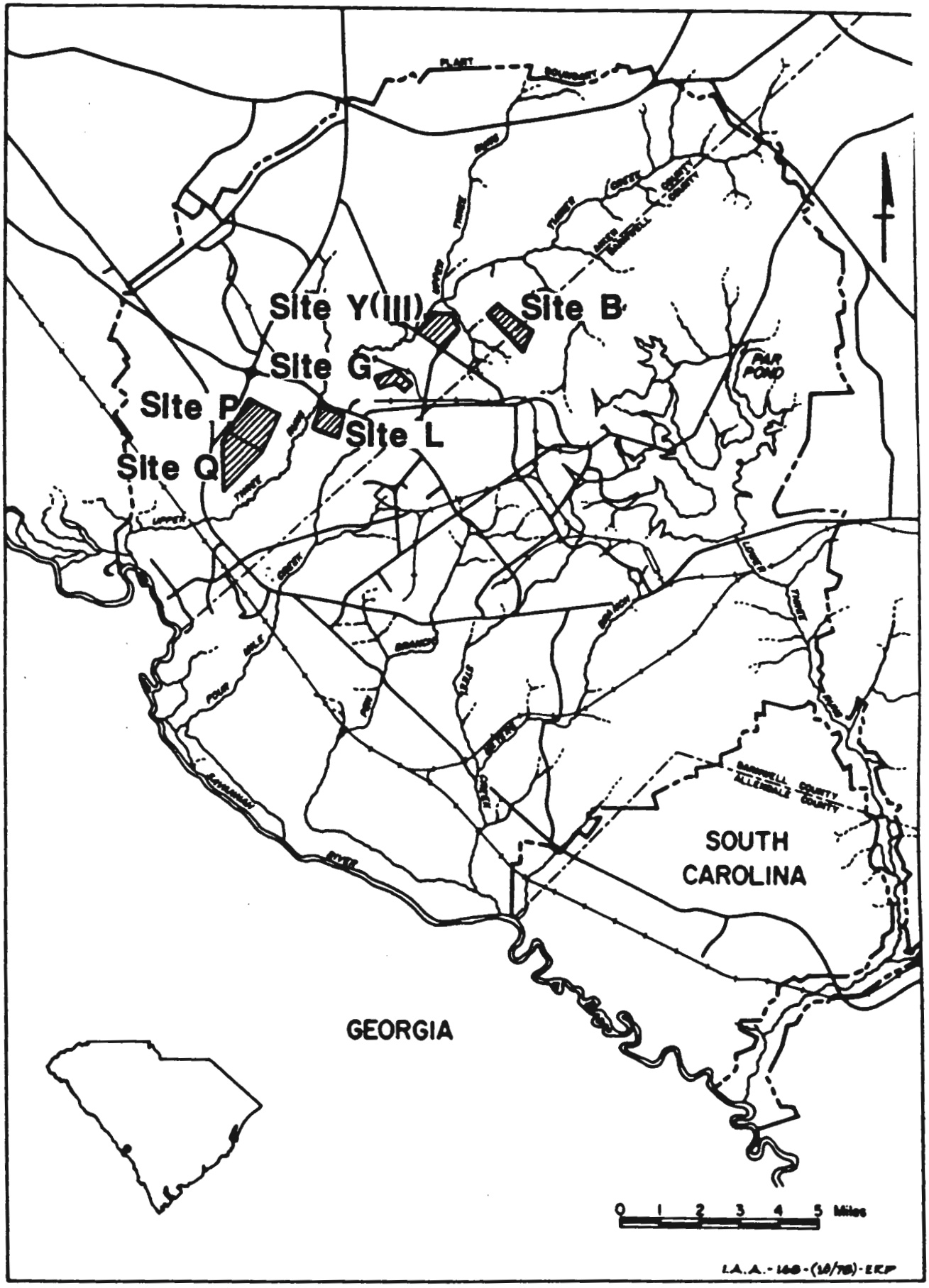

Figure 2: Location of the proposed waste management areas.

Table 3: Archaeological and Historical Sites within and adjacent to the Proposed Waste Management Areas

PARCEL	SITE #	COMPONENTS	LENGTH (m)	WIDTH (m)	DEPTH (cm)	IN/ OUT	RECOMMENDATION ON SIGNIFICANCE	RECOMMENDATION ON EFFECT
Y[III]	38AK298	MA, LA, EW, MW, 19th & 20th C.	200	40	30	OUT	Not Assessed	Not Assessed
Y[III]	38AK382	EA, MW, LW, M	75	25	30	OUT	Not Assessed	Not Assessed
Y[III]	38AK384	LA, MW	75	25	20	OUT	Not Assessed	Not Assessed
Y[III]	38AK386	EA, M	75	25	20	OUT	Not Assessed	Not Assessed
Y[III]	38AK380	19th & 20th C.	100	25	0	OUT	Not Assessed	Not Assessed
L	38AK267	Lithic	25	25	0	OUT	Not Assessed	Not Assessed
L	38AK421	MW	500	70	40	OUT	Not Assessed	Not Assessed
L	38AK422	Lithic & Ceramic	190	60	40	OUT	Not Assessed	Not Assessed
L	38AK423	MW	130	100	90	OUT	Not Assessed	Not Assessed
L	**38AK424**	**(See Tables 4, 5, & 6)**				**IN**	**Not Significant**	**No Effect**
L	**38AK425**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**

KEY:
EA = Early Archaic
MA = Middle Archaic
LA = Late Archaic
EW = Early Woodland
MW = Middle Woodland
LW = Late Woodland
M = Mississippian
IN = Within proposed waste management area
OUT = Outside proposed waste management area

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Table 3: Archaeological and Historical Sites within and adjacent to the Proposed Waste Management Areas

PARCEL	SITE #	COMPONENTS	LENGTH (m)	WIDTH (m)	DEPTH (cm)	IN/ OUT	RECOMMENDATION ON SIGNIFICANCE	RECOMMENDATION ON EFFECT
G	38AK106	EA, MW	50	200	80	OUT	Not Assessed	Not Assessed
G	38AK153	EA, LW	80	30	60	OUT	Not Assessed	Not Assessed
G	38AL154	Lithic& Ceramic	5	5	0	OUT	Not Assessed	Not Assessed
G	**38AK155**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
G	38AK156	EW, MW	50	50	65	OUT	Not Assessed	Not Assessed
G	38AK157	EW, MW, 20th C.	170	100	60	OUT	Not Assessed	Not Assessed
G	38AK158	LA, EW, MW, 18th & 19th C.	75	75	90	OUT	Not Assessed	Not Assessed
G	38AK159	MW	70	30	40	OUT	Not Assessed	Not Assessed
G	**38AK279**	**(See Tables 4, 5, & 6)**				**IN**	**Not Significant**	**No Effect**
G	**38AK280**	**(See Tables 4, 5, & 6)**				**IN**	**Not Significant**	**No Effect**
G	**38AK281**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
G	38AK332	EA, LA, EW, MW, LW	100	75	60	OUT	Not Assessed	Not Assessed
G	38AK334	MW, 20th C.	100	25	0	OUT	Not Assessed	Not Assessed
G	38AK336	EW, MW, LW	65	25	60	OUT	Not Assessed	Not Assessed
G	**38AK338**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
G	38AK420	EW, MW, LW, 19th & 20th C.	30	10	90	OUT	Not Assessed	Not Assessed
B	38AK225	EW, MW, LW, 19th C.	200	50	0	OUT	Not Assessed	Not Assessed
B	38BR227	LA, EW, MW	25	25	0	OUT	Not Assessed	Not Assessed
B	38BR232	MW, LW, 19th C.	60	60	0	OUT	Not Assessed	Not Assessed
B	38BR475	LA, EW, MW	60	15	0	OUT	Not Assessed	Not Assessed
B	38BR476	Ceramic	20	20	0	OUT	Not Assessed	Not Assessed
B	38BR477	MW, LW	5	5	0	OUT	Not Assessed	Not Assessed
P/Q	38AK129	MW, LW	20	15	60	OUT	Not Assessed	Not Assessed
P/Q	38AK130	LA, EW, MW, LW, 18th C.	60	30	60	OUT	Not Assessed	Not Assessed
P/Q	38AK136	Lithic	1	1	0	OUT	Not Assessed	Not Assessed
P/Q	38AK426	Lithic, 20th C.	40	50	60	OUT	Not Assessed	Not Assessed
P/Q	38AK427	Lithic	50	50	40	OUT	Not Assessed	Not Assessed
Y[III]	**38AK428**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	**38AK429**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	**38AK430**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	**38AK431**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	**38AK432**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	**38AK433**	**(See Tables 4 & 5)**				**IN**	**Not Significant**	**No Effect**
Y[III]	38AK168	LA, EW, 20th C.	20	10	0	OUT	Not Assessed	Not Assessed

from a Rank 3 tributary of Upper Three Runs Creek (Figure 2e). The site covers an area of about 25 x 50 meters (Figures 15 and 16), with debitage to a depth of 55 cm (Table 4). No temporally diagnositc artifacts were recovered (Tables 4 and 5). The low artifact density and low assemblage diversity, in conjunction with no temporally diagnostic artifacts, indicate that this site has little potential for providing significant new information of relevance to our understanding of the prehistory of the region.

38AK432: The site is characterized by subsurface prehistoric lithic debitage (solely small thinning flakes - see Table 5) located on a ridge nose approximately 530 meters from a Rank 3 tributary of Upper Three Runs Creek (Figure 2e). The site covers an area of about 25 x 50 meters (Figures 17 and 18), with debitage to a depth of 60 cm (Table 4). No temporally diagnostic artifacts were recovered (Tables 4 and 5). The low artifact density and low assemblage diversity, in conjunction with no temporally diagnostic artifacts, indicate that this site has little potential for providing new information of relevance to our understanding of the prehistory of the region.

38AK433: This site, located on a ridgetop 1,000 meters from Upper Three Runs Creek (Figure 2e), is characterized by a single, isolated surface find (thinning flake - see Table 5) in a disturbed context associated with a soil test area (Figure 19). Subsurface shovel testing in the vicinity (Figure 19) failed to produce any additional archaeological material. The extremely low artifact density and low assemblage diversity, in conjunction with a disturbed context and no temporally diagnostic artifacts, indicate that this site has no potential for providing new information of relevance to our understanding of the prehistory of the region.

(compare Tables 5 and 5a). Whereas Tables 5 and 5a indicate that 38AK428 has a moderate artifact density and assemblage diversity, which is generally not typical of the upland sandhills environment (see the subsistence-settlement model presented in Chapter III), protected sites 38AK34 and 38AK224 (reported in Hanson et al. 1978) contain comparable temporal components and occur in similar physiographic settings; thus, minimizing the research potential of 38AK428.

38AK429: This site is characterized by subsurface prehistoric lithic debitage (solely small thinning flakes - see Table 5) located on a ridge nose approximately 600 meters from Upper Three Runs Creek (Figure 2e). The site covers an area of about 40 x 70 meters (Figures 11 and 12), with debitage to a depth of 70 cm (Table 4). No temporally diagnostic artifacts were recovered (Tables 4 and 5). The low artifact density and low assemblage diversity, in conjunction with no temporally diagnostic artifacts, indicate that this site has little potential for providing significant new information of relevance to our understanding of the prehistory of the region.

38AK430: This site is characterized by subsurface prehistoric lithic debitage (solely small thinning flakes - see Table 5) located on a ridge nose approximately 333 meters from Upper Three Runs Creek (Figure 2e). The site covers an area of about 30 x 120 meters (Figures 13 and 14), with debitage to a depth of 60 cm (Table 4). No temporally diagnostic artifacts were recovered (Tables 4 and 5). The low artifact density and low assemblage diversity, in conjunction with no temporally diagnostic artifacts, indicate that this site has little potential for providing significant new information of relevance to our understanding of the prehistory of the region.

38AK431: This site is characterized by subsurface prehistoric lithic debitage (solely small thinning flakes - see Table 5) located on a ridge nose approximately 400 meters

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approximately 30 x 40 meters (Figures 7 and 8), with artifacts to a depth of 40 cm (Table 4). Ceramic Late Archaic and 20th Century components are represented (Table 4). Whereas this site contains intact archaeological deposits, the low prehistoric artifact density and assemblage diversity indicate that this site has little potential for providing significant new data of relevance to our understanding of the prehistory of the region. Similarly, the 20th Century component, as indicated by the surface brick remains (Figures 7 and 8) and the artifact assemblage (Table 6), is "typical" of the numerous other 1900 1920's tenant homesteads documented for the Savannah River Plant (e.g., Hanson et al. 1981; Martin et al. 1985; Brooks 1981).

38AK425: This site is characterized by a light surface scatter of prehistoric artifacts (Tables 5, 5a) located on a ridgetop 160 meters from a Rank 1 tributary of Upper Three Runs Creek (Figure 2c). Systematic and judgemental shovel testing produced no subsurface artifactual remains. The lithic and ceramic artifacts present (Tables 5, 5a) indicate a Middle Woodland occupation (Table 4). The surface context, and the high upland location characterized by erosion, suggest that this site has no integrity of deposits.

Parcel Y (III)

38AK428: This site is characterized by surface and subsurface prehistoric artifacts (Tables 5, 5a) located on a ridge nose approximately 666 meters from Upper Three Runs Creek (Figure 2e). This site covers an area of about 80 x 140 meters (Figures 9 and 10), with artifacts to a depth of 85 cm (Table 4; Table 5, Prov. 5G). Middle Woodland and Late Woodland components are represented (Table 4). Also, as indicated by Provenience 5 (secondary 1 x 2 meter test unit excavated in 10 cm levels), one or more Archaic components may be present (levels E-G) beneath the Woodland horizons

that is located upslope, just out of the area (Figure 2b). If this is the case, then it is likely that the prehistoric materials represent secondary deposits as well.

38AK281: This site is characterized by a surface scatter of prehistoric artifacts (Tables 5, 5a) located on a ridge slope 300 meters from a Rank 1 tributary of Upper Three Runs Creek (Figure 2b). Shovel testing produced no subsurface remains. The lithic and ceramic artifacts present (Tables 5, 5a) indicate a Late Woodland component (Table 4). The surface context, and the high upland location characterized by erosion, suggest that this site has no integrity of deposits.

38AK338: This site is characterized by surface and subsurface prehistoric artifacts (Tables 5, 5a) located on a ridge nose 35 meters from a Rank 1 tributary of Upper Three Runs Creek (Figure 2b). The site covers an area of approximately 30 x 90 meters (Figures 5 and 6), with artifacts to a depth of 65 cm (Table 4). Early Woodland and Middle Woodland components are represented (Table 4). Whereas this site contains intact archaeological deposits, and provides valuable supportive data for the subsistence-settlement model presented in Chapter III regarding the artifact assemblage variability expected to correlate with the prehistoric activities predicted for the upland sandhills environment, the relatively low artifact density and assemblage diversity indicate that the site has little potential for providing significant new data of relevance to our understanding of the prehistory of the region.

Parcel L

38AK424: This site is characterized by surface and subsurface prehistoric (Tables 5, 5a) and historic artifacts (Table 6) located on a terrace 350 meters from a Rank 1 tributary of Upper Three Runs Creek (Figure 2c). The site covers an area of

4). While shovel testing indicated the presence of some subsurface material (Table 5, Prov. 4X), most artifacts were recovered from a surficial context. The predominately surface context of the site suggests little or no integrity of deposits, due to the eroded condition of this upland location.

38AK279: This site is characterized by a light surface scatter of prehistoric (Table 5, 5a) and historic (Table 6) artifacts exposed on a dirt road along a ridge slope overlooking a tributary of Upper Three Runs Creek (Figure 2b). No subsurface remains were encountered. The artifacts present (Tables 5, 5a and 6) indicate Early Woodland, Middle Woodland, Late Woodland, 19th Century, and 20th Century components (Table 4). The surface context, and the high, upland location characterized by erosion, suggests that this site has no integrity of deposits. In addition, it is likely that the 19th Century component at this site, as well as that of 38AK280 (discussed below) was ultimately derived through grader activity from site 38AK158 that is located upslope, just out of the area (Figure 2b). If this is the case, then it is likely that the prehistoric materials represent secondary deposits as well.

38AK280: This site is characterized by a light surface scatter of prehistoric (Tables 5, 5a) and historic (Table 6) artifacts exposed on a dirt road along a ridge nose most directly associated with a Rank 2 drainage of Upper Three Runs Creek (Figure 2b). No subsurface remains were encountered. The artifacts present (Tables 5, 5a and 6) indicate Late Archaic, Early Woodland, Middle Woodland, Late Woodland, and 19th Century components (Table 4). The surface context, and the high upland location characterized by erosion, suggest that this site has no integrity of deposits. In addition, it is likely that the 19th Century component at this site, as well as that of 38AK279 (discussed above) was ultimately derived through grader activity from site 38AK158

Chapter V

ARCHAEOLOGICAL RESOURCES

Introduction

The forty-five archaeological sites within, or adjacent to, the six alternative waste disposal/storage areas (survey parcels) are summarized by parcel as to within or outside the survey areas and as to management assessments/recommendations in Table 3. The locations of the survey parcels and their associated archaeological sites are depicted in Figure 2 (a-e). Because they are not endangered and will be considered in the final cultural resource management report for the Savannah River Plant, the thirty-two archaeological sites outside the six areas of potential impact are not discussed further, nor assessed, in this report. In contrast, the thirteen archaeological sites recorded within parcels G, L and Y (III) (no archaeological sites were discovered in parcels B, P and Q) are discussed below by parcel and evaluated in Chapter VI (Archaeological Recommendations). The site locational and culture-historical affiliation(s) data for these sites are summarized in Table 4. Tables 5 and 6 summarize the prehistoric and historic artifact assemblage data, respectively, by archaeological site and provenience.

Parcel G

38AK155: This site, initially reported by Hanson, Most and Anderson (1978), is characterized by a scatter of prehistoric artifacts (Tables 5, 5a) located on a ridgeline overlooking and elevated 50' above a swampy tributary of Upper Three Runs Creek (Figure 2b). The site extends over about half an acre (Figures 3 and 4) and is located about one mile southeast of the intersection of Road C-4 and the dirt road to Area F and the Burial Grounds. The site area is disturbed by logging activity and erosion (Figure 3). The lithic and ceramic artifacts present (Table 5, 5a) indicate primarily a Late Woodland occupation with the Middle Archaic minimally represented (Table

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Wire nails: The date ranges from 1887 to present (Fontana 1965: 89). Earlier manufacture dates are known; however, the expense of these nails and their rarity likely precludes an earlier date.

Cut nails: Date range 1790 - present (Noel Hume 1970: 253). Rectangular in shape, usually without a head, and tapering to square end rather than a point. The acidity of the soil in most of the project area made identification of this type of nail impossible due to deterioration of the metal.

Brick: No date range. Refers to collected brickbats.

Tobacco

Pipe stem: The date range extends from the late 1600s to the late 1800s. The sample size is too small to use any dating method with accuracy.

Glass

Modern: This category is a catch-all for glass manufactured after 1860. The different types of glass recovered, and their respective date ranges, are described below. This includes the following colors:

Clear glass: This dates generally after 1860 (Jones 1971: 11). As the name implies, this glass exhibits no color or tint when held to white paper.

Manganese glass: This ranges in date from 1800 to 1915 (Kendrick 1976: 54-55; Toulouse 1972: 534). This is glass that was decolorized by the inclusion of manganese into the manufacturing process (Toulouse 1972: 534). This glass changes from clear to a purple color. The intensity of the purple is determined by how long it is exposed to sunlight (Kendrick 1976: 54-55). This is not to be confused with deliberately colored purple glass, which is much darker.

Brown glass: The date range is unknown. It exhibits the same color characteristics as the glass containing beer and whiskey for today's market, with the same range of colors.

Blue glass: This ranges in date from 1750 to present (Noel Hume 1970: 62). It is a well-made glass containing few, if any, bubbles, and is similar in appearance to glass produced today (i.e., Noxzema jars).

Architectural

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Albany slip stoneware: Date range unknown. "Usually exhibited by a black, brown or white slip glaze over the body of the vessel", (South, personal communication), probably locally made.

Red/Brown stoneware: Date range unknown. Probably locally made by an Edgefield pottery.

Earthenware

Whiteware: Date range 1813 - present (South 1977: 210-211). Whiteware/Ironstone appears in "various forms of hard whitewares and semi-porcelain that are extremely difficult to date with accuracy. . ." (Noel Hume 1970: 130-131).

Decorated whiteware: This date ranges from 1813 to present (South 1977: 210-211).

Pearlware: Date range 1780 - 1830 (South 1977: 212). ". . . it can readily be distinguished by the way in which the glaze appears blue in crevices of footrings and around handles" (Noel Hume 1970: 130). Also exhibits a slight blueish color when held to a piece of white bond paper.

Shell-edge pearlware: The date range for this type is 1780-1830 (South 1977: 212). It has a shell edge decoration either in blue or green (Noel Hume 1970: 131).

Finger-painted pearlware: Date range 1790-1820 (South 1977: 212). "Polychrome slip on Creamware, . . .occurring on banded . . .(creamware) are zones of cloudlike swirling lines generally in black, blue and white" (Noel Hume 1970: 132).

in light of the other data sets, can provide valuable insights into site functional variability.

Historic Analysis

The historic artifacts underwent several analyses. The first of which included the tabulation of the artifacts for the artifact tables. The second analysis included a close inspection of the glass and ceramics for distinguishable difference and/or individually marked pieces. Analyses of historic ceramics and glass were greatly facilitated by placing them on a white background. This was done because against a white background slight color changes in the glaze are readily distinguished. In the case of ceramics, pearlware exhibits a slight blue tinge in the glaze, as opposed to whiteware ironstone which exhibits none. The following artifact descriptions are keyed to the Historic Artifact table in the site descriptions.

Porcelain

Plain: This has no date range. No pieces of porcelain were found that exhibit characteristics of those of the eighteenth or early nineteenth century.

Stoneware

Alkaline glaze stoneware: Date range 1800 - present (Greer 1970). Usual colors range from light yellowish green to olive green, probably of local manufacture.

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are: raw material type; presence or absence of patina; percent cortex; maximum length, width, thickness (mm); mean lateral edge angle; weight; and broken (yes or no).

Other Lithic Tools: This residual lithic artifact class consists of such diverse, and relatively uncommon non-flaked subclasses as ground stone, polished stone, hammerstones, etc. Once sorted into their respective subclasses, they were simply counted and weighed. Additional attribute analyses may be conducted in the future, contingent upon more focused research.

Fire-Cracked Rock: Fire-cracked rock includes a wide variety of igneous/metamorphic and sedimentary materials, usually in rounded (stream worn) cobble form exhibiting evidence of having been heated (reddened and/or crazed with irregular breakage patterns resulting from use in hearths, earth ovens or stone boiling). Broken cobbles exhibiting no definite evidence of heating or of any use-wear patterns are also included in this class.

Ceramics: Ceramics recovered were classified using the South Carolina Institute of Archaeology and Anthropology's comparative type collection (Anderson n.d.), emphasizing the traditional sorting criteria of surface finish, paste and temper within a type-variety analytical framework. Such a framework has the potential of being sensitive to geographic as well as to temporal variation.

Other Artifacts and Materials: This broad class consists of a wide variety of residual subclasses including such items as daub, cobbles, bone, shell, charcoal, and various rock and mineral fragments. Although a detailed analysis beyond identification, counting and weighing was not warranted, the mere presence of such minority items can often provide a valuable body of inter and intra-site comparative data which, when examined

Debitage: This class was analyzed according to the presence or absence of cortex, with additional subclasses defined on the basis of raw material, presence or absence of thermal alteration, and whole vs. broken flakes. The flakes within each subclass were counted and recorded. The combined subclasses were then weighed. These data are particularly useful for examining technological variability.

Flake Tools: Flake tools are broadly subdivided into formally prepared unifaces and utilized flakes. Based on the techno-functional attributes recorded, these flake tool subclasses may be further subdivided (e.g. burin, graver, etc.). The flake tool attributes recorded consist of: raw material type; percent cortex; presence or absence of patina; presence or absence of indications of hafting; maximum length, width and thickness; number of used edges; edge(s) morphology and angle(s); and weight.

Hafted Bifaces: Most artifacts in this class are considered to be temporally diagnostic. Accordingly, they were initially classified as to established type, based on descriptions in the literature. Measures of attributes considered to be of techno-functional relevance were then recorded. These attributes are: condition (whole or, if broken, the fragment represented); raw material type; presence or absence of patina; maximum length and width (mm); blade length (mm); width @ ½ blade length (mm); shoulder and basal width (mm); maximum thickness (mm); weight (grams); presence or absence of evidence of resharpening; broken (yes or no); presence or absence of basal grinding; basal type; and basal shape.

Other Bifaces: This broad class consists of such diverse subclasses as preforms, flake cores, axes, adzes, etc. Once sorted into these subclasses, measures of attributes considered to be of techno-functional relevance were then recorded. These attributes

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methods have been refined over the course of 12 years through the benefit of a large survey sample in excess of 775 archaeological sites located across a broad environmental range. Although quantified predictive models of site location have not been formalized to date, certain regularities in site type-geographic location have been employed in the formulation of the human ecological model (Hanson, Brooks and White 1981) which provides a basis for examining settlement variation within a theoretical perspective.

Laboratory Analysis Methods

Introduction

All archaeological materials recovered during the course of the survey were logged and subsequently washed at the Savannah River Plant Archaeological laboratory. Prehistoric and historic artifacts were further sorted and cataloged by provenience, level (where appropriate) and major artifact class.

Prehistoric Analysis

The analysis of prehistoric materials was undertaken in accordance with standard analytical procedures established for the Savannah River Plant Archaeological Research Program. These procedures were designed in order to record a wide range of technological, functional and temporal data essential for addressing specific aspects of the model presented in Chapter 3. The prehistoric artifact classes consist of debitage, flake tools, hafted bifaces, other bifaces, other lithic tools (ground, polished, battered, pecked, etc.), fire-cracked rock, ceramics, and other artifacts and materials.

sites (38AK424, 38AK425, 38AK428, 38AK429, 38AK430, 38AK431, 38AK432, and 38AK433) were located during this phase of the survey.

Phase two consisted of the re-examination of four of the five known archaeological sites (38AK279, 38AK280, 38AK281, and 38AK338) and the eight newly discovered sites. One site (38AK155), recorded during previous SRP research was sufficiently well documented so as not to require additional investigation at this time. Shovel testing at the remaining sites employed a systematic procedure which was centered on the site datum, with shovel tests at ten or twenty meter intervals along transects extending outward from the datum. Additional judgemental shovel tests were excavated as needed. The 25 by 25 centimeter shovel tests were excavated in order to determine artifact density and intrasite patterning (i.e., spatial and stratigraphic variability).

Phase three research involved the excavation of a one by two meter unit at 38AK428, where subsurface artifact densities were determined to be highest. The unit was excavated in ten centimeter arbitrary levels because no culturally meaningful strata were recognized during phase two testing. All soils were screened through 1/4" hardware cloth sieves. Recovered artifacts were placed in plastic bags with appropriate provenience information and transported to the lab at the end of each work day. Field records describing soil changes, artifact locations, and other pertinent information were recorded on standardized forms which are curated by the South Carolina Institute of Archaeology and Anthropology. Unit profiles were drawn and photographed prior to backfilling.

In summary, the field methods employed in the survey were those developed by the Savannah River Plant Archaeological Research Program for use in Upper Coastal Plain contexts (c.f. Hanson, Most and Anderson 1978; Hanson, Brooks and White 1981). These

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Chapter IV

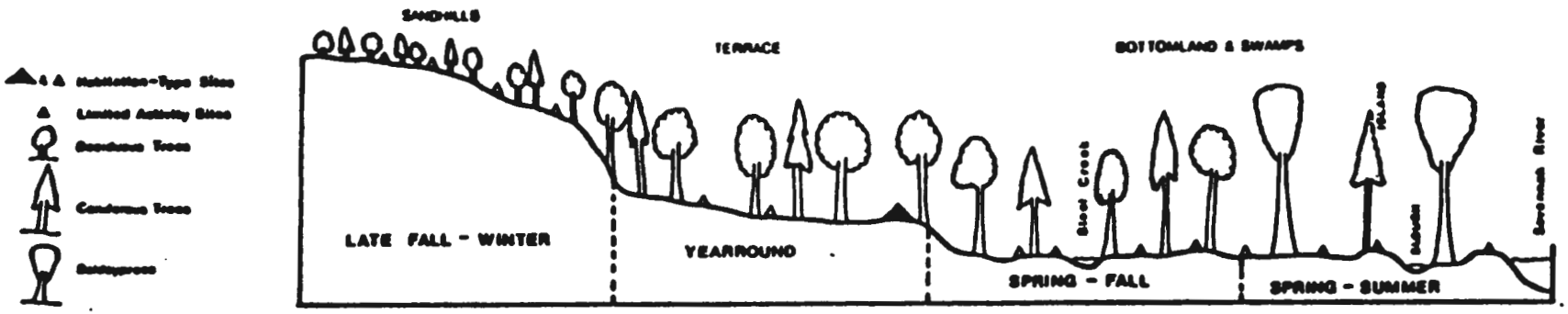
METHODS

Field Methods

The purpose of the field survey was to examine the six proposed waste disposal/storage areas for archaeological sites and to obtain data to evaluate the significance of each site through test excavation and surface collection. Each archaeological location was examined using standard field methods which are presented in this section.

Prior to implementation of the field survey and testing, maps of the proposed areas were compared with the master site maps for the Savannah River Plant to determine the location of known sites. Information for all known sites near the proposed areas was then examined to provide a preliminary assessment of the archaeological resources. Through the use of these preliminary data, the field crew was able to determine the site locations and their contents, as well as the association between known sites and the proposed areas while in the field.

Fieldwork was divided into three task specific phases in order to best utilize field time and to allow for phased decisions regarding level and extent of testing. Phase one fieldwork consisted of actual surface and subsurface survey within each of the six proposed areas. One crew consisting of two individuals walked the areas inspecting all ground surface exposures (e.g., dirt roads and cut-banks). In vegetated areas and areas where sediment deposition was known to have occurred (i.e. terrace edges and ridge noses) during the prehistoric period, subsurface shovel tests (.25 x .25 m) were placed at fifty meter intervals along parallel transects (50 m apart) oriented with the major landforms. All soil removed from the tests was screened through 1/4" hardware cloth to recover any cultural material. Eight previously unrecorded archaeological



	ZONE I UPLAND SANDHILLS	ZONE II MESIC TERRACES	ZONE III TRIBUTARIES AND BOTTOMLAND	ZONE IV SAVANNAH RIVER AND SWAMPS
KEY RESOURCES	Red oak acorns, deer, small terrestrial mammals, seeds, and hickory nuts.	White and red oak acorns, deer, small terrestrial mammals, seeds, greens, turkey, berries and fruits.	Fish, aquatic fauna, waterfowl, deer, small mammals, red and white oak acorns, greens, fruits, berries, and seeds.	Fish, aquatic fauna, freshwater mussels, small mammals, deer, greens, seeds, some acorns, and hickory.
SEASON(S) OF MAJOR UTILIZATION	Late fall and winter	Spring, summer, fall and winter	Spring, summer and fall	Spring and summer with minor use in fall
ACTIVITIES	Acorn and hickory gathering, deer hunting and processing, small game hunting, seed collecting, general foraging, and short term camping.	Acorn and nut gathering, small mammal hunting, deer hunting and processing, vegetal food foraging, food processing and storage, and habitation.	Fish procurement with spears and wiers, deer hunting, waterfowl hunting, acorn collecting, vegetal food foraging, and possible short term camping.	Fish procurement with spears, nets, wiers, & traps, mussel collecting, some deer hunting, and general vegetal foraging.
ARCHEOLOGICAL CORRELATES	Small lithic and/or ceramic scatters, debitage indicative of tool maintenance, broken hunting and meat processing tools, sites dispersed throughout the zone, and overall low lithic assemblage diversity.	Large base camp and habitation sites near either Zone III or Zone IV, high lithic assemblage diversity, seed and nut processing tools, storage containers, debitage reflecting tool manufacture and maintenance, and some small low tool diversity sites.	Stream edge fishing stations, fish traps and wiers, scattered meat processing sites with low tool diversity, broken hunting and meat processing tools, and a dispersed pattern of non-fishing sites.	Levee and slough edge fishing/mussel collecting stations, hunting and meat processing sites on islands, overall low tool diversity in all of these small sites, and possible large base camps on islands.

Figure 1: A general settlement-subsistence model for the Steel Creek watershed.

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resources in the zone, no specific expectations can be made for the nature of the assemblages other than an expected low artifact diversity. A generalized model of this settlement subsistence system is presented in Figure 1.

The preceding model of human land use constitutes the central focus of the prehistoric analyses that will be discussed in the report. It is through the examination of such models that archaeological sites can be evaluated to measure the scientific value of the archaeological resources. This is not to say that only settlement subsistence models are valuable criteria for assessing sites, but only that they form a basic first step in determining the information content of sites. As the sites are better understood, certain specific questions relating to chronology, culture change, ceramic variability, and other general problem domains can be addressed.

tools, exhausted flake tools, and resharpening debitage (House and Ballenger 1976). So with these material correlates considered, the expected site type in this zone would be small lithic scatters with evidence of meat processing expressed in the assemblage. The distribution of these sites is expected to be spatially random due to the even resource distribution.

To recapitulate, the seasonal settlement model proposed above suggests that under the assumption of a general dietary selection (Cleland 1976), exploitation would have consisted of three environmentally determined components. First, aquatic resources would have been collected during the spring and summer in Zones II and IV from small camps or stations within the zones that served as specialized activity loci visited for brief periods. Residence would have been in Zone II. Second, during late fall and winter, subsistence activity would have shifted to the upland sandhill zone for the procurement of deer and acorns. Since these activities would not have required facilities or long-term processing in the zone, use of the area would most probably have been during short term visits. Again habitation during these seasons is expected to have been in the mesic terrace zone. Third, the use of the mesic terrace zone is expected to have been the most intensive in terms of habitation and daily subsistence procurement, because the zone offers a rich multi-seasonal resource base and is intermediate between the lowland and upland zones. Sites within this zone would have been due to two types of activity: 1) long-term habitation for multiple seasons with assemblages reflecting diverse activities, and 2) limited activity associated with specific resource procurement. The former type of sites would have most probably been located near the contact edge between the mesic terrace and the tributary/bottomland or Savannah River swamp because of the improved access to water and aquatic resources. The latter type of sites would reflect the general resource specific procurement activities away from the habitation sites in the mesic terrace zone. Due to the richness and diversity of

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and protected areas for dwelling. Third, all areas within this zone are within 1 km of permanent water provided by streams. Fourth, if we assume that most of the prehistoric inhabitants of the region were dietary generalist (i.e. those who selected food resources in direct proportion to their occurrence in the environment), then this zone would have been the ideal residence location during most of the year because of the central location of the zone in immediate proximity to the tributary/bottomlands and the upland sandhills. By locating more permanent base camps and habitation in this zone, prehistoric groups would have been able to follow a logistic mobility pattern (Binford 1980) to exploit the more seasonally specific zones nearby.

Finally, the resources within the upland sandhills are, for the most part, available in the highest density during the late fall and winter. Although certain fauna use this zone during the entire year, the greatest concentration of deer occurs concomitant with the high red oak mast maturity. A limiting factor in the zone is water that occurs only in small springs and intermittent tributary streams. Furthermore, the large area represented by this zone (i.e. 75% of the watershed) and relative uniformity of the resource distribution over time would have contributed to decisions regarding human exploitation patterns. Thus, given the relative lack of water, the seasonal nature of the resources, and the evenness of the resource distribution, it is expected that the upland sandhills would have been used primarily during the late fall and winter for the procurement of oak mast and whitetail deer. The archaological correlates of this activity set would be relatively small, limited-activity loci with assemblages reflecting low-activity diversity. Because the collecting of bitter oak mast would require leeching in the flowing stream (Reidhead 1976: 233-236), no evidence of acorn processing is expected in this zone, but rather in the mesic terrace and tributary/bottomland zones. Hence, the primary contribution to the archaeological record would have been the hunting and meat-processing activities. These would have resulted in the deposition of broken

zones would have been rather inhospitable for long-term settlement due to excessive moisture and poorly drained soils; these are the Savannah River swamp (Zone IV) and the tributary/bottomlands (Zone III). With the expection of the small islands that occur in the swamp, no habitation or large scale limited activity loci are expected in these two zones. However, due to the extremely high productivity of these zones, they are expected to have been seasonally exploited during most of the year for aquatic resources (e.g. fish, turtles, mussles and aquatic plants). Due to low water levels in the river, which would have existed during the late spring and summer (Baldwin 1973: 24; Trinkely 1974: 14), mussels and certain fish species would have been intensively exploited during these seasons. Thus given the conditions and paramenters of these two environments, the expectation for human activity and the resultant archaeological record is of two kinds. First, in Zone III, it is expected that sites would represent narrow activities such as fishing and hunting and that more permanent residential sites would be elsewhere. Second, sites in Zone IV would represent, at most, seasonal procurement of certain swamp resources. One possible exception to this would have been a more sedentary occupation (i.e. multi-seasonal) which seems to have occurred during the Late Archaic Period in the Savannah River as evidenced by the Rabbit Mount site (Stoltman 1974). These more sedentary occupations in the swamp zone always occurred on sand ridges and old point-bar remnants within the floodplain which would have afforded protection from flooding. Thus, the overall prehistoric site distribution within the swamp and bottomland zones is expected to be composed of limited activity sites representing the procurement of locally available resources.

The zone with the greatest expected probability for yielding more permanent base camp and habitation sites is the mesic terrace. Four factors support this expectation. First, this zone is highly productive during the spring, summer and fall. Second, the soils and topography in the zone would have afforded prehistoric inhabitants with dry

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Overall, the resources of the swamp would have been available during most parts of the year, but procurement would not always have been equally economical. High flood waters would have made focused net fishing difficult because fish would have been able to move over most of the swamp. Instead, fishing would have been best during summer when water levels were lower and the swales became small lakes, or sloughs. Terrestrial and aquatic mammal exploitation could have been quite good if access to the resources was not inhabited by flood waters. In general this zone would have had an excellent source of fish, mussels, vegetal foods, and mammals.

The Structure of the Resources and Archaeological Implications

Variability in topography, hydrology, elevation, soils, vegetation and resources characterizes the project area and constitutes the basis for the definition of microenvironmental zones. Each of these zones would have contained food resources for the prehistoric human occupants of the area in varying quantities during different seasons of the year. This differential availability of resources would have established a basic structure in the effective environment, that would have been a central consideration in the development and implementation of procurement strategies. As components of the strategies, activity and habitation loci would be expected to reflect the structure in the environment. Because the emphasis in the present study is upon the nature of prehistoric settlement and subsistence, the distribution of different site types is examined in association with zones of resource production.

From the structure of the environment the following expectations can be deduced regarding the general structure of a seasonal subsistence activity system. Two of the

During most of the year the Savannah River swamp is partially flooded by modern stream and river flow. Prior to the construction of the two dams in the upper Savannah River, flooding was a recurring event that inundated the entire swamp-floodplain. The water run-off from Pen Branch, Four Mile Creek and Steel Creek would have contributed to the swamp water levels. Due to this problem with flooding, the low-lying areas of the swamp would have had an impossible habitation area. The islands, on the other hand, would have afforded adequate protection from flood water to have been suitable residences during at least part of the year. Evidence from Stave Island, a large point-bar remnant in the swamp, suggests occupation during the Late Archaic and possibly the Woodland periods.

Resources:

The aforementioned whitetail deer were probably an important resource procured from the swamp. Further, terrestrial manmals such as bear, rabbit, raccoon, and squirrel are common. Muskrat and beaver are also very common. Although the migratory birds are low relative to Zone III, a high density of wood ducks would have provided some food value. Aquatic resources including freshwater mussels, resident and anadromous fish, and turtles are very common in the river and swamp. Procurement of these species would have been a relatively low-cost endeavor. As noted by Limp and Reidhead (1979), the netting of fish and other aquatic fauna is a very economical activity which can produce extremely high food yields for labor expended. This fact suggests that the use of this zone would have been quite great. A review of the food resource data from the Rabbit Mount site (Stoltman 1974) supports the contention that swamp resources were used extensively during the Late Archaic and Mississippian periods.

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the swamp are a series of elevated ridges which parallel the river and form seasonal dry land. Thus, the topography of swamp, rather than being uniform as suggested by the topographic maps of the areas, consists of ridges and swales.

Soils:

No specific information exists on the soils of the swamp since Aydelott (n.d.) did not map its soil distributions nor did he evaluate the productivity of the area. Generally, the sediments in the upper surface levels of the swamp are predominantly silts and sands, which are depositional in origin (Stevenson 1981). Ridge soils are sandy and moderately well drained.

Vegetation:

Barry (1980) characterizes this zone as cypress-tupelo swamp which is composed of bald cypress and water-tupelo in setting with alluvial deposits and open water circulation. This vegetation system is that which dominates the Savannah River swamp swales. Other common species associated with cypress and water-tupelo are water ash, black willow, water elm, red bay, sweet bay magnolia, and American elm. On the ridge islands which are never subjected to continuous inundation by flood waters, oaks similar to those found in the mesic terrace zone are common, as are longleaf and loblolly pines. Of importance is the fact that the islands are in most cases long and narrow with not too much dry surface area. This fact would diminish their importance as oak mast procurement areas. However, the oaks are capable of supporting moderately high deer populations during the fall.

Hydrology:

are high, the zone could not have provided the total dietary requirements of any population above a minimal number, at least for vegetal resources.

Finally, the presence of resident and migratory avifauna in this zone would have made it more important to prehistoric inhabitants. Twenty-three species of avifauna spend at least a portion of the year in this zone and all of these birds are edible. Although these may not have been a critical resource due to possible problems in procurement, the fowl could have been an excellent caloric and protein source.

In summary, the food resources that would have been present in the tributary and bottomland zone are the densest and most diverse of any other zone in the region. The potential for near year-round exploitation would have made the zone very important as an energy extraction location. However, due to the presence of poorly drained soils and regular flooding, it is unlikely that human groups would have resided within the zone. Rather, by situating in the mesic terrace zone (II) near Zone III, they would have had dry living areas and ready access to the streams.

Zone IV: Savannah River Swamp and Savannah River

Elevation range: 80 to 90 feet a.m.s.l.

General topographic context:

The swamp zone is an irregular floodplain which has varied relief due to channel movements and associated geological formation processes. In the area at the mouth of Steel Creek the swamp is about 1.5 miles at its widest point. Throughout

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Hydrology:

Throughout the zone, water from flowing permanent streams is abundant. Small streams and springs provide continuous supplies of water in all areas. From a point roughly 2 miles upstream from the Savannah River swamp, the streams are narrow enough during nonflood seasons to have permitted the use of wires and nets for procurement of fish.

Resources:

In terms of year-round productivity and overall resource diversity, this zone has the potential to have provided the greatest amount of food to prehistoric hunter-gatherers. The cover provided by shrubs, vines and herbs (Whipple 1978) are capable of supporting very high deer populations. Whitetail deer tend to spend part of the day in this type of zone and the remainder in the terrace and sandhill zones. This diurnal pattern of movement would make Zone III a superb hunting area. Other fauna of both the terrestrial and aquatic types are moderately dense in the zone relative to Zones I and II. Fish are available on a permanent basis in the streams, while anadromous species enter the streams during the late winter and spring. Procurement of fish would have been a simple matter of placing either nets or weirs across the channel and collecting the catch regularly.

Vegetal resources would have been fairly dense in the zone and have provided a major dietary contribution. At least seven oak species, hickory, grass seeds, berries, and shoots are common in the zone. The only problem with the vegetal resources may have been the relative small area encompassed by the zone. Only 12% of the total land area in the Steel Creek watershed is in Zone III, and about 35% of this area is water. Thus, although the diversity and density of this zone

floodplain/bottomland along most of its margin. Since the streams and the bottomland are so mutually associated, the two are combined in this zone.

Soils:

Two soil types, Johnston and Okenee, and Grady and Bayboro, are most common in this zone. Each type is composed of finer-textured soils than found in other zones in the watershed and as a result is capable of holding more moisture. High nutrient values of these soils contribute to a very high productivity (Aydelott n.d.).

Vegetation:

Beavers et al. (1973: 34-35) and Langley and Marter (1973) refer to the community in the bottomlands of this zone as the small stream hydric. This community situated along narrow to moderately wide floodplains is characterized by black gum, sweetgum, yellow poplar, green ash, red maple, loblolly pine, and scyamore. In the middle reaches, a large stream hydric pattern exists which includes willow oak, water oak, overcup oak, nuttal oak, swamp chestnut oak, cottonwood, and sycamore. Near the junction with the Savannah River, swamp bald cypress and tupelo gum would have been common. A recent vegetation gradient study of the Upper Three Runs Creek bottomlands by Whipple (1978) indicates that the actual composition of the community is closely associated with water levels and periodicity of flooding. Generally most oak species tend to lack water tolerance and occur away from areas regularly flooded or saturated. Overall, the vegetation in this zone grades along the water course from moderately useful food species in the upper reaches to highly useful food species in the middle reaches to poor food resources in the lower reaches.

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intermediate location for access to both the upland sandhills and the small stream bottomlands.

Resources:

The entire range of terrestrial fauna occur in this zone making it an excellent hunting area during all but the winter season. The lack of good winter mast density in the zone due to low frequencies of red oak species may have made hunting a less productive pursuit compared to the upland sandhill zone. Other resources occur in moderate to high densities in this zone during most months of the year except winter. For this reason food procurement in the winter may have required either seasonal movement of residence to other resource zones or logistic foraging to these zones (Binford 1980). Overall, given the optimal location of this zone between two other zones and its moderate to high food resource productivity during most of the year, prehistoric inhabitants of the area would have most probably used this zone as a locus of long term residence and/or base camps.

Zone III: Tributaries and Bottomlands

Elevation range: 85 to 225 feet a.m.s.l.

General topographic context:

This zone crosscuts the elevation ranges of the upland sandhills and mesic terrace because it follows the course of creeks and their tributaries from the Savannah River swamp to the sandhills. Although the total gradient of the stream system drops 140 feet in approximately 12 miles, no radical drops in the channel are present. This gently falling stream system thus has a moderate

General topographic context:

Gradually sloping terrace (Sunderland) between the upland sandhills and the Savannah River swamp. Small backwater swamplands intrude into this zone in the vicinity of the Savannah River swamp.

Soils:

The predominant soil types situated in this zone are Kalmia and Johns, Ocilla and Albany, Troup (terrace phase), and Lucy and Wagram. Although sandy, these soils are very high in biotic productivity making the zone an excellent locus of food resources.

Vegetation:

Although the vegetation in this zone varies depending on edaphic conditions, the predominant community type is best described by Beavers et al. (1973: 34-35) as mesic. Barry (1980: 138-140) refers to this community as the mesic mixed hardwood and pine type which is characterized by a white oak dominance with loblolly pine. Other species common to this zone are black oak, swamp chestnut oak, willow oak, mockernut hickory, pignut hickory, water oak, sweetgum, persimmon, ash and dogwood. The actual composition of this community varies due to successional and soil parameters. Shelford (1963: 87) states that succession usually results in an oak-hickory climax.

Hydrology:

Ranging from small headwater streams originating in the sandhills to the larger tributaries of the Savannah River, the water resources near this zone are quite variable. Of importance is the fact that this zone is always very near permanent streams and the associated bottomland, thus making Zone II an excellent

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Overall, this zone contains a very high density of small red oak group species which are excellent mast producers.

Hydrology:

Small streams with one or two branches are characteristic of this zone. Also, some Carolina Bays and springs occur in the zone. However, the water resources are not year-round and would prohibit long term prehistoric occupation in the zone.

Resources:

Overall, the resources of this zone are the least dense of any zone, with the exception of oak mast. The low ground water content and related vegetative xericity result in broad water differences in seasonal resources productivity. Of particular interest is the high red oak group ("bitter") acorn productivity in the zone. This resource, unlike white oak group ("sweet") acorns are more predictable from year to year and much more efficient to procure and leach (cf. Reidhead 1976: 229-236). Further these acorns are able to resist worms due to their extremely tough shells. Finally, these acorns are more reliable as a resource because they do not germinate until late winter (Fowells 1965: 557-620; Olsen 1974: 692-701). This latter point makes the red oak group acorns important deer fodder during the winter which results in higher deer density in the upland sandhills during winter.

Zone II: Mesic Terraces

Elevation range: 90 to 170 feet a.m.s.l.

defined and described by Beavers et al. (1973) and Langley and Marter (1973) as the xeric, mesic, small stream hydric, and large stream hydric. However, because the emphasis in this study is upon the effective environment (i.e. those elements of the environment suitable for human exploitation), the zones defined below differ to some extent. Each of the microenvironmental zones is presented in terms of six key variables: elevation range, general topography, soils, vegetation, hydrology, and food resources.

Zone I: Upland Sandhills

Elevation range: 170 to 400 feet a.m.s.l.

General topographic context:

Primarily large interfluvial ridges that gradually slope to the south. This zone is composed mainly of areas within the Aiken Plateau and the Brandywine terrace.

Soils:

All soils in the upland sandhills zone are predominatly sandy and include the following types: Americus, Vaucluse and Blaney, Dothan and Norfolk, Fuquay and Wagram, Orangeburg and Red Bay, Troup, and Gunter and Lakeland.

Vegetation:

Very xeric on the high ridgetops grading to less xeric on the terminal ridgenoses and slopes. Referred to as a Xerosere by Shelford (1963: 86-87), this community contains longleaf pine, turkey oak, blackjack oak, bluejack oak, southern red oak, short-leaf pine and loblolly pine (Beavers et al. 1973: 34-35). More mesic stands contain a higher proportion of oaks relative to pines. According to Barry (1980: 97-116) this range in xericity accounts for three graded vegetation systems: the turkey oak barrens, the scrub oak barrens and the xeric pine-mixed hardwoods.

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and the Pleistocene Coastal Terraces. Composed of sandy sediments, the Aiken Plateau dominates the study area and generally ranges in elevation from 250 feet to 400 feet within the Savannah River Plant. Below the 250-foot elevation level are three coastal terraces: The Wicomico (below 100 feet), the Sunderland (between 100 and 170 feet), and the Brandywine (between 170 and 250 feet). The Wicomico is essentially the Savannah River floodplain of the recent era that floods on a seasonal basis. The Sunderland is a generally level feature that parallels and bounds the Savannah River swamp. Finally, the Brandywine is a well-dissected terrace that forms the transitional zone between the Aiken Plateau and the Sunderland (Siple 1967; Stevenson 1982).

The specific topography of the study area results from the erosive activity of streams on the plateau and terraces. Above the 150-foot contour, the presence of the terraces all but disappears due to this erosive activity. In general, the topography is most appropriately described as steep and dissected with river and small stream terraces adjacent to the channels.

The distribution of soil types in the area are described by Aydelott (1973). Although the study of soils was conducted for the specific purpose of forest management, the general information obtained can be used in the evaluation of the soils for a reconstructed vegetation pattern. The association of specific soil types in topographic zones will form the basis for delineating microenvironmental zones.

Microenvironmental Zones

Using the information provided by Aydelott (1973) for soils and the topographic variability present in the area, four microenvironments were defined for use in the examination of settlement variability. These conform with basic vegetation communities

Reconstructed Environments

As indicated in the preceding section, the general vegetative pattern in the southeastern Atlantic Slope has been basically similar over the past 7,000 years with the exception of areas altered by the economic pursuits of Euro- and Afro-American populations. Given a similar climate and overall vegetation pattern, it is possible to reconstruct the local environmental situation that existed since about 5000 B.C. The purpose of such a reconstruction is to examine the local variability in elements of the effective environment and to use this variability to predict the nature of human settlement and subsistence behavioral patterns. Such an investigation assumed that human behavior such as subsistence activities were directly related to the availability of natural resources.

The proposed waste storage/disposal areas offer an excellent laboratory for the examination of variability in human settlement-subsistence patterns in that the local environment varies widely from xeric uplands to hydric swamps. On the regional level, the study area falls within the Upper Coastal Plain physiographic province, which is composed primarily of unconsolidated sediments of Cretaceous age or younger (Langley and Marter 1973: 17). This general area falls within the Oak-Hickory-Magnolia Forest Ecotone described by Shelford (1963: 86-88). It is characterized by a pine to scrub oak succession in xeric areas and a more stable oak-hickory sere in hydric contexts. The climate common in the region is best described as mild, with monthly temperature averages ranging from 48°F in January to 81°F in July and an annual mean humidity of 70% (Langley and Marter 1973: 65). Precipitation averages 47 inches with extremes ranging from 28.8 inches to 73.5 inches (Langley and Marter 1973: 73).

The general topography of the study area can best be described in relation to the surface geological structure composed of two major components: the Aiken Plateau

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10860 and 7550 B.C. at White's Pond (Watts 1980). Spruce and jack pine greatly declined across all sample areas (Watts 1975, 1980; Watts and Stuiver 1970; and Whitehead 1965). The oak/hickory/hemlock/elm vegetation pattern extant during this period reflects a relatively warmer and moister climate than existed during the full glacial (Watts 1980: 326). It is during this climatic episode that the first well documented human occupation of the region occurs.

Post Glacial (8000 B.C. - present)

During the early Holocene segment of this period (8000 - 5000 B.C.), the oak and hickory vegetation pattern reached a maximum density and distribution throughout the region. Walnut, hemlock and hazelnut disappear from the pollen record. By 7550 B.C., the occurrence of hickory and ironwood species had greatly declined compared to previous high levels. Replacing these species were sweetgum and blackgum, which accompanied the more persistent oaks (Watts 1980; Watts and Stuiver 1970). The changes in vegetation prior to 5000 B.C. suggest several episodes of rapid warming accompanied by increased moisture.

By 5000 B.C. a major change in climate probably began as indicated by a pine maximum and concomitant rapid decrease in the percentage of gums (Watts 1980). Combined with the persistent oak vegetation, the pine suggest an overall drier climate than existed earlier in the Post Glacial (Watts 1980; Whitehead 1965: 390). Studies by Watts (1980) and Bond (1971) indicate that this pattern of mixed pine and oak represents the initiation of both modern climatic and vegetation conditions in the region. From this time forward, the nature of environmental variability does not register in the pollen studies.

TABLE 2 (Continued)

GENERALIZED PALEO-ENVIRONMENTAL RECONSTRUCTION
FOR THE TERMINAL PLEISTOCENE AND HOLOCENE

EPISODE	INFERRED CLIMATE	VEGETATION	DATES AND SAMPLE LOCATION
Post - 3000 B.C.	Essentially modern	Continued reversal of of pine dominance and development of cypress swamps	(Carbone 1983)

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TABLE 2 (Continued)

GENERALIZED PALEO-ENVIRONMENTAL RECONSTRUCTION
FOR THE TERMINAL PLEISTOCENE AND HOLOCENE

EPISODE	INFERRED CLIMATE	VEGETATION	DATES AND SAMPLE LOCATION
			Singletary Lake, N.C. 9050 B.C. (Watts 1975) Bladen Lake, N.C. 9050 B.C. (Whitehead 1965, 1973)
12000-8000 B.C.	Increased warmth, drier	Physiographic zone(s)-specific - Northern Georgia to Northern Florida - Forests became denser with pine and oak gradually colonizing previously unforested areas, suggesting a return to drier conditions.	(Sheehan, Whitehead and Jackson 1982; Carbone 1983)
Early Holocene 8000-5000	A continued warming trend accompanied by increased moisture	General trend - Oak and hickory maximum. Sharp decline in beech and increase in gums.	White's Pond, S.C. 7550-5050 B.C. (Watts 1980) Bladen Lake, N.C. (Whitehead 1965)
Late Holocene 5000 B.C. - Present	Continued warming with gradual desiccation	General trend - Oak and pine. Pine increases relative to the decreasing oaks. Generally modern vegetation patterns develop by 5000 B.C.	Okefenokee Swamp, Ga. 3250 B.C. (Bond 1971) White's Pond, S.C. 5050 B.C. (Watts 1980)
3000 B.C.	Hypsithermal interval	Physiographic zone(s) - specific - Piedmont, Gulf and Atlantic Coastal Plains - Change toward more open vegetation with oak and hickory replacing Southern Pine on the sandy uplands of the Gulf and Atlantic Coastal Plains. Oak-hickory-Southern Pine forest restricted to the Piedmont.	(Delcourt and Delcourt 1981; Carbone 1983)

TABLE 2

GENERALIZED PALEO-ENVIRONMENTAL RECONSTRUCTION
FOR THE TERMINAL PLEISTOCENE AND HOLOCENE

EPISODE	INFERRED CLIMATE	VEGETATION	DATES AND SAMPLE LOCATION
Full Glacial 23000 - 13000 B.C.	Much colder and drier than present	General Trend- Jackpine, spruce, herbs with a small occurrence of deciduous tree species.	White's Pond, S.C. 17150 - 10860 B.C. (Watts 1980)
16000 B.C.	Warm, temperate	Physigraphic zone(s) - specific - Southeast Coastal Plain - Oak, hickory and Southern Pine with hardwood forestS along major river valleys. A band of mixed northern hardwood/boreal conifer forest along the northern transitional margin (Middle Atlantic region) containing fully boreal jackpine/spruce forests.	(Delcourt and Delcourt 1981)
	Cool (?), temperate	Piedmont and South - Central Georgia - Patchy mosiac with local stands of boreal conifers and areas mantled with more mesic hardwood forests. Oak and other deciduous trees uncommon. Abundant and diverse herb taxa with boreal affinities suggest park-like vegetation frequently interrupted by patches of trees and shrubs.	(Sheehan, Whitehead and Jackson 1982; Watts 1971 Watts and Stuiver 1980 - Sheelar Lake, N. Florida
Late Glacial-Early Post-Glacial 13000-8000 B.C.	Warmer and moister than glacial; cooler and moister than present	General Trend- Oak, hickory, beech, and hemlock	White's Pond, S.C. 10860 - 7550 B.C. (Watts 1980) Pigeon Marsh, Ga. 11050-8850 B.C.

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research used to document the trends in ancient climates was conducted in Georgia, Florida and North Carolina, areas which offered suitable preservation of pollen, stratigraphy and datable material to establish chronological ordering (e.g. Watts 1975; Watts and Stuiver 1980; Bond 1971; Whitehead 1965, 1973). A single study based on sediments and pollen in South Carolina was conducted by Watts (1980) at White's Pond, near Columbia. Across this Atlantic Slope region, the general vegetational history has been documented to be similar. Table 2 synthesizes the general trends in the region and provides inferences relevant to physiographic zone-specific variation in the broader patterns. The following discussion correlates directly with the general trends presented in the tabular summary.

Full Glacial (23000 - 13000 B.C.)

Pollen studies at White's Pond, South Carolina, (Watts 1980); Bob Black and Quicksand Ponds, northwest Georgia (Watts and Stuiver 1970); Pigeon Marsh, northwest Georgia (Watts 1975); and Singletary and Bladen Lakes (Whitehead 1965, 1973) indicate a full glacial climatic condition in the region, which was xeric and cold. Throughout the Piedmont and Coastal Plain provinces of the region, cold-adapted vegetation composed of predominatly spruce and jack pine characterizes the pollen records. These species, accompanied by less common oak and ironwood, suggest a much colder and drier climate than exists today (Watts 1980: 326).

Late Glacial (13000 - 8000 B.C.)

A trend toward increased deciduous species marks this climatic episode as indicated by an abundance of oak, beech, hickory, black walnut, hemlock, hazelnut and ironwood (Watts 1980). These species reached a peak in occurrence during the period between

Chapter III

ENVIRONMENT AND HUMAN ADAPTATION

Introduction

Human systems, regardless of their level of technological complexity, have been subject to general and specific nuances of the environments in which they have operated. In order to establish the environmental framework within which human populations adapted in the vicinity of what is now the proposed transmission line right-of-way, this background is provided. Two types of environmental information are provided: 1) a paleo-environmental overview, which presents the general reconstruction of late Pleistocene and Holocene conditions within the southeastern Atlantic Coastal Plain and 2) a discussion of the Savannah River Plant in terms of specific elements of the effective environment partitioned into microenvironmental zones. These reconstructions are not a first attempt in the region (cf. Hanson and Most 1978), and they are not offered as a comprehensive statement of the total environment. Rather, the reconstructions are presented in terms of the effective environment (i.e. the variables in an environment that affect humans).

Paleo-environmental Reconstruction

This presentation of extant information of the general paleo-environment has been drawn from research conducted in the southeastern Atlantic Coastal Plain over the past 20 years by investigators attempting to document the evolution of flora in response to changing climatic conditions (e.g. Watts 1971, 1975, 1980; Watts and Stuiver 1980; Bond 1971; Whitehead 1963, 1965, 1973; Delcourt and Delcourt 1981; Sheehan, Whitehead and Jackson 1982; and Carbone 1983). Additional information was obtained from the work of Goodyear, House and Ackerly (1979) which provides a general southeastern synthesis of available research within an archaeological context. The majority of the

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in lo of rent was repairing tenant dwellings in hopes of recruiting new tenants. The owner tried growing tobacco, took in northern hunters during the season and provided beaters and guides. They went so far as to renovate the old family home to accomodate more people. There are many factors involved with the decline of southern farms, perhaps one of the most important was that the land could no longer support profitable crops. The land was exhausted by cotton production. Without extensive fertilizing, which was expensive, crops could not be supported by the depleted soil.

Until ca. 1735, the Three Runs area was visited only by English traders from Charles Towne, seeking furs from the nearby Indian inhabitants of Savanno Town. As can best be deduced from available records, actual settlement of the Three Runs area began in the late 1730s by Europeans with Royal Grants to the land. The area was sparcely settled until the end of the Revolutionary War. It was not until the 1820s-1830s when the area became more densely settled and most farmable land was under cultivation. With the end of Reconstruction, even the xeric uplands were settled. At the end of World War I, a portion of the Black population moved to the northern cities seeking employment. Because of this migration north, the larger tenant-farmed plantations began to become unprofitable and declined. Before the Korean War began, several of the area's tenant plantations were barely keeping up agricultural production. The general population and agricultural decline of the area was one of many factors leading to selection of this region for the construction of the Savannah River Plant.

to Point Comfort, near Ellenton, or to Stoney Bluff Landing, near the mouth of Lower Three Runs Creek. Once the railroads came through the area, river transport all but died.

Blacks left the plantations when their former masters were unable to provide them with food or work. Blacks, at least in Georgia, began moving to the cities by the thousands (Brooks 1914: 16), and others moved westward.

By 1912 the Talatha Telephone Company and the White Pond Telephone Company were operating in the Savannah River Plant area (Caughman 1912: 361, 365, 370). The Ellenton area was served by the Cassels Telephone Company, however, research has not yet determined the period and area served. In 1929, the town of Dunbarton signed a 30-year franchise with the South Carolina Power Company for electrical power. In 1929, there was a 50KVA hydro-electric power station owned by the town of Ellenton, named Western Carolina Oil and Power Company, and served a territory with a population of 620 (S.C. Power Rate Investigating Committee 1931). The company existed until about 1936. The dam was known as Cassels Pond and had a back-up gas engine generator. By 1938, Ellenton and Dunbarton were on the transmission line from Barnwell (Public Service Commission Map 1938).

During World War I, large scale migration of rural southern Blacks to the urban North resulted in large Black ghettos (Kellogg 1977: 310). This migration was caused in part by the fact that land farmed in the South could no longer support them and the northern cities offered a promise of industrial employment. This migration left many southern tenant farms empty and fields fallow. Plantations that employed tenants to work the plantation did all they could to survive. The documents relating to the Ashley Plantation (38BR101, 273-283, and 494) indicate that the plantation was in decline, the foreman,

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profitable to run large plantations when the help had to be paid, large plantations were broken up into smaller units for tenant farming. Better transportation and mechanization that would make farming on a large scale by individual landholders profitable were still in the future.

Once the railroads build tracks throught the plant area, small towns along their routes and crossings sprang up.

> Ellenton was born when the Charleston and Western Carolina Railroad was built in the 1870s. The section that ran from Charleston, South Carolina, to Augusta, Georgia, cut through Robert Jefferson Dunbar's plantation near his big three-storied home where the superintendent of construction, Mr. Millett, boarded. He became so charmed with Mr. Dunbar's attractive nine-year-old daughter, Ellen, that he requested the company to name the station near the Upper Three Runs neighborhood for her (Cassels 1971: 3).

By 1900 the Savannah River Plant area could boast of having nine small towns or communities (Ellenton, Dunbarton, Hawthorne, Donora, Hattieville, Robbins, Meyers Mill, Greenland, and Bush), and seven of these had rail connections. Population figures for Silverton township in Aiken County indicate a population increase in 1900, but a decrease in 1910. Fourmile township in Barnwell County decreased during that same period. Ellenton's population rose steadily from 1890 to 1910 (Bureau of the Census 1913). Once the railroads connected stations near enough for planters to economically transport their staple crop to the railroad, then river transport was no longer necessary. The railroads cut the time of transporting goods to the Augusta market. The ease of using rail transport would have allowed these late-nineteenth-century planters to move further from the river. Area farmers probably brought crops for shipment to Savannah either

With the end of the Revolution, the area once again received new settlers and large tracts of unimproved and unclaimed land began to be cleared for crops. Although farming practices differed greatly, the majority of farmers cultivated large tracts of land with little or no thought to fertilizing, or contour farming. The land quickly became worn out and the farmer would either move on to a new farm or open up a new tract of land (Sosin 1976: 173). Eli Whitney, near Savannah, and Robert Watkins, in Elbert County, Georgia, improved on older cotton gins (Watkins 1796: 1), helping cotton to become a major cash crop in the pre-Civil War years. Prior to the regional rail system, cotton and tobacco were transported to market by river carriers, either poleboats or steamboats.

Immediately after the Revolutionary War, Winton County (Aiken, Allendale, Barnwell and Edgefield Counties) was formed and a court system set up that administered the area. From 1786 to 1789, the formative years of Winton County, the court ordered roads to be built, and local landowners were ordered to oversee its construction and maintenance. One such road, 38BR286, was ordered to be constructed on 19 October 1786. This was the road from Silver Bluff to Mathews Bluff, crossing Steel Creek either on Stephen Smith's or Bartlett Brown's land by the Steel Creek Bridge (Holcomb 1978).

With the coming of the Civil War, agricultural production slowed, as it did in most of the South. With most able bodied men in the army, there were few to keep the plantations running efficiently, especially towards the end of the war. Research to this point implies that Federal troops were probably in the area during Sherman's march from Savannah to Columbia (Bartlett 1956), but whether or not they did damage to area plantations is unknown.

The era of reconstruction brought an end to the southern antebellum lifestyle, as the end of slavery brought difficult time to southern planters. Because it was no longer

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in the Carolina backcountry (Meriwether 1974: 179). This portion of the backcountry was slowly settled and had its detractions as well as attractions.

> New Windsor. . .had achived a reputation for ungodliness. Land in the region was not productive, and New Windsor's principal source of income was derived from the Indian trade. George Galphin, who established a base at Silver Bluff a few miles below Fort Moore, carried on a thriving business with the Creeks from about 1750 to the Revolution (Wright 1976: 87).

The settlement of Georgia took a somewhat different turn. It was not until Oglethorpe landed at Yamacraw Bluff in 1733 that Georgia began to be settled (McCall 1909: 21). In 1733, a treaty with the Creek Indians granted the Crown "all the lands and territories as we (the Creeks) have no occasion to use" (McCall 1909: 259). The territories specified were "all the lands between the Savannah and Altamaha Rivers, extending west to the extremity of the tide water. . ." (McCall 1909: 25). Along the Savannah River, settlement was slow; until the Treaty of 1763, people settled only slightly above Augusta (McCall 1909: 208), as problems with the Creek Indians held progress to a minimum.

The Revolutionary War was the next hindrance to new immigrants. Although the Savannah River Plant area itself saw no real action, Augusta was besieged three times by the American forces. In 1781 battles around the plant area included Wiggins Hill and Beech Island (McCrady 1901: 552). Vince's Fort, on Lower Three Runs Creek, was evacuated by Rebel forces upon hearing of the approach of Tory troops (McCrady 1901: 476). Rebel and Tory groups in the area surged back and forth, burning each others houses and scaring away others (Brown 1894).

From the time of the first English fur traders in the area, buckskins and fur pelts became the most valuable commodities from Cherokee and Creek traders. Obviously the furs were not obtained free; the government, in order to keep the Indians friendly, regulated the trade of furs for goods. Carolina Indian traders did not just trade in Carolina, but pushed westward to trade in both French and Spanish territories in Florida and Alabama. The Carolina fur traders were perhaps the most aggressive traders in North America.

With the founding of Augusta, about 1735, the Carolina fur trade began to decline. Settlers brought cattle and farming into the Three Runs area. However, before farming could begin, the land had to be cleared. Not to waste their efforts, the early settlers cut trees and in turn manufactured pitch and tar. For a number of years, processed meat and naval stores (pitch and tar) were the chief exports from the area.

Until the formation of New Windsor township in 1733, there were few settlers in the Barnwell/Aiken area near the Savannah River. The Royal government used many methods to bring settlers into the area: bounties for settlers, free land and pamphlets were written to entice settlers. Two of the more famous pamphlet writers and those responsible for many immigrants (mostly from Switzerland) were Johannes Tobler and Jean Pierre Purry. Tobler helped bring settlers to New Windsor, while Purry brought settlers to Purrysburg in the mid-to-late-1730s and after.

Beginning in 1736, a trickle of German-Swiss moved into the area. Johannes Tobler, with his family and 50 other Swiss families, set out from Switzerland for Carolina (Cordle 1939) to settle the New Windsor area. In 1572, Tobler started printing the South Carolina and Georgia Almanac. Although not printed every year, it was the first literary adventure

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and pigs. The second site, 38BR291, is as yet undocumented, however, excavations at this site afford a look at the life of a well-to-do cattle farmer.

European settlement of the central Savannah River area began in the mid-1730s with the origins of Augusta and New Windsor. The area of New Windsor, opposite Augusta, with Fort Moore at its center, was thinly settled.

Euro-American settlement of the Three Runs area probably began in the 1730s. The Proprietary/Royal government considered the Savannah River Valley as the frontier/border between Spanish Florida and English Carolina from 1670 to the founding of Georgia. Early records show that from 1690 English fur traders used several locations just below Augusta as trading centers with the Indians. The earliest trading center is recorded as Savanno Town, occupied by various tribes, but specifically by Shawnee at different times. The Proprietary/Royal government entreatied with many tribes to take up residence along the Savannah River as a buffer to warn of approaching Spanish, beginning with the Westoes in 1670 through Yamassee, Yuchi, Appalachians, Appalachicolas, Shawnee, and ending about 1775 with the final departure of the last band of Chicasaws. After the Yamassee War, the government set up a system of frontier forts; two were located on the Savannah River. The first was at Savanno Town (Fort Moore); the second was Fort Prince George, located at Palachicola Old Town. Fort Moore served also as an Indian trading center until the development of Augusta's Indian trading center and Galphin's trading post at Silver Bluff (McDowell 1955; McDowell 1970).

Fort Prince George served as an outpost for about 20 years. The main objective of the Rangers stationed there was to guard the river. They would sail or row a piraque up to Fort Moore and down to Savannah (Ivers 1972, 1974; McDowell 1955).

the population of the backcountry. Two great migrations help to settle the backcountry, the first began in the mid 1730s with the development of the township plan. One township, New Windsor, was to be settled between Horse Creek and Town Creek, in the vicinity of Fort Moore, while at the same time Georgia was being founded and settled. The second great migration began in the late 1750s with the Scots-Irish exodus out of Western Pennsylvania through the Shenandoah Valley of Virginia, into North Carolina and finally into South Carolina by the 1760s.

Act 433, passed in 1721, partially entitled ". . .for the Better settling the Frontiers of this province," mentioned settling the Three Runs area of the Savannah River. According to the act, no person was to raise cattle on the western side of the Savannah. This was enacted so that Carolina would become better settled and because settlers on the Georgia side could not readily join forces for their mutual defense at Savanno Town/Fort Moore (Cooper 1838: 122-126). The settlers could not enjoy relative safety from attack by Indians. This area became the frontier, as did other parts of the state until about 1740 when more settlers and townships began claiming land for more intensive farming and grazing purposes. The most promising grazing areas were the Savannas and cane swamps west of Orangeburg in the Forks of Edisto, around the headwaters of the Salkehatchie River, and between the Salkehatchie and Savannah Rivers. There were cowpens elsewhere, to be sure, but this was the "classic" cowpen area (Dunbar 1961: 128-129). This classic cowpen area is the area of the Savannah River Plant, and remained so until the development of the cotton gin brought the onslaught of cotton plantations. The cotton plantations had left little room on the landscape for cattle raising and the cattle industry moved west and north following the frontier. Ohio, for years was aleaders of cattle raising and evident in two sites on the SRP. One well documented site owned by Alexander Wood at Point Comfort (38AK228, the Lewis site) contained over 1000 head of cattle at his death in 1757. At this time, the term "cattle" also included horses

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The Historic Occupation of the Savannah River Valley

The first recorded exploration of the Carolina coast was in 1521 by a Spanish Captain in the employ of Lucas Vasques de Ayllon, a superior judge of Espanola. After several years of delays, Ayllon brought a group of settlers to the Carolina coast in 1526. Fever, a slave uprising, mutiny and Indian attacks brought an end to the settlement after only a few months.

In 1540, Hernando De Soto passed through South Carolina on an as yet undetermined route. Twenty-one years later the French, under the command of Jean Ribaut, tried to establish a colony in the Port Royal South area, calling it Charlesfort. This French attempt lasted less than a year; a mutiny brought an end to its short life. In 1566, the Spanish erected the first of many forts on Parris Island, and a city, known as Santa Elena (South 1979, 1980). The settlement lasted until about 1587 when it was finally abandoned, although there continued to be Spanish missions along the lower South Carolina coastal area, especially in the Edisto River mouth area.

The first serious attempt at colonization by the English began at Charles Towne in 1670. By 1680, English traders were operating at Savanno Town, later Fort Moore, near the Sand Bar Ferry Bridge. Fort Moore was constructed during the Yamassee War (1715-1718). The Yamassee War devastated the colony, especially the area between the Savannah River and Charles Towne. With the end of the war and the construction of Fort Moore settlers started to trickle into the backcountry again. By 1708 the colonies population was half slave, and the planters along the coast around Charles Towne continually feared a slave rebellion. In response to this fear they developed several different plans to bring new settlers into the colony. Most of their plans to bring in white settlers did not really address their problems with the slave population but did increase

more diverse than in previous periods including for the first time large numbers of ground stone tools, grinding tools, and both ceramic and steatite vessels.

The presence of diverse faunal assemblages, massive shell middens, diverse tool assemblages, and numerous features at some riverine sites indicates the first relatively sedentary populations. Stoltman (1972, 1974) suggests a largely riverine adaptation with some upland utilization. Sites on the Savannah River Plant do fit this pattern. Brooks and Hanson (1979: 10) recognize that the sites of the uplands within plant boundaries seem to contain fewer artifacts and be smaller than the terrace-floodplain sites.

The Early and Middle Woodlands represent a gradual lessening of reliance on floodplain resources. Hanson (1981: 12) suggests that a relative depletion of riverine aquatic resources caused by changes in river gradients and population growth prompted by reduced mobility resulted in the gradual reliance on upland resources. The Early Woodland sites on the Savannah River Plant seem to be more evenly distributed between the riverine and upland environments (Brooks and Hanson 1979: 12) and reflect an increased use of the uplands, suggesting a more diffuse resource base than the Late Archaic (Hanson, Most and Anderson 1978). Middle Woodland sites seem to be restricted to the uplands (Hanson, Most and Anderson 1978). Stoltman (1974: 214-215, 236-243) suggests a concentration on upland resources and perhaps some form of slash-and-burn agriculture.

The Late Woodland and Mississippian periods seem to be a continuation of the Middle Woodland settlement pattern. Use of terraces and floodplains take precedence over sandhills, but more use of the uplands is apparent than in the Late Archaic and Early Woodland periods.

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Prehistoric Background Summary

Gradual changes throughout the Holocene have resulted in changes in the resources available in the Savannah River area to prehistoric man and thus in his strategies to adapt to these changes.

The location of Paleo-Indian remains in this area suggest the focalization of food procurement on megafauna. Michie (1977) implies that sites on the margins of rivers would be the most favorable for these animals and thus a concentration of Paleo-Indian subsistence efforts for their procurement.

The Early Archaic period is accompanied by a warming climate and the exploitation of a wide range of plant and animal resources. A more diffuse subsistence strategy relying on the seasonal use of a great variety of resources scattered over a greater number of microenvironments is reflected by the first intensive use of upland areas within the Savannah River Plant boundaries (Brooks and Hanson 1979: 9). This environmental diversification is accompanied by a gradual diversity of tool assemblages needed to accomplish these new procurement tasks.

The Middle Archaic represents a continuance of this trend. Middle Archaic components are almost evenly divided between the different microenvironments recognized for the Savannah River Plant (Brooks and Hanson 1979: 9).

Evidence for the Late Archaic also demonstrates a very diffuse subsistence strategy but with an increased emphasis on riverine resources. Shellfish became abundant and were heavily used for the first time (Stoltman 1974). Artifact assemblages were much

floodplains)" (1974: 243), one may add to this the increased occupation of the estuarine area surrounding the mouth of the Savannah.

The Irene Phase has received greater attention in recent times along the coastal area of Georgia (Pearson 1977; Caldwell 1971). This phase, until most recently, has been defined by ceramics and mound complexes (Caldwell and McCann 1941; Caldwell and Waring 1939). Diagnostic ceramic indicators of this final Mississippian phase in the Savannah region are Irene Filfot Stamped, Irene Plain and Irene Incised (Caldwell and Waring 1939). Associated with these ceramics are mounds, flexed burials, shell ornaments, and some artifacts typical of the Southern Cult, a pan-Southeastern ceremonial complex of late Mississippian times. Irene evidence of subsistence reflects a reliance on corn, large mammals, fish, shellfish, and avifauna (Caldwell and McCann 1941).

Pearson's study of the coastal Irene settlement-subsistence pattern offers insight into the diverse subsistence base during the late Mississippian on Ossabaw Island (1977). The general results of the study indicates a structured settlement hierarchy composed of four site classes that correlate strongly with access to diverse environmental-resource zones. Smaller sites were associated with areas of less environmental variability while the large sites were located to provide maximal access to multiple resources (Pearson 1977: 96-98). Although this study examines an island-estuary situation, the value of the results is that the nature of late Mississippian settlement is more complex than the situation suggested by earlier results. In the context of the Savannah River drainage, Irene Phase sites must be examined with respect to diverse settlement structure and complex subsistence strategies. Previous work on the Savannah River Plant (Hanson, Most and Anderson 1978) located only five sites of the Mississippian period. Four of these occurred on the terraces of the Savannah River while only a single site was recorded in the uplands.

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Deptford, Haven Home ("Indian King's Tomb"), and Irene are the best documented of these estuary region sites. Due to the rich cultural deposits contained within these sites, (e.g., burials, grave goods, whole vessels, mounds, beads, and other exotic material culture), the information base is much better than for earlier periods. The first two sites mentioned, Deptford and Haven Home, contain a limited series of Savannah ceramics and are used by Stoltman (1974: 27-29) to characterize the Savannah I Phase. Both sites contain burials and large accumulations of artifactual debris. Only the Savannah Cord Marked and burnished types occur at these sites, in association with earlier Wilmington ceramics. Unlike most earlier sites, Haven Home and Deptford contain numerous burials indicating a more concentrated mortuary practice than was previously known for the Savannah Area. This development appears to be continued and elaborated in the following phases.

Research by Moore (1899) and Caldwell and McCann (1941) has revealed the nature of development in the Mississippian culture at the Irene site. This complex mound center documents the ceramic chronology from Savannah phases through the Irene Phase. Within the eight construction episodes at the Irene temple mound, ceramics of the Savannah phases are present in all levels, being gradually replaced by Irene ceramics in the final stages of the occupation (Caldwell and Waring 1939; Caldwell and McCann 1941: 43-46). Associated artifact assemblages for the Savannah phase occupation at Irene are unclear because of the pre-excavation disturbance at the site. Thus, one is faced with only a ceramic type description of the Late Woodland-Early Mississippian time period consisting of the Savannah Ware of complicated stamped and burnished sherds. Since only ceremonial sites have been excavated, and distributional inference would be misleading except to note Stoltman's comment that there was a "trend toward population nucleation (near

Although a distinction could not be readily made between Middle and Late Woodland sites on the Savannah River Plant because of a lack of good diagnostic artifacts, the arrangement of these sites mirrors the pattern at Groton Plantation (Hanson, Most and Anderson 1978). Sites of these time periods are scattered throughout the Savannah River Plant.

Late Woodland and Mississippian (A. D. 700 to 1700)

These two general periods have been combined because of a general lack of distinction between the ceramics of the Savannah I and II phases in the area of the study. The diagnostic ceramic type of the Savannah I Phase is Savannah Cord Marked (or Savannah Fine Cord Marked) defined by Caldwell and Waring (1939), while Savannah Complicated Stamped, Savannah Check Stamped and Savannah Burnished Plain are considered as diagnostic of the later Savannah II Phase (Stoltman 1974: 27-31). The problem arises from the lack of exclusiveness in the two ceramic distributions, i.e., Savannah Cord Marked almost always occurs with the latter types. Thus, from about A.D. 700 to 1200, the Savannah ceramic wares predominate without a great deal of distinction.

The Savannah phases are documented at sites from the Fall Line to the Atlantic Coast. Hollywood Mound, which was partially excavated by DeBaillou (1965) and Thomas (1894), is located near Augusta, Georgia, on the Savannah floodplain. The site contains all types of Savannah Ware ceramics associated with a large, multi-staged temple mound (DeBaillou 1965: 6-10). Although other sites with Savannah ceramics are known from the middle Savannah River, only Lawton Field (Moore 1899) has any published documentation. In the vicinity of Savannah, Georgia, the work of Waring (Williams 1968) and subsequent research during the Works Progress Administration period (Caldwell and McCann 1941) has yielded several sites of the Late Woodland-Early Mississippian period.

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and Stoltman (1974). Although sherd temper is considered to be a major attribute of this type (Caldwell and Waring 1939), Stoltman (1974: 25) argues that sand-tempering can be considered within the range of temper variabilty for the type since all other characteristics of the ceramics found at Groton Plantation fit the description. Basically, Wilmington is identified by a predominance of coarse cord-marked ceramics within the Savannah River area.

Sites that contain Middle Woodland ceramics within the Savannah drainage range from the mouth of the river to the Fall Line. These include Oemler, Walthous, Meldrim, Cedar Grove, Deptford Bluff, Greenseed Field, King's New Ground Field, White's Mound, Rabbit Mount, Clear Mount, and several others in Groton Plantation (Stoltman 1974: 24-27). Information from these sites primarily concerns ceramics with the notable addition of mound associations (Stoltman 1974) in several cases. Within the Groton Plantation survey, the majority of the ceramic sites occurred within the upland province in contrast to the preceding periods.

Little is known of the assemblages associated with the ceramics of this phase, but data from the Groton Plantation study allow for some understanding of the general settlement pattern. Stoltman (1974: 214-215, 236-241) concludes that since almost 80% of the Wilmington ceramics recovered in the survey were found in the uplands, a concentration on upland resources was the base of the subsistence technology, including some form of slash-and-burn agriculture. Although this is a conjecture based on minimal evidence, the strong association of these ceramics in the non-floodplain environment would indicate a shift in settlement and possible subsistence patterns. If this is the case, then the Middle Woodland should be a well-represented period within the plant because of the large area of upland composed of terraces and the Aiken Plateau.

Milanich (1973) must be credited with one of the only efforts directed at the reconstruction of the entire lifeway associated with the Deptford ceramic pattern; however, much of his information and results are focused on the coastal region and the Gulf sub-region that are far removed from the Savannah River.

The spatial distribution of Deptford sites has been investigated at Groton Plantation with the conclusion that the Deptford ceramic sample is distributed equally between the floodplain and upland (Stoltman 1974: 273). This pattern of increased use of the uplands is believed to correlate with an increasing dependence on the biotic resources of non-floodplain environments. Thus, one may expect to find Deptford ceramic sites in the areas of the plant removed from the swamp, such as the terraces and banks along the major streams.

In summary, there is a stylistic change in ceramic design that is correlated with a general change in settlement pattern during the Early Woodland period. This period is one of transition from the floodplain-oriented subsistence base in the Late Archaic to a more diffuse subsistence base in the Woodland, evenly distributed in most environmental contexts. The known settlement pattern present on the Savannah River Plant supports this conclusion in that sites of moderate and high artifact frequency and size occur on terraces and floodplains while those of smaller size and lower content occur in the uplands. This pattern suggests an increased use of the uplands indicative of a more diffuse subsistence base (Hanson, Most and Anderson 1978).

Middle Woodland (A. D. 1 to 700)

Most cord-marked ceramics with sand temper are included in the Wilmington Cord Marked (or Wilmington Heavy Cord Marked) type described by Caldwell and Waring (1939)

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similarity between Stallings sites and Thom's Creek/Refuge sites may provide some evidence to support a functional similarity argument although this is only conjecture at this time.

Deptford Phase evidence, in contrast to the preceding phases, has been recovered from sites on the Atlantic and Gulf Coastal Plains from North Carolina to Florida to Alabama. Milanich (1973) has provided the most comprehensive examination of the Deptford Phase throughout its geographic range. This study views the Deptford Phase as a non-agricultural economy dependent on intensive hunting and gathering. It is most readily identified in the archaeological record by sand-tempered ceramics with linear check-stamped, simple-stamped, and check-stamped designs (Milanich 1973; Caldwell and Waring 1939).

Within the Savannah River region, Deptford is well represented by evidence from the Bilbo Site (Williams 1968: 152-197), the Deptford Site (Williams 1968: 140-151), the Refuge Site (Williams 1968: 198-208), White's Mound (Phelps and Burgess 1964), the Groton Plantation sites (Stoltman 1974; Peterson 1971), Lewis Site (Hanson 1985), and the St. Catherine's Island Burial Mounds (Thomas and Larsen 1979). The majority of information concerning the Deptford Phase in the Savannah River region concerns ceramics with only minimal reference to the associated assemblages. The only general association present at these sites are small triangular projectile points, small-stemmed projectile points, shell and bone ornaments and tools, and assorted flake tools. Milanich (1973), however, suggests that Deptford sites have diverse lithic assemblages similar to those found in the Late Archaic with the exception of point types. This limitation in the information base for assemblages of Deptford can be traced to a rather single-minded concentration of most investigators on the ceramic development of the Deptford waregroup with little attention to the other characteristics of the assemblage.

the use of the term Woodland is useful only as an heuristic device for relative chronological purposes. The discussion of the various Woodland phases that follows will provide a general understanding of the variation in ceramic style and settlement patterns associated with the ceramic time indices.

Determination of the exact starting dates for the Early Woodland period in the Coastal Plains has been confused by similarities between many of the fiber-tempered and sand-tempered wares. The major problem arises with Thom's Creek/Awendaw types, which are sand-tempered, punctate design types similar to the fiber-tempered Stallings III ceramics. Other designs common on these ceramics are simple stamping and incising (Phelps 1968). South (1973) has grouped these Thom's Creek ceramics and those of the later Refuge complex into a Formative ware group association with those of the Stallings II and III phases. This latter grouping may best characterize the general transition between the two groups of ceramics since the only real basis for separation is the fiber-temper/sand-temper attribute. Ceramics of both temper types occur within Rabbit and Clear Mounts at Groton Plantation in similar contexts, furthering the contention that the sand-tempered types are transitional (Stoltman 1974: 215).

Within the Savannah drainage system, the locations of Thom's Creek and Refuge sites appear to be similar to those of the Late Archaic. Stoltman (1974: 215, 216) has mentioned that the Early Woodland ceramics occur in both floodplain-terrace and upland associations. This general pattern would seem a reasonable expectation for the Savannah River Plant because of the similar environmental contexts in the two localities.

Beyond the ceramic assemblages, little is really known of the Thom's Creek and Refuge phases, especially in terms of lithic artifacts. This paucity of information makes any inferences concerning the first half of the Early Woodland inconclusive. The overall

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assemblages are present at some large riverine sites, indicating relatively sedentary human populations (Hanson 1981: 8).

Based on the distribution of sites for the Late Archaic, there does not appear to be a major distinction in settlement patterns between the three phases; indeed, the phases may be simply taxonomic distinctions based on ceramics without any relevance to settlement or subsistence patterns. As in the other Archaic periods, sites tend to focus on large drainages and are often found within the floodplains of rivers on alluvial rises or mounts. Shellfish were heavily utilized as were mammalian fauna (Stoltman 1974). Excavation of sites has focused on the large shell-bearing locations that may be large riverine base camps, but little information is available for upland Late Archaic sites.

The known Late Archaic occupation of the Savannah River Plant is represented at 10 sites, the majority (6 sites) of which are situated on floodplains and terraces (Hanson, Most and Anderson 1978: 121-122). These sites are generally large and high in artifact content. On the other hand, the four upland sites contain relatively fewer artifacts and tend to be smaller than the terrace-floodplain sites.

Early Woodland (1000 B.C. to A.D. 1)

The Woodland Period has been defined by Willey (1966) as a general period during which ceramics, burial mounds and agriculture were common; however, this definition is based primarily on artifactual traits, the most common of which is ceramics. As mentioned in the description of the Late Archaic, ceramics are known from the Savannah River area well before the 1000 B.C. date given here. Stoltman (1974: 20-21) simply states that the Early Woodland is defined on the basis of sand-tempered ceramics for the region in the absence of definitive proof of mounds or agriculture. For this reason,

fiber-tempered ware in the Stallings II Phase as opposed to the occurrence of decorated ware in the Stallings III Phase. Dates of 2,750±150 B.C. and 2,500±150 B.C. at Stallings Island were derived from the pre-ceramic occupations (Stallings I). Charcoal from a pit at the bottom of the ceramic horizon of that site dates the beginning of Stallings II at 1,780±150 B.C. Earlier dates of ca. 2500 B.C. have been recorded at the Rabbit Mount Site (Stoltman 1972).

Associated with these sites is a variable lithic industry best represented at Stalling's Island, Rabbit Mount, Bilbo, and Lake Spring (Stoltman 1972: 45). The raw materials range from slate to chert depending on the local availability of these materials. Savannah River points dominate the assemblage with numerous unifacial tools, grinding tools, cruciform drills, large nonhafted bifaces, steatite "netsinkers," chipped adzes, bannerstones, ground axes, and steatite bowls (Stoltman 1972: 46-47). This diverse assemblage of tool types is complemented by various antler, bone and shell tools found at Rabbit Mount and Stalling's Island (Stoltman 1972).

Stallings I has basically the same assemblage as the other two phases except that it lacks ceramics. Some changes in projectile point morphology are recognizable between the pre-ceramic and ceramic phases. The large, broad-stemmed points of the pre-ceramic are replaced by smaller, more contracting-stemmed forms in Stallings II (Bullen and Green 1970: 13; Keel 1976). These later points are called Otarre points (Keel 1976).

Stoltman (1972, 1974) has synthesized the most recent information available on the Late Archaic in the Savannah drainage and has suggested a riverine adaptation focused on shellfish with some upland occupation and numerous features and diverse tool

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1978). As in the case of the Early Archaic sites, these were distributed in all major environments.

Late Archaic (3000 - 1000 B.C.)

Within the prehistoric sequence of the Savannah River Valley, the Late Archaic is perhaps the best examined cultural period stressing its importance in understanding the initial development in ceramic technology.

The most noticeable change in tool assemblages from those of the Middle Archaic is the addition of fiber-tempered pottery. Radiocarbon dates from White and Rabbit Mounts suggest that these are the earliest ceramic sites in North America (Stoltman 1972, 1974). Data representing this period have been excavated from 24 sites along the Savannah River from the lower Piedmont to the Atlantic Ocean. These sites are discussed by Stoltman (1972) in great detail, especially with reference to the presence of fiber-tempered pottery. Among the more important of these sites, because of the availability of radiocarbon dates, are Stalling's Island (Claflin 1931; Fairbanks 1942; Bullen and Green 1970), White's Mound (Phelps and Burgess 1964), Rabbit Mount (Stoltman 1974), Bilbo (Williams 1968: 152-197), Dulany (Williams 1968), and Sapelo Island (Williams 1968). Other sites include Refuge (Williams 1968: 198-208), Lake Spring (Miller 1949), Chester Field (Williams 1968: 208), Daws Island (Hemmings 1972), Walthour (Caldwell 1952: 314), Meldrim (Williams 1968: 182-183), and Oemler (Williams 1968: 182-183).

At several of these sites, both ceramic and pre-ceramic occupations are recognizable. The presence of fiber-tempered ceramics at sites of the Late Archaic is restricted to what Stoltman (1974: 19) refers to as the Stallings II and Stallings III phases. Basically, these two phases are distinguished from each other by the presence of only plain

The Middle Archaic concludes with the presence of Morrow Mountain and Guilford point types. The Morrow Mountain points consist of slightly shouldered points with slightly tapering stems and round bases. Little is known about associated assemblages. Burial goods from the Stanfield-Worley Rockshelter in northern Alabama suggest the presence of crude unifacial side- and endscrapers (DeJarnette et al. 1962: 83). Chapman (1977: 106) reports the presence of drills and scrapers in the Little Tennessee Valley. A hearth with associated projectile points from site 38LX5 at the Fall Line of South Carolina dates the Morrow Mountain phase to 3,520+170 B.C. (Anderson 1797: 90). Other dates from Alabama and Tennessee range from 4750 to 4030 B.C. (Chapman 1976: 8).

The Guilford point can be described as a leaf shaped or lanceolate point with an excurvate or incurvate base (Coe 1964). Stratigraphic evidence in the North Carolina Piedmont suggests 4000 B.C. as the probable beginning for the Guilford phase. Coe (1964: 51) suggests that this phase differs from the preceding Morrow Mountain by the appearance of notched, chipped axes and, perhaps, the disappearance of unifacial tools.

The common distribution and density of these point forms throughout the Coastal Plain and Piedmont would suggest a greater population and extensive pattern of land use. With the exception of Lake Spring (Miller 1949), Theriault (Brockington 1971) and Cal Smoak (Lee and Parler 1972; Anderson, Lee and Parler 1979) sites, a few sites in the area of the Savannah River Plant have been excavated and have produced evidence of the Middle Archaic. Little is known of the Middle Archaic assemblage for the Coastal Plain region aside from the ubiquitous hafted bifaces (projectile points).

The Middle Archaic components, 8 Kirk and 2 Stanly-Morrow Mountain, were recorded during the general reconnaissance of the Savannah River Plant (Hanson, Most and Anderson

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This period is characterized by a continuance of a generalized hunting and gathering pattern with changes in projectile point morphology. Four projectile point forms are typical of this period: Kirk, Stanley, Morrow Mountain, and Guilford.

The Kirk includes a variety of corner-notched point types that differ largely from the Palmer in that the Kirk lacks both basal grinding and straight based, serrated forms (Coe 1964). Radiocarbon 14 dates cluster between 7500 and 7000 B.C. Dates from sites in the Little Tennessee Valley include figures of 7,485±270 B.C., 7,400±215 B.C., and 7,225±240 B.C. from Icehouse Bottom; 7,460±290 B.C. from the Patrick site; and 7,160±140 B.C. and 7,380±250 B.C. from Rose Island (Chapman 1977: 161-162). Other dates, 6,430±130 B.C. from the Six Toe site in northern Georgia, and 6,570±300 B.C. and 7,900±500 B.C. from the St. Albans site in West Virginia, have been recorded for Kirk corner- and side-notched forms (Broyles 1971).

Kirk tool kits differ from earlier assemblages by the occasional appearance of grinding tools. Two metates were reported from Russell Cave in northern Alabama (Griffin 1974: 2). Whether these tools represent an intensification of nut resources or the first intensive use of small seeds is unclear (Goodyear, House, and Ackerly 1979: 103), but their presence suggests an increased exploitation of vegetation from earlier periods. Overall, Kirk corner-notched assemblages represent transitional Early Archaic/Middle Archaic adjustments to a changing environment.

The Kirk forms are succeeded by indented based, stemmed Stanly points. These are radiocarbon-dated at 5,840+215 B.C. at Icehouse Bottom (Chapman 1977). Changes in tool kits are represented by the disappearance of the well-made "tear drop" endscrapers found in earlier assemblages and the first appearance of ground stone tools represented by semi-lunate atlatl weights (Coe 1964: Table 2; Chapman 1977).

systems and these Early Archaic types. Dalton period occupations in Arkansas, however, are spread both along and between the large stream systems, suggesting the first intensive human occupation of the inter-riverine areas of the southeastern United States (Morse 1973; Goodyear, House and Ackerly 1979: 98).

Cal Smoak and other Palmer components from the Fall Line and Coastal Plain (Michie 1971; Coe 1964) suggest strong associations with large stream systems, although in the Piedmont, House and Ballenger (1976) and Goodyear (1978) indicate an extensive upland, ridgetop association for small Palmer components. These results may indicate a widespread occupation and diffuse land use pattern related to a broad spectrum subsistence base during the latter portions of the Early Archaic. This and any other inference for the period within South Carolina, however, must await evaluation through excavation and more intensive analysis.

To characterize the Early Archaic period, it must be mentioned that the evidence is minimal, at best, for the Coastal Plain. Dalton-Hardaway and Palmer occupations are surely present based on the common occurrence of projectile points, but associated assemblages are as yet poorly understood. Distributional studies (Goodyear 1978; Goodyear, Ackerly and House 1979) indicate a wide-ranging land use pattern, which is suggested to relate to the exploitation of deer in the uplands and riverine resources in major drainages of the Piedmont. The general survey of the Savannah River Plant located 10 Early Archaic components, 3 Dalton and 7 Palmer, in geographical contexts ranging from high uplands to the river terraces of the Savannah (Hanson, Most and Anderson 1978).

Middle Archaic (7500 - 3000 B.C.)

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the Coastal Plain of South Carolina, and Palmer and Kirk points have been recorded throughout South Carolina and adjoining states within the Coastal Plain and Piedmont physiographic province.

Limited stratigraphic evidence from the Theriault site on Brier Creek in Georgia suggests that Taylor points underlie Palmer points (Brockington 1971). Materials recovered from the nearby Cal Smoak Site in the Edisto drainage (Lee and Parler 1972; Anderson, Lee, and Parler 1979) suggest a clear priority of Palmer occupations to Kirk and Middle Archaic forms.

The Early Archaic represents the initial response of prehistoric inhabitants of the Coastal Plain, and North America in general, to the ameliorating climatic conditions of the Holocene. The changes in climate and associated vegetational patterns and faunal populations during the immediate post-Pleistocene provided a much more suitable environment for human population growth. Hunting and gathering resources were more plentiful due to this change from a cooler climate to a milder climate with increases in deciduous nut and seed-bearing vegetation. Although variation occurred in this Holocene climate sequence, the present-day character of the Coastal Plain was beginning to develop at this time.

Floral and faunal remains associated with Dalton sites of the Southeast and Midwest include white-tailed deer, turkeys, cotton-tail rabbits, squirrels, raccoons, fishes, mussels, and wildfowl (McMillian 1972).

Locational studies of Dalton sites have been done in several parts of the South. The locations of Dalton-Hardaway associations in the Coastal Plain of Georgia have been examined by Fish (1976: 22-23), who suggests a strong association between large stream

Early Archaic (9500 - 7500 B.C.)

Archaeological evidence of the earliest Holocene hunter-gatherers is composed of the presence of the Dalton-Hardaway phase (Goodyear 1974; Coe 1964) throughout the Eastern United States. During this period, lanceolate, indented-base Dalton points are gradually replaced by small indented-base, side-notched forms (Hardaway side-notched). Coe (1964: 64, 81) suggests these points to be roughly contemporaneous. The Hardaway side-notched points are rare in most parts of South Carolina (Goodyear 1978: 79) and do not seem to be present on the Savannah River Plant.

Radiocarbon dates for the Dalton phase range between 8480 and 6920 B.C. Lower layers of Graham Cave in Missouri containing Dalton points cluster between 7700 and 7000 B.C. (Crane and Griffin 1968). Standfield Worley Bluff Shelter in northern Alabama contained layers producing both Daltons and side-notched points that were dated at 6920 and 7640 B.C. Rogers Shelter in Tennessee produced dates of 8,350±330 and 8,480±650 B.C. (Griffin 1974: 94).

Associated with this temporal phase and with Paleo-Indian and later Early Archaic phases is a variety of unifacial blade and flake tools intentionally retouched for the tasks of scrapping, cutting, and graving (Goodyear, House, and Ackerly 1979: 97). Unique to the Dalton-Hardaway phase of Arkansas, and, perhaps, South Carolina, is the presence of bifacial adzes (Morse and Goodyear 1973; Goodyear, House and Ackerly 1979: 96).

Following the Dalton-Hardaway phase, the latter portion of the Early Archaic is represented by a series of corner- and side-notched projectile points. These include the Taylor, Palmer, and Kirk points (the Kirk point is considered here as transitional between the Early and Middle Archaic periods). Taylor points are known throughout

Although complete assemblages have yet to be found in association with the diagnostic fluted points typical of all of the above localities, the presence of the points would suggest some activity within the region during the latter portions of the Pleistocene.

Michie's 1977 study suggests a general model for the location of Paleo-Indian sites within the Coastal Plain based on the distribution of fluted points. He concludes that:

> The overall pattern of projectile point distribution seems to involve the larger river systems (of South Carolina) such as the Broad, Savannah, Wateree, Pee Dee, Congaree, and the smaller Edisto Rivers. When these rivers are involved with point distributions and location, the points usually occur at the intersection of creeks and the highest portion of land near that intersection (Michie 1977: 92).

Due to geological conditions following this Pleistocene adaptation, the recognition of Paleo-Indian sites is difficult. Holocene changes in stream hydrology have resulted in the deposition of recent sediments on many locations believed to be favored by these early hunter-gatherers (Michie 1977). These changes may in part account for the scarcity of Paleo-Indian remains at the Savannah River Plant. Given Michie's data, sites may occur at the confluences of major tributaries (Upper Three Runs, Four Mile, Pen Branch, Steel and Lower Three Runs), but their presence is probably obscured by alluvial sediments of great depths.

The two points discovered on plant property were found at locations that do not fit Michie's model. One was discovered on Lower Three Runs 15 miles from the Savannah River. The other point was discovered in the xeric sandhills far from any large stream. Both discoveries suggest that a much more complicated settlement pattern exists for the Upper Coastal Plain than that predicted by Michie.

overall similarities in tool assemblages, it is generally assumed that most Paleo-Indians of North America were similarly adapted to a system focusing on the exploitation of now-extinct, large herbivores (Mason 1962: 243).

Recent data from the eastern United States have resulted in questions being raised about the role that the hunting of the megafauna played in the subsistence strategies of these people. Food remains from Meadowcroft Rockshelter in Pennsylvania included white-tailed deer (Odocoileus virginianus), elk (Cervus canadensis), nuts, and chenopod seeds (Adovasio et al. 1977: 154). Shawnee-Minisink in Pennsylvania produced hawthorn pits and fish remains (McNett, McMillian, and Marshall 1977). These sites suggest that resources other than megafauna may have played a very important role in the Paleo-Indian diet.

In the Southeast, studies by Williams and Stoltman (1965) and Michie (1977) suggest a strong geological correlation between the several forms of Paleo-Indian projectile points and the margins of rivers that are often the locations of mastodon fossil recovery. Bullen, Webb, and Waller (1970) also produced evidence of a mastodon vertebra that was apparently cut while the bone was green. These studies suggest that areas suitable for megafauna such as wide river margins may be closely correlated with Paleo-Indian site locations in the Southeast.

Settlement data for the Paleo-Indian period occupation for the Savannah River Plant are rare. Prior to this survey, only two fluted points have been recovered within the plant boundaries.

Evidence for Paleo-Indian occupation has, however, been recovered from the Coastal Plain of South Carolina (Michie 1977) and from the Theriault Site (Brockington 1971).

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CULTURAL PERIOD	TIME SCALE		DIAGNOSTIC ARTIFACTS
Historic			Non-native material products (e.g. mass-produced goods)
	A.D. 1700		
		Irene	Irene filfot stamped, incised & plain ceramics, small triangular projectile points and Southern Cult objects
Mississippian	A.D. 1200		
		Savannah I	Savannah complicated stamped, plain & burnished ceramics, and small triangular points
	A.D. 1000		
Late Woodland		Savannah II	Savannah fine cordmarked and burnished ceramics, and small triangular points
	A.D. 700		
Middle Woodland		Wilmington	Wilmington coarse cordmarked ceramics, large triangular points.
	A.D. 1		
		Deptford	Deptford linear check stamped, simple stamped and check stamped ceramics
Early Woodland	500 B.C.		
		Refuge Thom's Creek	Simple stamped, linear punctate, punctate and incised ceramics with sand temper
	1000 B.C.		
		Stallings III	Decorated fiber tempered ceramics & Otarre points
Late Archiac		Stallings II	Plain fiber tempered ceramics, & Savannah River & Otarre points.
		Stallings I	Savannah River Points
	3000 B.C.		
Middle Archaic			Guilford points Morrow Mountain points Stanly, and Kirk points
	7500 B.C.		
Early Archaic			Palmer, Taylor, and Dalton points
	9500 B.C.		
Paleo Indian			Quad,Suwanee, and Clovis points
	11000 B.C.		

[Based on Stoltman (1974), Ferguson and Widmer (1976), Michie (1977) and Coe (1964)]

TABLE 1: General occupational sequence for the Savannah River Basin below the Fall Line.

of the Albert Love site. This is one of the few Upland Late Archaic sites excavated in the Upper Coastal Plain. Excavations at four sites tested for the Southeastern Columbia Beltway Project (Anderson 1979) and at the Cal Smoak site (Anderson, Lee and Parler 1979) provided data useful in formulating prehistoric chronologies for the Upper Coastal Plain of South Carolina. Brooks (1980) provided both survey and excavated data to suggest settlement/subsistence patterns for the lower interior Coastal Plain. Larson (1980) also suggested patterns of late prehistoric subsistence within the interior Coastal Plain. The combined results of these research efforts form the basis for the present understanding of prehistoric development within the Savannah River Valley below the Fall Line. Although a synthetic overview of the prehistory of the area is yet to be written, the initial foundation exists for a general chronological framework (Table 1).

Paleo-Indian (10500 - 9500 B.C.)

The Paleo-Indian period of the eastern United States is largely recognizable by the presence of the fluted Clovis (or Clovis-like) points and, in the Southeast, by unfluted lanceolate points such as the Quad and Suwanee types. Radiocarbon dates from the Delbert site in Nova Scotia and the Shawnee-Minisink site on the Delaware River of Pennsylvania average 8600 B.C. for fluted point forms. Dates from west of the Mississippi suggest earlier occupations for that area beginning at ca. 9500 B.C. (Wormington 1957).

The subsistence resources exploited by Paleo-Indian populations of the eastern United States are poorly known. Little subsistence data have been recovered from Paleo-Indian sites east of the Mississippi River. Because of the lack of data, the earliest reconstructions of the subsistence patterns of this period were based upon faunal information borrowed from sites located on the Western Plains. Based on similarities in projectile points and

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to Stoltman (1974: 229-244) radical differences in subsistence and settlement practices at various times.

Following Stoltman's research, Drexel Peterson (1971) intensified the survey of the Groton Plantation area in order to refine specific hypotheses regarding ceramic chronology and cultural development. The general result of the study was the discovery that changes in subsistence strategies were not appreciable during the Woodland period, as was thought by Stoltman (1974). Another result was a ceramic chronology that included several additional "phases" during the Early Woodland period and later times. These latter results have yet to be substantiated from other research in the general area.

Concomitant with the latter research was the expansion of study in other areas of the Savannah drainage. This research included survey and excavation at White's Mound (Phelps and Burgess 1964; Phelps 1968), Hollywood Mound (DeBaillou 1965), the Theriault site (Brockington 1971), Mississippian sites along the Savannah River, the Augusta area (Ferguson and Widmer 1976), and work at Stalling's Island (Bullen and Green 1970). Thomas et al. (1978) provided an updated chronology for the Late Archaic of the lower Savannah River Valley through their work at St. Catherine's Island.

Works by DePratter (1976, 1977) refined the chronology of the Early Woodland in the Savannah River Valley and Georgia coast, and suggested changes in the subsistence and settlement patterns that occurred within this region during this period. Trinkley (1980) made similar contributions toward our understanding of the settlement changes and chronology of the Woodland period of the coast and Coastal Plains of South Carolina.

Other works from outside of the Savannah River Valley have increased our knowledge of the interior Coastal Plain of South Carolina. Trinkley (1974) reported the findings

In the delta region of the Savannah River, Antonio Waring was instrumental in the initial understanding of the prehistoric archaeological record. During his brief life, Waring, in cooperation with various archaeologists, recorded, collected and/or excavated many of the key archaeological sites that would form the foundation of future archaeological research in the Savannah River area. Waring and others were responsible for the description of the basic ceramic types and general ceramic complexes such as the Deptford ceramic complex (Waring and Holder 1968), Woodland and Mississippian ceramic types (Caldwell and Waring 1939), and Early Woodland ceramic types and assemblages (Williams 1968: 152-215). The summary of Waring's work provided by Williams (1968) stands as a major contribution to the study of Savannah River prehistory.

Other research in the Savannah River area was conducted during the W.P.A. period on the Irene Mound Site, a Mississippian Period site. Conducted over the course of several years, the excavations revealed the existence of a long-term occupation associated with a ceremonial center (Caldwell and McCann 1941). The excavations yielded the first comprehensive plan of such a ceremonial complex within the Atlantic Coastal area and extended the known archaeological record into protohistoric times.

Subsequent research was delayed for almost two decades, until the 1960s when renewed interest in the initial ceramic period prompted the work of James Stoltman at Groton Plantation (Stoltman 1974). This research project involved the survey and test excavation of sites within the plantation for purposes of exploring the development of Late Archaic and Woodland cultures in the riverine area of the Coastal Plain. The major outcome of this research was the excavation of two sand mounts, Rabbit Mount and Clear Mount. These contained shell middens associated with some of the earliest known ceramics in North America. In addition, sites representative of Archaic, Woodland and Mississippian occupations were located in the survey, and the distribution of these sites suggested

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Chapter II

ARCHAEOLOGICAL BACKGROUND

The Prehistoric Occupation of the Savannah River Valley

Within the drainage of the Savannah River below the Fall Line, investigations of cultural heritage from an archaeological perspective have been focused on selected areas. For this reason, an overview of the prehistory of the area must rely on information selectively investigated without regard for general archaeological pattern. This general discussion of the occupational history within the study area and immediate environs will be an attempt to characterize the general prehistory of the Savannah River drainage within the Coastal Plain (Table 1).

Archaeological undertakings of a controlled nature were begun in the latter half of the last century by Thomas (1894) and Moore (1899) in their studies on prehistoric mound sites within river valleys of the eastern United States. Their efforts resulted in the location of and collection from selected large sites within the Savannah River area. Although these pioneer studies were of value only in documenting the presence of sites within the drainage, these were the preliminary efforts in the study of the region's archaeological resources.

Increasingly scientific archaeological research within the area began with the efforts of William Claflin in the vicinity of the Fall Line at Stalling's Island. Claflin excavated a large shellmound, the Stalling's Island Site, on an island within the Savannah River during the 1920s and documented an assemblage of the earliest ceramic complex in the eastern United States (Claflin 1931; Sears and Griffin 1950; Bullen and Green 1970). For this reason, the Stalling's Island Site has become one of the most important cultural resources known in the Southeast and has been subjected to intermittent investigations since Claflin's first study (Fairbanks 1942; Sears and Griffin 1950; Bullen and Green 1970).

This report documents all theoretical, methodological and technical aspects of the research associated with the study. It further presents the archaeological and locational information for the sites which permit independent review of the findings. Overall, the archaeological resources are presented in reference to current archaeological issues regarding the prehistoric and historic occupations of the region as a means of evaluating the potential of the sites and the information contained within them for yielding significant new information and understanding.

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Chapter I

INTRODUCTION

The intensive archaeological survey and testing of the six alternative waste storage/disposal areas within the boundaries of the Savannah River Plant was conducted by the South Carolina Institute of Archaeology and Anthropology under the supervision of Glen T. Hanson (Program Manager, Savannah River Plant Archaeological Research Program) and Mark J. Brooks (Project Archaeologist). The purpose of this field study was the identification and evaluation of significant archaeological and historical sites within the alternative waste storage/disposal areas. Background research consisted of a review of all archaeological sites known to exist in the vicinity of the proposed areas using the computer based archaeological data management system at the Savannah River Plant Archaeological Research Program laboratory. No sites presently on the National Register of Historic Places occur within the study areas.

Fieldwork consisted of intensive examination of all six areas by one-two person crew using a combination of surface inspection and subsurface techniques to discover previously unrecorded sites. Thirty-two archaeological sites are recorded adjacent to the six areas. Of these adjacent sites, only six (38AK420, 38AK421, 38AK422, 38AK423, 38AK426, and 38AK427) were discovered during the present survey. In contrast, a total of 13 archaeological sites have been recorded within three of the six areas and are, therefore, assessed in this report. Of these 13 sites, five (all previously recorded) are located within Area G. Area L contains two sites (38AK424 and 38AK425) and Area Y (III) contains six sites (38AK428, 38AK429, 38AK430, 38AK431, 38AK432, and 38AK433); all of which were discovered during the present survey. None of these 13 archaeological sites are recommended as having sufficient research potential and scientific significance to warrant eligibility for nomination to the National Register of Historic Places.

Management Summary

Under modification No. A011 to contract No. DE-AC09-81SR10479 with the Department of Energy, the South Carolina Institute of Archaeology and Anthropology, University of South Carolina, conducted (November 6, 1985 through February 21, 1986) an intensive archaeological/historical survey and testing of six alternative, new low-level radioactive and hazardous/mixed waste storage/disposal facilities (areas) located primarily in the upland, sandhills zone of the Savannah River Plant, Aiken and Barnwell Counties, South Carolina. An examination of the Statewide Archaeological Site Inventory Record prior to the field survey indicated that 32 archaeological sites were known to exist within, or immediately adjacent to, these six areas. Thirteen additional archaeological sites were discovered during the field survey. Those archaeological sites outside the areas of potential impact are not assessed in this report because: 1) they are not endangered, and; 2) they will be considered in the final cultural resource management report for the Savannah River Plant. Of the six areas, archaeological sites (N=13) are recorded only in Areas G (38AK155, 38AK279, 38AK280, 38AK281 and 38AK338), L (38AK424 and 38AK425), and Y III (38AK428, 38AK429, 38AK430, 38AK431, 38AK432 and 38AK433). Either because of their limited extent, content, disturbed surface context, and/or the presence of similar, preserved sites nearby, none of these 13 archaeological sites are considered to be potentially eligible for the National Register of Historic Places. Therefore, we conclude that: 1) there will be no effect on the archaeological resources through the development of any of the alternative waste storage/disposal areas; and 2) no further archaeological work is recommended within these areas. Further, it is recommended that the Department of Energy request a determination of no effect from the South Carolina State Historic Preservation Officer for the development of any of the alternative waste storage/disposal facilities.

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AN INTENSIVE ARCHAEOLOGICAL SURVEY AND TESTING OF ALTERNATIVE, NEW LOW-LEVEL RADIOACTIVE AND HAZARDOUS/MIXED WASTE STORAGE/DISPOSAL FACILITIES, SAVANNAH RIVER PLANT, AIKEN AND BARNWELL COUNTIES, SOUTH CAROLINA

by

Mark J. Brooks, Glen T. Hanson and
Richard D. Brooks

This study was conducted through funding provided by the United States Department of Energy under contract number DE-AC09-81SR10749.

Prepared by the

Savannah River Plant
Archaeological Research Program
Grants and Contract Division
South Carolina Institute of Archaeology and Anthropology
University of South Carolina
March 1986

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APPENDIX G

ARCHAEOLOGICAL SURVEY

Table F-32 Concentrations and Doses at Savannah River - Alternative 6 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.7E-16
H-3	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.9E-27	2.0E-27	2.6E-32
Tc-99	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.6E-17	6.3E-15	6.3E-15
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.2E-08
H-3	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.0E-22	1.1E-22	1.4E-27
Tc-99	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.0E-11	6.8E-09	6.8E-09

Table F-31 Concentrations and Doses at Savannah River - Alternative 5 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	1.5E-16	1.5E-16	1.5E-16	1.5E-16	1.5E-16	1.5E-16	1.4E-16
H-3	0.0E-01	0.0E-01	0.0E-01	2.8E-15	1.0E-17	3.6E-20	1.3E-22	4.6E-25	1.6E-27	2.1E-32
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.3E-22	8.7E-18
Tc-99	0.0E-01	0.0E-01	0.0E-01	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	1.0E-08	1.0E-08	1.0E-08	1.0E-08	1.0E-08	9.9E-09	9.7E-09
H-3	0.0E-01	0.0E-01	0.0E-01	1.5E-10	5.4E-13	1.9E-15	6.9E-18	2.5E-20	8.8E-23	1.1E-27
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	9.7E-14	2.0E-09
Tc-99	0.0E-01	0.0E-01	0.0E-01	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09

Table F-30 Concentrations and Doses at Savannah River - High Activity Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.7E-33	5.2E-24
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.5E-35	8.5E-21	4.1E-18	4.0E-17	1.1E-16	2.1E-16
Tc-99	0.0E-01	8.7E-15	8.8E-15	8.8E-15	8.8E-15	8.8E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15
Doses (mrem/yr)										
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.0E-25	3.6E-16
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.4E-28	1.3E-13	6.4E-11	6.3E-10	1.7E-09	3.3E-09
Tc-99	0.0E-01	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09

Table F-29 Concentrations and Doses at Savannah River - Intermediate Activity Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	3.3E-17	3.5E-17	3.4E-17	3.4E-17	3.3E-17	3.3E-17	3.2E-17
H-3	0.0E-01	0.0E-01	0.0E-01	7.3E-22	2.6E-24	9.3E-27	3.3E-29	1.2E-31	4.3E-34	1.0E-35
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.6E-23	2.0E-18
Tc-99	0.0E-01	0.0E-01	0.0E-01	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	2.2E-09	2.4E-09	2.3E-09	2.3E-09	2.3E-09	2.3E-09	2.2E-09
H-3	0.0E-01	0.0E-01	0.0E-01	3.9E-17	1.4E-19	5.0E-22	1.8E-24	6.4E-27	2.3E-29	5.4E-31
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.7E-14	4.5E-10
Tc-99	0.0E-01	0.0E-01	0.0E-01	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09

Table F-28 Concentrations and Doses at Savannah River - Low Level Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.8E-16	2.6E-23	1.3E-32	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	3.9E-16	7.9E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	2.5E-19	6.5E-18	2.3E-20	5.2E-24	7.7E-28	1.0E-31	1.3E-35	0.0E-01
Tc-99	0.0E-01	6.6E-15	3.1E-23	3.0E-33	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	1.9E-08	1.8E-15	8.7E-25	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	2.1E-11	4.2E-22	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	5.6E-11	1.5E-09	5.2E-12	1.2E-15	1.8E-19	2.3E-23	3.0E-27	0.0E-01
Tc-99	0.0E-01	7.2E-09	3.3E-17	3.3E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

Table F-27 Concentrations and Doses at Savannah River - High Activity Wastes, Alternatives 1 and 2 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.6E-16	2.6E-16	2.6E-16	2.5E-16	2.5E-16	2.5E-16	2.5E-16	2.4E-16	2.4E-16
H-3	0.0E-01	4.7E-10	1.7E-12	5.9E-14	2.1E-17	7.6E-20	2.7E-22	9.7E-25	3.5E-27	4.4E-32
I-129	0.0E-01	4.3E-19	1.5E-17	1.5E-17	1.5E-17	1.5E-17	1.5E-17	1.5E-17	1.5E-17	1.5E-17
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.7E-33	5.2E-24
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.5E-35	8.5E-21	4.1E-18	4.0E-17	1.1E-16	2.1E-16
Tc-99	0.0E-01	8.7E-15	8.8E-15	8.8E-15	8.8E-15	8.8E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15
Doses (mrem/yr)										
C-14	0.0E-01	1.8E-08	1.8E-08	1.7E-08	1.7E-08	1.7E-08	1.7E-08	1.7E-08	1.6E-08	1.6E-08
H-3	0.0E-01	2.5E-05	9.0E-08	3.2E-10	1.1E-12	4.1E-15	1.5E-17	5.2E-20	1.7E-22	2.4E-27
I-129	0.0E-01	9.9E-11	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.0E-25	3.6E-16
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.4E-28	1.3E-13	6.4E-11	6.3E-10	1.7E-09	3.3E-09
Tc-99	0.0E-01	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09

Note: H-3, C-14, and I-129 are not present in high activity waste in Alternative 2.

Table F-26 Concentrations and Doses at Savannah River - Intermediate Activity Wastes, Alternatives 1 and 2 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	1.6E-15	2.4E-23	1.3E-32	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	1.6E-15	9.5E-27	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	1.1E-16	4.1E-18	1.9E-21	3.7E-25	5.5E-29	7.6E-33	1.0E-35	0.0E-01
Tc-99	0.0E-01	2.4E-14	3.6E-23	4.1E-33	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	1.1E-07	1.6E-15	9.0E-25	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	8.8E-11	5.1E-22	5.4E-31	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	2.4E-08	9.2E-10	4.3E-13	8.3E-17	1.3E-20	1.7E-24	2.3E-27	0.0E-01
Tc-99	0.0E-01	2.6E-08	3.9E-17	4.5E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

Table F-25 Concentrations and Doses at Savannah River - Low Level Wastes, Alternatives 1 and 2 - - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	9.1E-17	9.9E-25	5.5E-34	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	4.8E-33	9.1E-17	4.2E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	1.0E-24	8.3E-18	1.5E-19	5.9E-23	1.1E-26	1.6E-30	2.2E-34	1.0E-35	0.0E-01
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.0E-22
Tc-99	2.1E-33	1.3E-15	1.6E-24	1.8E-34	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	6.2E-09	6.7E-17	3.7E-26	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	2.6E-28	4.9E-12	2.3E-23	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	2.3E-16	1.9E-09	3.4E-11	1.4E-14	2.5E-18	3.7E-22	5.0E-26	2.3E-27	0.0E-01
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.6E-15
Tc-99	2.2E-27	1.5E-09	1.7E-18	2.0E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

Table F-24 Concentrations and Doses at Savannah River - Alternative 6 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	1.9E-16	1.9E-16	1.9E-16	1.9E-16	1.8E-16	1.8E-16	1.8E-16	1.7E-16
H-3	0.0E-01	0.0E-01	9.7E-13	3.5E-15	1.2E-17	4.4E-20	1.6E-22	5.6E-25	2.0E-27	2.5E-32
I-129	0.0E-01	0.0E-01	3.1E-18	1.1E-17	1.1E-17	1.1E-17	1.1E-17	1.1E-17	1.1E-17	1.1E-17
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	9.3E-31	3.1E-26	3.2E-24	2.1E-22
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.9E-23	3.2E-19	6.7E-18	2.9E-17	6.7E-17	1.4E-16
Tc-99	0.0E-01	0.0E-01	6.3E-15	6.3E-15	6.3E-15	6.3E-15	6.3E-15	6.3E-15	6.3E-15	6.3E-15
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	1.3E-08	1.3E-08	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08
H-3	0.0E-01	0.0E-01	5.2E-08	1.9E-10	6.7E-13	2.4E-15	8.5E-18	3.0E-20	1.1E-22	1.4E-27
I-129	0.0E-01	0.0E-01	7.0E-10	2.4E-09	2.4E-09	2.4E-09	2.4E-09	2.4E-09	2.4E-09	2.4E-09
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.1E-15	5.1E-12	1.1E-10	4.6E-10	1.0E-09	2.2E-09
Tc-99	0.0E-01	0.0E-01	6.8E-09	6.8E-09	6.8E-09	6.8E-09	6.8E-09	6.8E-09	6.8E-09	6.8E-09
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.7E-27	4.1E-20
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.3E-28	3.1E-21

Table F-23 Concentrations and Doses at Savannah River - Alternative 5 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	1.6E-16	1.6E-16	1.5E-16	1.5E-16	1.5E-16	1.5E-16	1.5E-16	1.4E-16
H-3	0.0E-01	0.0E-01	7.9E-13	2.8E-15	1.0E-17	3.6E-20	1.3E-22	4.6E-25	1.6E-27	2.1E-32
I-129	0.0E-01	0.0E-01	6.5E-18	8.7E-18	8.7E-18	8.7E-18	8.7E-18	8.7E-18	8.7E-18	8.7E-18
Rb-87	0.0E-01	0.0E-01	0.0E-01	1.0E-35	1.4E-27	1.2E-24	3.6E-23	2.6E-22	8.8E-22	3.3E-21
Se-79	0.0E-01	0.0E-01	3.3E-35	4.9E-21	2.3E-18	2.3E-17	6.4E-17	1.0E-16	1.3E-16	1.4E-16
Tc-99	0.0E-01	0.0E-01	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15	5.1E-15
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.3E-31	1.2E-26	4.3E-24	1.7E-22	1.3E-20
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.7E-31	1.5E-25	1.8E-23	9.9E-23	1.2E-22	2.1E-23
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.7E-31	1.5E-25	1.8E-23	9.9E-23	1.2E-22	2.1E-23
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	1.1E-08	1.1E-08	1.0E-08	1.0E-08	1.0E-08	1.0E-08	9.9E-09	9.5E-09
H-3	0.0E-01	0.0E-01	4.3E-08	1.5E-10	5.4E-13	1.9E-15	6.9E-18	2.5E-20	8.8E-23	1.1E-27
I-129	0.0E-01	0.0E-01	1.5E-09	2.0E-09	2.0E-09	2.0E-09	2.0E-09	2.0E-09	2.0E-09	2.0E-09
Rb-87	0.0E-01	0.0E-01	0.0E-01	7.0E-28	9.5E-20	8.4E-17	2.5E-15	1.8E-14	6.2E-14	2.3E-13
Se-79	0.0E-01	0.0E-01	5.1E-28	7.7E-14	3.6E-11	3.6E-10	1.0E-09	1.6E-09	2.0E-09	2.2E-09
Tc-99	0.0E-01	0.0E-01	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09	5.6E-09
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.8E-21	2.4E-16	8.9E-14	3.6E-12	2.8E-10
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.5E-23	1.4E-17	1.6E-15	9.0E-15	1.1E-14	1.9E-15
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.9E-24	1.1E-18	1.3E-16	6.9E-16	8.6E-16	1.5E-16

Table F-22 Concentrations and Doses at Savannah River - High Activity Wastes, Alternative 3 - Normal Infiltration

Nuclide	YEARS SINCE CLOSURE 1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
Rb-87	0.0E-01	0.0E-01	1.0E-35	1.3E-27	1.6E-24	5.7E-23	4.3E-22	1.4E-21	3.3E-21	8.0E-21
Se-79	0.0E-01	0.0E-01	2.6E-21	2.8E-18	3.4E-17	1.0E-16	1.6E-16	2.1E-16	2.3E-16	2.4E-16
Tc-99	0.0E-01	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.8E-31	2.5E-26	8.8E-24	3.5E-22	4.2E-21	9.8E-20
Sr-90	0.0E-01	0.0E-01	0.0E-01	4.1E-30	2.8E-24	3.6E-22	2.0E-21	2.5E-21	1.3E-21	1.0E-22
Y-90	0.0E-01	0.0E-01	0.0E-01	4.2E-30	2.9E-24	3.7E-22	2.1E-21	2.6E-21	1.4E-21	1.0E-22
Doses (mrem/yr)										
Rb-87	0.0E-01	0.0E-01	7.0E-28	9.2E-20	1.1E-16	4.0E-15	3.0E-14	1.0E-13	2.3E-13	5.6E-13
Se-79	0.0E-01	0.0E-01	4.1E-14	4.4E-11	5.4E-10	1.6E-09	2.6E-09	3.3E-09	3.6E-09	3.8E-09
Tc-99	0.0E-01	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.2E-20	5.2E-16	1.8E-13	7.3E-12	8.9E-11	2.0E-09
Sr-90	0.0E-01	0.0E-01	0.0E-01	3.7E-22	2.6E-16	3.3E-14	1.8E-13	2.3E-13	1.2E-13	9.1E-15
Y-90	0.0E-01	0.0E-01	0.0E-01	2.9E-23	2.0E-17	2.5E-15	1.4E-14	1.8E-14	9.7E-15	7.0E-16

Table F-21 Concentrations and Doses at Savannah River - Intermediate Activity Wastes, Alternative 3 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	3.5E-17	3.5E-17	3.5E-17	3.4E-17	3.4E-17	3.3E-17	3.3E-17	3.2E-17
H-3	0.0E-01	0.0E-01	2.1E-19	7.3E-22	2.6E-24	9.3E-27	3.3E-29	1.2E-31	4.3E-34	1.0E-35
I-129	0.0E-01	0.0E-01	1.2E-18	2.0E-18	2.0E-18	2.0E-18	2.0E-18	2.0E-18	2.0E-18	2.0E-18
Rb-87	0.0E-01	0.0E-01	0.0E-01	1.0E-35	1.5E-28	1.3E-25	3.8E-24	2.9E-23	1.1E-22	5.0E-22
Se-79	0.0E-01	0.0E-01	1.0E-35	5.6E-22	2.6E-19	3.1E-18	1.0E-17	1.9E-17	2.6E-17	3.2E-17
Tc-99	0.0E-01	0.0E-01	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15	1.2E-15
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.3E-32	1.1E-27	4.2E-25	1.7E-23	1.4E-21
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.0E-32	1.6E-26	1.8E-24	9.7E-24	1.2E-23	2.3E-24
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.0E-32	1.6E-26	1.8E-24	9.7E-24	1.2E-23	2.3E-24
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	2.4E-09	2.4E-09	2.4E-09	2.3E-09	2.3E-09	2.3E-09	2.2E-09	2.2E-09
H-3	0.0E-01	0.0E-01	1.1E-14	3.9E-17	1.4E-19	5.0E-22	1.8E-24	6.4E-27	2.3E-29	5.4E-31
I-129	0.0E-01	0.0E-01	2.8E-10	4.5E-10	4.5E-10	4.5E-10	4.5E-10	4.5E-10	4.5E-10	4.5E-10
Rb-87	0.0E-01	0.0E-01	0.0E-01	7.0E-28	1.0E-20	8.7E-18	2.7E-16	2.1E-15	7.7E-15	3.5E-14
Se-79	0.0E-01	0.0E-01	1.6E-28	8.7E-15	4.1E-12	4.8E-11	1.6E-10	2.9E-10	4.0E-10	5.0E-10
Tc-99	0.0E-01	0.0E-01	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.8E-22	2.4E-17	8.7E-15	3.6E-13	2.8E-11
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.7E-24	1.4E-18	1.6E-16	8.8E-16	1.1E-15	2.1E-16
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.1E-25	1.1E-19	1.3E-17	6.8E-17	8.4E-17	1.6E-17

Table F-20 Concentrations and Doses at Savannah River - Low Level Wastes, Alternative 3 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	2.6E-17	2.2E-19	1.6E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	4.2E-15	1.6E-19	8.4E-32	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	1.2E-17	2.9E-20	6.2E-24	9.0E-28	1.2E-31	1.5E-35	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.4E-30	6.0E-26	4.0E-24	4.2E-23	4.1E-22
Se-79	0.0E-01	0.0E-01	0.0E-01	8.3E-22	9.0E-19	1.1E-17	2.6E-17	3.1E-17	2.4E-17	7.4E-18
Tc-99	1.7E-15	2.3E-18	3.3E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.8E-27
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.3E-33	1.0E-28	2.0E-26
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.3E-33	1.0E-28	2.0E-26
Doses (mrem/yr)										
C-14	1.8E-09	1.5E-11	1.1E-20	6.8E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	2.3E-10	8.7E-15	4.5E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	2.7E-09	6.6E-12	1.4E-15	2.0E-19	2.7E-23	3.4E-27	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.2E-22	4.2E-18	2.8E-16	3.0E-15	2.9E-14
Se-79	0.0E-01	0.0E-01	0.0E-01	1.3E-14	1.4E-11	1.7E-10	4.1E-10	4.8E-10	3.7E-10	1.2E-10
Tc-99	1.8E-09	2.5E-12	3.5E-22	1.1E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.6E-16
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.6E-25	1.0E-20	1.8E-18
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.0E-26	7.7E-22	1.4E-19

Table F-19 Concentrations and Doses at Savannah River - High Activity Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.6E-16	2.6E-16	2.5E-16	2.5E-16	2.5E-16	2.4E-16	2.4E-16	2.4E-16	2.3E-16
H-3	0.0E-01	4.6E-10	1.6E-12	5.9E-15	2.1E-17	7.6E-20	2.7E-22	9.7E-25	3.4E-27	4.4E-32
I-129	0.0E-01	7.1E-18	1.4E-17	1.4E-17	1.4E-17	1.4E-17	1.4E-17	1.4E-17	1.4E-17	1.4E-17
Rb-87	0.0E-01	0.0E-01	1.0E-35	1.3E-27	1.6E-24	5.7E-23	4.3E-22	1.4E-21	3.3E-21	8.0E-21
Se-79	0.0E-01	0.0E-01	2.6E-21	2.8E-18	3.4E-17	1.0E-16	1.6E-16	2.1E-16	2.3E-16	2.4E-16
Tc-99	0.0E-01	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15	8.7E-15
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.8E-31	2.5E-26	8.8E-24	3.5E-22	4.2E-21	9.8E-20
Sr-90	0.0E-01	0.0E-01	0.0E-01	4.1E-30	2.8E-24	3.6E-22	2.0E-21	2.5E-21	1.3E-21	1.0E-22
Y-90	0.0E-01	0.0E-01	0.0E-01	4.2E-30	2.9E-24	3.7E-22	2.1E-21	2.6E-21	1.4E-21	1.0E-22
Doses (mrem/yr)										
C-14	0.0E-01	1.7E-08	1.7E-08	1.7E-08	1.7E-08	1.7E-08	1.6E-08	1.6E-08	1.6E-08	1.6E-08
H-3	0.0E-01	2.5E-05	9.0E-08	3.2E-10	1.1E-12	4.1E-15	1.4E-17	5.2E-20	1.8E-22	2.3E-27
I-129	0.0E-01	1.6E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09	3.3E-09
Rb-87	0.0E-01	0.0E-01	7.0E-28	9.2E-20	1.1E-16	4.0E-15	3.0E-14	1.0E-13	2.3E-13	5.6E-13
Se-79	0.0E-01	0.0E-01	4.1E-14	4.4E-11	5.4E-10	1.6E-09	2.6E-09	3.3E-09	3.6E-09	3.8E-09
Tc-99	0.0E-01	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09	9.5E-09
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.2E-20	5.2E-16	1.8E-13	7.3E-12	8.9E-11	2.0E-09
Sr-90	0.0E-01	0.0E-01	0.0E-01	3.7E-22	2.6E-16	3.3E-14	1.8E-13	2.3E-13	1.2E-13	9.1E-15
Y-90	0.0E-01	0.0E-01	0.0E-01	2.9E-23	2.0E-17	2.5E-15	1.4E-14	1.8E-14	9.7E-15	7.0E-16

Note: H-3, C-14, and I-129 are not present in high activity waste in Alternative 2.

Table F-18 Concentrations and Doses at Savannah River - Intermediate Activity Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	8.2E-16	5.7E-18	6.5E-27	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	1.0E-13	4.5E-18	3.6E-30	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	1.7E-26	1.3E-16	5.7E-19	1.6E-22	2.7E-26	3.9E-30	5.3E-34	1.0E-35	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	1.0E-35	2.4E-27	2.7E-24	9.2E-23	6.8E-22	2.2E-21	7.5E-21
Se-79	0.0E-01	0.0E-01	2.8E-23	1.8E-18	5.5E-17	2.0E-16	3.3E-16	3.4E-16	2.6E-16	9.1E-17
Tc-99	4.1E-14	6.3E-17	1.4E-26	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.5E-33	2.4E-27	1.9E-24	1.8E-21
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	8.6E-30	2.1E-25	8.9E-23	3.1E-23	1.4E-23
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	8.6E-30	2.1E-25	8.9E-23	3.1E-23	1.4E-23
Doses (mrem/yr)										
C-14	5.6E-08	3.9E-10	4.4E-19	6.8E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	5.6E-09	2.5E-13	1.9E-24	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	3.9E-18	3.0E-08	1.3E-10	3.7E-14	6.2E-18	8.9E-22	1.2E-25	2.3E-27	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	7.0E-28	1.7E-19	1.9E-16	6.4E-15	4.7E-14	1.6E-13	5.3E-13
Se-79	0.0E-01	0.0E-01	4.4E-16	2.9E-11	8.6E-10	3.2E-09	5.1E-09	5.3E-09	4.1E-09	1.4E-09
Tc-99	4.4E-08	6.8E-11	1.5E-20	1.1E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-22	5.0E-17	4.0E-14	3.7E-11
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.8E-22	1.9E-17	8.2E-16	2.8E-15	1.2E-15
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.9E-22	1.5E-18	6.3E-17	2.1E-16	9.6E-17

Table F-17 Concentrations and Doses at Savannah River - Low Level Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	6.8E-17	3.9E-19	4.4E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	8.6E-15	3.2E-19	2.5E-31	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	2.9E-26	9.9E-18	4.0E-20	1.1E-23	1.9E-27	2.7E-31	3.6E-35	1.0E-35	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	3.2E-34	1.4E-27	5.3E-25	1.2E-23	6.9E-23	2.1E-22	6.1E-22
Se-79	0.0E-01	0.0E-01	2.0E-23	2.6E-19	5.4E-18	1.7E-17	2.6E-17	2.6E-17	2.0E-17	6.6E-18
Tc-99	3.4E-15	4.4E-18	9.5E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.8E-31	4.9E-27	1.0E-24	3.4E-22
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.0E-35	1.5E-28	1.9E-25	2.7E-24	5.5E-24	1.6E-24
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.0E-35	1.5E-28	1.9E-25	2.7E-24	5.5E-24	1.6E-24
Doses (mrem/yr)										
C-14	4.6E-09	2.6E-11	3.0E-20	6.8E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	4.6E-10	1.7E-14	1.4E-26	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	6.7E-18	2.3E-09	9.0E-12	2.5E-15	4.2E-19	6.1E-23	8.2E-27	2.3E-27	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	2.2E-26	9.8E-20	3.7E-17	8.1E-16	4.9E-15	1.4E-14	4.3E-14
Se-79	0.0E-01	0.0E-01	3.1E-16	4.0E-12	8.4E-11	2.7E-10	4.1E-10	4.1E-10	3.1E-10	1.0E-10
Tc-99	3.6E-09	4.8E-12	1.0E-21	1.1E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.8E-21	1.2E-16	2.4E-14	7.3E-12
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	9.1E-28	1.4E-20	1.7E-17	2.5E-16	5.0E-16	1.4E-16
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.0E-29	1.1E-21	1.3E-18	1.9E-17	3.9E-17	1.1E-17

Table F-16 Concentrations and Doses at Boundary Well - Alternative 6 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.1E-11
H-3	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.6E-20	5.6E-22	7.1E-27
Tc-99	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.3E-10	1.7E-09	1.7E-09
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.1E-05
H-3	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.5E-15	3.0E-17	3.8E-22
Tc-99	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.0E-04	1.7E-03	1.7E-03

Table F-15 Concentrations and Doses at Boundary Well - Alternative 5 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	1.8E-10	1.8E-10	1.8E-10	1.8E-10	1.7E-10	1.7E-10	1.7E-10
H-3	0.0E-01	0.0E-01	0.0E-01	3.4E-09	1.2E-11	4.3E-14	1.5E-16	5.4E-19	1.9E-21	2.5E-26
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.8E-12	1.0E-11
Tc-99	0.0E-01	0.0E-01	0.0E-01	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	2.3E-04	2.3E-04	2.3E-04	2.2E-04	2.2E-04	2.1E-04	2.1E-04
H-3	0.0E-01	0.0E-01	0.0E-01	1.8E-04	6.4E-07	2.3E-09	8.1E-12	2.9E-14	1.0E-16	1.3E-21
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.5E-03	2.0E-03
Tc-99	0.0E-01	0.0E-01	0.0E-01	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03

Table F-14 Concentrations and Doses at Boundary Well - High Activity Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	8.7E-15	1.8E-14	2.1E-14
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.5E-10	3.3E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10
Tc-99	0.0E-01	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08
Doses (mrem/yr)										
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.3E-08	7.1E-08	8.1E-08
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-03	1.9E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
Tc-99	0.0E-01	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02

Table F-13 Concentrations and Doses at Boundary Well - Intermediate Activity Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	0.0E-01	4.8E-11	4.7E-11	4.7E-11	4.6E-11	4.6E-11	4.5E-11	4.4E-11
H-3	0.0E-01	0.0E-01	0.0E-01	1.0E-15	3.6E-18	1.3E-20	4.6E-23	1.6E-25	5.8E-28	7.4E-33
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-12	2.7E-12
Tc-99	0.0E-01	0.0E-01	0.0E-01	1.6E-09	1.6E-09	1.6E-09	1.6E-09	1.6E-09	1.6E-09	1.6E-09
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	0.0E-01	6.1E-05	6.0E-05	5.9E-05	5.9E-05	5.8E-05	5.7E-05	5.6E-05
H-3	0.0E-01	0.0E-01	0.0E-01	5.4E-11	1.9E-13	6.8E-16	2.4E-18	8.7E-21	3.1E-23	4.0E-28
I-129	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.8E-04	5.4E-04
Tc-99	0.0E-01	0.0E-01	0.0E-01	1.5E-03	1.5E-03	1.5E-03	1.5E-03	1.5E-03	1.5E-03	1.5E-03

Table F-12 Concentrations and Doses at Boundary Well - Low Level Wastes, Alternative 3 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.2E-11	1.3E-21	2.8E-31	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	6.1E-12	3.2E-25	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	4.9E-12	8.9E-14	3.7E-18	2.7E-22	2.4E-26	2.4E-30	2.5E-34	0.0E-01
Tc-99	0.0E-01	8.3E-11	1.2E-21	6.1E-32	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	2.7E-05	1.6E-15	3.5E-25	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	3.3E-07	1.7E-20	5.3E-31	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	0.0E-01	9.8E-04	1.8E-05	7.3E-10	5.3E-14	4.7E-18	4.7E-22	5.0E-26	0.0E-01
Tc-99	0.0E-01	7.9E-05	1.1E-15	5.8E-26	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

Table F-11 Concentrations and Doses at Boundary Well - High Activity Wastes, Alternatives 1 and 2 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	3.6E-10	3.6E-10	3.5E-10	3.5E-10	3.4E-10	3.4E-10	3.4E-10	3.3E-10	3.2E-10
H-3	0.0E-01	6.4E-04	2.3E-06	8.2E-09	2.9E-11	1.0E-13	3.7E-16	1.3E-18	4.7E-21	6.0E-26
I-129	0.0E-01	1.9E-10	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	8.7E-15	1.8E-14	2.1E-14
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.5E-10	3.3E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10
Tc-99	0.0E-01	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08
Doses (mrem/yr)										
C-14	0.0E-01	4.6E-04	4.5E-04	4.5E-04	4.4E-04	4.4E-04	4.3E-04	4.3E-04	4.2E-04	4.1E-04
H-3	0.0E-01	3.4E+01	1.2E-01	4.4E-04	1.6E-06	5.6E-09	1.9E-10	7.1E-14	2.5E-16	3.2E-21
I-129	0.0E-01	3.9E-03	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.3E-08	7.1E-08	8.1E-08
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-03	1.9E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
Tc-99	0.0E-01	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02

Note: H-3, C-14, and I-129 are not present in high activity waste in Alternative 2.

Table F-10 Concentrations and Doses at Boundary Well - Intermediate Activity Wastes, Alternatives 1 and 2 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.8E-11	4.2E-21	1.1E-30	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	8.6E-09	1.2E-11	1.4E-24	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	2.1E-11	6.6E-11	8.2E-15	6.4E-19	5.9E-23	6.0E-27	6.5E-31	7.3E-35	0.0E-01
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.4E-11
Tc-99	3.7E-09	1.6E-10	5.4E-21	3.2E-31	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	3.5E-05	5.3E-15	1.4E-24	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	4.1E-03	1.3E-02	1.6E-06	1.3E-10	1.2E-14	1.2E-18	1.3E-22	1.5E-26	0.0E-01
Tc-99	3.5E-03	1.6E-04	5.1E-15	3.0E-25	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

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Table F-9 Concentrations and Doses at Boundary Well - Low Level Wastes, Alternatives 1 and 2 - Low Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	2.4E-13	3.7E-23	9.7E-33	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	1.0E-12	5.2E-13	4.8E-17	3.8E-21	3.6E-25	3.6E-29	4.0E-33	1.0E-35	0.0E-01
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.1E-12
Tc-99	4.8E-10	1.5E-12	5.0E-23	3.0E-33	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Doses (mrem/yr)										
C-14	0.0E-01	3.0E-07	4.6E-17	1.2E-26	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	0.0E-01	2.1E-04	1.0E-04	9.5E-09	7.6E-13	7.1E-17	7.2E-21	7.8E-25	2.0E-27	0.0E-01
Se-79	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.4E-05
Tc-99	4.6E-04	1.4E-06	4.8E-17	2.8E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01

Table F-8 Concentrations and Doses at Boundary Well - Alternative 6 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	2.1E-11	2.1E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	1.9E-11	1.9E-11
H-3	0.0E-01	0.0E-01	7.1E-08	2.6E-10	9.1E-13	3.3E-15	1.2E-17	4.1E-20	1.5E-22	1.9E-27
I-129	0.0E-01	0.0E-01	1.2E-12	1.2E-12	1.2E-12	1.2E-12	1.2E-12	1.2E-12	1.2E-12	1.2E-12
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.3E-16	9.5E-16	1.1E-15	1.2E-15	1.2E-15
Se-79	0.0E-01	0.0E-01	0.0E-01	6.0E-12	1.7E-11	1.9E-11	1.9E-11	2.0E-11	2.0E-11	2.0E-11
Tc-99	0.0E-01	0.0E-01	6.8E-10	6.8E-10	6.8E-10	6.8E-10	6.8E-10	6.8E-10	6.8E-10	6.8E-10
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.6E-13	8.0E-13
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.6E-14	1.1E-14	1.2E-16
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.6E-14	1.1E-14	1.2E-16
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	2.6E-05	2.6E-05	2.6E-05	2.5E-05	2.5E-05	2.5E-05	2.4E-05	2.4E-05
H-3	0.0E-01	0.0E-01	3.8E-03	1.4E-05	4.9E-08	1.7E-10	6.2E-13	2.2E-15	7.9E-18	1.0E-22
I-129	0.0E-01	0.0E-01	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.0E-09	3.6E-09	4.2E-09	4.5E-09	4.6E-09
Se-79	0.0E-01	0.0E-01	0.0E-01	3.5E-05	1.0E-04	1.1E-04	1.1E-04	1.2E-04	1.2E-04	1.1E-04
Tc-99	0.0E-01	0.0E-01	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.8E-03	1.5E-02
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.2E-06	6.9E-07	7.8E-09
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.2E-07	5.3E-08	6.0E-10

Table F-7 Concentrations and Doses at Boundary Well - Alternative 5 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	1.9E-10	1.9E-10	1.8E-10	1.8E-10	1.8E-10	1.7E-10	1.7E-10	1.7E-10
Co-60	0.0E-01	0.0E-01	0.0E-01	2.7E-20	2.2E-25	5.8E-31	1.0E-35	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	0.0E-01	9.4E-07	3.4E-09	1.2E-11	4.3E-14	1.5E-16	5.4E-19	1.9E-21	2.5E-26
I-129	0.0E-01	0.0E-01	1.0E-11	1.0E-11	1.0E-11	1.0E-11	1.0E-11	1.0E-11	1.0E-11	1.0E-11
Rb-87	0.0E-01	0.0E-01	2.0E-15	8.7E-15	1.0E-14	1.1E-14	1.1E-14	1.1E-14	1.1E-14	1.1E-14
Se-79	0.0E-01	0.0E-01	1.2E-10	1.7E-10	1.7E-10	1.7E-10	1.7E-10	1.7E-10	1.7E-10	1.7E-10
Tc-99	0.0E-01	0.0E-01	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09	6.1E-09
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.4E-08	2.4E-07	4.6E-07
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.0E-09	1.3E-08	2.6E-08
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	9.0E-09	4.0E-08	7.7E-08
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.5E-07	6.7E-07	1.3E-06
Np-237	0.0E-01	0.0E-01	0.0E-01	3.1E-12	7.0E-12	8.7E-12	9.5E-12	9.9E-12	1.0E-11	1.0E-11
Sr-90	0.0E-01	0.0E-01	0.0E-01	1.5E-08	2.3E-09	2.3E-10	2.2E-11	2.0E-12	1.8E-13	1.4E-15
Y-90	0.0E-01	0.0E-01	0.0E-01	1.5E-08	2.3E-09	2.3E-10	2.2E-11	2.0E-12	1.8E-13	1.4E-15
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.2E-04	2.2E-04	2.2E-04	2.1E-04
Co-60	0.0E-01	0.0E-01	0.0E-01	4.2E-13	3.4E-18	9.2E-24	1.6E-28	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	0.0E-01	5.0E-02	1.8E-04	6.4E-07	2.3E-09	8.1E-12	2.9E-14	1.0E-16	1.3E-21
I-129	0.0E-01	0.0E-01	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
Rb-87	0.0E-01	0.0E-01	7.4E-09	3.3E-08	3.9E-08	4.1E-08	4.1E-08	4.2E-08	4.2E-08	4.2E-08
Se-79	0.0E-01	0.0E-01	7.0E-04	9.9E-04	1.0E-03	1.0E-03	1.0E-03	1.0E-03	1.0E-03	1.0E-03
Tc-99	0.0E-01	0.0E-01	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.7E+00	2.9E+01	5.7E+01
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.6E-01	1.6E+00	3.1E+00
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.1E+00	4.7E+00	9.2E+00
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.7E+01	7.3E+01	1.4E+02
Np-237	0.0E-01	0.0E-01	0.0E-01	5.7E-02	1.3E-01	1.6E-01	1.7E-01	1.8E-01	1.8E-01	1.9E-01
Sr-90	0.0E-01	0.0E-01	0.0E-01	9.7E-01	1.5E-01	1.5E-02	1.4E-03	1.3E-04	1.2E-05	9.4E-08
Y-90	0.0E-01	0.0E-01	0.0E-01	7.4E-02	1.1E-02	1.2E-03	1.1E-04	9.8E-06	8.9E-07	7.0E-09

Table F-6 Concentrations and Doses at Boundary Well - High Activity Wastes, Alternative 3 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
Co-60	0.0E-01	0.0E-01	2.0E-14	1.4E-19	3.6E-25	7.4E-31	1.0E-35	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	2.4E-15	1.7E-14	2.0E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14
Se-79	0.0E-01	2.2E-10	3.3E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10
Tc-99	0.0E-01	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.3E-09	9.8E-09	1.3E-08	1.7E-08
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.9E-11	1.1E-10	1.4E-10	1.9E-10
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.2E-10	7.9E-10	1.0E-09	1.4E-09
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.6E-10	4.8E-10	6.5E-10	8.6E-10
Np-237	0.0E-01	0.0E-01	7.2E-12	1.5E-11	1.8E-11	1.9E-11	1.9E-10	2.0E-11	2.0E-11	2.0E-11
Sr-90	0.0E-01	0.0E-01	3.7E-07	5.3E-08	5.3E-09	4.9E-10	4.5E-11	4.0E-12	3.6E-13	2.8E-15
Y-90	0.0E-01	0.0E-01	3.7E-07	5.3E-08	5.3E-09	4.9E-10	4.5E-11	4.0E-12	3.6E-13	2.8E-15
Doses (mrem/yr)										
Co-60	0.0E-01	0.0E-01	3.2E-07	2.3E-12	5.6E-18	1.1E-23	1.5E-28	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	9.2E-09	6.7E-08	7.8E-08	8.1E-08	8.2E-08	8.2E-08	8.2E-08	8.2E-08	8.2E-08
Se-79	0.0E-01	1.3E-03	1.9E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
Tc-99	0.0E-01	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.6E-01	1.2E+00	1.6E+00	2.1E+00
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.1E-03	1.3E-02	1.7E-02	2.3E-02
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.1E-02	9.4E-02	1.2E-01	1.6E-01
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.8E-02	5.3E-02	7.1E-02	9.5E-02
Np-237	0.0E-01	0.0E-01	1.3E-01	2.7E-01	3.2E-01	3.4E-01	3.5E-01	3.6E-01	3.6E-01	3.7E-01
Sr-90	0.0E-01	0.0E-01	2.4E+01	3.4E+00	3.4E-01	3.2E-02	2.9E-03	2.6E-04	2.3E-05	1.8E-07
Y-90	0.0E-01	0.0E-01	1.7E+00	2.6E-01	2.6E-02	2.4E-03	2.2E-04	1.9E-05	1.7E-06	1.4E-08

Table F-5 Concentrations and Doses at Boundary Well - Intermediate Activity Wastes, Alternative 3 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	0.0E-01	3.1E-11	3.0E-11	3.0E-11	3.0E-11	2.9E-11	2.9E-11	2.9E-11	2.8E-11
Co-60	0.0E-01	0.0E-01	0.0E-01	6.0E-21	3.7E-26	1.2E-31	1.0E-35	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	0.0E-01	1.4E-13	5.0E-16	1.8E-18	6.4E-21	2.3E-23	8.2E-26	2.9E-28	3.7E-33
I-129	0.0E-01	0.0E-01	1.7E-12	1.7E-12	1.7E-12	1.7E-12	1.7E-12	1.7E-12	1.7E-12	1.7E-12
Rb-87	0.0E-01	0.0E-01	2.4E-16	1.2E-15	1.6E-15	1.8E-15	1.8E-15	1.9E-15	1.9E-15	1.9E-15
Se-79	0.0E-01	0.0E-01	1.5E-11	2.7E-11	2.9E-11	2.9E-11	2.9E-11	2.9E-11	2.9E-11	2.9E-11
Tc-99	0.0E-01	0.0E-01	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.1E-14	4.7E-14	9.3E-14
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.0E-15	8.7E-15	1.7E-14
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	8.6E-13	3.7E-12	7.4E-12
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.2E-15	9.4E-15	1.9E-14
Np-237	0.0E-01	0.0E-01	0.0E-01	3.5E-13	8.4E-13	1.2E-12	1.4E-12	1.6E-12	1.7E-12	1.7E-12
Sr-90	0.0E-01	0.0E-01	0.0E-01	1.6E-09	2.8E-10	3.3E-11	3.3E-12	3.1E-13	2.9E-14	2.3E-16
Y-90	0.0E-01	0.0E-01	0.0E-01	1.6E-09	2.8E-10	3.3E-11	3.3E-12	3.1E-13	2.9E-14	2.3E-16
Doses (mrem/yr)										
C-14	0.0E-01	0.0E-01	3.9E-05	3.9E-05	3.8E-05	3.8E-05	3.7E-05	3.7E-05	3.6E-05	3.5E-05
Co-60	0.0E-01	0.0E-01	0.0E-01	9.3E-14	5.8E-19	1.8E-24	1.6E-28	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	0.0E-01	7.5E-09	2.7E-11	9.6E-14	3.4E-16	1.2E-18	4.4E-21	1.6E-23	2.0E-28
I-129	0.0E-01	0.0E-01	3.4E-04	3.4E-04	3.4E-04	3.4E-04	3.4E-04	3.4E-04	3.4E-04	3.4E-04
Rb-87	0.0E-01	0.0E-01	9.2E-10	4.4E-09	6.0E-09	6.6E-09	6.9E-09	7.0E-09	7.1E-09	7.1E-09
Se-79	0.0E-01	0.0E-01	9.0E-05	1.6E-04	1.7E-04	1.7E-04	1.7E-04	1.7E-04	1.7E-04	1.7E-04
Tc-99	0.0E-01	0.0E-01	9.6E-04	9.6E-04	9.6E-04	9.6E-04	9.6E-04	9.6E-04	9.6E-04	9.6E-04
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-06	5.8E-06	1.2E-05
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.4E-07	1.0E-06	2.1E-06
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.0E-04	4.4E-04	8.8E-04
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.4E-07	1.0E-06	2.1E-06
Np-237	0.0E-01	0.0E-01	0.0E-01	6.6E-03	1.5E-02	2.2E-02	2.6E-02	2.8E-02	3.0E-02	3.2E-02
Sr-90	0.0E-01	0.0E-01	0.0E-01	1.1E-01	1.8E-02	2.1E-03	2.1E-04	2.0E-05	1.8E-06	1.5E-08
Y-90	0.0E-01	0.0E-01	0.0E-01	8.0E-03	1.4E-03	1.6E-04	1.6E-05	1.5E-06	1.4E-07	1.1E-09

Table F-4 Concentrations and Doses at Boundary Well - Low Level Wastes, Alternative 3 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	2.7E-10	7.5E-19	1.3E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	3.6E-08	2.9E-19	3.9E-32	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	5.0E-12	7.7E-15	3.1E-19	2.2E-23	2.0E-27	2.0E-31	2.1E-35	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.2E-15	1.1E-15	4.4E-16	1.8E-16	7.5E-17	1.5E-17
Se-79	0.0E-01	0.0E-01	3.3E-11	1.7E-11	3.0E-12	6.1E-13	1.4E-13	3.5E-14	9.1E-15	6.8E-16
Tc-99	8.7E-09	5.9E-18	2.2E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.2E-13	6.3E-13	4.9E-13
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.1E-12	1.7E-13	1.0E-14	2.6E-17
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.1E-12	1.7E-13	1.0E-14	2.6E-17
Doses (mrem/yr)										
C-14	3.5E-04	9.5E-13	1.6E-22	1.3E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	1.9E-03	1.6E-14	2.1E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	9.9E-04	1.5E-06	6.1E-11	4.4E-15	4.0E-19	4.0E-23	4.2E-27	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.5E-09	4.1E-09	1.7E-09	6.7E-10	2.8E-10	5.7E-11
Se-79	0.0E-01	0.0E-01	1.9E-04	1.0E-04	1.7E-05	3.6E-06	8.3E-07	2.1E-07	5.3E-08	4.0E-09
Tc-99	8.3E-03	5.6E-12	2.1E-22	9.5E-30	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.8E-03	1.1E-02	9.0E-03
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.9E-05	1.1E-05	6.6E-07	1.7E-09
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.3E-06	8.2E-07	5.1E-08	1.3E-10

Table F-3 Concentrations and Doses at Boundary Well - High Activity Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	0.0E-01	3.6E-10	3.5E-10	3.5E-10	3.4E-10	3.4E-10	3.4E-10	3.3E-10	3.3E-10	3.2E-10
Co-60	0.0E-01	0.0E-01	2.0E-14	1.4E-19	3.6E-25	7.4E-31	1.0E-35	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	6.4E-04	2.3E-06	8.2E-09	2.9E-11	1.0E-13	3.7E-16	1.3E-18	4.7E-21	6.0E-26
I-129	0.0E-01	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11	2.0E-11
Rb-87	0.0E-01	2.4E-15	1.7E-14	2.0E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14	2.1E-14
Se-79	0.0E-01	2.2E-10	3.3E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10	3.4E-10
Tc-99	0.0E-01	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08	1.2E-08
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.3E-09	9.8E-09	1.3E-08	1.7E-08
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.9E-11	1.1E-10	1.4E-10	1.9E-10
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	4.2E-10	7.9E-10	1.0E-09	1.4E-09
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.6E-10	4.8E-10	6.5E-10	8.6E-10
Np-237	0.0E-01	0.0E-01	7.2E-12	1.5E-11	1.8E-11	1.9E-11	1.9E-10	2.0E-11	2.0E-11	2.0E-11
Sr-90	0.0E-01	0.0E-01	3.7E-07	5.3E-08	5.3E-09	4.9E-10	4.5E-11	4.0E-12	3.6E-13	2.8E-15
Y-90	0.0E-01	0.0E-01	3.7E-07	5.3E-08	5.3E-09	4.9E-10	4.5E-11	4.0E-12	3.6E-13	2.8E-15
Doses (mrem/yr)										
C-14	0.0E-01	4.5E-04	4.5E-04	4.4E-04	4.4E-04	4.3E-04	4.3E-04	4.2E-04	4.2E-04	4.1E-04
Co-60	0.0E-01	0.0E-01	3.2E-07	2.3E-12	5.6E-18	1.1E-23	1.5E-28	0.0E-01	0.0E-01	0.0E-01
H-3	0.0E-01	3.4E+01	1.2E-01	4.3E-04	1.5E-06	5.5E-09	1.9E-11	7.1E-14	2.5E-16	3.2E-21
I-129	0.0E-01	3.9E-03	3.9E-03	3.9E-03	3.9E-03	3.9E-03	3.9E-03	3.9E-03	3.9E-03	3.9E-03
Rb-87	0.0E-01	9.2E-09	6.7E-08	7.8E-08	8.1E-08	8.2E-08	8.2E-08	8.2E-08	8.2E-08	8.2E-08
Se-79	0.0E-01	1.3E-03	1.9E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
Tc-99	0.0E-01	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
U-234	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.6E-01	1.2E+00	1.6E+00	2.1E+00
U-235	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	7.1E-03	1.3E-02	1.7E-02	2.3E-02
U-236	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	5.1E-02	9.4E-02	1.2E-01	1.6E-01
U-238	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.8E-02	5.3E-02	7.1E-02	9.5E-02
Np-237	0.0E-01	0.0E-01	1.3E-01	2.7E-01	3.2E-01	3.4E-01	3.5E-01	3.6E-01	3.6E-01	3.7E-01
Sr-90	0.0E-01	0.0E-01	2.4E+01	3.4E+00	3.4E-01	3.2E-02	2.9E-03	2.6E-04	2.3E-05	1.8E-07
Y-90	0.0E-01	0.0E-01	1.7E+00	2.6E-01	2.6E-02	2.4E-03	2.2E-04	1.9E-05	1.7E-06	1.4E-08

Note: H-3, C-14, and I-129 are not present in high activity waste in Alternative 2.

Table F-2 Concentrations and Doses at Boundary Well - Intermediate Activity Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	1.3E-09	3.5E-18	6.3E-28	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Co-60	0.0E-01	0.0E-01	0.0E-01	0.0E-01	9.0E-26	7.6E-31	1.0E-35	0.0E-01	0.0E-01	0.0E-01
I-129	2.9E-10	4.5E-14	2.0E-18	1.5E-22	1.4E-26	1.4E-30	1.5E-34	1.0E-35	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	5.7E-15	3.6E-14	1.6E-14	6.1E-15	2.5E-15	1.1E-15	4.8E-16	1.1E-16
Se-79	0.0E-01	1.1E-10	5.3E-10	8.9E-11	1.8E-11	4.0E-12	9.7E-13	2.5E-13	6.7E-14	5.1E-15
Tc-99	3.2E-08	2.6E-17	1.0E-27	1.0E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.4E-12	1.2E-11	1.7E-11	1.1E-11	7.2E-12	2.8E-12
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.6E-09	4.2E-10	2.3E-11	1.2E-12	5.7E-14	1.5E-16
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	3.6E-09	4.2E-10	2.3E-11	1.2E-12	5.7E-14	1.5E-16
Doses (mrem/yr)										
C-14	1.7E-03	4.4E-12	8.0E-22	1.3E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Co-60	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.4E-18	1.2E-23	1.6E-28	0.0E-01	0.0E-01	0.0E-01
H-3	5.8E-03	5.4E-14	7.7E-27	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	5.8E-02	8.9E-06	4.0E-10	3.0E-14	2.7E-18	2.8E-22	3.0E-26	2.0E-27	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	2.2E-08	1.4E-07	5.9E-08	2.3E-08	9.5E-09	4.1E-09	1.8E-09	4.0E-10
Se-79	0.0E-01	6.2E-04	3.1E-03	5.3E-04	1.0E-04	2.3E-05	5.7E-06	1.5E-06	3.9E-07	3.0E-08
Tc-99	3.1E-02	2.5E-11	9.8E-22	9.5E-30	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	6.1E-02	2.2E-01	3.1E-01	2.0E-01	1.3E-01	5.0E-02
Sr-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.3E-01	2.7E-02	1.5E-03	7.4E-05	3.7E-06	9.4E-09
Y-90	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.8E-02	2.1E-03	1.2E-04	5.7E-06	2.8E-07	7.3E-10

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Table F-1 Concentrations and Doses at Boundary Well - Low Level Wastes, Alternatives 1 and 2 - Normal Infiltration

	YEARS SINCE CLOSURE									
Nuclide	1	80	180	280	380	480	580	680	780	980
Concentrations (Ci/m^3)										
C-14	1.8E-11	5.0E-20	9.0E-30	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Co-60	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.3E-29	5.6E-35	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	1.5E-09	1.5E-20	2.1E-33	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	4.6E-12	6.4E-16	2.9E-20	2.2E-24	2.0E-28	2.0E-32	1.0E-35	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	2.3E-16	4.7E-16	2.1E-16	8.0E-17	3.3E-17	1.4E-17	6.5E-18	1.5E-18
Se-79	0.0E-01	6.4E-12	7.4E-12	1.3E-12	2.5E-13	5.7E-14	1.4E-14	3.6E-15	9.7E-16	7.5E-17
Tc-99	4.6E-10	3.8E-19	1.5E-29	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	1.2E-13	2.4E-13	2.2E-13	1.5E-13	9.4E-14	3.7E-14
Sr-90	0.0E-01	0.0E-01	0.0E-01	2.6E-10	7.0E-11	5.5E-12	3.0E-13	1.5E-14	7.2E-16	1.9E-18
Y-90	0.0E-01	0.0E-01	0.0E-01	2.6E-10	7.0E-11	5.5E-12	3.0E-13	1.5E-14	7.2E-16	1.8E-18
Doses (mrem/yr)										
C-14	2.3E-05	6.3E-14	1.1E-23	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Co-60	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.0E-22	8.7E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01
H-3	8.2E-05	7.9E-16	1.1E-28	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
I-129	9.1E-04	1.3E-07	5.8E-12	4.3E-16	4.0E-20	4.0E-24	2.0E-27	0.0E-01	0.0E-01	0.0E-01
Rb-87	0.0E-01	0.0E-01	8.8E-10	1.8E-09	7.8E-10	3.1E-10	1.3E-10	5.5E-11	2.5E-11	5.5E-12
Se-79	0.0E-01	3.8E-05	4.3E-05	7.3E-06	1.5E-06	3.4E-07	8.2E-08	2.1E-08	5.7E-09	4.4E-10
Tc-99	4.4E-04	3.6E-13	1.4E-23	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01	0.0E-01
Np-237	0.0E-01	0.0E-01	0.0E-01	0.0E-01	2.2E-03	4.4E-03	4.1E-03	2.7E-03	1.7E-03	6.6E-04
Sr-90	0.0E-01	0.0E-01	0.0E-01	1.7E-02	4.5E-03	3.6E-04	1.9E-05	9.3E-07	4.6E-08	1.2E-10
Y-90	0.0E-01	0.0E-01	0.0E-01	1.3E-03	3.5E-04	2.7E-05	1.5E-06	7.2E-08	3.6E-09	9.3E-12

APPENDIX F

CONCENTRATION AND DOSE SUMMARY TABLES

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References for Appendix E

1. C. F. Baes III and R. D. Sharp, **J. Environ. Qual.**, Vol 12, p. 17-28, 1983.

2. B. B. Looney, M. W. Grant, and C. M. King, **Estimation of Geochemical Parameters for Assessing Subsurface Transport at the Savannah River Plant**, DPST-85-904 (Draft), 1985.

3. J. Crank, **The Mathematics of Diffusion**, 2nd Ed., Oxford, 1976.

4. W. Jost, **Diffusion**, Revised, Academic Press, 1960.

5. R. M. Wallace, W. W. F. Yau, and M. W. Grant, **Simple Approximation of Nitrate Diffusion from Saltstone**, DPST-85-939 (1985).

Table E-9 Parameters Specific to High Activity Waste Disposal

Dimension of Waste Volume Parallel to Groundwater Flow	95 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	95 m
Thickness of Waste Volume	6 m
Total Volume of Waste	2.8×10^4 m^3
Thickness of Cover Over the Waste	5 m
Waste Density	1600 kg/m^3
Container Lifetime	30 yr

Table E-8 Parameters Specific to Above Grade Vaults

Dimension of Waste Volume Parallel to Groundwater Flow	470 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	470 m
Thickness of Waste Volume	5.2 m
Total Volume of Waste	5.7×10^5 m^3
Thickness of Cover Over the Waste	5 m
Waste Density	1600 kg/m^3
Container Lifetime	115 yr

Table E-7 Parameters Specific to the Monolith of the Earth Mounded Concrete Bunker

Dimension of Waste Volume Parallel to Groundwater Flow	110 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	110 m
Thickness of Waste Volume	6 m
Total Volume of Waste	3.8×10^4 m^3
Thickness of Cover Over the Waste	5 m
Waste Density	1600 kg/m^3
Container Lifetime	115 yr

Table E-6 Parameters Specific to Above Grade Operations and Below Grade Vaults*

Dimension of Waste Volume Parallel to Groundwater Flow		455 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	AGO (LLW):	395 m
	BGV (ILW):	60 m
Thickness of Waste Volume		6 m
Volume of Waste	LLW:	4.5×10^5 m^3
	ILW:	8.3×10^4 m^3
Thickness of Cover Over the Waste		5 m
Waste Density		1600 kg/m^3
Container Lifetime	LLW:	0 yr
	ILW:	115 yr

* Above Grade Operations (AGO) are used for disposal of low-level wastes and Below Grade Vaults (BGV) are used for disposal of intermediate-level wastes.

Table E-5 Parameters Specific to Engineered Trenches: Second Alternative

Dimension of Waste Volume Parallel to Groundwater Flow		450 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	LLW:	375 m
	ILW:	75 m
Thickness of Waste Volume	LLW:	5.2 m
	ILW:	5 m
Total Volume of Waste	LLW:	4.5×10^5 m^3
	ILW:	8.2×10^4 m^3
Thickness of Cover Over the Waste		5 m
Waste Density		1600 kg/m^3
Container Lifetime		0 yr

E.4.2 Engineered Trenches: Second Alternative

Table E-5 lists parameters specific to the engineered trenches used in the second alternative given in Section E.2. Only the waste volume and horizontal dimensions of the disposal areas change, reflecting the removal of some of the waste for storage or disposal outside SRP.

E.4.3 Above Grade Operations and Below-Grade Vaults: Third Alternative

Table E-6 lists parameters specific to the Above Grade Operations and below-grade vaults used to dispose of low-level and intermediate-level wastes, respectively, in the third alternative given in Section E.2.

E.4.4 Engineered Disposal - Monoliths: Fifth Alternative

Table E-7 lists parameters specific to the monoliths of the engineered disposal system used for disposal of treated low-level and intermediate-level wastes in alternative 5 described in Section E.2. The volume of waste and the area of the disposal cells are smaller for this alternative because the lower activity waste has been removed and the remaining higher activity waste has been treated to reduce its volume.

E.4.5 Above Grade Vaults: Sixth Alternative

Table E-8 lists the parameters specific to the above-grade vaults used in Alternative 6 given in Section E.2. Since no waste segregation or treatment is assumed to take place in this alternative, the volume of waste and the area needed for disposal are large.

E.4.6 High Activity Waste Disposal

Table E-9 lists parameters specific to disposal of the High Activity waste. For the purpose of calculating concentrations in water and dose rates, the 20 year total of High Activity waste is assumed to be gathered in a single square monolith at the new low-level waste disposal facility. This is conservative because the cells of waste will actually be distributed over a wider area.

Table E-4 Parameters Specific to Engineered Trenches: First Alternative

Dimension of Waste Volume Parallel to Groundwater Flow		455 m
Horizontal Dimension of Waste Volume Perpendicular to Groundwater Flow	LLW:	375 m
	ILW:	80 m
Thickness of Waste Volume	LLW:	5.2 m
	ILW:	5 m
Volume of Waste	LLW:	4.5×10^5 m^3
	ILW:	9.0×10^4 m^3
Thickness of Cover Over the Waste		5 m
Waste Density		1600 kg/m^3
Container Lifetime		0 yr

species. Also some radionuclides are likely incorporated into the matrix. The one-dimemsional solution for a semi-infinite system with no barriers predicts significantly larger releases at early times. Three factors, however, tend to damp out the effects of this peaking: 1) the fact that the wasteform is a large but finite source in a flow system, 2) the fact that emplacement of the monoliths is spatially and temporally distributed, and 3) the presence of a barrier. Thus, the release of contaminants from the facilities has been assumed to be characterized by the lower, more slowly decreasing release occurring at later times.

When a concrete barrier is present a transit time for contaminant movement from the waste to the soil can be estimated. A finite barrier introduces resistance to the diffusion process resulting in both peak attenuation and a delay in the release to the environment. The barrier transit time is used as a container lifetime in PATHRAE. Initial estimates of the transit time, i.e., container lifetime, were made via a simple relation which defines the mean time t_c required for a contaminant to diffuse a distance x:

$$t_c = x^2/2D$$

where

x = barrier thickness (cm)

D = diffusion coefficient for the contaminant to diffuse through the barrier (cm^2/yr)

A value of 15.8 cm^2/yr has been assumed for D in all cases. This number is typical for diffusion in construction concrete. Estimates based on steady-state numerical calculations have also been used.

For wastes in concrete containers in vaults, a three foot concrete barrier thickness is assumed (one foot for the container and two feet for the vault wall). For wastes in concrete containers in an Above-Grade Operation facility, a one foot concrete barrier (container wall only) is used.

E.4.1 Engineered Trenches: First Alternative

Table E-4 lists parameters used in the performance assessments for engineered trenches that were not the same for all analyses of disposal at the new low-level waste disposal site. These trenches are used in the first alternative listed in Section E.2. These parameters describe the general dimensions of the buried waste, the vertical location of the waste, dimensions of the cover over it, and characteristics of vertical water movement. In some cases separate entries are made for trenches used for disposal of low-level waste (LLW) or intermediate-level waste (ILW).

- A diffusion coefficient of $5x10^{-6}$ cm^2/sec was assumed for the ILW placed in below-grade vaults, for compacted waste placed in the monolith, and wastes placed in the above-grade vault.

- Waste mixed with concrete, with a diffusion coefficient of $5x10^{-7}$ cm^2/sec, was assumed for incinerated wastes whose ash is solidified (alternative 5) and for all high activity waste.

The leach rates based on sorption equilibria are sensitive to radionuclide K_d's, the annual infiltration rate, the depth of the waste, the soil/waste matrix density, and the effective porosity of the soil/waste matrix:

$$L_L = (P/d)(1 + (p_s/n)K_d)^{-1}$$

with

L_L = leach rate (yr^{-1})

P = infiltration rate (m/yr)

n = effective porosity

p_s = bulk density (g/cm^3)

d = thickness of waste layer (m)

Here the leaching is assumed to be driven by equilibrium distribution of the contaminant between the soil-waste matrix and soil moisture. The kinetic aspects of mass transfer are not taken into consideration and the leach rates obtained with the model are expected to be equal to or greater than those observed in the environment.*

Radionuclide release rates for systems with cement wasteforms and/or concrete containers or barriers have been estimated using one-dimensional diffusion models for a semi-infinite system.[3,4,5] Diffusion in the waste and the barrier is assumed to control the release of contaminants into the environment, i.e., diffusion and convective transport processes in the soil offer little resistance in the mass transfer process. Retardation effects in the cement and concrete are ignored as quantitative data are not available of all species. It is likely that retardation effects do occur for some

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* This is in the absence of chelating or other chemical agents which may react with the leached species. In addition to enhancing the mobility of the radionuclide, chelation "removes" it from the leachate; it is there in solution but masked as another chemical species. Thus the concentration gradient driving the primary leach process is maintained and leaching is enhanced. On the other hand, dispersive influences such as the channelling of the water percolating through the waste will increase resistance to mass transfer, thereby retarding the leach process.

Table E-3 Sorption and Retardation Coefficients

Contaminant	Aquifer Sorption (ml/g)	Aquifer Retardation
Ag-110m	1.0E+2	8.0E+2
Ba-137m	5.0E+2	4.0E+3
C-14	1.0E-2	1.1E+0
Cd-115m	6.0E+0	4.9E+1
Cf-252	3.0E+3	2.4E+4
Co-60	1.0E+1	8.1E+1
Cs-134	5.0E+2	4.0E+3
Cs-137	5.0E+2	4.0E+3
Eu-154	1.0E+3	8.0E+3
Eu-155	1.0E+3	8.0E+3
H-3	1.0E-3	1.0E+0
I-129	2.0E-1	2.6E+0
Mn-54	5.0E+0	4.1E+1
Ni-63	1.0E+2	8.0E+2
Pm-147	1.0E+3	8.0E+3
Rb-87	5.0E+0	4.1E+1
Rh-106	1.6E+2	1.3E+3
Ru-106	1.6E+2	1.3E+3
Sb-125	4.0E+3	3.2E+4
Se-75	2.5E+0	2.1E+1
Se-79	2.5E+0	2.1E+1
Sm-151	1.0E+3	8.0E+3
Tc-99	1.0E-3	1.0E+0
Te-125m	4.0E+3	3.2E+4
Sr-90	8.0E+0	6.5E+1
Y-90	8.0E+0	6.5E+1
Ce-144	1.0E+3	8.0E+3
Pr-144	1.0E+3	8.0E+3
Th-232	1.0E+2	8.0E+2
U-234	4.0E+1	3.2E+2
U-235	4.0E+1	3.2E+2
U-236	4.0E+1	3.2E+2
U-238	4.0E+1	3.2E+2
Np-237	1.0E+1	8.1E+1
Pu-238	1.0E+2	8.0E+2
Pu-239	1.0E+2	8.0E+2
Pu-241	1.0E+2	8.0E+2
Pu-242	1.0E+2	8.0E+2
Am-241	1.0E+2	8.0E+2
Am-243	1.0E+2	8.0E+2
Cm-244	3.0E+3	2.4E+4

Table E-2 Common Site Parameters for the Analyses

Duration of Facility Operation	20 yr
Flow Rate of Upper Three Runs Creek	1.7×10^8 m^3/yr
Flow Rate of the Savannah River	9.1×10^9 m^3/yr
Distance to Upper Three Runs Creek	750 m
Density of the Aquifer	1600 kg/m^3
Longitudinal Dispersivity	38 m
Lateral Dispersion	0
Distance to Downstream Well	1 m
Permeability of the Vertical Zone	2.2 m/yr
Porosity of the Aquifer	0.2
Horizontal Velocity of the Aquifer	35 m/yr
Mixing Thickness of the Aquifer	10 m
Fraction of Food Consumed that is Grown on Site	0.5

E.3.2 Site Parameters

Tables E-2 and E-3 list common parameters that quantify the major features of Site G, the site selected for modeling the new low-level waste disposal facility. Most of the parameters relate to the hydrogeology of the area; others, such as duration of facility operation, while not site specific, must be specified to perform the analyses.

Table E-3 lists both sorption coefficients and retardation coefficients. The latter are complex functions of the former and are used directly in the risk assessment models.

Parameter values in Table E-2 and E-3 are used in all the analyses involving disposal in the new low-level waste facility.

Finally, two water infiltration rates were analyzed for each alternative: a normal infiltration rate of 15 inches per year (0.38 m/yr) and a lower infiltration rate dependent on the alternative. In each alternative the lower infiltration rate represents a reasonable, achievable value which might be obtained using currently available technology appropriate to that alternative. For example, one would expect better cover performance over a concrete vault than over a trench. The alternative-specific values for the reduced infiltration rates are included in the appropriate Tables in the following sections.

E.4 Parameters That Are Specific to Individual Disposal Technologies

A number of parameters important to the performance assessments differ for each disposal technology. The following paragraphs present technology-specific parameters used in the performance assessments.

Radionuclide release rates were estimated using models that assumed either sorption equilibrium or diffusion controlled release:

- For LLW and ILW in trenches and for LLW waste in Above-Grade Operations, the method prescribed by Baes and Sharp[1,2] was used. This method provides radionuclide-specific release rates because it is based, in part, on the soil sorption characteristics of each nuclide.

- For the other disposal alternatives, release rates were based on one-dimensionsal diffusion in and from the untreated waste form or in and from waste mixed with concrete. For untreated LLW and ILW the diffusion was assumed to take place through 2 feet of uncontaminated concrete. This resulted in an effective container life of 115 years whenever the diffusion-based release rates were used. For High Activity waste, only one foot walls are assumed but, the wastes are mixed with a cement grout (see below). The effective container life for a one foot wall is approximately 30 years.

Table E-1 Initial Inventory of Radionuclides (Curies)

Nuclide	Low-Level Waste	Intermediate Level Waste	GCD Waste
H-3	2.7E-02	3.6E-01	1.7E+06
C-14	1.1E-04	1.5E-03	6.4E-03
Mn-54	5.3E+00	7.1E+01	1.6E+04
Co-60	4.7E+01	1.8E+05	1.4E+05
Ni-63	1.7E+01	2.3E+02	5.0E+04
Zn-65	1.9E+01	2.5E+02	5.7E+04
Se-75	6.8E+00	9.1E+01	2.1E+04
Se-79	1.1E-04	1.4E-03	6.0E-03
Rb-87	6.7E-09	8.9E-08	3.8E-07
Sr-90	2.3E+01	3.3E+02	1.3E+03
Y-90	2.3E+01	3.3E+02	1.3E+03
Tc-99	3.6E-03	4.8E-02	2.1E-01
Ru-106	2.2E+00	2.9E+01	1.2E+02
Rh-106	2.2E+00	2.9E+01	1.2E+02
Ag-110m	9.6E-03	1.3E-01	5.4E-01
Cd-115m	7.1E-13	9.5E-12	4.0E-11
Sb-125	6.3E-01	8.4E+00	3.6E+01
Te-125m	1.6E-01	2.1E+00	8.7E+00
I-129	6.2E-06	8.2E-05	3.5E-04
Cs-134	2.6E+00	3.4E+01	1.5E+02
Cs-137	2.4E+01	3.5E+02	1.4E+03
Ba-137m	2.4E+01	3.5E+02	1.4E+03
Ce-144	7.4E+00	9.8E+01	4.2E+02
Pr-144	7.4E+00	9.8E+01	4.2E+02
Pm-147	1.8E+01	2.4E+02	1.0E+03
Sm-151	1.8E-01	2.3E+00	9.9E+00
Eu-154	4.6E-01	6.2E+00	2.6E+01
Eu-155	3.7E-01	4.9E+00	2.1E+01
Th-232	6.8E-02	3.0E+05	1.3E-04
U-234	3.8E+01	1.4E-05	4.5E-01
U-235	2.2E+00	2.6E-06	5.0E-03
U-236	6.5E+00	1.1E-03	3.6E-02
Np-237	6.5E-06	8.6E-05	3.6E-04
U-238	1.1E+02	2.8E-06	2.2E-02
Pu-238	5.6E-01	1.1E+02	3.1E+01
Pu-239	1.8E+01	2.1E+00	3.0E-01
Am-241	8.0E-03	1.1E-01	4.5E-01
Pu-241	6.2E-01	8.3E+00	3.5E+01
Pu-242	4.4E-06	5.9E-05	2.5E-04
Am-243	4.3E-06	5.7E-05	2.4E-04
Cm-244	1.2E-04	1.6E-03	6.8E-03
Cf-252	1.2E-15	1.7E-14	9.0E+00
Total Activity	4.1E+02	1.8E+05	2.0E+06

the first stage raffinate of the solvent extraction process, e.g. the Purex process, or to commercial spent fuel.

In some alternatives the intermediate level and high activity wastes will be disposed of together, whereas in other alternatives the high activity wastes will be disposed of in a separate colocated facility. The combined inventory of these two waste streams includes (referring to Table 2.3):

5% by volume of the Fission Products (93% of the total fission product activity)

5% by volume of the Induced Activity (93% of the total induced activity)

100% of the Cobalt, Cesium, Strontium, Pu-238, and tritium inventories

When the high activity wastes are disposed of separately, an annual volume of 50,000 ft^3 is assumed. The annual inventory is:

Cobalt	20 curies
Cesium	1.8 curies
Fission Products	335 curies
Induced Activity	12,640 curies
Strontium	0.2 curies
Tritium	75,500 curies
Natural Uranium	0.01 curies
Enriched Uranium	0.01 curies

Note that even though the low activity wastes are assumed to contain 100% of of the natural and enriched uranium there are small amounts present in the other streams. This is not a discrepancy, but merely reflects roundoff in the estimates.

The volumes and activities in Table 2.3 were scaled up to a 1,000,000 ft^3/yr level of waste generation for calculating volumes and activities to be placed at the site over its 20 year operating period.

Table E-1 lists the initial inventories for the low, intermediate, and high activity waste streams. Tables 2.4 and 2.5 were used to estimate the isotopic breakdowns of the fission products and induced activity. These inventories were used in all analyses. The inventories represent the total quantities of potential contaminants emplaced for disposal in the site and do not account for decay during operations. Such decay is addressed by transport algorithms.

E.2.5 Untreated Wastes in Above-Grade Vaults

In alternative 6 all wastes will be placed in above-grade vaults, and the spaces between the wastes will be grouted. A leachate collection system below the vaults will be operated for 100 years after facility closure.

It was estimated that a 470-meter square facility will be needed.

E.3 Parameters Common to All Disposal Alternatives

A number of parameters used in the performance assessments are the same regardless of which disposal technology is being analyzed. They represent the disposal site, disposal facility operations, factors converting exposures to risks, and the inventory of contaminants to be placed in the disposal site. These are presented in the following sections.

E.3.1 Inventory of Radionuclides

In order to model the different alternatives the waste inventory - activities and volumes - has to be estimated. To this end the inventory has been divided into three distinct groups on the bases of beta-gamma activity and radionuclide content provided in Tables 2.3 and 2.8. Those wastes labeled "low-level" or "low activity" have beta-gamma levels below 300 mR per hour or are alpha wastes containing less than 10 nanocuries per gram alpha activity. Referring to the classifications and inventory in Table 2.3, low activity wastes include:

95% by volume of the Fission Products (7% of the total fission product activity)

95% by volume of the Induced Activity (7% of the total induced activity)

90% by volume of the Pu-239 (90% of the total Pu-239 activity)

100% of the Depleted Uranium, Natural Uranium, Enriched Uranium, Pu-242, Am-241, Curium, U-233, Np-237, and Thorium inventories

"Intermediate level" wastes are those wastes which have beta-gamma levels in excess of 300 mR per hour or alpha activity in excess if 10 nanocuries per gram and yet have radionuclide concentration below the criteria for the greater confinement disposal test as presented in Table 2.8. "High activity wastes" are those wastes in which the concentrations of one or more radionuclides exceeds the corresponding limit in Table 2.8. High activity wastes are not the same as high-level waste. This latter term specifically refers to

E.2.2 Modified Near Surface Trench Disposal

Alternative 2 resembles the near surface trench disposal alternative of the preceding section except that all major tritium, carbon-14, and iodine-129 waste streams are removed from the waste. The tritium wastes are stored in engineered storage facilities similar to those described in Chapter 2. The wastes are stored for 120 years or until they decay to acceptable levels and then are placed in trenches at the new low-level waste disposal facility. The carbon-14 and iodine-129 are stored awaiting ultimate disposition.

E.2.3 A Combination of Facilities

In Alternative 3, described in Chapter 2, the intermediate-level waste will be placed in below grade vaults. These vaults are described in that chapter. Tritium, carbon-14, and iodine-129 wastes will be treated as described for Alternative 2 in Section E.2.2. The low-level waste will be disposed of in Above Grade Operations, again described earlier in Chapter 2.

A 455 m x 455 m disposal facility was assumed in the analyses of this alternative. It was assumed that the Above Grade Operations (AGO's) were not placed on top of the below grade vaults because the area required for the AGO's is considerably larger than that needed for the vaults.

E.2.4 Earth Mounded Concrete Bunkers

This is Alternative 5 presented in Chapter 2. In this alternative, volume reduction techniques are used whenever possible. Suspect radioactive wastes are disposed in tumulii, or above grade structures. This corresponds to approximately half of all the waste before processing, by volume. The radioactive wastes are disposed in below grade monoliths.

Treatment will consist of incineration of the two-thirds of the waste that is incinerable, and solidification of the incinerator ash; and compaction of the remaining one-third. In the analyses, the incineration and solidification were assumed to result in a net volume reduction ratio of 10, while compaction was assumed to result in a net volume reduction ratio of 5.

Because of the small volume of the radioactive wastes, a separate 110-meter square area in the facility was assumed to be used for the disposal monoliths. The tumulii containing the non-radioactive wastes were assumed to be placed in other parts of the facility and not over the monoliths.

A leachate collection system beneath the monoliths will be operated for 100 years after facility closure.

APPENDIX E. MODELING THE NEW LOW-LEVEL WASTE DISPOSAL FACILITY

This Appendix describes the location of the new low-level waste disposal facility and the alternative disposal technologies analyzed. It provides key information used in analyses and describes the origins and values of parameters.

E.1 The Disposal Site

The site chosen for modeling the new low-level waste disposal facility is Site G, about 200 acres immediately north of the current burial ground. Site G is described in Sections 1.1.2.2 and 1.2.2 of this document.

E.2 Alternative Disposal Technologies

Of the seven alternatives described in Chapter 2, five actually dispose of the wastes in new facilities, one entails storage, and one is the "no action" case. Performance assessments were made only for those alternatives in which the wastes are disposed of in new facilities. These include alternatives 1, 2, 3, 5, and 6. The alternatives utilize a number of the disposal technologies discussed in Chapter 2.

In this section the physical facilities required by the alternatives are specified. These specifications are a direct result of waste volumes, activities, and classification, e.g. low activity, intermediate level, or high activity. The classification scheme is discussed below in the section on inventories.

E.2.1 Near Surface Trench Disposal

In Alternative 1 the low-level or low activity wastes (LLW) are placed in the engineered low-level trenches described in Chapter 2. Intermediate level wastes (ILW) are placed in the 20 foot by 20 foot smaller trenches described in the same section. Wastes in both types of trenches will be covered with a 5 meter cover. High activity waste will be placed in an appropriate facility at the same disposal site.

In the analysis of this alternative a 455 meter by 455 meter square disposal facility for the low and intermediate level wastes was assumed. This total area is based on waste depth of 5.2 m (B-25 boxes stacked 4 high) for low activity wastes and 5 meters high (16 feet) for the intermediate level waste. The intermediate level waste trenches were assumed to be located along one side of the disposal facility along a 80 m x 455 m strip parallel to the direction of groundwater flow. The high activity waste is disposed in a separate onsite 95 m x 95 m facility.

In sizing the LLW/ILW facility a 50 percent burial efficiency was assumed. That is, the area of the portion of the disposal facility that lies within the boundaries that circumscribe the disposal cells, multiplied by the vertical dimension of the emplaced waste is twice the volume of the containerized waste delivered to the site for disposal.

References for Appendix D

1. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation, **The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980**, 1980.

2. President's Commission on the Accident at Three Mile Island, **Report of the Public Health and Safety Task Force on Radiation Health Effects**, October 1979.

3. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), **Sources and Effects of Ionizing Radiation - 1977**, United Nations, 1977.

4. International Commission on Radiological Protection, **Radiation Protection**, ICRP Publication 26, Pergamon Press, 1977.

5. C. M. King, W. L. Marter, B. B. Looney, and J. B. Pickett, **Methodology and Parameters for Assessing Human Health Effects for Waste Sites at the Savannah River Plant**, DPST-86-298 (Draft), 1986.

Table D-1 Comparison of Radiation Risk Estimators

Organ	Fatal Cancers or Genetic Deaths per Person Rem		
	ICRP-26*	WASH-1400**	1977 UNSCEAR Report***
Bone	5×10^{-6}	-	3×10^{-6}
Red Marrow (Leukemia)	2×10^{-5}	2.8×10^{-5}	2.5×10^{-5}
Lung	2×10^{-5}	2.2×10^{-5}	5×10^{-5}
Liver	1×10^{-5}	-	-
GI-LLI wall	1×10^{-5}	-	1.2×10^{-5}
Thyroid	5×10^{-6}	-	1×10^{-5}
Kidney	1×10^{-5}	-	-
Other soft tissue	5×10^{-5}	2.2×10^{-5}	-
Whole body	1.65×10^{-4}	1.2×10^{-4}	1×10^{-4}
Gonadal tissue Genetic risk	4×10^{-5}	-	-
Breast	2.5×10^{-5}	2.6×10^{-5}	3.0×10^{-5}

* Published by ICRP for radiation protection purposes; considered to represent upper limit of range of possible risks.

** Used to estimate expected fatalities attributable to radionuclides released from reactor accidents.

*** For exposures to a "general population".

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There are three primary sources of numerical estimates for correlating exposure (dose) to "expected" numbers of "extra" fatal cancers and/or genetic deaths in irradiated populations. These are a series of BEIR committee reports of the National Academy of Sciences, the most recent of which was published in 1980;[1] a 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation;[3] and ICRP publication 26.[4] Risk estimators based on these sources are compiled in Table D-1. It should be noted that the estimators given in the table were originally intended for a variety of purposes.

All of the values in Table D-1 are based on the "linear-nonthreshold" dose-response assumption and provide estimates of "absolute risk". Absolute risk expresses the number of fatal cancers expected in an exposed population without regard to the existing or naturally occurring frequency of cancers of each type in the population.

The determination of values for radiation-induced cancer and genetic risks depends both on epidemiological observations and numerous assumptions which are external to the "observed" data set. These assumptions include such factors as the expected duration of risks, the time behavior of those risks, and variations on radiosensitivity by age groups and populations. A major assumption, and the subject of much debate, is the shape and slope of the dose-effects response curve, particularly at low doses where there is little or no epidemiological data and extrapolation from higher dose regions is required.

Risk estimates in this document use a conservative value of 2.8×10^{-4} cancer deaths per person-rem for assessing potential human radiological impacts.[5]

APPENDIX D BIOLOGICAL EFFECTS OF RADIATION AND RISK ESTIMATORS

D.1 Somatic Effects

Somatic effects of radiation refer to any effects that manifest themselves in the individuals exposed to the radiation. A wide range of somatic effects have been observed in humans exposed to ionizing radiation, ranging from subtle changes at the cellular level, to clinically observable effects, to severe effects up to and including death. In the present study, projected doses are low, and somatic effects that tend to manifest themselves in exposed individuals or groups at some time interval or latency period after exposure are of primary interest. Acute effects, which are observed in individuals exposed to doses in the range of 25 rems and above in a short period of time are not of concern.

The principal somatic effect of concern in individuals and groups exposed to low levels of radiation is the induction of cancer, i.e. carcinogenesis. A summary of the major aspects regarding radiation-induced cancer in humans can be found in the 1980 report of the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation.[1]

D.2 Genetic Effects

Genetic effects[2] of radiation, in contrast to the somatic effects, manifest themselves in the descendants of the exposed individuals. Genetic health effects are those resulting from heritable changes in the germ cells or their precursors of one generation but expressed only in the following or subsequent generations. They result from alterations in the genetic material (DNA) or from aberrations of the microscopic structures, called chromosomes, that contain the cell's DNA. It has long been known that ionizing radiation is capable of inducing such changes, but it is important to recognize that radiation is only one among a large number of chemical and physical agents that can do so.

D.3 Risk Estimators

The application of risk estimators which relate numbers of radiation-induced cancers, cancer deaths, genetic deaths (or other effects) to dose is subject to much uncertainty. The situation is particularly difficult for doses which are below a few tens of rems. These doses represent the lower range of doses where increased cancers have been observed in exposed human populations.

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References for Appendix C

1. G. B. Merrell, V. C. Rogers, and M. K. Bollenbacher, **The PATHRAE-RAD Performance Assessment Code for the Land Disposal of Radioactive Wastes**, Rogers and Associates Engineering Corp. Report RAE-8511-28 (1986).

2. D. A. Baker, G. R. Hoenes, and J. K. Soldat, **Proceedings of the Conference on Environmental Modeling and Simulation**, April 19-22, 1976, Cincinnati, OH, EPA 600/9-76-016, published July 1976.

3. U.S. Nuclear Regulatory Commission, **De Minimis Waste Impacts Analysis Methodology**, NUREG/CR-3585, February 1984.

4. U.S. Nuclear Regulatory Commission, **Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR Part 50, Appendix I**, Regulatory Guide 1.109, March 1976, and October 1977.

5. M. W. Grant, et al., **PRESTO-CPG: Users Guide and Documentation for Critical Population Group Modifications to the PRESTO Code**, U.S. Environmental Protection Agency report, (in press).

6. U.S. Department of Energy, **Committed Dose Equivalent Tables for U.S. Department of Energy Population Dose Calculations**, Draft Report, 1985.

7. International Commission of Radiological Protection, **Radiation Protection**, ICRP Publication 26, Pergamon Press, 1977.

Table C-6 Dose Factors for Radionuclides

Nuclide	Ingestion Dose Factor (mrem/pCi)	Direct Gamma Dose Factor (mrem/pCi)
Ag-110m	1.1E-5	7.7E-9
Ba-137m	---	1.7E-9
C-14	2.1E-6	---
Cd-115m	1.5E-5	6.0E-11
Cf-252	4.8E-4	1.3E-12
Co-60	2.6E-5	6.6E-9
Cs-134	7.4E-5	4.4E-9
Cs-137	5.0E-5	---
Eu-154	9.1E-6	3.3E-9
Eu-155	1.3E-6	2.0E-10
H-3	6.3E-8	---
I-129	2.8E-4	4.4E-11
Mn-54	2.7E-6	2.4E-9
Ni-63	5.4E-7	---
Pm-147	9.5E-7	1.0E-14
Rb-87	4.8E-6	---
Rh-106	---	6.0E-10
Ru-106	2.1E-5	---
Sb-125	2.6E-6	1.2E-9
Se-75	8.8E-6	1.2E-9
Se-79	8.3E-6	---
Sm-151	3.4E-7	1.4E-14
Tc-99	1.3E-6	1.6E-15
Te-125m	3.4E-6	4.2E-11
Sr-90	1.3E-4	---
Y-90	1.0E-5	---
Ce-144	2.0E-5	5.5E-11
Pr-144	1.1E-7	8.2E-11
Th-232	2.8E-3	1.5E-12
U-234	2.6E-4	1.8E-12
U-235	2.5E-4	4.5E-10
U-236	2.5E-4	1.6E-12
U-238	2.3E-4	1.4E-12
Np-237	3.9E-4	7.7E-11
Pu-238	3.8E-4	1.9E-12
Pu-239	4.3E-4	8.8E-13
Pu-241	8.6E-6	---
Pu-242	4.1E-4	1.5E-12
Am-241	2.2E-3	7.1E-11
Am-243	2.2E-3	1.6E-10
Cm-244	1.1E-3	1.8E-12

Table C-5 Foodchain Parameters

Watershed Infiltration	0.43 m/yr
Grass Production	0.67 kg/m^2yr
Vegetation Production	0.65 kg/m^2yr
Surface Density for Soil	240 kg/m^2
Weathering Decay Constant	0.0021 hr^{-1}
Period Pasture Exposed During Growing Season	720 hr
Period Crops Exposed During Growing Season	1440 hr
Period Between Harvest Pasture and Ingestion	0.0 hr
Period Between Stored Feed and Ingestion by Animal	2160 hr
Period Between Harvest Leafy Vegetation and Ingestion by Man	24 hr
Period Between Harvest Produce and Ingestion by Man	1440 hr
Period Between Harvest Leafy Vegetables and Ingestion by Man	336 hr
Fraction of Year Animals Graze on Pasture	1.0
Fraction of Daily Feed that is Fresh Grass While Animals are on Pasture	0.83
Amount of Feed Consumed Daily by Cattle	50 kg
Transport Time Feed-Mill-Receptor for Population Exposure	96 hr
Time From Slaughter of Meat to Consumption	480 hr
Fraction of Year Crops are Irrigated	0.40
Irrigation Rate	0.015 l/m^2hr
Amount of Water Consumed by Cows	60 l/d
Amount of Water Consumed by Beef Cattle	50 l/d
Fraction of land irrigation using contaminated water	0.0
Fraction of livestock drinking water that is contaminated	0.5
Fraction of human drinking water that is contaminated	1.0
Human consumption of leafy vegetables	18 kg/yr
Human consumption of produce	176 kg/yr
Human consumption of cow's milk	112 ℓ/yr
Human consumption of beef	85 kg/yr
Human consumption of drinking water	370 ℓ/yr

C.4 Foodchain Parameters

Parameters representative of the Southeast were taken from reference 5. These parameters are given in Table C-5.

C.5 Dose Factors

Ingestion and direct gamma dose factors for radionuclides were taken from References 6 and 4 respectively. They are listed in Table C-6. Wherever more than one dose factor was listed in the reference, the largest one was used. The dose represented by these dose factors is the 50-year whole body committed dose equivalent as defined in ICRP-26 (Reference 7). This dose represents the weighted sum of the committed dose equivalent to individual tissues resulting from a unit intake. The tissue-specific weighting factors are based on cancer and genetic effects. Health effects from these doses can be calculated using various dose to health effect factors, such as those provided in Appendix D.

The direct gamma dose factors assume uniform distribution of the radioactivity over a 16,000 square meter area with no shielding.

Table C-4 Water-to-Seafood Transfer Factors (1/kg)

Element	Freshwater Fish (f_{12}) Ref 1	Ref 2	Ref 15	Freshwater Seafood ($f_{12}P$) Ref 1	Ref 2
Hydrogen	9.0E-1[a]	9.0E-1		9.0E-1	9.0E-1
Carbon	4.6E+3	4.6E+3		9.1E+3	9.1E+3
Sodium	1.0E+2	1.0E+2		2.0E+2	2.0E+2
Phosphorus	1.0E+5	1.0E+5		2.0E+4	2.0E+4
Sulphur	7.5E+2			1.0E+2	
Chlorine	5.0E+1			1.0E+2	
Calcium	4.0E+1			3.3E+2	
Scandium	2.0E+0			1.0E+3	
Chromium	2.0E+2	2.0E+2		2.0E+3	2.0E+3
Manganese	4.0E+2	4.0E+2		9.0E+4	9.0E+4
Iron	1.0E+2	1.0E+2		3.2E+3	3.2E+3
Cobalt	5.0E+1	5.0E+1		2.0E+2	2.0E+2
Nickel	1.0E+2	1.0E+2		1.0E+2	1.0E+2
Zinc	2.0E+3	2.0E+3		1.0E+4	1.0E+4
Selenium	1.7E+2			1.7E+2	
Rubidium	2.0E+3	3.0E+3		1.0E+3	1.0E+3
Strontium	3.0E+1	3.0E+1		1.0E+2	1.0E+2
Zirconium	3.3E+0	3.3E+0		6.7E+0	6.7E+0
Niobium	3.0E+4	3.0E+4		1.0E+2	1.0E+2
Molybdenum	1.0E+1	1.0E+1		1.0E+1	1.0E+1
Technetium	1.5E+1	1.5E+1		5.0E+0	5.0E+0
Ruthenium	1.0E+1	1.0E+1		3.0E+2	3.0E+2
Silver	2.3E+0			7.7E+2	
Cadmium	2.0E+2			2.0E+3	
Tin	3.0E+3			1.0E+3	
Antimony	1.0E+0			1.0E+1	
Iodine	1.5E+1	1.5E+1		5.0E+0	5.0E+0
Cesium	2.0E+3	2.0E+3		1.0E+2	1.0E+3
Barium	4.0E+0	4.0E+0		2.0E+2	2.0E+2
Lanthanum	2.5E+1	2.5E+1		1.0E+3	1.0E+3
Cerium	1.0E+0	1.0E+0		1.0E+3	1.0E+3
Europium	2.5E+1			1.0E+3	
Ytterbium	2.5E+1			1.0E+3	
Lead	1.0E+2			1.0E+2	
Polonium	5.0E+2			2.0E+4	
Radon	1.0E+0			1.0E+0	
Radium	5.0E+1			2.5E+2	
Actinium	2.5E+1			1.0E+3	
Thorium	3.0E+1			5.0E+2	
Protactinium	1.1E+1			1.1E+2	
Uranium	2.0E+0			6.0E+1	
Neptunium	1.0E+1	1.0E+1		4.0E+2	4.0E+2
Plutonium	3.5E+0		2.5E+1	1.0E+2	
Americium	2.5E+1		2.5E+2	1.0E+3	
Curium	2.5E+1			1.0E+3	
Californium	2.5E+1			1.0E+3	

(a) Values selected for use in this report have been underlined.

Table C-3 Feed- and Water-to-Milk Transfer Factors (day/L)

Element	Ref 1	Ref 2	Ref 12	Ref 13	Ref 19	Ref 19
Hydrogen	1.0E-2[a]	1.0E-2			1.4E-2	1.4E-2
Carbon	1.2E-2	1.2E-2			1.5E-2	1.5E-2
Sodium	4.0E-2	4.0E-2			3.5E-2	3.5E-2
Phosphorus	2.5E-2	2.5E-2			1.6E-2	1.6E-2
Sulphur	1.8E-2				1.6E-2	1.6E-2
Chlorine	5.0E-2				1.7E-2	1.7E-2
Calcium	8.0E-3				1.1E-2	1.1E-2
Scandium	5.0E-6					5.0E-6
Chromium	2.2E-3	2.2E-3			1.6E-3	1.0E-3
Manganese	2.5E-4	2.5E-4			3.3E-4	8.4E-5
Iron	1.2E-3	1.3E-3			2.7E-4	5.9E-5
Cobalt	1.0E-3	1.0E-3			1.8E-3	2.0E-3
Nickel	6.7E-3	6.7E-3			1.0E-3	1.0E-3
Zinc	3.9E-2	3.9E-2			1.0E-2	1.0E-2
Selenium	4.5E-2				4.0E-3	4.0E-3
Rubidium	3.0E-2	3.0E-2			1.2E-2	1.2E-2
Strontium	8.0E-4	8.0E-4		2.4E-3	1.4E-3	1.4E-3
Zirconium	5.0E-6	5.0E-6			3.0E-5	2.0E-2
Niobium	2.5E-3	2.5E-3				2.0E-2
Molybdenum	7.5E-3	7.5E-3			1.4E-3	1.4E-3
Technetium	2.5E-2	2.5E-2		9.9E-3		9.9E-3
Ruthenium	1.0E-6	1.0E-6			6.1E-7	6.1E-7
Silver	5.0E-2	5.0E-2			1.9E-2	1.0E-2
Cadmium	1.2E-4				1.0E-3	2.0E-3
Tin	2.5E-3				1.2E-3	1.2E-3
Antimony	1.5E-3				1.1E-4	2.0E-5
Iodine	6.0E-3	6.0E-3		1.0E-2	9.9E-3	9.9E-3
Cesium	1.2E-2	1.2E-2		5.6E-3	7.1E-3	7.1E-3
Barium	4.0E-4	4.0E-4			3.5E-4	3.5E-4
Lanthanum	5.0E-6	5.0E-6				2.0E-5
Cerium	6.0E-4	1.0E-4			2.0E-5	2.0E-5
Europium	5.0E-6					2.0E-5
Ytterbium	5.0E-6					2.0E-5
Lead	6.2E-4		1.2E-4	9.9E-5	2.6E-4	2.6E-4
Polonium	3.0E-4			1.2E-4	3.4E-4	1.4E-4
Radon	2.0E-2					2.0E-2
Radium	8.0E-3		5.9E-4	5.9E-4	4.5E-4	4.5E-4
Actinium	5.0E-6			2.0E-5		2.0E-5
Thorium	5.0E-6		5.0E-6	5.0E-6		5.0E-6
Protactinium	5.0E-6			5.0E-6		5.0E-6
Uranium	5.0E-4		6.1E-4	1.2E-4	6.1E-4	6.1E-4
Neptunium	5.0E-6	5.0E-6				5.0E-6
Plutonium	2.0E-6			4.5E-8	1.0E-7	1.0E-7
Americium	5.0E-6				4.1E-7	2.0E-5
Curium	5.0E-6					2.0E-5
Californium	5.0E-6					2.0E-5

(a) Values selected for use in this report have been underlined.

Table C-2 Feed- and Water-to-Meat Transfer Factors (day/kg)

Element	Ref 1	Ref 2	Ref 12	Ref 13	Ref 17	Ref 15
Hydrogen	1.2E-2[a]	1.2E-2				
Carbon	3.1E-2	3.1E-2				
Sodium	3.0E-2	3.0E-2			8.3E-2	
Phosphorus	4.6E-2	4.6E-2			5.7E-2	
Sulphur	1.0E-1					
Chlorine	8.0E-2					
Calcium	4.0E-3				7.2E-4	
Scandium	1.6E-2					
Chromium	2.4E-3	2.4E-3			9.2E-3	
Manganese	8.0E-4	8.0E-4			3.9E-4	
Iron	4.0E-2	4.0E-2			1.9E-2	
Cobalt	1.3E-2	1.3E-2			9.7E-3	
Nickel	5.3E-3	5.3E-3			2.0E-3	
Zinc	3.0E-2	3.0E-2			1.2E-1	
Selenium	1.5E-2					
Rubidium	3.1E-2	3.1E-2			1.1E-2	
Strontium	6.0E-4	6.0E-4		3.0E-4	5.9E-4	
Zirconium	3.4E-2	3.4E-2			2.1E-2	
Niobium	2.8E-1	2.8E-1			2.5E-1	
Molybdenum	8.0E-3	8.0E-3			6.8E-3	
Technetium	4.0E-1	4.0E-1		8.7E-3		
Ruthenium	4.0E-1	4.0E-1				
Silver	1.7E-2	1.7E-2			1.9E-3	
Cadmium	5.3E-4					
Tin	8.0E-2					
Antimony	4.0E-3					
Iodine	2.9E-3	2.9E-3		7.0E-3		
Cesium	4.0E-3	4.0E-3		1.4E-2		
Barium	3.2E-3	3.2E-3			9.7E-5	
Lanthanum	2.0E-4	2.0E-4				
Cerium	1.2E-3	1.2E-3				
Europium	4.8E-3					
Ytterbium	4.0E-3					
Lead	2.9E-4		7.1E-4	9.1E-4		
Polonium	1.2E-2			4.0E-3		
Radon	2.0E-2					
Radium	3.4E-2		5.1E-4	5.0E-4		
Actinium	6.0E-2			1.6E-6		
Thorium	2.0E-4		2.0E-4	1.6E-6		
Protactinium	8.0E-2			1.6E-6		
Uranium	2.4E-4		3.4E-4	1.6E-6		
Neptunium	2.0E-4	2.0E-4				
Plutonium	1.4E-5			4.1E-7		3.9E-4
Americium	2.0E-4					3.9E-3
Curium	2.0E-4					
Californium	2.0E-4					

(a) Values selected for use in this report have been underlined.

Table C-1 Soil-to-Plant Transfer Factors (dimensionless)

Element	Ref 1	Ref 2	Ref 12	Ref 13	Ref 14	Ref 15
Hydrogen	4.8E+0(a)	4.8E+0				
Carbon	5.5E+0(b)	5.5E+0				
Sodium	5.2E-2	5.2E-2			4.6E-3	
Phosperous	1.1E+0	1.1E+0				
Sulphur	5.9E-1					
Chlorine	5.0E+0					
Calcium	3.6E-2					
Scandium	1.1E-3					
Chromium	2.5E-4	2.5E-4			1.3E-2	
Manganese	2.9E-2	2.9E-2			1.2E-1	
Iron	6.6E-4	6.6E-4			4.2E-4	
Cobalt	9.4E-3	9.4E-3			1.5E-2	
Nickel	1.9E-2	1.9E-2			2.1E-2	
Zinc	4.0E-1	4.0E-1			1.1E-1	
Selenium	1.3E+0					
Rubidium	1.3E-1	1.3E-1				
Strontium	1.7E-2	1.7E-2		2.9E-1	7.5E-2	
Zirconium	1.7E-4	1.7E-4			7.7E-4	
Niobium	9.4E-3	9.4E-3				
Molybdenum	1.2E-1	1.2E-1				
Technetium	2.5E-1	2.5E-1		1.1E+0		
Ruthenium	5.0E-1	5.0E-2			1.4E-3	
Silver	1.5E-1	1.5E-1				
Cadmium	3.0E-1					
Tin	2.5E-3					
Antimony	1.1E-2					
Iodine	2.0E-2	2.0E-2		5.5E-2	4.5E-3	
Cesium	1.0E-2	1.0E-2		9.3E-3	5.0E-3	
Barium	5.0E-3	5.0E-3			1.3E-3	
Lanthanum	2.5E-3	2.5E-3				
Cerium	2.5E-3	2.5E-3			7.3E-4	
Europium	2.5E-3					
Ytterbium	2.5E-3					
Lead	6.8E-2		4.0E-3	3.9E-3		
Polonium	1.5E-1			2.6E-4		
Radon	3.5E+0					
Radium	3.1E-4		1.4E-3	6.2E-2		
Actinium	2.5E-3			2.5E-3		
Thorium	4.2E-3		4.2E-3	3.5E-4		
Protactinium	2.5E-3			2.5E-3		
Uranium	2.5E-3		2.5E-3	2.9E-4		
Neptunium	2.5E-3	2.5E-3			6.0E-2	
Plutonium	2.5E-4			2.0E-4		5.6E-4
Americium	2.5E-4					5.6E-3
Curium	2.5E-3					
Californium	2.5E-3					

(a) Values selected for use in this report have been underlined.
(b) For carbon-14, Reference 16 suggests that a transfer factor equal to 5.5E-1 may be more appropriate.

Q_f = animal's daily intake of forage (kg/d)

Q_w = cow's daily intake of water (ℓ/d)

C_F = concentration of tritium in animal's flesh (pCi/kg)

F_f = fraction of the animal's daily intake of H-3 that appears in each kg of flesh (d/kg)

The exponential term is neglected due to the relatively long half life of tritium in comparison with timescale of the foodchain.

The root uptake of carbon-14 from irrigation water is considered negligible and therefore has been set equal to zero. The rest of the calculations are the same.

C.2 Calculation of Food Uptake Factors via Contaminated Soil Excavation

The food uptake factor is the uptake resulting from the consumption of vegetation, beef and milk but the implicit unit concentration is the concentration on soil - not water. Thus:

$$U_3 = Q_{ing} = Q_{veg} + Q_{beef} + Q_{milk} \qquad \text{(C-15)}$$

with the concentration in vegetation given by

$$\overline{C}_v = B \exp(-\lambda t_h)\ (1) \qquad \text{(C-16)}$$

(1) = unit concentration in soil (1 pCi/kg or 1 mg/kg).

C.3 Plant and Animal Bioacummulation Factors

Soil to plant transfer factors, B, representing steady-state ratios of concentrations of contaminants in plants to concentrations in the soil were taken from the underlined values in Table D-11 of Reference 3. Feed and water to meat, milk, and seafood transfer factors, relating concentrations of contaminants on food to daily uptakes of these contaminants by the organism eaten were taken from the same source (Tables D-12 through D-14). Where values were not available in Reference 3 for radionuclides, they were taken from Reference 4. These tables are reproduced here as Tables C-1, 2, 3, and 4.

$$Q_v = C_p U_p + C_v U_v$$

$$Q_{milk} = C_m U_m$$

$$Q_{beef} = C_f U_{beef} \qquad \text{(C-9)}$$

$$Q_w = U_{water}$$

where

U_p = annual consumption of produce by an individual (kg/yr)

U_v = annual consumption of leafy vegetables by an individual (kg/yr)

U_{beef} = annual consumption beef by an individual (kg/yr)

U_{water} = annual consumption of water by an individual (l/yr)

C.1.3 Concentrations of Tritium and Carbon-14 in Vegetables and Animal Products via the Use of Contaminated Water

The equations given above do not apply directly to calculations of concentrations of H-3 or C-14 in foodstuffs. For application of tritium in irrigation water, it has been assumed that the concentration in all vegetation C_v is the same as the tritium concentration in drinking water. Therefore:

$$C_v = C_w \qquad \text{(C-12)}$$

where C_v and C_w are in pCi/kg and pCi/l, respectively. The concentration of H-3 in animal's feed, C_f, is also equal to C_w. It follows that the concentration of tritium in milk and beef can be written as:

$$C_m = F_m C_w (Q_f + Q_w) \qquad \text{(C-13)}$$

$$C_f = F_f C_w (Q_f + Q_w) \qquad \text{(C-14)}$$

where

C_m = concentration of tritium in milk (pCi/ℓ)

F_m = fraction of the animal's daily intake of H-3 that appears in each liter of milk (days/ℓ)

C_w = H-3 concentration in animal's drinking water (pCi/ℓ)

where

C_m = the concentration in milk (pCi/ℓ or mg/ℓ)

C_f = the concentration in the animal's feed (pCi/kg or mg/ℓ)

F_m = the average fraction of the animal's daily intake of a given radionuclide which appears in each liter of milk (d/ℓ)

Q_f = the amount of feed consumed by the animal per day (wet kg/d)

t_f = the average transport time of the activity from the feed into the milk and to the receptor (hr)

λ = radiological decay constant (hr^{-1})

Q_w = the amount of water consumed by the animal (ℓ/d)

The contaminant concentration in beef depends, as with milk, on the amount of feed consumed and its level of contamination:

$$C_F = F_f(C_f Q_f + C_w Q_w) \exp(-\lambda t_s) \qquad \text{(C-9)}$$

where

C_F = the concentration in the beef (pCi/kg or mg/kg)

F_f = the fractions of the animal's daily intake of a given contaminant which appears in each kilogram of flesh (d/kg)

C_f = the concentration of radionuclide in the animal's feed (pCi/kg or mg/kg)

Q_f = the amount of feed consumed by the animal per day (kg/d)

t_s = the average time from slaughter to consumption (hr)

Once concentrations in all the various foodstuffs are calculated, the annual ingestion rate for each contaminant is given by the sum:

$$Q_{ing} = Q_v + Q_{milk} + Q_{beef} + Q_w \qquad \text{(C-10)}$$

where the variables on the right-hand side are uptakes for vegetation, milk, beef, and water. These are calculated using annual rates of consumption by humans:

The rate constant for contaminant removal from the soil, λ_s, is estimated using:

$$\lambda_s = \frac{r_s}{(0.15)(8760)R} \qquad \text{(C-6)}$$

where

λ_s = removal rate coefficient (yr^{-1})

r_s = watershed infiltration (m/yr)

0.15 = depth of contaminated soil layer (m)

R = contaminant retardation factior (unitless)

The term in brackets in equation C-5 represents an averaging over t' where depletion is attributed to radioactive decay and leaching.

Equation C-4 is used to estimate contaminant concentrations in produce and leafy vegetables consumed by humans and in forage (pasture grass or stored feed) consumed by dairy cows and beef cattle.

The concentration of each contaminant in animal forage is calculated as:

$$C_f = f_p f_s C_p + (1 - f_p f_s) C_s \qquad \text{(C-7)}$$

where

C_f = the concentration in the animal's feed (pCi/kg or mg/kg)

C_p = the concentration on pasture grass (pCi/kg or mg/kg)

C_s = the concentration in stored feeds pCi/kg or mg/kg)

f_p = the fraction of the year that animals graze on pasture (unitless)

f_s = the fraction of daily feed that is pasture grass when the animals graze on pasture (unitless)

In milk concentration of each species is estimated as:

$$C_m = F_m(C_f Q_f + C_w Q_w) \exp(-\lambda t_f) \qquad \text{(C-8)}$$

where

$\overline{C}$ = measures in pCi/kg or mg/kg

F_r = the fraction of deposited activity or mass retained on crops (unitless)

λ_e = the removal rate constant for physical loss by weathering

t_w = the time period for irrigation (hr)

Y_v = The agricultural productivity (yield) kg(wet weight)/m 2

B = the contaminant concentration factor for uptake from soil by edible parts of crops [pCi/kg (wet weight) per pCi/kg dry soil or mg/kg per mg/kg]

C_{soil} = the steady state value of soil contaminant concentration (pCi/m2 or mg/m2)

P = the effective "surface density" for soil [kg(dry soil)/m2]

t_h = the time interval between harvest and consumption of the food (hr)

λ = radiological decay constant.

The translocation factor, d, is 1.0 for pasture grass and leafy vegetables, and 0.1 for stored feed and produce.[2]

The steady-state soil concentration is given by

$$C_{soil} = \frac{8760\ I_r}{t'\lambda_s} \left[\frac{1-e^{-\lambda t'}}{\lambda} - \frac{1-e^{-(\lambda+\lambda_s)t'}}{\lambda + \lambda_s} \right] \qquad \text{(C-5)}$$

where

$t' = \min \frac{1}{\lambda_L}, (t_{max} - t_o)$

t_{max} = maximum time at which doses are a concern

t_o = time of arrival of contaminant in river or well

λ_L = leach constant (yr^{-1})

8760 - number of hours in a year

Q_{milk} = annual contaminant uptake from milk (pCi/yr or mg/yr)

Q_{beef} = annual contaminant uptake from meat (pCi/yr or mg/yr)

Q_w = annual contaminant uptake from drinking water (pCi/yr or mg/yr)

The determination of the Q's is briefly described in the following paragraphs.

C.1.2 Concentration of Contaminants in Vegetables and Animal Products via the Use of Contaminated Water

The deposition rate onto food surfaces or soil that is used in subsequent calculation of contaminant content on the food chain comes from spray irrigation and is:

$$I_r = C_w \cdot W_I \qquad \text{(C-3)}$$

where

I_r = contaminant application rate (pCi/m^2 • h or mg/m^2•h)

C_w = contaminant concentration in irrigation water (pCi/ℓ or mg/ℓ)

W_I = irrigation rate (ℓ/m^2 • h)

The concentration of the contaminant in water, C_W, is the appropriate well or river water concentration.

The following equation estimates the steady-state concentration C_V of a given nuclide in and on vegetation at the deposited location (except for tritium and carbon)

$$\bar{C}_v = \frac{I_r d\ F_r[1-\exp(\lambda_e t_w)]}{Y_v \lambda_e} + \frac{B \cdot C_{soil}}{P} \exp(-\lambda t_h) \qquad \text{(C-4)}$$

APPENDIX C. PATHWAY UPTAKE FACTORS AND DOSE CONVERSION FACTORS

C.1 Calculation of Equivalent Uptake Factors for Water Usage

Equivalent uptake factors used in PATHRAE[1] groundwater and food pathways analyses allow the consolidation of all ingestion intakes arising from the direct and indirect consumption of contaminated water into a single parameter for each contaminant. The intakes can include: (1) drinking the contaminated water, (2) eating contaminated vegetation, (3) drinking contaminated milk, and (4) eating contaminated beef. Equivalent uptake factors are dependent on a large number of foodchain parameters, and as such are sensitive to changes in the underlying "scenario".

C.1.1 Basic Definition

The equivalent uptake factor, U, for a contaminant may be defined via the following relation:

$$Q_{ing} = UC \qquad \text{(C-1)}$$

where

Q_{ing} = total amount of contaminant ingested via all direct and indirect water usage in one year (pCi or mg).

C = concentration of contaminant in the water (Ci/m^3 or kg/m^3).

(Note: In addition to incorporating the mechanisms of contaminant uptake, U may also contain various unit conversion factors). The equivalent uptake factor, U, is equal to Q_{ing} when the concentration of the contaminant at the access location is unity:

$$Q_{ing} = U \text{ for } C = 1. \qquad \text{(C-2)}$$

Indeed, this is how the U's are determined.

Q_{ing} may be broken down into a number of components:

$$Q_{ing} = Q_v + Q_{milk} + Q_{beef} + Q_w$$

where

Q_v = annual contaminant uptake from vegetation (pCi/yr or mg/yr).

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References for Appendix B

1. G. B. Merrell, V. C. Rogers, and M. K. Bollenbacher, **The PATHRAE-RAD Performance Assessment Code for the Land Disposal of Radioactive Wastes**, Rogers and Associates Engineering Corp. Report RAE-8511-28 (1986).

2. H. C. Burkholder and E. L. J. Rosinger, "A Model for the Transport of Radionuclides and Their Decay Products Through Geologic Media", **Nuclear Technology**, Vol. 49, p. 150 (1980).

3. International Commission on Radiological Protection, **A Compilation of the Major Concepts and Quantities in Use by the ICRP**, ICRP Publication 42, Pergamon Press, New York, 1984.

4. K. Z. Morgan and J. E. Turner (eds.), **Principles of Radiation Protection**, John Wiley & Sons, Inc., p. 270 (1967).

B.3 Direct Gamma

The dose from direct gamma exposure to an intruder is calculated using:

$$D = \frac{Q}{A\mu_w t_w} B(\mu_c t_c) \exp(-\mu_c t_c) \cdot \left[1 + \frac{3\pi}{4E_\gamma} - B(\mu_w t_w) \exp(-\mu_w t_w)\right] f_{exp} \, (8760)(DFG) \qquad \text{(B-6)}$$

where

$B(\mu t) = 1 + (\mu t)^{1.5}/E$

μ_w = gamma attenuation constant of the waste (1/m)

μ_c = gamma attenuation constant of the cover (1/m)

t_w = thickness of the waste (m)

t_c = thickness of the cover (m)

f_{exp} = fraction of the year the individual is exposed

A = plane area of the waste, the waste is assumed to be a circular horizontal plane with the exposed individual standing at the center (m2)

E = weighted average gamma energy emitted by radionuclide (MeV)

DFG = infinite ground plane dose conversion factor (mrem/hr per pCi/m^2)

The function, B, in equation B-6 is the gamma buildup factor which is used to account for the effects of gamma ray scattering in the waste and in the cover. It is an empirical relation based on gamma scattering data at energies from 0.25 MeV to 1.0 MeV.[4]

The components $B(\mu_c t_c)$ and $\exp(-\mu_c t_c)$ account for buildup effects in the cover and attenuation by the cover, respectively. The term in brackets is empirical and accounts for self-shielding and buildup in the waste itself.

The weighted average gamma energy, E, is radionuclide dependent. It is computed as the weighted average of all gamma energies, E_i, emitted by the radionuclide of interest. The weighting factors are the probabilities of occurrence - i.e., the probabilities of gamma emission, P_i. Thus

$$E_\gamma = \sum_i P_i E_i / \sum_i P_i . \qquad \text{(B-7)}$$

In this scenario it is assumed that at some future time a reclaimer moves onto the site and builds a house. By excavating a basement for the house and by drilling a well on the property, some of the waste material may be brought to the surface and mixed with the surface soil. Under these assumptions, the factor f_m representing the dilution of waste in the surface soil is given by:

$$f_m = \frac{t_m - t_c}{t_g\left(\frac{A_\ell}{A_h} - 1\right)} + \frac{t_w}{t_g\left(\frac{A_\ell}{A_h'} - 1\right)}$$

where

t_w = thickness of the waste (m)

t_c = thickness of cover (m)

t_m = depth of maximum mechanical disturbance (m)

t_g = depth to which contaminants are mixed with surface soil (m)

A_ℓ = lot area (m^2)

A_h = house area (m^2)

A_h' = cross sectional area of wells drilled (m^2)

The first term is considers the excavation of a basement. The second term is the well drilling component. Because a five meter cover is installed at closure the first term is set equal to zero, i.e., excavation for a basement does not bring contamination to the surface.

Nonradioactive contaminant uptakes are determined by deleting the dose factor, DF, from equation B-5.

B.1.3 Surface Water Pathway

Because the annual flow rate of surface waters is so great compared to the volume of contaminated water discharged from the aquifer to those waters, the dilution volume can be set numerically equal to those surface water flow rates. Dose calculations involving human use of surface waters differ from the well case only in that the former include seafood in the uptake factors.

B.1.4 Wetlands

Wetlands waters are those marshy areas where the groundwater discharges to a surface water such as Upper Three Runs Creek. In order to evaluate impacts on this wildlife habitat estimates of contaminant concentrations on these waters must be made. The choice of an appropriate dilution volume for equation B-1 is not obvious. Concentrations are expected to lie between estimated stream concentrations and aquifer 'centerline' concentrations. Based on basin and Site G hydrology and facility dimensions the wetlands concentrations are estimated to be approximately a thousand times greater than estimated concentrations in Upper Three Runs Creek.

B.2 Food Grown on Site by an Intruder

The equation for the dose resulting from the consumption of food grown in an intruder garden over the disposal site is:

$$D = \frac{Q f_d f_g f_L f_m U_3 (DF)_{ing}}{V \rho_s} \qquad \text{(B-5)}$$

where

V = volume of waste (m3)

ρ_s = soil density (kg/m3)

f_d = dilution factor representing the dilution of waste in the facility before excavation occurs

f_g = fraction of individual's diet consisting of food grown over the disposal site

f_L = fraction of inventory remaining after leaching

f_m = dilution factor representing the dilution of waste in the surface soil

U_3 = total equivalent uptake factor for food (kg/yr)

where U is the pathway and radionuclide dependent equivalent uptake factor (1/yr) and $(DF)_{ing}$ is the radionuclide ingestion dose factor (mrem/pCi). Both of these quantities are considered in greater detail in Appendix C. By omitting $(DF)_{ing}$ in equation B-2 the uptake of a nonradioactive species may be calculated.

B.1.2 Well Pathway

The concentration of a contaminant in well water is calculated using Equation B-1. The dilution factor, q_w, is given by

$$q_w = \begin{cases} WL_p v_a p \text{ for } H_w < L_p \\ WLP \text{ for } H_w \geq L_p \end{cases} \qquad \text{(B-3)}$$

where

W = width of waste pit perpendicular to aquifer flow (m)

P = infiltration rate (m3/m2-yr)

L_p = length of perforated well casing in aquifer (m)

p = effective porosity of the aquifer

Equation B-3 states that the dilution volume depends on the vertical extent of the contaminated zone, H_w. This quantity is in turn related to other site and facility parameters:

$$H_w = \frac{P\ L}{p\ v_a}. \qquad \text{(B-4)}$$

Basically, a well that intercepts the contaminated zone of the aquifer is assumed to draw in uncontaminated water if the length of the perforated well casing, L_p, exceeds H_w. The dilution volume is then determined by the aquifer flow past the well ($v_a p$), L_p, and the extent of the facility transverse to the direction of flow (W). If H_w is equal to or greater than L_p the contaminated plume completely envelops the perforated region and the dilution volume is given by the infiltration into the facility, WLP.