3.3.1.2 Stratigraphy

Coastal Plain sediments in South Carolina range in age from Cretaceous to Quaternary; they form a seaward-dipping and thickening wedge of interstratified beds of mostly unconsolidated sediments. At the L-Reactor site, these sediments are approximately 400 meters thick (Siple, 1967). The base of the sedimentary wedge rests on a Precambrian and Paleozoic crystalline basement, which is similar to the metamorphic and igneous rocks of the Piedmont, and on the siltstone and claystone conglomerates of the down-faulted Dunbarton Triassic Basin. Immediately overlying the basement is the Tuscaloosa Formation of Upper Cretaceous age, which is about 230 meters thick and composed of prolific water-bearing sands and gravels separated by prominent clay units. Overlying the Tuscaloosa is the Ellenton Formation, which is about 18 meters thick and consists of sands and clays interbedded with coarse sands and gravel. Four of the formations shown in Figure 3-5--the Congaree, McBean, Barnwell, and Hawthorn--comprise the Tertiary (Eocene and Miocene) sedimentary section, which is about 85 meters thick and consists predominantly of clays, sands, clayey sands, and sandy marls. The near-surface sands of the Barnwell and Hawthorn Formations are usually in a loose to medium-dense state; they often contain thin sediment-filled fissures (clastic dikes) (Du Pont, 1980a).

Quaternary alluvium has been mapped at the surface in floodplain areas. Soil horizons at the site are generally uniform and relatively shallow, about 1 meter deep. They are characterized by bleached Barnwell-Hawthorn sediments, which result in a light tan sandy loam.

Section 3.4.2 and Appendix F present additional stratigraphic information.

3.3.2 <u>Seismology</u>

3.3.2.1 Geologic structures

The Dunbarton Triassic Basin, which is similar to grabens in the Basin and Range Province in Nevada, underlies the Savannah River Plant at the L-Reactor site (Siple, 1967). Other Triassic-Jurassic basins have been identified in the Coastal Plain tectonic province within 300 kilometers of the site (Du Pont, 1980a; Popenoe and Zietz, 1977). The Piedmont, Blue Ridge, and Valley and Ridge tectonic provinces, which are associated with Appalachian mountain building, are northwest of the Fall Line. Several fault systems occur in and adjacent to the Piedmont and the Valley and Ridge tectonic provinces of the Appalachian system; the closest of these is the Belair Fault Zone, about 40 kilometers from the site. The U.S. Nuclear Regulatory Commission has determined that the Belair Fault is not capable within the meaning of 10 CFR 100 (Case, 1977). Studies sponsored by Georgia Power Company have shown that the faults postulated to occur near the southeastern boundary of the Savannah River Plant and about 40 kilometers southeast (Faye and Prowell, 1982) are not capable and that they might not exist (Georgia Power Company, 1982). There is no evidence of any recent displacement along any faults within 300 kilometers of the L-Reactor site (Du Pont, 1980a). In addition, no apparent association exists between local seismicity and specific faults near the Savannah River Plant, with the possible exception of the geophysically inferred faults (Lyttle et al., 1979; Behrendt et al., 1981; Talwani, 1982) in the meizoseismal area of the 1886 Charleston earthquake, which occurred approximately 145 kilometers from the Plant (Du Pont, 1982b).

Surface mapping and subsurface investigations in the L-Reactor region did not detect any faulting of the sedimentary strata or any other geologic hazards that would pose a threat to the reactor. Several surficial faults, generally less than 300 meters in length and with displacements of less than 1 meter, were mapped within several kilometers of the L-Reactor site. None of these faults is considered capable (Du Pont, 1980a).

3.3.2.2 Seismicity

Two major earthquakes have occurred within 300 kilometers of the L-Reactor site: the Charleston earthquake of 1886, which had an epicentral Modified Mercalli Intensity (MMI) of X, was located about 145 kilometers away; and the Union County, South Carolina, earthquake of 1913, which had an epicentral shaking of MMI VII to VIII, was located approximately 160 kilometers away (Langley and Marter, 1973). An estimated peak horizontal shaking of 7 percent of gravity (0.07g) was calculated for the site during the 1886 Charleston earthquake (DOE, 1982a). No reservoir-induced seismicity is associated with Par Pond (see Figure 3-2) (Du Pont, 1982b).

Probabilistic and deterministic analyses commensurate with the criteria used by NRC (10 CFR 100) have established a design-basis earthquake acceleration of 0.20g for key seismic-resistant buildings at Savannah River Plant. This acceleration is predicted to be exceeded only once in about 5000 years (Du Pont, 1982b). (See Section 4.2.2.3.)

3.4 HYDROLOGY

3.4.1 Surface-water hydrology

3.4.1.1 Savannah River

The Savannah River Plant (SRP) is drained almost entirely by the Savannah River, one of the major drainage networks in the southeastern United States (Langley and Marter, 1973). The peak historic flood between 1796 and 1983--10,190 cubic meters per second--corresponds to a stage of about 36 meters (DOE, 1982a), which is about 40 meters below the elevation of L-Reactor. A domino-type failure of dams on the Savannah River above Savannah River Plant would produce a flow of 42,500 cubic meters per second with a corresponding stage of 43.6 meters at Savannah River Plant (Du Pont, 1980a), which is well below the elevation of L-Reactor. The two nearest upstream reservoirs, Clarks Hill (completed in March 1953, with 3.1×10^9 cubic meters of storage) and Hartwell (completed in June 1961, with 3.1×10^9 cubic meters of storage), provide power, flood control, and recreational areas. These reservoirs and the New Savannah River Bluff Lock and Dam at Augusta, Georgia, have stabilized the river flow at Augusta to a yearly average of 288.8 cubic meters per second (Bloxham, 1979) and 295 cubic meters per second at Savannah River Plant. Russell Reservoir, which began filling in December 1983, will furnish 1.2 x 10^9 cubic meters of storage to further stabilize Savannah River flows. TC

Since 1963, it has been the operating practice of the U.S. Army Corps of Engineers to attempt to maintain a minimum flow of 178.4 cubic meters per second below the New Savannah River Bluff Lock and Dam at Butler Creek (River Mile 187.4, near Augusta, Georgia) (COE, 1981). During the 18-year period from 1964 to 1981 (climatic years ending March 31), the average of the lowest 7-consecutive-day flow each year measured at the New Savannah River Bluff Lock and Dam was 181 cubic meters per second (Watts, 1982) or about 2.3 cubic meters per second less than at Savannah River Plant (Ellenton Landing, River Mile 156.8).

An extreme value analysis was used to assess low-flow conditions on the Savannah River. Due to the change in the operating practice of the Corps of Engineers in 1963, the annual lowest 7-day flow data for years prior to 1963 were not considered; a 20-year period of record, climatic years 1964 to 1983 (through March), was used in the analysis. Table 3-3 presents the results of this analysis.

Table 3-3. Seven-day low-flow conditions on the Savannah River at Savannah River Plant[a]

Recurrence interval (yrs)	Flow at Ellenton Landing (m^3/sec)
2	182.8
5	168.5
10	159.0
20	149.9
30	144.6
50	138.0

[a]Based on an external distribution that provided the best fit value (0.9909) of the eight extreme value models suggested by Petruaskas and Aagaard (1970).

Figure 3-6 shows the mean monthly flow rates for the Savannah River measured at Augusta, Georgia from January 1964 through September 1981. Highest flows occur in the winter and spring, and the lowest occur in the summer and fall. Also indicated in this figure are long-term mean and 7-day, 10-year low flows at Ellenton Landing. River flow at Ellenton Landing is usually 9 to 13 cubic meters per second greater than at Augusta, Georgia.

Table 3-4 compares the total river flows at Ellenton Landing for 1979 to 1982. The effects of the 1981 drought are clearly seen. Based on the low-flow analysis (Table 3-3), the drought produced 1-in-50-year 7-day low flows at Savannah River Plant.

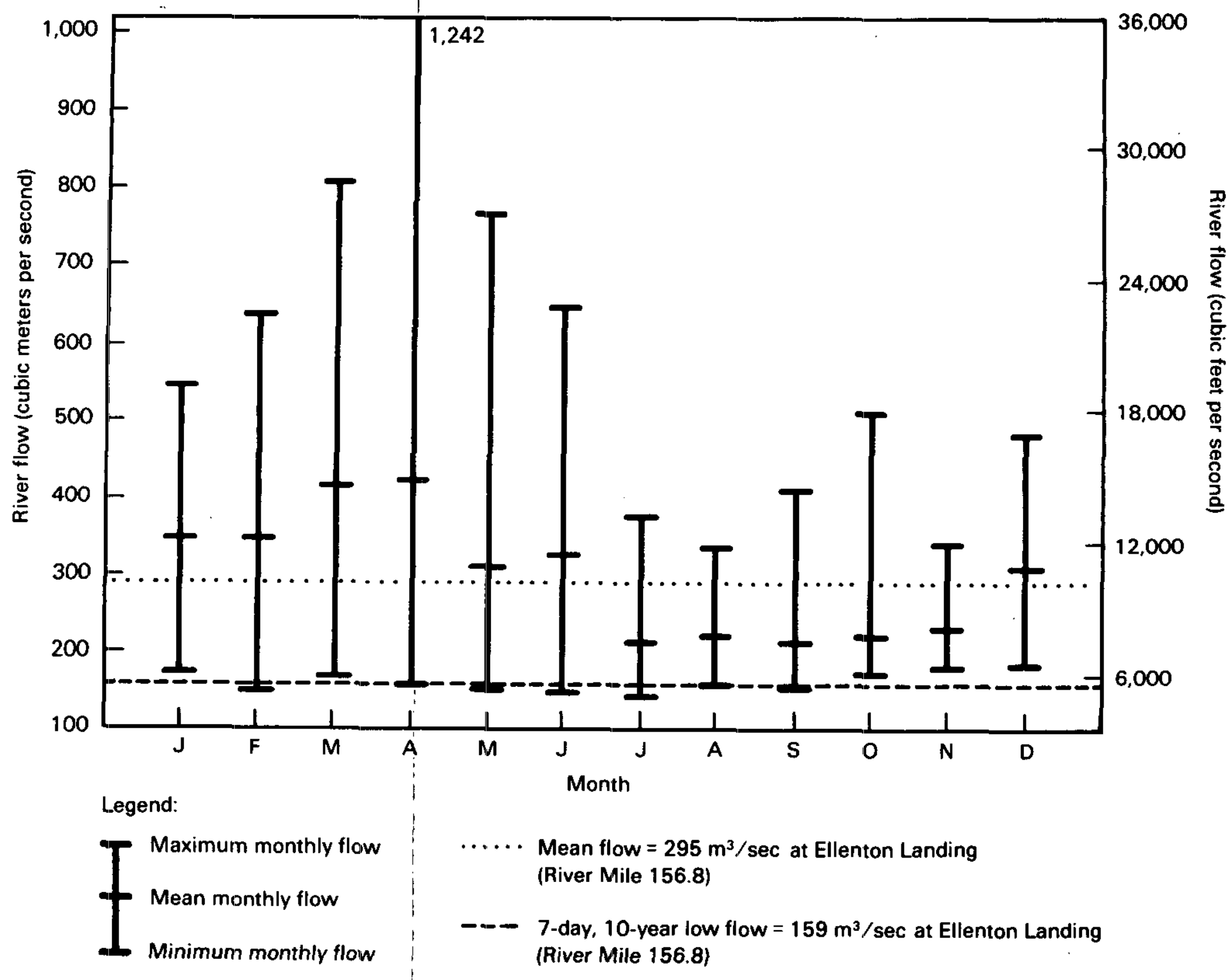


Figure 3-6. Mean monthly flow rates of the Savannah River from 1964-1981 at River mile 187.5 (data derived from USGS gaging station, near Augusta, Georgia).

TC

Table 3-4. Summary of Savannah River flow and temperature measurements 3 kilometers above and 16 kilometers below Savannah River Plant, 1979-1982[a]

Parameter	1979		1980		1981		1982	
	Above	Below	Above	Below	Above	Below	Above	Below
Total flow volume (10^{13} liters per year)	1.0	1.3[b]	1.1	1.3	0.44[c]	0.53[c]	0.65	0.78
Temperature (°C)								
Mean	17.2	17.5	18.0	18.0	19.0	20.0	17.0	18.0
±2 Std. Dev.	11.7	11.9	11.1	11.3	9.5	10.0	10.0	11.0
Maximum	24.5	24.5	25.0	26.0	25.0	26.0	24.0	25.0
Minimum	8.5	8.5	1.5	8.0	12.0	12.0	6.8	6.5

[a]Adapted from Du Pont (1980b, 1981a, 1982c, 1983a).
[b]Estimated from Ellenton Landing flow data.
[c]Includes third quarter 1981 data when the Corps of Engineers reduced flows to conduct minimum flow testing at SRP pumphouses.

Duke Power Company has entered into an agreement with the City of Greenville, South Carolina, to provide an interbasin transfer of as much as 0.53 cubic meter per second in 1985 and 8.3 cubic meters per second by 2020 from Lake Keowee. The States of Georgia and South Carolina have asked the Corps of Engineers for permission to withdraw as much as 1.8 cubic meters per second (total) from Lake Hartwell.

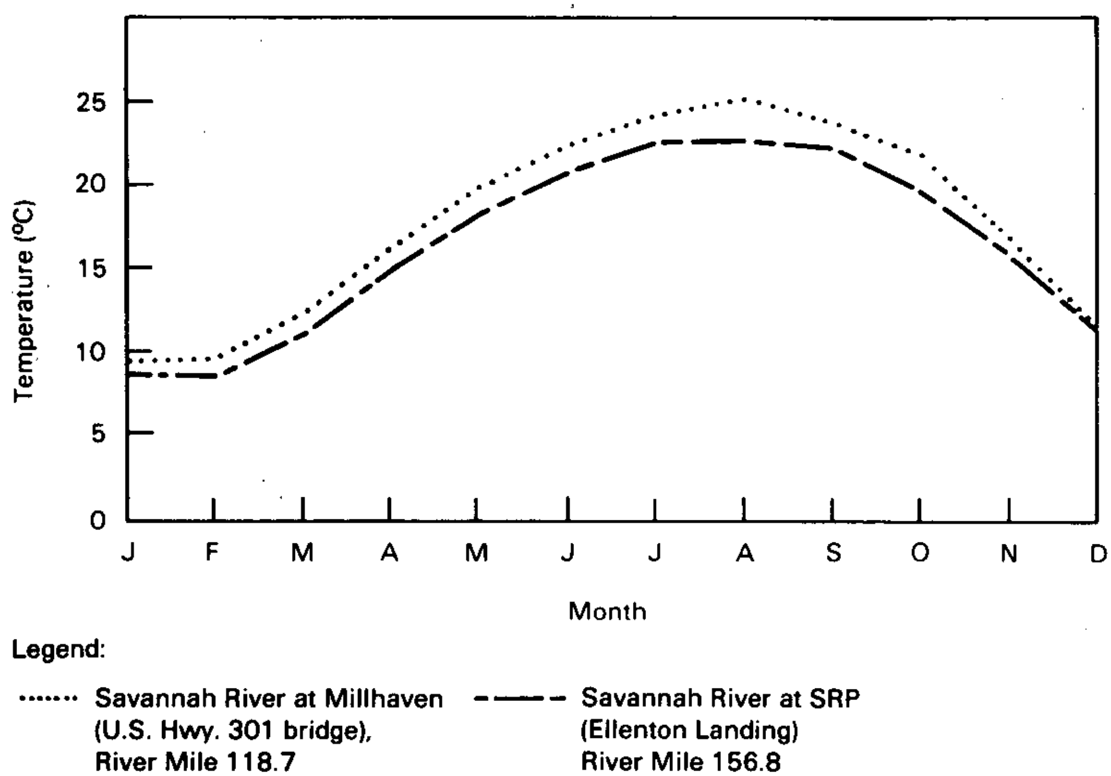
EL-1 The Corps of Engineers maintains, in accordance with its agreement with Duke Power Company, that the interbasin transfer from Lake Keowee to the City of Greenville is legal provided it has no effect on the ability of the Corps to generate electric power at Lake Hartwell and Clarks Hill. The Corps of Engineers is presently assessing the requests by South Carolina and Georgia to withdraw water from Lake Hartwell. This assessment will include the ability of the Corps to maintain its navigation project below the New Savannah Bluff Lock and Dam and to meet its electric-power-generation requirements. It will also consider the effects of the interbasin transfer. Until the Corps of Engineers completes its assessment, it will maintain the flow below the New Savannah Bluff Lock and Dam at the current levels.

TC The 1979-1982 average temperature of the Savannah River 3 kilometers above Savannah River Plant was 17.8°C with a range of 1.5 to 26.0°C (see Table 3-4). Similarly, below Savannah River Plant the average temperature was 18.4°C and the range was 6.5 to 26.0°C. Monthly average daily-maximum temperatures above and below Savannah River Plant for the period 1960-1970 are presented in Figure 3-7. The river temperature increased by 1.1°C on the average over the 40 river miles between Ellenton Landing and the U.S. Highway 301 bridge. This was due, in part, to the natural warming as the water tended toward its equilibrium temperature; discharges from Clarks Hill Lake were typically about 5°C cooler than the water temperatures prior to dam construction (Neill and Babcock, 1971).

As shown in Figure 3-7, June, July, August, and September are the warmest river temperature months; monthly average temperatures and standard deviations are listed in Table 3-5. The average river temperature during these months was about 25 percent higher than the annual average river temperature. From June 1955 through September 1982, the river temperature at Ellenton Landing equalled or exceeded 28°C three times and equalled or exceeded 28.3°C once.

TC Table 3-5. Mean maximum daily temperature, 1960-1969 (°C)

Month	Ellenton Landing		Highway 301 bridge	
	Monthly average	Standard deviation	Monthly average	Standard deviation
June	21.0	1.5	22.9	2.2
July	22.7	0.7	24.8	1.3
August	23.1	0.7	25.1	1.0
September	22.3	0.9	23.9	1.0



Source: DOE (1982a).

Figure 3-7. Savannah River monthly average daily-maximum temperatures for 1960-1970.

During the February, March, April, and May fish spawning season the monthly average daily-maximum temperatures and standard deviations at Ellenton Landing for the same period of record were 8.7°C and 1.0°C, 11.0°C and 1.3°C, 15.4°C and 1.3°C, and 18.8°C and 1.6°C, respectively.

3.4.1.2 SRP streams and swamp

The SRP site is drained almost entirely by five principal systems (drainage areas are in parentheses): (1) Upper Three Runs Creek (490 square kilometers); (2) Four Mile Creek (including Beaver Dam Creek) (90 square kilometers); (3) Pen Branch (90 square kilometers); (4) Steel Creek (90 square kilometers); and (5) Lower Three Runs Creek (470 square kilometers). These streams rise on the Aiken Plateau and descend 30 to 60 meters before discharging to the Savannah River. The sandy soils of the area permit rapid infiltration of rainfall; seepage from these soils furnishes the streams with a rather constant supply of water through most of the year (Langley and Marter, 1973).

Upper Three Runs Creek is the only major onsite stream that has never received thermal discharges (Du Pont, 1982a). One of the principal tributaries of Upper Three Runs Creek, Tims Branch, received process and nonprocess liquid effluents (from the 700-A and 300-M Areas of Savannah River Plant) of about 0.05 cubic meter per second until May 1982. After this time, discharges of wastewater effluents from M-Area (0.016 cubic meter per second) were diverted to the M-Area basin.

Lower Three Runs Creek has the second largest watershed of the SRP streams. In 1958, its headwaters were impounded to form Par Pond for the recirculation of cooling water from P- and R-Reactors. Cooling water from P-Reactor was discharged to Steel Creek until 1963, when it was diverted to Par Pond. Four Mile Creek receives nonthermal discharges from F- and H-Separations Areas and thermal discharges from C-Reactor. Pen Branch receives thermal discharges from K-Reactor. Reactor secondary cooling-water effluent is discharged at a rate of 11 cubic meters per second.

The L-Reactor site is drained by both Steel Creek and Pen Branch. Steel Creek has been used in the past to receive the reactor coolant discharge. The headwaters of Steel Creek rise near P-Area and flow southwesterly for about 7 kilometers, turn south for about 9 kilometers, and enter the Savannah River swamp about 3 to 5 kilometers from the river. A delta of about 100 acres surrounded by a partial tree-kill zone of another 180 acres has developed where the creek enters the swamp (Du Pont, 1983b). Beyond the delta, Steel Creek is joined by the flow from Pen Branch and some flow from Four Mile Creek before it discharges into the Savannah River near Steel Creek Landing (see Figure 3-2).

TC

During the 1983 water year (October 1982 through September 1983), the flow of Steel Creek at Road B ranged between 0.28 and 3.96 cubic meters per second. The average flow for this period was 0.62 cubic meter per second. Of this average flow, about 0.45 cubic meter per second was discharged from P-Reactor at near-ambient temperatures (McAllister, 1983). Farther downstream at Cypress Bridge, about 2.8 kilometers below Road A, the average flow of Steel Creek for calendar years 1978 through 1980 was 1.36 cubic meters per second. After subtracting the P-Reactor contribution, the natural flow of Steel Creek at Cypress

Bridge is calculated to be about 0.91 cubic meter per second. Du Pont (1982a) estimated the natural flow of Steel Creek to be 1.0 cubic meter per second, based on drainage area considerations. Maximum daily flow rates (both natural and with discharges from P-Reactor) were measured between 4.2 and 8.2 cubic meters per second during the past 8 years. TC

As listed in Table 3-6, Steel Creek has had a varied history with respect to the release of reactor effluents. The release of thermal effluents into Steel Creek from L- and P-Reactors reached a peak of about 23 cubic meters per second in 1961. In 1963, P-Reactor effluents were diverted to Par Pond, and thermal discharges to the creek were reduced to about 11 cubic meters per second, about 1.3 times the maximum flow expected at Cypress Bridge after heavy rains. Since 1968, Steel Creek has received only infrequent and short-term inputs of thermal effluents (Smith, Sharitz, and Gladden, 1981, 1982a; Du Pont, 1982a).

Table 3-6. Reactor-Area discharges to Steel Creek[a]

Years	Discharge (m^3/sec)		
	P-Reactor	L-Reactor	Total
1954 to 1958	5.6	5.7	11.3
1958 to early 1961	9.3	9.3	18.6
Mid-1961	11.3	11.3	22.6
Late 1961 to late 1963	9.3	11.3	20.6
November 1963 to February 1968	0.4[b]	11.3	11.7
February 1968 to 1980	0.4[b]	0.0	0.4[b]
1981 to present	0.5[b]	0.002[c]	0.5[b,c]

[a]Adapted from Du Pont (1982a).
[b]Flow from P-Area sources at about ambient temperature.
[c]Flow from sanitary and domestic sources from L-Area at ambient temperature. During cold-water testing, the flow has approached 6.2 cubic meters per second.

Table 3-7 compares stream characteristics before and after Steel Creek received heated discharges from L- and P-Reactors. Between 1951 and 1972, the Steel Creek channel width increased more than three times due to effluent scour.

The three streams that have received the greatest input of thermal effluent (Four Mile Creek, Pen Branch, and Steel Creek) flow into a contiguous swamp of about 10,240 acres (Du Pont, 1983b) that is separated from the main flow of the Savannah River by a 3-meter-high natural levee along the river bank. These streams generally flow as shallow sheets, with well-defined channels only where they enter the swamp and near breaches in the levee (Smith, Sharitz, and Gladden, 1981). The combined natural flow and reactor effluent discharges have a strong influence on water levels in the swamp during nonflood conditions.

The flow of water in the swamp is altered when the Savannah River is in flood stage (about 27.7 meters) with a flow rate of about 440 cubic meters per second. Under flooding conditions, Four Mile Creek, Pen Branch, and Steel Creek

Table 3-7. Steel Creek stream characteristics[a]

Date	Width (m)	Average depth (m)	Flow rate (m^3/sec)	Temperature (°C)
May 1951	5.1	0.30	0.59[b]	16.1
June 1972	16.5	0.37	0.79	24.6

[a]Based on measurements taken at Road A and adapted from Du Pont (1982a).
[b]July 1951 determination.

discharge to the Savannah River at Little Hell Landing after crossing an offsite swamp (Creek Plantation Swamp). An analysis of the data from 1958 through 1980 indicates that on the average the Savannah River reaches flood stage at the Savannah River Plant 79 days, or 22 percent of each year, predominantly from January through April (see Figure 3-6). This result is in agreement with the results of a similar analysis performed by Langley and Marter (1973).

3.4.1.3 Surface-water use

The Savannah River downstream from Augusta, Georgia, is classified by the State of South Carolina as a Class B waterway, suitable for agricultural and industrial use, the propagation of fish, and--after treatment--domestic use. The river upstream from the Savannah River Plant supplies municipal water for Augusta, Georgia, and North Augusta, South Carolina. Downstream, the Beaufort-Jasper Water Authority in South Carolina (River Mile 39.2) withdraws about 19,700 cubic meters per day (0.23 cubic meter per second) to supply domestic water for a population of about 51,000. The Cherokee Hill Water Treatment Plant at Port Wentworth, Georgia (River Mile 29.0), withdraws about 116,600 cubic meters per day (1.35 cubic meters per second) to supply a business-industrial complex near Savannah, Georgia, that has an estimated consumer population of about 20,000 (Du Pont, 1982a). Plant expansions for both systems are planned for the future.

The Savannah River Plant currently withdraws a maximum of 26 cubic meters per second (about 63 percent of the maximum pumping rate of 41 cubic meters per second) from the river, primarily for use as cooling water in production reactors and coal-fired power plants (Du Pont, 1982a). Almost all of this water returns to the river via SRP streams (Du Pont, 1981b). The river receives sewage treatment effluents from Augusta, Georgia, and North Augusta, Aiken, and Horse Creek Valley, South Carolina, and other waste discharges along with the heated cooling water from Savannah River Plant via its tributaries. The cooling-water withdrawal and discharge rate of about 1.2 cubic meters per second for both units of the Alvin Vogtle Nuclear Plant is expected later in the 1980s (Georgia Power Company, 1974). The Urquhart Steam Generating Station at Beech Island withdraws approximately 7.4 cubic meters per second of once-through cooling water. Upstream, recreational use of impoundments on the Savannah River, including water contact recreation, is more extensive than it is near Savannah

River Plant and downstream. No uses of the Savannah River for irrigation have been identified in either South Carolina or Georgia (Du Pont, 1982a).

The water quality of the Savannah River is discussed in Chapter 4. Historic data demonstrate that the water quality of the river downstream of Savannah River Plant is similar to the water quality upstream.

3.4.2 Subsurface hydrology

3.4.2.1 Hydrostratigraphic units

Three distinct hydrogeologic systems underlie Savannah River Plant: (1) the Coastal Plain sediments, where water occurs in porous sands and clays; (2) the buried crystalline metamorphic rock beneath the sediments, where water occurs in small fractures in schist, gneiss, and quartzite; and (3) the Dunbarton Basin (Triassic age) within the crystalline metamorphic complex, where water occurs in intergranular spaces in mudstones and sandstones. The latter two systems are unimportant as ground-water sources near SRP.

The Coastal Plain sediments, which contain several prolific and important aquifers, consist of a wedge of stratified sediments that thickens to the southeast. Near L-Reactor, the sediments are about 400 meters thick and consist of sandy clays and clayey sands. The sandier beds form aquifers and the clayier beds form confining beds. The Coastal Plain sediments across the SRP generally consist of the Barnwell (combined with the Hawthorn as one mapping unit), McBean, Congaree, Ellenton, and Tuscaloosa Formations (Figure 3-5). Among these, the Tuscaloosa Formation is a particularly prolific ground-water unit because of both its thickness, approximately 180 meters beneath H-Area, and its high permeability. Surficial deposits, including terrace sediments and alluvium, are not important sources of ground water at SRP. The lithology and water-bearing characteristics of the hydrostratigraphic units underlying Savannah River Plant are described in Table 3-8. Additional detail is provided in Table F-1 and the text of Appendix F.

Ground water beneath the central portions of the SRP, including the L-Area, generally occurs under confined (artesian) conditions; in wells, the ground water rises to a potentiometric (piezometric) level above the water level encountered in the formation. However, ground water in the Barnwell Formation and overlying units generally occurs under unconfined (water table) conditions; in wells, this ground water remains at the level encountered in the formation. The elevation of the free-standing ground water above a sea-level datum is referred to as the "head."

In the central part of the Savannah River Plant [including the Separations (F- and H-) Areas and the L-Area], the Barnwell and McBean Formations and the McBean and Congaree Formations (Figure 3-8) are separated by layers informally called the "tan clay" and the "green clay," respectively, in SRP studies. The lowest unit of the Barnwell Formation is the tan clay. Borings in the Separations Areas and about 2 kilometers east of the Central Shops (Figure 3-2) indicate that the tan clay is about 2 meters thick, and that it commonly consists of two thin clay layers separated by a sandy zone (D'Appolonia, 1980; Du Pont, EL-11

Table 3-8. Hydrostratigraphic units in the vicinity of SRP[a]

Geologic unit	Geologic age	Outcrop	Description	Water yield	Thickness (m)
Alluvium[b]	Recent epoch	River and creek bottoms	Fine to coarse sand, silt, and clay	Very little	0 to 9.5
Terrace deposits[b]	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 9.5
Alluvium[b]	Pliocene epoch	Surface of Aiken Plateau	Gravel and sandy clay	Little or none	0 to 6
Hawthorn[b]	Miocene epoch	Large part of ground surface	Tan, red, and purple sandy clay with numerous clastic dikes	Little or none	0 to 25
Barnwell[b]	Eocene epoch	Large part of ground surface near streams	Red, brown, yellow, and buff, fine to coarse sand and sandy clay	Limited but sufficient for domestic use	0 to 30
McBean and Congaree[b]	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	30 to 75
Ellenton[b]	Upper Cretaceous epoch	None on SRP	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	1 to 30
Tuscaloosa[b]	Upper Cretaceous epoch	None on SRP	Tan, buff, red, and white; crossbedded, micaceous quartzitic and arkosic sand and gravel imbedded with red, brown, and purple clay and white kaolin	Large, well production up to 7.6 m^3/min; soft; low in total solids	170 to 250

Table 3-8. Hydrostratigraphic units in the vicinity of SRP[a] (continued)

Geoglogic unit	Geologic age	Outcrop	Description	Water yield	Thickness (m)
Newark Series "Red Beds"[c]	Triassic period	None on SRP	Dark-brown and brick-red sandstone, siltstone, and clay-stone containing gray calcar-eous patches. Fanglomerates near border.	Very little	>900
Basement rocks of the Slate Belt and Charlotte group[d]	Precambrian and Paleozoic eras	None on SRP	Hornblende gneiss, chlorite-hornblende schist, lesser amounts of quartzite. Covered by saprolite layer derived from basement rock.	Very little	Many thousands

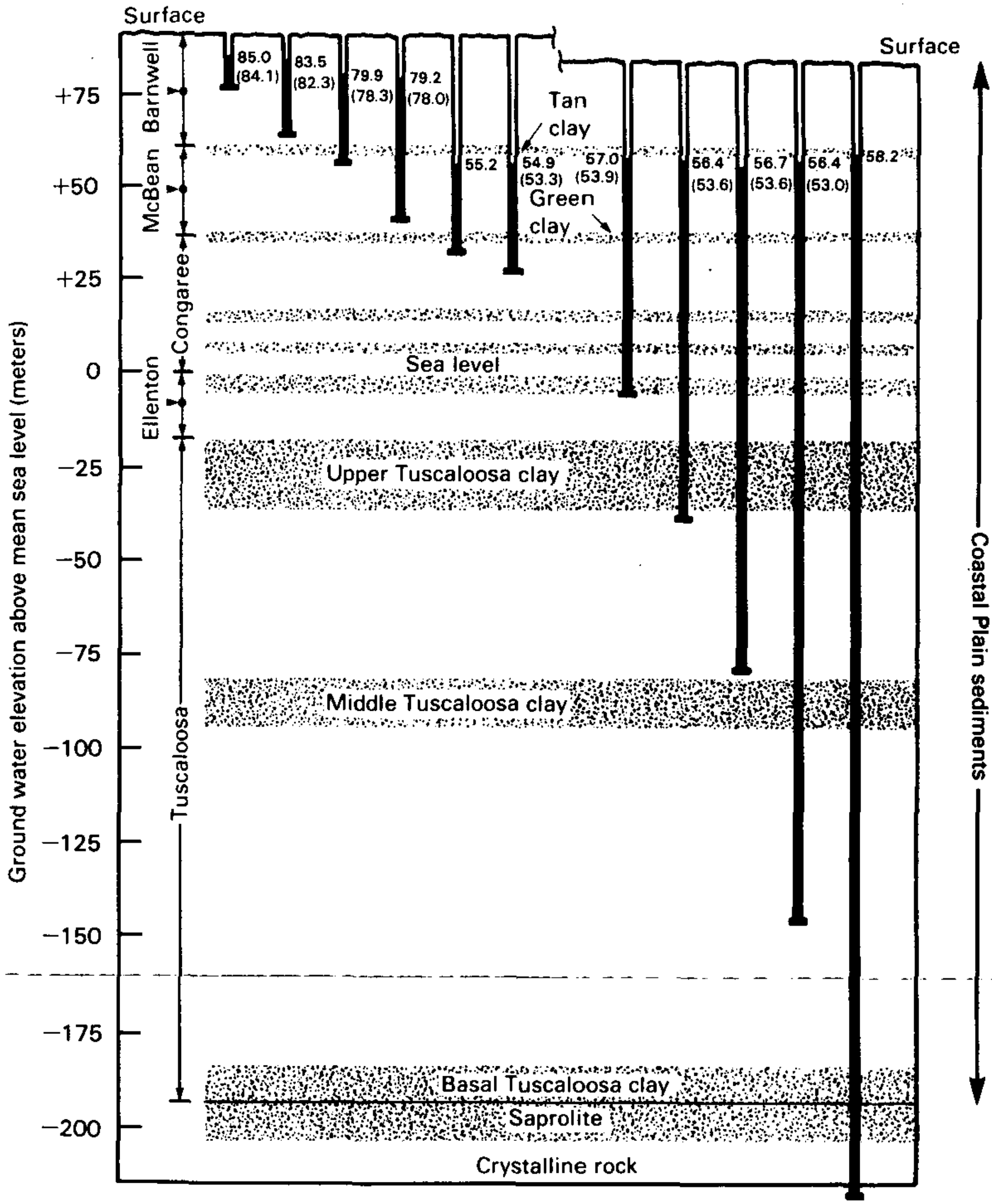
[a]Adapted from Siple (1967); see Table F-1 for a more detailed summary of properties of the hydrostratigraphic units. |TC

[b]Coastal-plain sediments.

[c]Dunbarton Basin sediments.

[d]Crystalline and metamorphic rock.

TE



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85 Water elevations (heads) in meters. Values are those existing in 1972 with 1982 measurements given in parentheses.

TC

Sources: ERDA (1977), Du Pont (1983c).

Figure 3-8. Hydrostatic head of ground-water near H-Area in relation to principal hydrostratigraphic units.

1983c). In the L-Area, the tan clay is not readily evident from foundation borings, drillers, logs, or geophysical logs; however, even in other SRP areas where it supports a significant head difference, this clay is not always apparent in soil cores.

The green clay, deposited under marine conditions and therefore expected to be continuous over large areas, is hydrogeologically significant because it supports a large head difference between ground water in the McBean and ground water in the Congaree Formations; this head difference is as much as 21 meters near the Central Shops and 24 meters in the Separations Areas, even though the clay is only 2 to 3 meters thick (D'Appolonia, 1980; Du Pont, 1983c). The green clay is effective in preventing the downward migration of contaminants (based on tritium measurements) from the McBean into the Congaree in H-Area (Marine, 1965). This observation is supported by recent analyses of ground water from well 35-D (see the boring location on Figure F-34). During investigations on the capability of the postulated Millett fault, the green clay near P-Area was correlated with the Blue Bluff Member of the Lisbon Formation in Georgia (Georgia Power Company, 1982); in the southeastern part of SRP downdip from the Separations Areas, the green clay is believed to be about 18 meters thick (Du Pont, 1983c). Based on geophysical logs of water wells in the L-Area (see Figure F-24), the green clay is about 7 meters thick. At the Par Pond pumphouse, along the strike from L-Reactor, the green clay also supports a large head difference; it also appears to have effectively protected the Congaree ground water from the large (27,000 picocuries per liter) concentrations of tritium in Par Pond (Ashley and Zeigler, 1979). In the central part of SRP, this clay directs much of the water in the McBean laterally to local creeks. EL-11

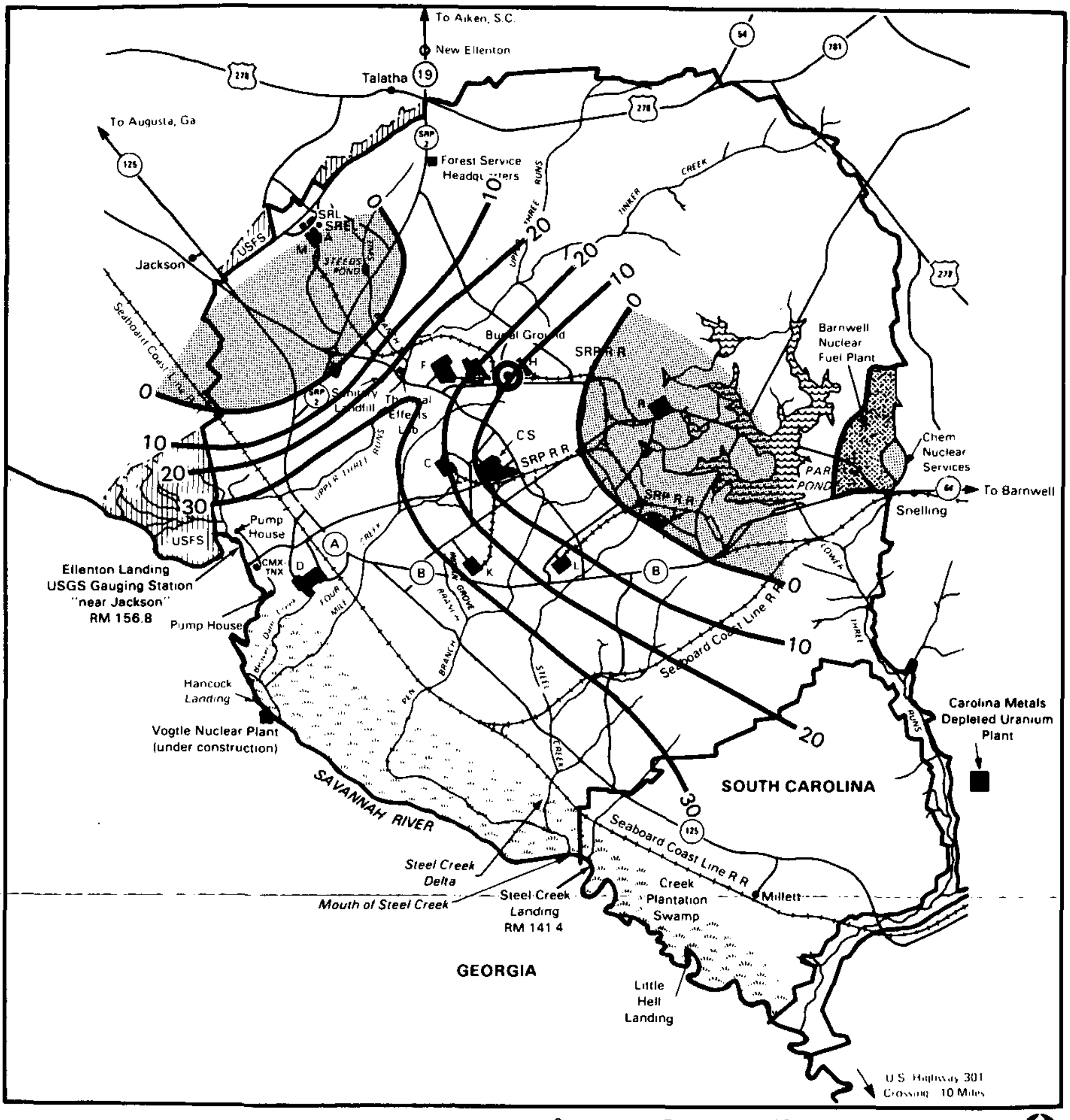
Up dip from the Separations Areas, the tan clay seems to be absent from the stratigraphic section and the green clay is discontinuous. However, in A-Area the green clay might be sufficiently continuous to affect ground-water flow patterns. The ground-water flow direction is to the west-southwest in the water table. Lower in the Tertiary section, the predominant flow is to the south.

Throughout the SRP, the clay at the base of the Congaree and the upper clay layer of the Ellenton Formation provide an effective confining unit for the sands of the Ellenton-upper Tuscaloosa aquifer (see Table F-1).

As shown on Figure 3-8, the heads in the Ellenton and Tuscaloosa Formations are higher than those in the Congaree (upward head differentials) in the central portion of SRP, thus preventing downward movement of water from the Congaree to the Ellenton. This condition is caused by the drawing down of the head in the Congaree by natural drainage into Upper Three Runs Creek and the Savannah River. An approximation of the area where the head difference is upward from the Tuscaloosa to the Congaree is shown in Figure 3-9. F-, H-, and L-Areas are within this area, but M-Area is not.

The head relationships in the Coastal Plain sediments in the northwest part of Savannah River Plant (M-Area) are quite different from those near the L-Reactor. In this updip area, the green clay is discontinuous and is thinner than it is farther downdip, and the tan clay (Figure 3-8) has disappeared entirely. Thus, there is less impedance to downward vertical flow within the Tertiary sediments. Another important factor is that the hydrologic conductivity of the Congaree Formation in M-Area is less than that in the central part of Savannah River Plant because the sediments near M-Area are not as well

AW-1



Legend:

C, K, R, L, P Reactor Areas (C, P, K are operating)
F, H Separations Areas
M Fuel and Target Fabrication
D Heavy Water Production
A Savannah River Laboratory and Administration Area
U Temporary construction area
RM River Mile

Road A = Highway 125

Area where the Congaree head exceeds the Tuscaloosa head.
Contour showing locations where the head in the Tuscaloosa is 10 feet (1.0 foot = 0.3048 meter) above the head in the Congaree.
Developed from Figures F-9 and F-10.

Developed from Figures F-9 and F-10.

Figure 3-9. Head difference between upper Tuscaloosa and Congaree Formations at SRP (May 11, 1982).

sorted. As a result of these hydrogeologic characteristics, water elevations decrease with increasing depth from the Congaree to the Tuscaloosa in M-Area (i.e., a downward head differential exists between the Congaree and Tuscaloosa Formations). Closer to the Savannah River, the natural discharge from the Congaree draws its head down below that of the Tuscaloosa. This is an important factor in reducing the likelihood that any surface contamination will enter the important, prolific Tuscaloosa aquifer from the Congaree.

The locations of areas where there is a head reversal between the Congaree and the Tuscaloosa Formations (i.e., the latter's head being higher than the former's) are shown in Figure 3-9; these relationships are general and are not valid in the vicinity of production wells. This head difference map shows that the head in the Tuscaloosa is higher than the head in the Congaree in a broad area within about 10 kilometers of the Savannah River and Upper Three Runs Creek. The head in the Congaree is higher than that of the Tuscaloosa in an area surrounding A- and M-Areas and in the vicinity of Par Pond.

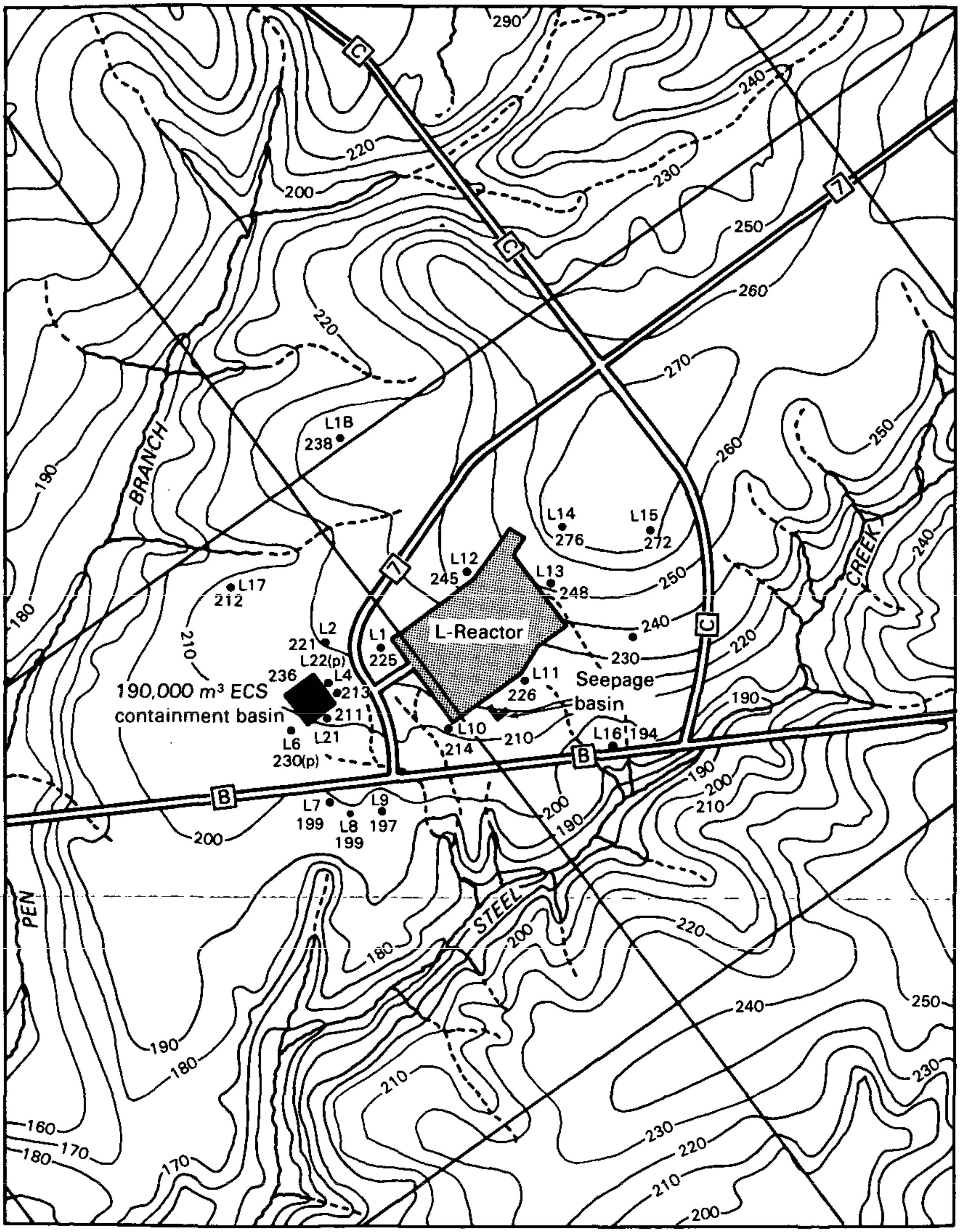
In the L-Reactor area, the water table is generally 3 to 6 meters below the ground surface (Appendix F, Figure F-24). Shallow ground water beneath the L-Reactor area generally moves to the south-southeast in the direction of Steel Creek and to the west-southwest in the direction of Pen Branch (Figure 3-10).

A more detailed discussion of the hydrostratigraphic units and their head relationships across the entire site and in specific areas is given in Appendix F and in Du Pont (1983c).

3.4.2.2 Ground-water movement

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, the gradient is seaward from the higher areas of the Aiken Plateau toward the continental shelf. Of major significance is the modification of this general southeastward movement caused by the incision of the Savannah and Congaree Rivers and, on a local basis, the incision of the smaller tributaries to these rivers. Ground water in the regions of these rivers and tributaries is diverted toward the hydraulic-energy low caused by natural discharge to the surface water. The depth of dissection at Savannah River Plant by the southwestward-flowing site streams has a significant influence in the direction of flow in most hydrostratigraphic units. The direction of flow in the shallow ground water is most affected by small streams; the direction of flow in the deeper ground water is most affected by major tributaries. The direction of flow in the Ellenton and Tuscaloosa Formations is affected only by the Savannah River itself. Locally, the normal direction of ground-water flow in any unit is modified by ground-water withdrawals from wells.

The energy levels (heads) of the Tuscaloosa Formation, the primary aquifer in the region, and the location of its outcrop areas, are shown in Figures 3-5 and F-1 (Appendix F). Where the outcrop area is high in elevation, as on the Aiken Plateau in the northeast sector of SRP (Figure F-1), water naturally recharged to the Tuscaloosa Formation exceeds the water naturally discharged to local streams, and this excess water moves southeastward through the aquifer.



Note: 1.0 foot = 0.3048 meter.

Source: Langley and Marter (1973).

Figure 3-10. Water table elevation when it was at its highest elevation during the period 1961-1967.

Where the outcrop area is low in elevation, such as along the Savannah River Valley in the northwest sector of the SRP, water naturally discharges from the formation to the river. Under the Savannah River Plant the direction of Tuscaloosa ground-water movement is southwesterly toward the outcrop of this formation in the Savannah River Valley (Figure F-25). The Ellenton Formation, which lies above the Tuscaloosa, is apparently hydraulically connected to the Tuscaloosa Formation, and its flow pattern is probably similar.

At the Savannah River Plant, the recharge of the Congaree is from offsite areas and from infiltration of precipitation; the higher formations at the Plant are recharged from infiltration of precipitation (about 40 centimeters per year) (Root, 1983). However, discharge into Upper Three Runs Creek and the Savannah River has a dominant effect on Congaree ground-water flow paths. As discussed in Section 3.4.2.1, the energy levels (heads) in the Congaree are lower than those in the Tuscaloosa over much of Savannah River Plant, precluding any downward infiltration in these areas. TC

On a regional basis, the dissecting creeks divide the ground water in the Congaree and higher formations into discrete or compartmentalized subunits. Depending on the depth of dissection, ground water is confined to its own subunit. Even though the hydraulic characteristics of the formations may be similar throughout the area, each subunit has its own natural recharge and discharge areas. The directions of ground-water flow within the Congaree Formation are shown in Figure F-26.

In the central part of Savannah River Plant, the only stream that cuts into the Congaree is Upper Three Runs Creek. The McBean is incised by Upper Three Runs Creek, several of its larger tributaries, Four Mile Creek, Pen Branch, and Steel Creek. Thus, ground water that enters the McBean Formation over much of the interior of Savannah River Plant is restricted in its connection with other subunits of the McBean because of stream incision.

At Savannah River Plant, the water table is commonly within the Barnwell Formation, although in the creek valleys it successively occupies positions in the lower formations. The surface drainage and topography strongly influence the water-table flow path at any point. Even small tributaries to the larger creeks cause depressions in the water table, diverting ground-water flow towards them. The Hawthorn Formation, which is perhaps the most extensive surficial deposit in this region, is usually unsaturated because of its high permeability. Its flow paths are predominantly vertical, with only short horizontal paths.

Flow pathways within each of the Savannah River Plant areas potentially impacted by L-Reactor operation are summarized in Table 3-9. These include other SRP areas that will support the operation of L-Reactor and, therefore, might be affected by increased support activity. Only in M-Area is there significant potential for water table discharges to reach the major regional aquifer (the Tuscaloosa). A more detailed discussion of site-specific aquifer characteristics, including potentiometric contours and flow paths, is included in Appendix F.

In some localities, drawdown from pumping water production wells in the Tuscaloosa Formation might reduce its water level below that of the Congaree. Thus in a small local area, water could theoretically move from the Congaree

Table 3-9. Flow paths at L-affected areas

Area	Water-table discharge
L-Area	Steel Creek, Pen Branch
L-Area seepage and retention basin	Steel Creek
F- and H-Separation Area	Four Mile Creek, Upper Three Runs Creek
Burial grounds	Four Mile Creek, Upper Three Runs Creek
Central shops	Four Mile Creek, Pen Branch
M-Area	Tim's Branch, Savannah River swamps, Hollow Creek (northwest of SRP), vertically

through the Ellenton into the Tuscaloosa. However, such areas do not underlie
TE| L-, K-, and F-Area seepage basins and the burial grounds or central shops.

3.4.2.3 Ground-water quality

The water in the Coastal Plain sediments tends to be of good quality, suitable for industrial and municipal use with minimal treatment. It is generally soft, slightly acidic, and low in dissolved and suspended solids. Appendix F contains a detailed description of the ground-water quality in the vicinity of the various areas of Savannah River Plant that will be affected by L-Reactor operation.

In December 1983, the computerized Well Data File (WDF) contained records for 6404 wells and borings. The WDF provides a central source of information on well and boring construction, geology, and water quality. As many as 66 variables can be entered for each well. There are currently 620 monitoring wells and 70 production wells in the WDF. The remaining records are for engineering and test borings, grout wells, and about 600 old wells, the exact location and status of which are unknown (locations are known within 100 meters).

EL-25

Based on pre-SRP well-drilling practices, many of these old wells are believed to have been shallow hand-dug domestic wells. Some probably penetrated the Tuscaloosa, including some drilled flowing wells discovered on SRP in the Savannah River valley. Any open holes, rusted-out casings, or otherwise defective wells can provide a direct route for contaminated surface water or shallow ground water to deeper aquifers, even the Tuscaloosa. Contamination of lower aquifers cannot occur from flowing wells. No hand-dug or abandoned wells are known to exist at or adjacent to L-Reactor or the waste disposal sites of any of its support facilities. In addition, no contamination of the Tuscaloosa aquifer by radionuclides and chlorinated hydrocarbons has been noted in the central portion of the SRP. Contamination of well water by chlorinated hydrocarbons from A-Area wells producing from the Tuscaloosa was confirmed earlier in 1983; these hydrocarbons were used as degreasers in M-Area. The contamination appears to have resulted from chlorinated hydrocarbons that entered the well annuli from the contaminated, shallow (Tertiary) aquifer in A- and M-Areas, and not from any generalized contamination, of the Tuscaloosa aquifer itself. Additional details are provided in Section 5.1.1.2, Appendix F, and Du Pont (1983c). EL-25

3.4.2.4 Ground-water use

Most municipal and industrial water supplies in Aiken County are developed from the Tuscaloosa Formation, which occurs at shallower depths as the Fall Line is approached. Domestic water supplies in Aiken County are primarily developed from the Barnwell, McBean, and Congaree Formations. In Barnwell and Allendale Counties (Figure 3-4), the Tuscaloosa Formation occurs at increasingly greater depths; some municipal users are therefore supplied from the shallower Congaree and McBean Formations or from their limestone equivalent. In these counties, domestic supplies are developed from the Barnwell and McBean Formations.

Forty-four municipalities and industries within 32 kilometers of the center of Savannah River Plant that presently use more than 18.9 cubic meters per day from ground-water sources have been identified. Total pumpage for these users is about 106,300 cubic meters per day. The locations of these users are shown in Figure F-25; pertinent data are listed in Appendix F, Tables F-8 through F-10. TC

Twenty municipal users were identified, as shown in Table F-8. Talatha community, the municipal user nearest to the center of Savannah River Plant (about 11 kilometers away) uses about 150 cubic meters per day. The largest municipal user is the town of Barnwell, about 26 kilometers away; it uses 15,140 cubic meters per day, some of which is supplied to local industry.

Twenty-four industrial users were identified (refer to Appendix F). Total industrial pumpage from the Tuscaloosa Formation is about 67,300 cubic meters per day. This includes 13 users on the Savannah River Plant. TC

Of the total municipal pumpage of 39,000 cubic meters per day, at least 23,500 cubic meters is from Tuscaloosa Formation and 15,000 cubic meters is from the Congaree Formation. TC

In addition to the large municipal and industrial users, 25 small communities and mobile home parks, 4 schools, and 11 small commercial interests are listed in the files of the South Carolina Department of Health and Environmental Control as users of ground water. Wells serving these and other miscellaneous users are generally equipped with pumps with capacities from 54 to 325 cubic meters per day and do not draw large quantities of water. Most wells draw from shallow aquifers. The total withdrawal for these 40 users is estimated to be about 1000 cubic meters per day. In addition to the municipal and industrial users, there are a number of domestic wells near the Savannah River Plant; many of these wells also draw from the shallow aquifers. Two South Carolina State Parks are within a 30-kilometer radius of the center of Savannah River Plant: Aiken State Park, with seven wells, and Barnwell State Park, with two wells. The Edisto Experimental Station at Blackville pumps an average of 70 cubic meters per day from the Congaree Formation. Several shallow wells produce small quantities of water for guardhouses at the Savannah River Plant. TC

3.4.2.5 Relationship of ground-water use to water levels

Hydrographs of five Tuscaloosa wells and one Ellenton well are shown in Figure 3-11. Five of these wells are located at the Savannah River Plant. The sixth well, AK-183, is located 29 kilometers northwest of the center of SRP in the Tuscaloosa outcrop area and is not influenced by pumpage in the vicinity of SRP. The winter (December, January, and February) precipitation is plotted at the top of Figure 3-11; precipitation during these months is the principal source of ground-water recharge. An exception occurred in the summer of 1964, when, due to abundant precipitation (about twice the mean), recharge continued throughout the summer. As a result, record high-water levels occurred in 1965 and 1966. A low in winter precipitation occurred in 1968, and this resulted in low water levels in 1970. Generally high Tuscaloosa water levels occurred in 1974, but from then until 1982 Tuscaloosa water levels declined. From 1972 to 1981, there was a general decline in the winter precipitation, which might partially account for the declining water levels, as shown by wells AK-183 and P7A. However, since 1975, SRP pumping has increased by about 80 percent, from 14.9 to 27.0 cubic meters per minute.

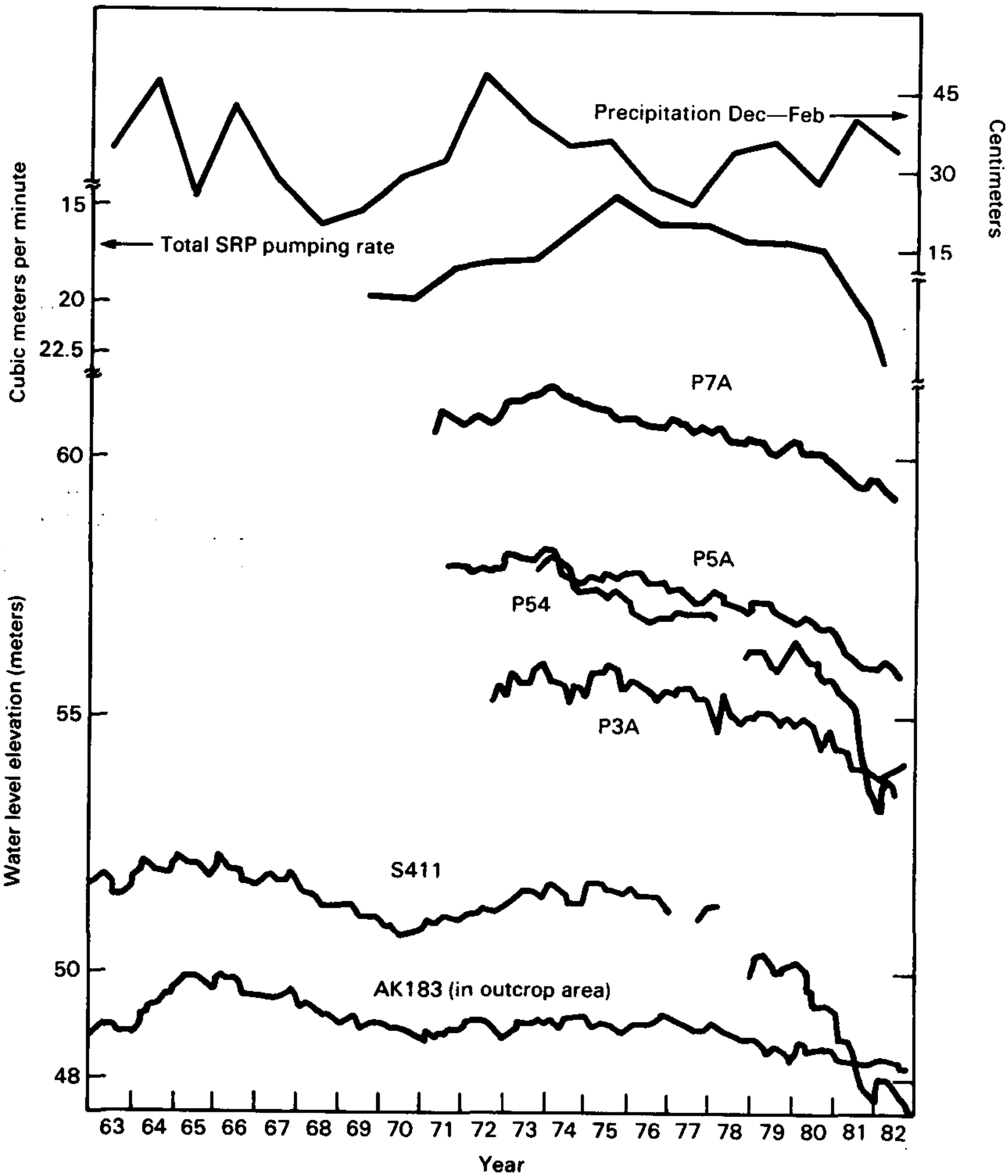
Figure 3-11 shows the total SRP pumping rate (the highest rates are plotted toward the bottom of the Figure to facilitate a comparison of pumping rates and water levels in monitoring wells). Calculations show that the decline in water levels at monitoring wells P7A, P54, and P3A is related primarily to increased ground-water withdrawal at SRP. The drawdowns at these wells reflect adjustments in equilibrium levels rather than aquifer depletion (i.e., withdrawals and flow from an area exceed the ground-water flux into the area). Near-equilibrium water levels are expected to occur quickly (within 100 days) in response to changes in pumping rates (Mayer et al., 1973).

The current (1983) estimate of the total pumpage from the Tuscaloosa Formation within 32 kilometers of the Savannah River Plant is 63 cubic meters per minute (Figure F-25). Usage within the Marine and Routt (1975) ground-water-flux study area (Figure F-31) is currently about 38.5 cubic meters per minute (11.5 from offplant users and 27 from SRP), and should not exceed the natural
AW-1, ground-water flux, which is conservatively estimated to be 51 cubic meters per
EL-15 minute through the study area. When the F-Area powerhouse is placed in standby status in September 1984, the withdrawal of ground water in F-Area is expected to decrease from 6.44 to 3.41 cubic meters per minute. At that time, the projected usage in the study area will be 35.5 cubic meters per minute.

Ground-water withdrawal in A-Area might decrease in August 1984, when the production air stripper is placed in service in M-Area (see Section F.6). Wastewater from the stripper (about 1.1 cubic meters per minute) will be used in the A-Area powerhouse to augment its process-water requirements.

Siple (1967) indicated that withdrawals from the Tuscaloosa at SRP could reach 37.8 cubic meters per minute without exeeeding allowable drawdown in existing (1960) production wells. Potentially, the aquifer could produce more water if well fields were better designed. In 1960, the SRP pumpage from the Tuscaloosa was about 18.9 cubic meters per minute (Siple, 1967).

As noted in Section F.4.2, the best estimate of the flux when the model was run in 1974 was 110 cubic meters per minute; this value is now conservatively estimated to be 51 cubic meters per minute. However, incremental pumpage since



Note: Well S411 is producing from the Ellenton Formation, the remaining wells are producing from the Tuscaloosa Formation.

Source: Du Pont (1983c).

Figure 3-11. Hydrographs of Tuscaloosa and Ellenton wells.

the model study was performed might be enough to affect local water levels as new equilibrium levels are established.

AW-1, EL-15 The decline of water levels in the Tuscaloosa Formation since the mid-1970s has reduced the head reversal at the Congaree Formation that occurs southeast of Upper Three Runs Creek. The upward head differential has declined at a rate of about 0.16 meter per year over the last 10 years, primarily because of increased SRP pumping from the Tuscaloosa. The map of the head difference between the Tuscaloosa and Congaree Formations at Savannah River Plant (Figure 3-9) shows that in 1982 the head reversal was still a general situation in the Savannah and Upper Three Runs Creek valleys.

To illustrate the 1982 vertical head relationship in the central part of the Savannah River Plant, Figure 3-8 compares water levels measured in 1972 with water levels measured on November 7, 1982. Heads in the Barnwell, McBean, and Congaree in 1982 were from 1.0 to 1.5 meters below the 1972 level, but the Tuscaloosa water levels were 2.5 to 3.5 meters below the 1972 level. Even though the upward head differential between the Congaree and the Tuscaloosa Formations was still present, it was reduced. Closer to the Savannah River, the current head differential is about 9 meters, as shown in Figure 3-9.

As water is pumped from an aquifer, the water level in the vicinity of the well must be depressed. The amount of head depression to obtain a given pumping rate depends on the transmissivity of the aquifer. The transmissivity of the Tuscaloosa is very high (i.e., a median value of 1366 cubic meters per day per meter at Savannah River Plant). Thus the cones of depression at the pumping centers for the Tuscaloosa are not areally extensive or very deep. The drawdowns in the vicinity of most 3.5- to 4.0-cubic-meter-per-minute wells in the Tuscaloosa are about 6 to 12 meters. During a pumping test at the Barnwell

TC Nuclear Fuel Plant (Mayer et al., 1973), water was withdrawn from the Tuscaloosa for 60 days at a rate of 10,900 cubic meters per day. A drawdown of about 0.15 meter was observed at SRP monitoring well P54, which is about 9 kilometers from the pumping well.

Even though these cones of water-level depression are not areally extensive, drawdowns of 6 to 12 meters are adequate to negate the upward head differential between the Congaree and Tuscaloosa Formations where it exists (see Sections 4.1.1.3, 5.1.1.4, and F.4.3). In areas where a downward head differen-

EL-12 tial exists, such as M-Area, the drawdowns increase the natural downward head differential in the area immediately around the pumping wells.

In South Carolina, the direction of ground-water flow in the Tuscaloosa and

TC Congaree Formations is from offsite areas through the SRP to the Savannah River. Similarly, in Georgia the ground-water flow in these formations is toward the river (Figures F-25 and F-26).

3.5 METEOROLOGY AND CLIMATOLOGY

The description of the meteorology of Savannah River Plant (SRP) and of the L-Reactor area is based on data collected at the Savannah River Plant and at

Bush Field, Augusta, Georgia (Du Pont, 1980c, 1982a; NOAA, 1981). Meteorological data tapes for 1975 through 1979 from the onsite meteorological program provided additional data for this analysis.

3.5.1 Regional climatology

The Savannah River Plant has a temperate climate, with mild winters and long summers. The region is subject to continental influences, but it is protected from the more severe winters in the Tennessee Valley by the Blue Ridge Mountains to the north and northwest. The SRP site and the surrounding area are characterized by gently rolling hills with no unusual topographical features that would have a significant influence on the general climate.

Winters are mild and although cold weather usually lasts from late November to late March, less than one-third of the days have a minimum temperature below freezing.

3.5.2 Local meteorology

3.5.2.1 SRP meteorology data system

Meteorological data are collected from a system of seven towers located adjacent to each production area on the plant site and from the WJBF-TV tower located about 15 kilometers northwest of the SRP boundary. The seven towers are instrumented at the stack height of 61 meters with vector vanes designed for turbulence measurements (Kern and Mueller, 1979). The TV tower is instrumented at seven levels (Garrett and Hoel, 1982) with bivanes and fast-response cup anemometers to provide the same type of information as that received from the SRP towers (Kern and Mueller, 1979). Platinum resistance thermometers at each of eight levels on the TV tower provide temperature information in the lowest 300 meters of the atmosphere.

The data measured by this tower system are received in the Weather Center Analysis Laboratory (WCAL) by the PDP 11/40 (Digital Equipment Corporation) minicomputer. The latest two weeks of averaged data are also kept on the computer and made available to the VAX 11/780 (Digital Equipment Corporation) super minicomputer for use with various atmospheric transport and dispersion models.

The data collected from the SRP tower system and the WJBF-TV tower are used for real-time emergency response applications. Quality assurance inspections of meteorological data summaries generated hourly by the VAX 11/780 are routinely conducted. Regular inspection of the data summaries allows early detection of major system malfunctions so that necessary repairs can be made on a timely basis.

Automated quality assurance is incorporated into the system through the use of a quality control computer code (Pendergast, 1980). For each variable of the SRP tower data, a spatial average is calculated, as is the deviation of individual values from the spatial average. Deviations larger than the expected standard deviation of the variable indicate that the variable value is in error, and it is replaced with the new spatial average calculated without the erroneous value. Quality control of the WJBF-TV tower data is accomplished in the same manner after first being adjusted, using standard procedures, to the 61-meter SRP tower height. After corrections are made, data are adjusted back to the original heights.

In addition to the tower data, daily records consisting of maximum and minimum temperatures, rainfall, and continuous measurements of temperature, relative humidity, and pressure are kept. Rain gauges are also located at various locations on the SRP site.

An Echosonde doppler acoustic sounder has also been used and is available to provide real-time information on vertical mixing in the lowest 1 kilometer of the atmosphere (i.e., information on thermals, inversions, and depth of the mixed layer).

Regional and national meteorological data are available in the WCAL through the National Weather Service's Automated Field Operations and Service (AFOS) minicomputer system. Data on the AFOS system are available from any point within the AFOS network and can be received in either alphanumeric or graphic display form.

3.5.2.2 Temperature and humidity

Table 3-10 shows the average and extreme temperatures recorded for the Savannah River Plant. The annual average temperature at Savannah River Plant is 18°C. The monthly average temperature ranges from 7°C in January to 27°C in July (see Table 3-10). The extreme temperatures observed at the SRP site are -16°C and 41°C. The Augusta, Georgia, long-term temperature data are in agreement with the SRP data.

The length of the growing season for the Augusta area is normally 241 days, with the first freeze on November 12 and the last freeze on March 16. Freezing temperatures have been observed, however, as early as October 17 and as late as April 21.

The annual average daily relative humidity ranges from 43 percent to 90 percent for Savannah River Plant.

3.5.2.3 Average wind speed and direction

The average wind speed measured in Augusta from 1951 to 1981 was 3.0 meters per second. The average wind speed recorded at a height of 10 meters on the WJBF-TV tower near Beech Island, about 15 kilometers northwest of the SRP boundary, was 2.5 meters per second from 1976 to 1977. The average monthly wind speed for Augusta, Georgia, is shown in Table 3-11 along with the prevailing wind direction for each month. The monthly and annual average wind speeds for three levels of the television tower are also shown. Calms and wind speeds below 2 meters per second at the 62-meter height occur 15 percent of the time at the H-Area tower and 10 percent of the time at the K-Area tower.

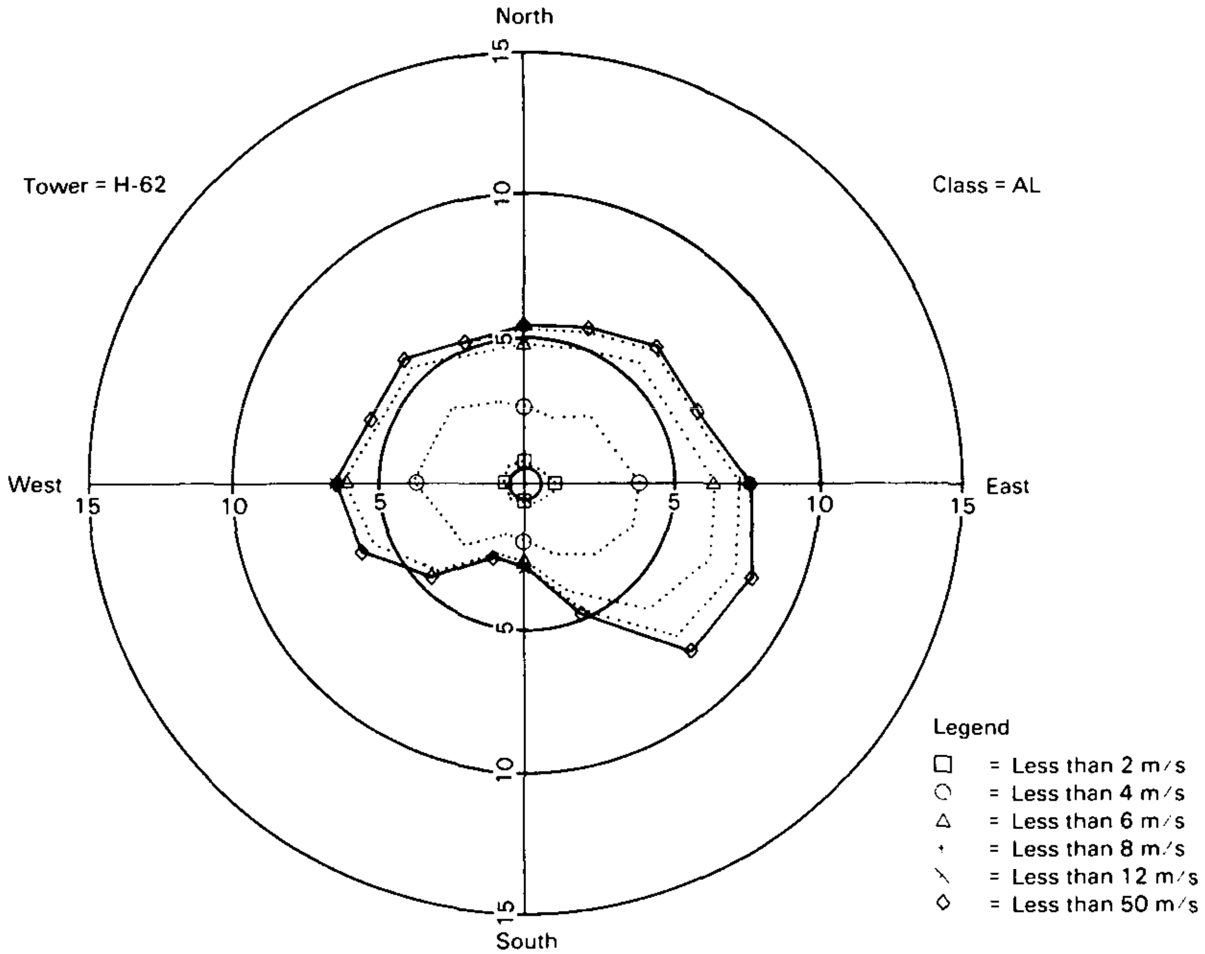
Table 3-10. Average and extreme temperatures at Savannah River Plant, 1961-1981

Month	Average temperature (°C) Daily maximum	Daily minimum	Monthly	Extreme temperature (°C) Record maximum	Record minimum
Jan.	13	2	7	30	-16
Feb.	16	3	9	27	-16
Mar.	20	7	13	32	-12
Apr.	25	12	18	35	0
May	28	16	22	37	5
June	32	19	26	41	9
July	33	21	27	41	14
Aug.	32	21	27	40	13
Sept.	29	18	24	38	5
Oct.	24	12	18	33	-2
Nov.	19	7	13	32	-8
Dec.	15	3	9	28	-11
Year	24	12	18	41	-16

Table 3-11. Average monthly wind speed for Augusta, Georgia, 1951-1981 and WJBF-TV tower, 1966-1977

Month	Mean speed (m/sec)	Prevailing direction	Tower elevation (m) 10	36	91
Jan.	3.2	W	3.0	4.5	6.1
Feb.	3.4	WNW	2.9	4.6	5.8
Mar.	3.6	WNW	3.3	4.5	5.9
Apr.	3.4	SE	2.8	4.2	5.4
May	2.9	SE	2.5	3.7	5.0
June	2.8	SE	2.4	4.0	4.8
July	2.6	SE	2.0	3.1	4.4
Aug.	2.5	SE	2.1	3.2	4.3
Sept.	2.5	NE	2.1	3.3	4.7
Oct.	2.6	NW	2.4	4.1	5.6
Nov.	2.8	NW	2.4	4.1	5.6
Dec.	3.0	NW	2.7	4.4	6.3
Annual	3.0	SE	2.5	3.9	5.3

Annual wind direction frequencies for SRP's H- and K-Areas are shown in the transport plots, Figures 3-12 and 3-13. The figures show the percent of time that the wind blows toward each of 16 directions (22.5° sectors). The data presented with these figures indicate the frequency with which the wind was blowing from the indicated direction. The information presented in these figures was

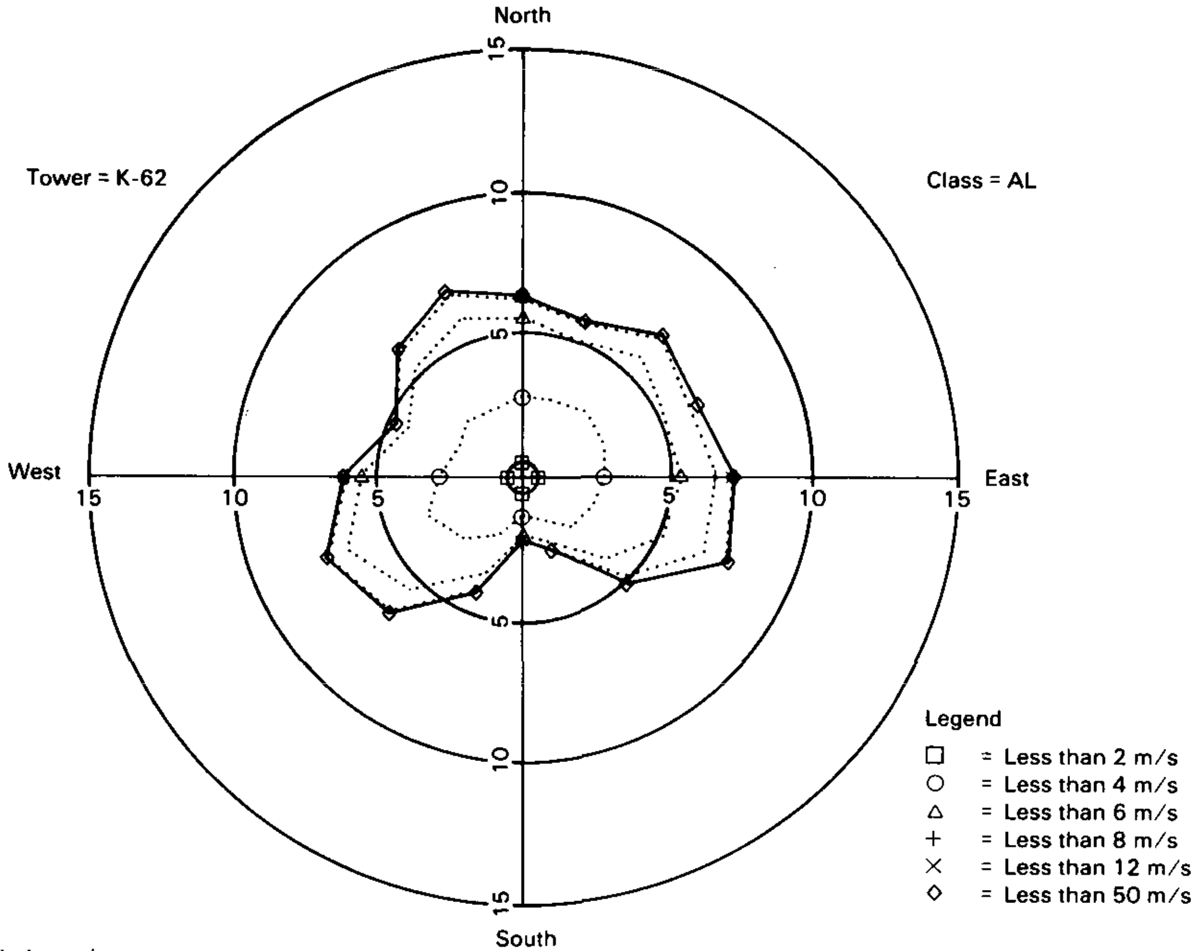


Windrose data

Minimum date	MMDDYY	10175	Maximum date	MMDDYY	123179
Minimum time	ZULU	0000	Maximum time	ZULU	2400
Entries all classes		111005	Entries this class		111005

	Speed in meters sec						Average		Percent time wind @ speed						
Direction	0-2	2-4	4-6	6-8	8-12	12	speed	Total	0-2	2-4	4-6	6-8	8-12	12	Total
N	695	1468	841	144	34	0	2.48	3182	63	1 32	76	13	03	0 00	2 87
NNE	699	1422	789	109	10	0	2.37	3029	.63	1 28	71	09	00	0 00	2 73
NE	908	2408	1439	285	35	0	2.64	5075	.82	2.17	1.30	26	.03	0 00	4 57
ENE	774	2636	2863	528	33	0	3.13	6834	.70	2 37	2.58	.48	03	0 00	6 16
E	844	3455	2665	321	22	0	2.98	7307	.76	3.11	2 40	29	02	0.00	6 58
ESE	794	2934	2318	268	13	0	2 95	6327	.72	2.64	2 09	24	01	0.00	5.70
SE	891	3039	2195	395	35	0	2.88	6555	.80	2 74	1 98	36	03	0 00	5 91
SSE	789	2487	2015	441	72	0	2.98	5804	.71	2.24	1.82	40	06	0 00	5 23
S	825	2087	2328	593	107	0	3.01	5940	.74	1.88	2 10	.53	09	0.00	5 35
SSW	665	1985	2831	708	130	1	3 29	6320	.60	1 79	2.55	.64	12	00	5 69
SW	752	2777	2794	730	157	0	3.21	7210	.68	2.50	2.52	66	14	0.00	6 50
WSW	860	2751	2568	739	203	22	3.14	7143	.77	2.48	2.31	67	18	02	6.43
W	1151	3257	2891	910	393	33	3.09	8635	1.04	2.93	2.60	82	35	.03	7 78
WNW	1126	3314	3250	1046	622	58	3.23	9416	1.01	2.99	2.93	94	.56	.05	8.48
NW	925	2944	2946	1409	841	42	3.43	9107	.83	2.65	2 65	1.27	.76	.03	8.20
NNW	850	2083	1535	549	308	9	2.91	5334	.77	1.88	1.38	.49	.28	00	4.81
No direct	3043	3066	1273	226	51	128	1.86	7787	2.74	2.76	1.15	.20	04	.12	2.87
Avg speed	1.21	2.96	4.78	6.68	9.17	15.39	2.90								
Total entry	16591	44113	37541	9401	3066	293		111005							

Figure 3-12. Savannah River Plant H-Area wind rose, 1975-1979.



Windrose data

Minimum date	MMDDYY	10175	Maximum date	MMDDYY	123179
Minimum time	ZULU	0000	Maximum time	ZULU	2400
Entries all classes		113511	Entries this class		113511

	***********Speed in meters/sec***********						Average		**************Percent time wind @ speed***********						
Direction	0-2	2-4	4-6	6-8	8-12	>12	speed	Total	0-2	2-4	4-6	6-8	8-12	>12	Total
N	469	1076	747	195	48	0	2.66	2535	.41	.95	.66	.17	.04	0.00	2.23
NNE	634	1774	1696	691	168	12	3.11	4975	.56	1.56	1.49	.61	.15	.01	4.38
NE	563	2807	2922	1145	114	38	3.52	7589	.50	2.47	2.57	1.01	.10	.03	6.69
ENE	710	3336	3446	848	107	9	3.38	8456	.63	2.94	3.04	.75	.09	.00	7.45
E	569	2744	3069	613	83	26	3.42	7104	.50	2.42	2.70	.54	.07	.02	6.26
ESE	542	2173	2212	469	48	2	3.22	5446	.48	1.91	1.95	.41	.04	.00	4.80
SE	644	2368	3013	815	97	4	3.41	6941	.57	2.09	2.65	.72	.08	.00	6.11
SSE	496	2336	3755	1043	177	18	3.73	7825	.44	2.06	3.31	.92	.16	.01	6.89
S	536	2569	3037	752	185	12	3.55	7091	.47	2.26	2.68	.66	.16	.01	6.25
SSW	559	2600	2532	700	131	13	3.35	6535	.49	2.29	2.23	.62	.12	.01	5.76
SW	688	2828	3018	1072	167	18	3.42	7791	.61	2.49	2.66	.94	.15	.01	6.86
WSW	608	2789	2606	1034	330	38	3.48	7405	.54	2.46	2.30	.91	.29	.03	6.52
W	631	2588	2982	1391	675	56	3.71	8323	.56	2.28	2.63	1.23	.59	.04	7.33
WNW	614	2339	3011	1725	995	84	3.87	8768	.54	2.06	2.65	1.52	.88	.07	7.72
NW	614	2090	1881	944	343	37	3.33	5909	.54	1.84	1.66	.83	.30	.03	5.21
NNW	444	1315	951	324	74	1	2.89	3109	.39	1.16	.84	.29	.06	.00	2.74
No direct	2247	3071	1623	555	132	81	2.23	7709	1.98	2.71	1.43	.49	.12	.07	2.23
Avg speed	1.25	2.99	4.86	6.69	9.16	14.85	3.31								
Total entry	11568	40803	42501	14316	3874	449		113511							

Figure 3-13. Savannah River Plant K-Area wind rose, 1975-1979.

produced from data taken at the 61-meter level (the stack height in most of the production areas) for the H- and K-production areas on the SRP site. Because pollutant dispersion depends on atmospheric stability, wind frequencies are presented for each of seven Pasquill-type stability classes discussed in Appendix B. Annually, the predominant transport is from the west-northwest toward the east-southeast with a secondary maximum from the east-northeast toward the west-southwest. The transport for winter is generally from the northwest toward the southeast. The spring transport is generally from the west toward the east, the summer transport generally toward the southeast through north to northeast, and the autumn transport generally toward the southwest and southeast. Because the pollutant dispersion depends on atmospheric stability, annual wind roses are available for each of seven Pasquill-type stability classes; seasonal wind roses are also available (Hoel, 1983).

3.5.2.4 Precipitation

The average annual rainfall at Savannah River Plant from 1952 through 1978 was about 120 centimeters (Du Pont, 1982a). The average annual rainfall at Augusta from 1941 to 1970 was about 108 centimeters (NOAA, 1981). Table 3-12 lists the means and extremes of precipitation for Savannah River Plant from 1952 to 1982. The maximum monthly precipitation at Savannah River Plant was about 31.6 centimeters, recorded in August 1964. Hourly observations in Augusta show that the intensity of the rainfall is normally less than 1.3 centimeters per hour.

Table 3-12. Precipitation at Savannah River Plant, 1952-1982[a]

Month	Monthly precipitation (cm)		
	Maximum	Minimum	Average
Jan.	25.6	2.3	10.7
Feb.	20.3	2.4	10.9
Mar.	28.0	3.8	12.9
Apr.	21.0	1.5	8.9
May	27.9	3.4	10.8
June	27.9	3.9	11.1
July	29.4	2.3	12.5
Aug.	31.6	2.6	11.7
Sept.	22.3	1.4	10.2
Oct.	27.8	0.0	6.2
Nov.	16.5	0.5	5.9
Dec.	24.4	1.2	9.5
Annual			121.3

[a]Adapted from Du Pont (1983b).

3.5.3 Severe weather

3.5.3.1 Extreme winds

The strongest winds in the SRP area occur in tornadoes, which can have wind speeds as high as 116 meters per second. The next strongest surface winds occur during hurricanes. During the history of the Savannah River Plant, only Hurricane Gracie, in September 1959, had winds in excess of 34 meters per second. Winter storms with winds as high as 32 meters per second have been recorded occasionally (Du Pont, 1982a). Thunderstorms can generate winds as high as 18 meters per second and even stronger gusts. The fastest 1-minute wind speed recorded at Augusta between 1951 and 1980 was 28 meters per second. Table 3-13 lists the extreme wind speeds for 50- and 100-year return periods for three locations about equally distant from Savannah River Plant (Simiu, Changery, and Filliben, 1979). Section 4.2.2.4 contains return periods from 1-minute wind speeds at Augusta.

Table 3-13. Extreme wind speeds for SRP area[a] (meters per second)

Station	Return period	
	50-year	100-year
Greenville, S.C.	35	38
Macon, Ga.	30	31
Savannah, Ga.	35	39

[a]Adapted from Simiu, Changery, and Filliben (1979).

3.5.3.2 Thunderstorms

There is an average of 54 thunderstorm days per year at SRP. The summer thunderstorms occur primarily during the late afternoon and evening; they may be accompanied by strong winds, heavy precipitation, or, less frequently, hail (NOAA, 1981). Summer thunderstorms are due primarily from convective activity resulting from solar heating of the ground and radiational cooling of cloud tops. Thunderstorm activity in the winter months is due mainly to frontal activity.

3.5.3.3 Tornadoes

In the southeastern United States most tornadoes occur in early spring and late summer, with over 50 percent occurring from March through June. In South Carolina, the greatest percentage of tornadoes occurs in April and May, about 20 percent (Pepper and Schubert, 1978) in August and September. The latter are mainly the result of spawning by hurricanes and waterspouts. One or two tornadoes can be expected in South Carolina during April and May, with one expected in each of the months March, June, July, August, and September (Purvis, 1977).

Weather Bureau records show 278 tornadoes in Georgia over the period
TE| 1916-1958 and 258 tornadoes in South Carolina for the period 1950-1980 (Table 3-14). The general direction of travel of confirmed tornado tracks in Georgia and South Carolina is from southwest to northeast.

Table 3-14. Tornado occurrence by month

Month	Georgia (1916-1958)		South Carolina (1950-1980)[a]	
	Number	Percent	Number	Percent
Jan.	24	8.6	6	2.3
Feb.	23	8.3	14	5.4
Mar.	49	17.6	26	10.1
Apr.	93	33.5	40	15.5
May	20	7.2	53	20.5
June	14	5.0	20	7.8
July	5	1.8	17	6.6
Aug.	10	3.6	25	9.7
Sept.	8	2.9	23	8.9
Oct.	2	0.7	8	3.1
Nov.	15	5.4	11	4.3
Dec.	15	5.4	15	5.8
Total	278		258	

[a]Tornado Frequency Table for South Carolina 1950-1980. Obtained from National Severe Storms Forecast Center, Kansas City, Missouri.

Occasional tornadoes are to be expected in the SRP area. Investigations of tornado damage near Savannah River Plant in 1975 and 1976 indicated wind speeds varying from 45 to 78 meters per second (Du Pont, 1980c).

The annual probability of a tornado striking a building the size of L-Reactor at SRP is discussed in Section 4.2.2.4.

3.5.3.4 Hurricanes and high winds

Thirty-eight hurricanes have caused damage in South Carolina during the 272 years of record (1700 to 1972); the average frequency was one storm every 7 years. The hurricanes affecting South Carolina predominantly occurred during August and September. At the SRP site, 160 kilometers inland, hurricane wind speeds are significantly less than observations along the coast. Winds of 34 meters per second were measured on the 61-meter towers only once during the history of the Savannah River Plant, when Hurricane Gracie passed to the north on September 29, 1959 (Du Pont, 1982a).

3.5.3.5 Precipitation extremes

Heavy precipitation can occur in the SRP area in association with either localized thunderstorms or hurricanes. The maximum 24-hour total was about 15.2 centimeters, which occurred during August 1964 in association with Hurricane Cleo.

3.5.3.6 Hail and ice storms

Hail in association with a severe thunderstorm can be expected to occur in the area about once every 2 years. Damage from such hail is rare. Ice storms caused by freezing rain can be expected about once every 4 years and are usually of short duration (Du Pont, 1982a).

3.5.4 Atmospheric dispersion

3.5.4.1 Atmospheric stability

Transport and dispersion of airborne material are direct functions of air movement. The direction and speed of transport are governed by the large-scale movements (i.e., by general synoptic flow patterns and by the nature of the terrain), whereas the diffusion of airborne material is governed by small-scale, random eddying of the atmosphere (i.e., turbulence). Turbulence is indicated by atmospheric stability classification. Approximately 25 percent of the time, the atmosphere is unstable in the SRP region; 25 percent of the time, it is neutral; and 50 percent of the time it is stable.

3.5.4.2 Mixing heights and low-level inversions

The mixing height is the level of the atmosphere below which pollutants are easily mixed; it is often equal to the base of an elevated inversion. The depth of the mixed layer at Savannah River Plant has been measured by an acoustic sounder (Schubert, 1975). The acoustic data indicate that, as the day progresses, the mixing height rises beyond the 1000-meter range of the sounder.

An analysis of 5 years of upper-air meteorological data recorded at several stations in the SRP area (Holzworth, 1972) provides further mixing-height information. The average afternoon mixing height is about 1005 meters in the winter, 1700 meters in the spring, 1890 meters in the summer, and 1400 meters in the autumn. Mixing heights over the rural SRP site could be expected to be slightly lower.

Temperature inversions (air temperature increases with the height above the ground) inhibit atmospheric turbulence and, hence, are associated with small rates of atmospheric diffusion. Detailed temperature inversion data are available from instruments on the WJBF-TV tower. The 1974 temperature measurements between 3 and 335 meters were analyzed to determine the frequency of occurrence of several categories of temperature structure (Pendergast, 1976). About 30 percent of the time, a temperature inversion extended to or beyond the 3- to 335-meter layer. About 12 percent of the time, there was an elevated inversion with an unstable layer below; this represents the early morning breakup of a nighttime inversion. About 9 percent of the data showed an inversion at the lower levels with an unstable layer above; this represents the transition period between an unstable daytime regime and the onset of a nighttime inversion.

3.5.4.3 Restrictive dilution conditions

The dilution capacity of the atmosphere depends on local wind speed, wind direction variability, mixing depth, and vertical temperature profile. From 1960 to 1970 the SRP area had about 50 forecast-days of high meteorological potential for air pollution (episodes), or an average of about 5 days per year (Holzworth, 1972). Episodes are most frequent in autumn, when large anticyclones, which are characterized by low wind speeds, clear weather, and large-scale temperature inversions, become nearly stationary off the Atlantic coast, affecting much of the eastern United States.

3.5.4.4 Air quality

The South Carolina and Georgia state governments have established air quality sampling networks. The Savannah River Plant operates an onsite sampling network. These networks monitor suspended particulates, sulfur dioxide, and nitrogen dioxide. Ambient concentrations of these pollutants near Savannah River Plant in 1980 were below the local air quality standards in effect at that time.

3.5.4.5 Correlation of predicted to measured offsite airborne radionuclide concentrations

A statistical air pollution model, XOQDOQ, uses joint-frequency data on wind speed, wind direction, and atmospheric stability class to estimate average relative effluent concentrations, X/Qs, and average relative deposition values, D/Qs, at specified locations and at standard radial distances for downwind. It is based on a modified Gaussian plume equation which assumes uniform horizontal dispersion over each of 16 sectors and calculates vertical dispersion using curves fitted with polynomials (Sagendorf and Goll, 1977). The mixing height is set to 1000 meters.

Predictions of the model were compared with measurements in air of the inert radioactive gas, krypton-85, which is routinely emitted in small quantities from the chemical separations facilities at Savannah River Plant (Telegadas et al., 1980). The model predictions were slightly higher than monitored values.

3.6 ECOLOGY

Savannah River Plant (SRP) was approximately one-third forested and the remaining area consisted of cropland when it was acquired by the U.S. Government in 1951. During the past 32 years, forestry management practices, natural succession, and the construction and operation of nuclear reactors and their support facilities have resulted in the ecological complexity and diversity of the site. The Savannah River Plant is one of the most intensively studied environments in this country; results of these studies and environmental studies in Steel Creek, the Savannah River swamp, and the Savannah River are presented in Appendix C.

3.6.1 Terrestrial ecology

3.6.1.1 Soils

Soils are an important component of the environment because they influence the occurrence and distribution of the vegetation, wildlife, and potential land use by man. The distribution of soils of the Steel Creek watershed is shown in Figure C-2. The portion of the watershed depicted here covers approximately 20,000 acres and includes 24 different soil types. The most widely distributed soils of the Steel Creek watershed are Blanton sand (14 percent), Wagram loamy sand (13 percent), Troup sand (12 percent), Orangeburg loamy sand (8 percent), Rembert sandy loam (8 percent), Fuquay loamy sand (7 percent), and Wehadkee loam (7 percent). Streambed soils of Steel Creek consist primarily of Bibb sandy loam; these soils were scoured and eroded during previous reactor operations. The dominant texture of the surficial horizons is loamy sand and sandy loam. Slopes typically range less than 6 percent and most soils are well drained.

3.6.1.2 Vegetation

The Savannah River Plant is near the line that divides the oak-hickory-pine forest and the southern mixed forest (Kuchler, 1964). Consequently, it has species representative of each forest association. In addition, SRP vegetation has been influenced strongly by farming, fire, soil features, and topography; no virgin forest remains in the region (Braun, 1950). Except for the production areas and their support facilities, many previously disturbed areas have been reclaimed by natural plant succession or planted with pine by the U.S. Forest Service.

The operation of L-Reactor will produce impacts on plant communities in two wetland areas: (1) those associated with the Steel Creek corridor from the L-Reactor outfall to the delta, and (2) those associated with the Steel Creek delta and that portion of the swamp near the confluence of Steel Creek with the Savannah River. The structure and species composition of these areas reflect not only the heterogeneity of the physical environment, but also the impacts of earlier reactor operations. The wetlands, for example, are the culmination of 15 years of natural succession; they are structurally different from the closed canopy of mature cypress and tupelo gum that existed prior to the existence of the SRP (Sharitz, Irwin, and Christy, 1974). The Fish and Wildlife Service has classified these wetlands as Resource Category 2. The designation criteria for this resource category include "high value for evaluation species and scarce or becoming scarce." The mitigation planning goal specifies that there be "no net loss of inkind habitat value" (USDOI, 1981).

TC

FK-6

3.6.1.2.1 Steel Creek corridor

The vegetation of the Steel Creek corridor, which is classified as palustrine wetland (Cowardin et al., 1979), varies markedly above the delta (Figure C-3). More than 85 species of plants representing 50 families were listed from this area in the summer of 1981 (Appendix C). This parcel consists of aquatic beds, emergents, scrub-shrub wetland, and forested wetland; the dominant flora of these cover types is described briefly in the following sections (Smith, Sharitz, and Gladden, 1981).

Aquatic bed

The outfall canal of L-Reactor contains open water bordered by persistent herbaceous species and occasional shrubs.

Emergent wetland

Emergent wetland communities consists of both persistent and nonpersistent vegetation. Persistent vegetation is dominated by dense grasses and forbs with scattered low shrubs. Polygonum dominates a single nonpersistent community just north of the Steel Creek delta. This deeply rooted, emergent annual is bordered by persistent herbs, including cattail, burreed, Canada rush, and sugarcane beardgrass.

Scrub-shrub wetland

Two scrub-shrub wetland communities exist in the corridor. One is dominated by a dense canopy of buttonbush and willow. The second covers approximately 24 percent of the floodplain and is dominated by alder, the dominant species on Steel Creek. Beneath these shrubs, blackberry is abundant over a diverse herbaceous flora of false nettle, goldenrod, wapato, jewelweed, cutgrass, knotgrass, and water purslane. The alder community generally borders the steam channels and, for most of the length of Steel Creek, extends nearly across the width of the floodplain.

Forested wetland

Approximately 73 percent of the wetland vegetation from the outfall to the delta consists of broad-leaved deciduous and coniferous/deciduous communities. Nearly half (46 percent) of these wetlands are dominated by wax myrtle and alder. These codominants reach heights of more than 7 meters and grow in dense stands. Willow-dominated communities rank second (13 percent) in vegetative coverage; they are more common near the mouth of Steel Creek. The herbaceous stratum is sparse. A mixed deciduous/coniferous community codominated by cypress and tupelo occurs just above Road A and also above the Seaboard Coast Line Railroad. This type of community is much more common in the swamp. Many small communities containing a mixture of sweetgum, red maple, and willow occur intermittently below the outfall. Upland arboreal species adjacent to Steel Creek have become established on the more stable sandbars and near bridges and dikes. Also common are tulip tree, sycamore, and various shrubs. The herbaceous flora is diverse.

3.6.1.2.2 Steel Creek delta

The Steel Creek delta contains ten vegetative associations and four zones differentiated by the degree of prior reactor discharges of thermal effluent (refer to Figure C-4). Impacted zones that have experienced structural reductions of the vegetative canopy include deepwater habitats and the deltaic fan. Bottomland hardwoods and deepwater and upland habitats constitute the non-impacted zones. Since the shutdown of L-Reactor in 1968, vegetative recovery has varied according to the hydrologic regime (refer to Figure C-4).

The deltaic fan zone, which was formed by the deposition of sediments at the mouth of Steel Creek, consists of a raised substrate composed primarily of organic and alluvial deposits over sand (Ruby, Rinehart, and Reel, 1981). Measuring approximately 1200 meters by 500 meters, it is stabilized by vegetation. The more successionally advanced vegetation stages include (1) broad-leaved deciduous forest (willow), (2) scrub-shrub wetland (buttonbush and willow), and (3) persistent emergent wetland.

The impacted deepwater zone (refer to Figure C-4) extends as an arc on the periphery of the deltaic fan. Most of the trees in this zone were eliminated during earlier thermal discharges. The zone is characterized by scattered cypress, an abundance of stumps bearing shrubs, and submergent and nonpersistent aquatic herbs. The rooted vascular aquatic bed, nonpersistent emergent wetland, mixed forest/scrub-shrub wetland, and mixed scrub-shrub/rooted vascular wetland associations have their best developments here.

The nonimpacted deepwater zone contains mixed deciduous forest that was typical of the swamp before the beginning of thermal discharges. The underlying substrate near the impacted zone is composed of fine particulate material less than 0.5 meter deep (Ruby, Rinehart, and Reel, 1981).

The bottomland hardwood zone generally is flooded in the spring, but not during the growing season. Two types of broad-leaved deciduous forest are found exclusively in this zone: areas dominated by laurel oak that are inundated only during the flood stage; and an area of intermixed overcup oak, water hickory, and water tupelo that might retain standing water until early in the growing season.

Figure C-5 shows the distribution of the principal plant communities of the Steel Creek delta, as determined from 1978 aerial photography and field studies conducted in the summer of 1981; the classification and mapping terminology follow Cowardin et al. (1979), with minor modifications (Smith, Sharitz, and

Gladden, 1981). All categories are termed palustrine, which includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, or emergent mosses or lichens.

Approximately one-fourth of the delta area is covered by shrub communities dominated by buttonbush and willow. Five habitat types are similar in coverage, and three minor habitat types also occur. Forested areas dominated by cypress and water tupelo border the delta. More than 123 species of plants representing 66 families were listed during the 1981 field studies (Smith, Sharitz, and Gladden, 1981).

Smith, Sharitz, and Gladden (1982b) present another vegetative map of the Steel Creek delta based on more recent (1981) aerial photography and revised ordination analyses. The principal difference between the vegetative maps is that buttonbush and willow shrub communities have expanded into areas previously occupied by emergent grasses and other herbaceous species. Additionally, vegetative cover types have been modified slightly.

3.6.1.2.3 Commercially valuable biota

Commercially valuable plant biota on the Savannah River Plant include approximately 175,000 acres of timber managed by the U.S. Forest Service.

3.6.1.3 Wildlife

The abundance and diversity of wildlife that inhabits the Savannah River Plant reflect the interspersion and heterogeneity of the habitats occurring there. Emphasis has been given to those fauna that inhabit Steel Creek and the Savannah River swamp. No species have been found in the Steel Creek system that have not been found elsewhere on the SRP site.

TC

Amphibians and reptiles

Because of its temperate climate and the variety of aquatic habitats, the SRP site contains a diversified and abundant herpetofauna. Species include 17 salamanders, 26 frogs and toads, 10 turtles, 1 crocodilian, 9 lizards, and 31 snakes that have zoogeographic ranges that include the Savannah River Plant (Conant, 1975). The ranges of many other species are peripheral to Savannah River Plant, and they could also occur on SRP lands. Gibbons and Patterson (1978) provide an overview of the herpetofauna, including the abundance and peripheral species.

During field studies conducted in 1981 and 1982, more than 1560 individuals representing 65 species were collected or observed in the Steel Creek area. In the order of decreasing relative abundance, frogs and toads, turtles, and salamanders constituted more than 85 percent of the species. Six habitat types were examined during the surveys: (1) the stream channel below the delta, (2) the stream channel above the delta, (3) the delta, (4) islands, (5) the floodplain, and (6) the swamp forest. Twice as many species were collected on the floodplain as in the other habitats, because of its greater habitat interspersion (Smith, Sharitz, and Gladden, 1981).

Earlier studies (Freeman, 1955; Jenkins and Provost, 1964) indicate that the alligator has always been a resident of the area. Its abundance probably increased greatly after the Savannah River Plant was closed to the public in the early 1950s.

Studies of the American alligator in the Steel Creek ecosystem were begun in 1981 and have included censuses by foot, boat, and air; capture and release; and radiotelemetry (Smith, Sharitz, and Gladden, 1981, 1982a,b). These investigations confirm that alligators have utilized the Steel Creek ecosystem from the L-Reactor outfall to the Steel Creek delta and swamps, including other areas near Steel Creek such as Carolina bays, backwater lagoons, and beaver ponds. The population of alligators in 1981 and 1982 in the Steel Creek ecosystem was estimated to range between 23 and 35 individuals (Smith, Sharitz, and Gladden, 1982b). Sex ratios and size data suggest a higher reproductive potential in Steel Creek than in Par Pond, where nearly 80 percent of the adults are males (Murphy, 1977).

Studies of the wintering behavior and movements of alligators in the Steel Creek ecosystem were initiated in 1981 using radiotelemetry (Smith, Sharitz, and Gladden, 1982a). Generally, it was found that alligators on the Savannah River Plant do not utilize over-wintering dens, but remain active whenever winter temperatures are suitable. Alligators were able to survive with a body temperature as low as 3.3°C (Smith, Sharitz, and Gladden, 1982a), the coldest ever recorded for a free-ranging alligator. Based on radiotelemetric studies using three individuals, alligators moved between the lagoons near S.C. Highway 125. Alligators also utilized the swamp forest below the Steel Creek delta (Smith, Sharitz, and Gladden, 1982b). In 1981, a single alligator nest was located at the edge of the Steel Creek delta, but hatching was unsuccessful. No nests have been located in the Steel Creek system since 1981.

Birds

Birds of the Steel Creek ecosystem were studied in the summer of 1981 at eight locations, using a combination of strip censuses, mist nets, and aerial surveys. A total of 1062 birds representing 59 species were tabulated during the summer survey; these species presumably breed locally.

Active nests of the Bachman's sparrow, parula warbler, and red-headed woodpecker were observed, as were juveniles of 22 other species. The white-eyed vireo was the most abundant species based on all census techniques, followed closely by the Carolina wren (Smith, Sharitz, and Gladden, 1981). The frequency of observation or capture of the other species was relatively similar, and no single species dominated the census results.

Because of the interspersion of habitats and isolation from public hunting, the Steel Creek delta and Savannah River swamp provide an important sanctuary for regional waterfowl. Based on ground counts and aerial surveys, nine species of waterfowl have been observed in the Steel Creek delta area. The mallard and wood duck were the most predominant species of water fowl; both extensively utilized the Steel Creek delta for roosting and feeding. The maximum numbers of mallards and wood ducks that have been tabulated on the delta were approximately 1100 and 400, respectively. Comparisons of the use by waterfowl of the Steel Creek delta with the use of Pen Branch, Four Mile Creek, and Beaver Dam Creek showed that (1) in 1982, utilization was highest in the Steel Creek delta,

(2) Pen Branch delta is unattractive to waterfowl during winter, and (3) the Four Mile and Beaver Dam Creek areas periodically provide good waterfowl habitat.

The wood stork, which is an endangered species, uses the Steel Creek delta for feeding grounds. A total of 102 individuals were observed feeding on or near the Steel Creek delta in late June to early July 1983. The maximum number TC of observations throughout the SRP swamp during this same period was 478 (Smith, Sharitz, and Gladden, 1983). The Savannah River swamp, particularly the deltas of Beaver Dam and Steel Creeks, provide important feeding habitat for wood storks from the Birdsville rookery near Millen, Georgia.

Mammals

The Savannah River Plant includes zoogeographic ranges of more than 40 species of mammals, including the muskrat and black bear, which are known to occur near Steel Creek.

The short-tailed shrew, the least shrew, and the southeastern shrew predominated among the small mammals captured by means of drift fences, pitfall traps, and board transects during the summer of 1981. The Steel Creek delta provides habitat for the rice rat, and probably for the eastern woodrat and the hispid cotton rat. The gray squirrel, the fox squirrel, and the southern flying squirrel were common in the upland and lowland forests along Steel Creek. Large mammals such as the feral pig and the white-tailed deer were common on the Steel Creek floodplain and delta. Other inhabitants of the floodplain and delta included the raccoon, the opossum, and the gray fox. Beaver signs were common along the length of Steel Creek.

3.6.1.4 Endangered and threatened species

TC Two species that are listed as endangered by the U.S. Fish and Wildlife Service (USDOI, 1983, 1984)--the American alligator and the wood stork--have been identified in the area. No plant species with protective status has been found. No "critical habitat," as defined by the U.S. Fish and Wildlife Service, exists on the Savannah River Plant.

American alligator - Listed federally as endangered (USDOI, 1983), the alligator is common locally and breeds in Par Pond, in the Savannah River swamp (Gibbons and Patterson, 1978; Murphy, 1977), and along Steel Creek. The ecology of this species has been examined intensively on the Savannah River Plant.

AD-12 Wood stork - The endangered wood stork (USDOI, 1984) forages in the Steel Creek delta. According to recent studies, these birds are from the Birdsville rookery. The Steel Creek delta and other sites in the Savannah River swamp provide important feeding habitat for wood storks from the rookery.

These species and those listed by the State of South Carolina and the U.S. Fish and Wildlife Service as endangered, threatened, or of "special concern" are discussed in greater detail in Appendix C.

3.6.1.5 Commercially and recreationally valuable biota

Although the ecosystems on the SRP site support many populations of game and fish, commercial exploitation is prohibited and recreational use is restricted to controlled hunts of the white-tailed deer and feral hog.

3.6.2 Aquatic ecology

3.6.2.1 Aquatic flora

Approximately 400 species of algae have been discovered in the Savannah River near the Savannah River Plant (Patrick, Cairns, and Roback, 1967). Diatoms predominate the flora; blue-greens are sometimes common upstream from the site due to organic loading from municipal sources. Since 1951, when algae studies began, diversity has decreased, presumably as a result of increased organic loading to the Savannah River (ANSP, 1961; 1974).

Aquatic macrophytes in the river, most of which are rooted, are limited to shallow areas of reduced current and along the shallow margins of tributaries. Eight species of vascular plants have been discovered in the river adjacent to Savannah River Plant, the most abundant being water milfoil, hornwort, alligatorweed, water weed, and duck potato.

In the SRP streams that receive thermal effluents, the flora is sparse, reflecting the influence of high flow and elevated (greater than 40°C) water temperatures. In these streams, thermophilic bacteria and blue-green algae thrive (Gibbons and Sharitz, 1974).

A deepwater zone occurs where the main flow of Steel Creek courses toward the Savannah River. In this area, the vegetation is currently dominated by submergent and emergent macrophytes. Patches of duckweed occupy mats of submerged vascular plants such as hornwort and parrotfeather. Where the water flow is slow moving, smartweed forms dense colonies (Smith, Sharitz, and Gladden, 1981).

3.6.2.2 Aquatic fauna

3.6.2.2.1 Aquatic invertebrates

Shallow areas and quiet backwaters and marshes of the Savannah River near the SRP site support a diverse aquatic invertebrate fauna. However, the bottom substrate of most open portions of the river consists of shifting sand that does not provide the best habitat for bottom-dwelling organisms (Appendix C). A decrease during the 1950s in the total number of invertebrate species occurring in the river has been attributed primarily to the effects of dredging (Patrick, Cairns, and Roback, 1967). The stabilization of the river discharge and the elimination of habitat caused by the reduction in the flooding of backwater areas might have contributed to the decline. Some recovery occurred during the early 1960s, but complete recovery has not taken place. The groups most affected are those sensitive to the effects of siltation and substrate instability. Mayflies and dragonflies predominated among insect fauna in earlier surveys. In more recent surveys, true flies have been dominant. Results of insect faunal studies conducted during 1972 (ANSP, 1974) indicated substantial organic loading to the river upstream from Savannah River Plant.

An investigation of the aquatic invertebrate communities living on wood substrate and submerged macrophytes in the Steel Creek ecosystem is being conducted by the Savannah River Ecology Laboratory in the upper and lower reaches of the Steel Creek and in the floodplain swamp (Appendix C). Preliminary investigations and current literature show these habitats to be diverse, with high productivity.

During the spring and summer of 1982, macrobenthic drift population studies were conducted in the Savannah River, the pumphouse intake canals, Upper Three Runs Creek, Four Mile Creek, and Steel Creek as part of the Biological Measurement Program (Appendix C). The drift communities were dominated by true-flies (particularly chironomids), which is typical of a riverine system.

Mollusks, such as snails and clams, are an important component of the Savannah River invertebrate community (Patrick, Cairns, and Roback, 1967), but they do not occur in the drift communities, presumably because their relatively high density (weight) prevents them from floating. The Asiatic clam, Corbicula, is found in the Savannah River and larger tributary streams in the vicinity of the SRP.

3.6.2.2.2 Fish

The Savannah River and its associated swamp and tributaries are typical of southeastern coastal plain rivers and streams; they support a diverse fish fauna. Numerous aquatic studies have been conducted during the past 32 years. The results of these investigations are summarized in Appendix C. The diversity and abundance of fish in the thermally affected streams are high only during periods of reactor shutdown (McFarlane, 1976). In addition, the fauna upstream of the thermal effluents is depauperate in both numbers and diversity. With the exception of the mosquitofish, few fish live in the SRP thermal streams when heated effluent is present. During reactor shutdown, the streams return to ambient temperature and are invaded quickly by many fish from adjacent nonthermal areas. The diversity and abundance of species in the headwater tributaries of Four Mile Creek and Pen Branch upstream from reactor thermal effluents are reduced greatly in contrast to comparable areas in Upper Three Runs Creek or Steel Creek (McFarlane, 1976). Collection efforts have revealed that the first- and second-order tributaries of these streams are essentially devoid of fish.

Fish population studies conducted in the Steel Creek swamp system (Appendix C) indicate a high species diversity. Fish of all sizes were collected in the swamp and a wide range of sizes was collected for most species. The collections were representative of both relative abundance and species composition of the swamp fish community. A total of 5313 fish representing 55 species was collected from the Steel Creek river-swamp from November 1981 through July 1982. The high diversity of fish species is the result of the wide array of habitat types and niches available within the creek-swamp environment. The greatest abundance and diversity of fish occurred in deepwater areas where the tree canopy was eliminated during previous reactor operations, and the vegetation currently is dominated by submergent and emergent macrophytes.

The use of the Steel Creek delta-swamp area by anadromous fish species (e.g., American shad and blueback herring) was minimal during 1982, although some American shad and blueback herring spawned near the mouth of Steel Creek that year. The appearance of American shad in Steel Creek was late and the numbers were quite small. However, it appears that the shad spawning run in the Savannah River was smaller than in previous years. In 1983, the shad and herring spawning runs occurred earlier than in 1982. There was greater utilization of the Steel Creek delta-swamp by adults of the species in 1983 than in 1982. Also, two striped bass were collected in the delta-swamp area in 1983, while none were found the previous year.

The Biological Measurement Program in the Savannah River was initiated in March 1982 (Appendix C). This long-term study focused on fish populations, meroplankton communities, and fish impingement and entrainment. Results of studies completed to date are presented in reports by Environmental and Chemical Sciences, Inc. (ECS, 1983a-c). The program involved meroplankton, electrofishing, and hoopnet collections in the Savannah River, Upper Three Runs Creek, Four Mile Creek, Steel Creek, and at two pumphouse intake canals. Collections were also made of fish impinged on the traveling screens at the three pumphouse intake canals. Additionally, ichthyoplankton samples were collected by the Savannah River Ecology Laboratory (SREL) in the Steel Creek delta and Steel Creek during the 1982 and 1983 spawning runs (Smith, Sharitz, and Gladden, 1983).

The fish larvae collected during the March-through-August-1982 period in the Savannah River were primarily herring and shad, with unidentified minnows and spotted suckers being abundant. Fish eggs collected were primarily American shad. Striped bass and blueback herring eggs were abundant during a short period of time. Peak spawning activity occurred in May. Striped bass spawning, previously not recorded from the central Savannah River area, was noted in May and July. Fifteen sturgeon larvae were also collected; these have been identified as including both the Atlantic and shortnose sturgeon.

In 1983, ichthyoplankton collections were made in the river from March through July. The peak spawning activity again occurred in May. The larvae collected in greatest numbers were species of the clupeid family (i.e., Dorosoma sp., blueback herring, American shad). Larvae of the crappie and various minnows were also abundant. As in 1982, most of the fish eggs collected were American shad. Striped bass eggs and larvae were prevalent in May and June, and a few were also found in April. Ten sturgeon larvae were collected in the river in 1983; four were shortnose sturgeon (in March) and six were Atlantic sturgeon (in April, May, and June). TC

The 1983 data indicate a trend in the distribution of fish spawning in the river. In general, during February, March, and April, densities of total ichthyoplankton (eggs and larvae combined) were highest in the lower reaches of the river (from River Mile 30 to River Mile 120); they decreased in an upstream direction. May was a transitional month when densities were more uniform throughout the river. During June and July, densities were generally higher in the nearfield (from River Mile 130 to River Mile 157) and upper farfield (from River

Mile 167 to River Mile 187) than in the areas downstream. The trend of generally higher densities nearer the river mouth earlier in the year is probably due to the fact that the lower Savannah River warmed more rapidly than the upper reaches and provided suitable spawning conditions for a longer period of time. However, factors such as the migratory movement of spawning adults might also play a role in these trends.

The intake canals had high densities of larvae and low densities of eggs. The eggs entrained in the canals probably settled to the bottom because of low-flow rates in the canal.

In 1982, Steel Creek and Upper Three Runs Creek contained numerous larvae and were sites for blueback herring spawning. In 1983, the larvae taken in Steel Creek were predominantly minnows, yellow perch, sunfish, and bass. Many blueback herring eggs were also collected. When compared with 19 other creeks that were sampled 10 or more times, Steel Creek ranked eighth in the density of all larval species combined. This creek was distinctive in that minnows and yellow perch represented about 27 and 30 percent, respectively, of the fish larvae collected. In all other streams of similar size, these two species represented no more than about 13 and 7 percent of the total larvae, respectively. In Steel Creek, densities of crappie larvae relative to other species were much lower than in the other large streams sampled.

Much more fish spawning occurred in Four Mile Creek in 1983 than in 1982, apparently because high river levels reversed stream flow enough to allow fish to enter the creek. A high density of larvae, mostly blueback herring, was observed on April 4, 1983. However, similar medium-sized streams that were sampled had higher larval densities and longer spawning periods than Four Mile Creek. Apparently, the elevated water temperature in this stream was a factor that limited spawning.

Ichthyoplankton collections made by SREL in Steel Creek and the Steel Creek delta from February 28 to June 2, 1983 (Smith, Sharitz, and Gladden, 1983), were dominated by yellow perch, brook silversides, blueback herring, and black crappie.

3.6.2.3 Endangered and threatened species

Two species listed as "endangered" by the Federal Government (USDOI, 1983) and/or the State of South Carolina (Forsythe and Ezell, 1979) are known to occur on or in the vicinity of the SRP. These are the shortnosed sturgeon (Federal list) and the brother spike mussel (state list).

The shortnose sturgeon is found only on the east coast of North America in tidal rivers and estuaries. Prior to 1982, this species had not been reported in the middle reaches of the Savannah River in the vicinity of SRP. However, in 1982 and 1983, shortnose sturgeon larvae were collected in the river near the site, indicating that spawning had occurred in this area. The only known occurrence of the brother spike mussel in the Savannah River occurred in 1972, approximately 15 river miles downstream from the mouth of Steel Creek.

3.6.2.4 Commercially and recreationally valuable biota

Although the ecosystems on the SRP site support many populations of game and fish, commercial exploitation is prohibited. The Savannah River supports both commercial and sport fisheries. Most fishing is confined to the marine and brackish waters of the coastal regions of South Carolina and Georgia. The only commercial fish of significance near the Savannah River Plant are the American shad, the channel catfish, and the Atlantic sturgeon. (The commercial catch of American shad from the Savannah River during 1979 was 57,600 kilograms.) These species are exploited to a limited degree by local fishermen.

Sport fishermen are the principal consumers of river fishes, primarily sunfish and crappie. Striped bass are classified as game fish in South Carolina and Georgia (Ulrich et al., 1978).

The Fisheries Section of the Georgia Department of Natural Resources recently published the results of a fisheries study conducted on the Savannah River during the period July 1, 1981, to June 30, 1982 (Hornsby, 1982). Data on fishing effort, harvest, species sought, habitat or location fished, and angler origin were collected from sports fishermen (Appendix C).

Approximately 4600 anglers fish in the freshwater section of the Savannah River. Georgia residents constitute 68.2 percent of these anglers. The anglers fish in both the mainstream (58.2 percent) and oxbows, creeks, and lakes (41.8 percent) of the Savannah River. Freshwater anglers spend the most time (43.8 percent) trying to catch bream (i.e., bluegill, redbreast sunfish, warmouth, redear sunfish, and spotted sunfish). Bream account for 73 percent of the fish caught. Largemouth bass is the next most popular species (38 percent of the time); however, success is low (2.5 percent of the fish caught). About 90,000 kilograms of freshwater fish are harvested from the lower Savannah River annually.

3.7 RADIATION ENVIRONMENT

3.7.1 Sources of environmental radiation

Environmental radiation consists of natural background radiation from cosmic, terrestrial, and internal body sources; medical radiation; radiation from weapons test fallout; radiation from consumer and industrial products; and radiation from nuclear facilities.

Natural radiation contributes about 48 percent of the annual dose of 195 millirem received by an average member of the population within 80 kilometers of the Savannah River Plant. Medical exposure accounts for 47 percent of the annual dose and the combined doses from weapons test fallout, consumer and industrial products, and air travel account for about 5 percent of the dose. Releases of radioactivity to the environment from Savannah River Plant account for less than 0.1 percent of the total annual dose.

External radiation from natural sources comes from cosmic rays and the emissions from natural radioactive ores. It is highly variable with location and altitude.

Internal radiation from natural sources arises primarily from potassium-40, carbon-14, rubidium-87, and daughters of radium-226. The widespread distribution of fertilizers and food, as well as population mobility, have 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 millirem per year (BEIR III, 1980).

Medical radiation is the largest source of population exposure to man-made radiation in the United States. The average dose to an individual from medical and dental X-rays, prorated* over the total population, was 78.4 millirem per year (BEIR III, 1980). In addition, radiopharmaceuticals administered to patients for diagnostic and therapeutic purposes account for an average annual dose of 13.6 millirem 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 0.45 millirem per year when prorated over the total population. Thus, the average medical radiation dose in the U.S. population is about 92.5 millirem per year.

Fallout from nuclear weapons tests is a small source of radioactivity in the environment. The large-scale atmospheric tests conducted by the United States and the Soviet Union in 1961 and 1962 introduced radioactive materials into the stratosphere that 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 contributes to human exposure through the following:

- External radiation from radioactive material on the earth's surface
- Internal radiation from inhalation of airborne fallout
- Internal radiation from ingestion 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 millirem per year (EPA, 1972).

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*Prorating the dose over the population, as used here and in following parts of this section, is a means of arriving at an average dose, which, when multiplied by the population size, produces an estimate of population exposure. It does not mean that every member of the population receives a radiation exposure from these sources.

Most doses from inhalation of fallout are received in the years immediately 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. The annual dose from inhaled fallout radioactivity was estimated to be only 0.04 millirem in 1969 (EPA, 1972) and is currently even lower.

Ingestion of radioactivity in food and water is the largest source of radiation exposure from fallout. It is estimated that this source of exposure was 3.7 millirem per year in 1980, consisting of 0.6 millirem from carbon-14, 0.4 millirem from cesium-137, and 2.7 millirem from strontium-90.

The average annual total-body dose in 1980 from fallout from nuclear weapons tests is estimated to be 4.6 millirem (0.9 from external gamma and 3.7 from ingested radioactivity).

A variety of consumer and industrial products yield ionizing radiation or 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, smoke detectors, tobacco products, fossil fuels, and building materials. The estimated whole-body dose for the U.S. population from these sources is 4 to 5 millirem per year (BEIR III, 1980). About three-fourths of this dose is from external exposure to naturally occurring radionuclides in building materials. |DA-12

Persons who travel by aircraft receive additional 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 millirem, which when prorated over the entire U.S. population amounts to an average dose rate of 0.5 millirem per year (BEIR III, 1980).

3.7.1.1 Environmental radiation levels in the southeastern United States

The contribution of cosmic radiation to natural background dose varies with both latitude and altitude and thus will be unique to a particular location. Sea-level dose rates range from 30 millirem per year in Florida to 45 millirem per year in Alaska; the exposure rate increases to 200 millirem per year at an altitude of about 2400 meters (EPA, 1977). The average unshielded cosmic radiation dose rate in Georgia and South Carolina is 40 millirem per year (EPA, 1972).

Terrestrial gamma radiation (external to the human body) is attributed primarily to gamma-emitting radionuclides in the natural radioactive series derived from uranium and thorium, with some additional contribution from potassium-40. Variation in 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 millirem and 70 millirem per year in Georgia and South Carolina, respectively. However, the variation in these States (including the SRP area) ranges from 6 to more than 350 millirem.

Nuclear facilities in an area will also contribute to the environmental radiation level. The growth of nuclear industry and facilities in the southeastern United States (from West Virginia to Florida and from Arkansas to South Carolina) has been rapid, most of it occurring in the 1970s. In this region there were 24 power reactors either operating or licensed to operate in 1981. There were another 34 power reactors under construction and 4 reactors being planned. When all of these are operating, there will be 62 power reactors in the southeastern United States. Typically, the average radiation dose to individuals within 80 kilometers of a nuclear facility is quite low. Data on releases from 46 nuclear power plants operating in 1979 indicate that the average radiation dose within 80 kilometers of a plant was 0.025 millirem per capita (NUREG/CR-2850, PNL-4221, Vol. 1, December 1982).

An airborne radiological survey of the Savannah River marine region was performed in 1975 to establish terrestrial dose equivalent rates (Hayes, 1977). These rates varied from about 0.001 millirem per hour over water to 0.009 millirem per hour at one location on Wassaw Island. In general, the higher rates occurred over beaches, where heavy minerals containing (natural) thorium and uranium occur. Excluding the water areas, the terrestrial rate averages about 0.003 millirem per hour in this area, which is compatible with other Coastal
:F-6 Plain rates of 0.002 to 0.003 millirem per hour and which is about one-half that measured for the Savannah River Plant. The average dose equivalent rate for the Savannah River marine area is about the same as those measured in Galveston, Texas, and Cape Canaveral, Florida, and somewhat less than that in the Los Angeles, California, area. One radiation anomaly defined in this survey was noted on Hutchinson Island, where dredge spoils have been deposited. The cesium-137 concentration of the post-1957 dredge soil sediment ranges from about 0.3 to 2.7 picocuries per gram. About half the cesium-137 in the post-1957 sediment can be attributed to fallout from weapons testing (Marter, 1974).

3.7.1.2 Environmental radiation levels in the vicinity of Savannah River Plant

A summary of the major sources of exposure for the population within 80 kilometers of the Savannah River Plant and for the river-water-consuming population in Beaufort and Jasper Counties, South Carolina, and in Port Wentworth, Georgia, is presented in Table 3-15. Many of the factors such as the internal radionuclide dose and the medical dose are independent of the site. The factors that are site-dependent are discussed below.

The Savannah River Plant and surrounding area lie between latitudes 33°N and 34°N, with an altitude variation between sea level and roughly 300 meters. It has been estimated that the total unshielded dose equivalent from cosmic radiation in the vicinity of Savannah River Plant (80-kilometer radius) is 35 millirem per year, of which 29 millirem per year is from the ionizing component and 6 millirem per year is from neutrons (Langley and Marter, 1973). Shielding by buildings and the body reduces the cosmic radiation dose to about 32 millirem per year, a 10-percent reduction.

Within 80 kilometers of the Savannah River Plant, measured external gamma dose rates range from 6 millirem to 385 millirem per year (Langley and Marter, 1973). A value of 55 millirem per year represents the average unshielded external terrestrial background in the vicinity of the Savannah River Plant.

Table 3-15. Major sources of radiation exposure in the vicinity of Savannah River Plant

Source of exposure	Dose to average individual (mrem/yr)	Percent of exposure
Natural background radiation		
Cosmic radiation	32.0	
External terrestrial gamma	33.0	
Internal	28.0	
Total	93.0	47.6
Medical radiation		
Diagnostic X-rays	78.4	
Radiopharmaceuticals	13.6	
Medical and dental personnel	0.5	
Total	92.5	47.3
Weapons test fallout	4.6	2.4
Consumer and industrial products	4.5	2.3
Air travel	0.5	0.3
Nuclear facilities (other than SRP)	<0.1	<0.1
Savannah River Plant - environmental radioactivity (1980)	0.2	0.1
Grand total	195.3	

Shielding by buildings and the body reduces this terrestrial radiation dose to about 33 millirem per year, a 40-percent reduction.

Atmospheric testing caused 25,600,000 curies of cesium-137 to be deposited on the earth's surface (United Nations, 1977). About 104 millicuries of cesium-137 per square kilometer were deposited in the latitude band (30°N to 40°N) where South Carolina is located. The total resultant deposition was 2850 curies in the 27,400 square kilometers of the Savannah River watershed and 80 curies of cesium-137 in the 780 square kilometers of SRP. The deposited cesium-137 became attached to soil particles and has undergone only slow transport from the watershed. Results from routine health protection monitoring programs indicate that since 1963 about 1 percent of the 2850 curies of cesium-137 deposited on the total Savannah River watershed has been transported down the river (Du Pont, 1983c).

Onsite monitoring conducted by the Health Protection Department of SRP shows that an average of 50 millicuries per square kilometer (1976-1982 average) of cesium-137 are in the upper 5 centimeters of the soil column. This value is one-half of the amount originally deposited. The difference demonstrates that some of the radiocesium has moved down in the soil column and some has undergone hydrologic transport to the Savannah River.

Releases of radioactive material to the environment from current SRP operations (1978-1980) cause an average dose of about 0.2 millirem per year of operation to the 80-kilometer-radius population and to downstream consumers of Savannah River water (Du Pont, 1980b,d; 1981a).

The only other nuclear facility within 80 kilometers of the Savannah River Plant that has been operational 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 (Chem-Nuclear Systems, Inc., 1980), and the population dose from normal operations is negligible. The 80-kilometer-radius population receives an immeasurably small radiation dose from transportation of low-level radioactive waste to the burial site.

3.7.1.3 Radiation levels in and around L-Reactor area

In 1980, radiation-level survey measurements made outside the L-Reactor area perimeter fence yielded an average dose rate of about 66 millirem per year, approximately equal to background. In 1981, radiation survey measurements were made inside the L-Reactor area perimeter fence, but outside the reactor building. These measurements also indicated an exposure rate of about 66 millirem per year. This indicates that only very small amounts of radionuclides, if any, were deposited in the L-Reactor area during its years of operation. Additionally, a radiation survey is made annually along major SRP roads. The most recent survey indicated no significant contamination along any major SRP road, including Road B, which runs next to L-Reactor.

The L-Reactor area low-level liquid seepage basin has been sampled regularly. The basin is now empty, but it is contaminated from releases made during earlier L-Reactor operations. Table 3-16 lists maximum concentrations measured in the soil of the seepage basin for three radionuclides detected in 1978.

Table 3-16. Radionuclide concentrations in L-Area seepage basin soil

Radionuclide	Concentration (pCi/g dry weight)
Cobalt-60	12,800
Strontium-90	112
Cesium-137	400

The L-Area oil and chemical pit, which is approximately 70 meters northeast of the L-Reactor seepage basin, received low levels of radioactive oil and chemical waste from 1961 to 1979. This pit is no longer in use; it will not be used when L-Reactor operation is resumed. DA-11

Beginning in May 1981, water from miscellaneous sumps and the disassembly basin in L-Area was released to Steel Creek. The disassembly basin contained small amounts of radionuclides (primarily tritium, cesium-137, and strontium-90) associated with the operation of the L-Reactor in past years. Water in the basin was removed to allow replacement or repair of all underwater equipment prior to reactivation of this facility.

Prior to release of disassembly basin water to Steel Creek, a continuous water sampler was installed in the L-Area effluent canal for routine monitoring of L-Area releases. The sampling location is upstream of the entry of the canal into Steel Creek to ensure that no radioactivity from P-Area is measured. The total amount of activity released from L-Area in 1982 was 68 curies of HTO, 0.11 microcurie of cobalt-60, 0.56 microcurie of cesium-137, and 0.21 microcurie of strontium-89/strontium-90. The average concentrations of radionuclides in the L-Area effluent canal in 1982 were 14 picocuries per liter of tritiated water, 9.3 picocuries per liter of cesium-137, 0.3 picocurie per liter of gross alpha, 5.5 picocuries per liter of strontium-89/strontium-90, and 7.4 picocuries per liter of gross beta.

3.7.2 Steel Creek-Savannah River system

3.7.2.1 Radiocesium

Since 1955, approximately 560 curies of radiocesium have been discharged to onsite streams from Savannah River Plant. Of this total, about 284 curies were released to Steel Creek. Annual releases ranged from about 0.02 curie since 1978 to a maximum of about 53 curies in 1964. The primary source of this radiocesium was leaking failed fuel elements stored in disassembly basins in the P- and L-Areas. Water was released routinely from these basins to maintain the clarity needed for underwater manipulation of irradiated fuel elements, hence the release of radiocesium (with a cesium-134-to-cesium-137 ratio of about 1:20).* A sharp decrease in the release of cesium-137 to Steel Creek occurred in the late 1960s and early 1970s when (1) the P-Reactor area basin was fitted with sand filters and water was demineralized before its release; and (2) the leaking fuel elements were removed to an environmentally safe storage area.

After the radiocesium was discharged from the P- and L-Areas to Steel Creek, it became associated primarily with the silts and clays in the Steel Creek system. Here the sediments and associated cesium-137 were subjected to continued resuspension, transport, and deposition by the flow regime in the creek.

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*For convenience, the radiocesium will usually be described as cesium-137, when the presence of both cesium-134 and -137 is implied.

In addition to SRP releases, nuclear weapons testing, since the mid-1940s, has deposited approximately 2850 curies of radiocesium on the Savannah River watershed, including about 80 curies on the Savannah River Plant.

DA-14 The subsections that follow describe radiocesium in Steel Creek and Savannah River sediments, the radiocesium inventory in Steel Creek, cesium-137 in biota, and cesium-137 in water. Appendix D provides more details.

Cesium in sediments

Radiocesium, primarily cesium-137 in Steel Creek, is predominantly associated with the bottom sediments. The principal mechanisms for the association are (1) cation exchange with kaolinite and gibbsite clay minerals; (2) sorption on minerals; and (3) chelation with naturally occurring organic material. A distribution coefficient (K_d = 3960) measured for sediments from Four Mile and Steel Creeks (Kiser, 1979) demonstrates the affinity of cesium-137 for the sediments in the Steel Creek system.

Soil cores collected in 1974 at two transects in Steel Creek between Road A and the swamp showed that 69 percent of the radiocesium was located within the upper 20 centimeters of sediment and 86 percent was confined to the upper 40 centimeters. Findings of more extensive detailed coring conducted in 1981 at 12 transects between the Steel Creek delta and P-Reactor generally confirm the 1974 results; about 61 percent of the radiocesium was found in the upper 20 centimeters and 83 percent in the upper 40 centimeters (Du Pont, 1982a; Smith, Sharitz, and Gladden, 1982a). Sediment samples taken in 1981 from the center of the creek had markedly lower radiocesium concentrations than the sediments near the edges of the floodplain. The radiocesium is predominantly associated with smaller soil particles (Tables 3-17 and 3-18).

Table 3-17. Range of cesium-137 concentrations (pCi/g dry weight) of soil types in Steel Creek, 1981

Soil type[a]	Number of samples	Percentage	Concentrations Mean	Concentrations Standard error
1 (clay)	101	19	137	20
2	108	21	80	16
3	127	24	39	7
4	83	16	55	12
5 (sand)	106	20	17	3

[a]Soil samples were graded visually from 1 to 5, according to their "average" particle size; samples with the highest clay content are type 1 and those with the least clay and silt (i.e., predominantly sand) are type 5 (Smith, Sharitz, and Gladden, 1981).

Table 3-18. Mean radiocesium concentration in soils of Steel Creek floodplain by soil particle size[a] (picocuries per gram)

Location[c]	Soil type[b] 1	2	3	4	5
Above L-Reactor	166	105	62	117	43
L-Reactor to Road A	171	112	38	36	8
Road A to delta	79	46	18	21	9
Delta	219	59	13	24	17

[a]Data from Smith, Sharitz, and Gladden (1982a).

[b]Soil samples were graded visually from 1 to 5, according to their "average" particle size; samples with the highest clay content are type 1 and those with the least clay and silt (i.e., predominantly sand) are type 5 (Smith, Sharitz, and Gladden, 1982a).

[c]Figure 3-2 shows the locations of these areas; estimated radiocesium concentration as a function of depth are provided for major Steel Creek sections in Table D-3. DA-14

Ground-level (at a height of 1 meter) gamma dosimetry measurements were conducted in Steel Creek along the 12 soil-sampling transects, and the results were compared with radiocesium concentrations in 1-meter-long soil cores and vegetation samples (Smith, Sharitz, and Gladden, 1982b). Maximum exposure rates (see Appendix D for details) were found at upstream transects near the sources of the contamination and downstream in the Steel Creek delta area. Mean exposure rates of 0.057 to 0.100 milliroentgen per hour were observed in the transects nearest P- and L-Reactors, and 0.092 milliroentgen per hour were observed in the delta area. In general, the radiocesium content (in picocuries per 0.1 cubic meter) in the surface soils was the most important of four variables for explaining variations in exposure rates. The relative importance of the other variables, plant concentration (picocuries per gram), soil concentration (picocuries per gram) as a function of depth, and soil texture, varied substantially along the length of Steel Creek (Smith, Sharitz, and Gladden, 1982b). According to the gamma exposure rate data, radiocesium concentrations in the Steel Creek system can be characterized as being patchily distributed across the floodplain. Replicate transects within locations (any of the 12 transect locations) show little similarity in either the locations or the magnitudes of the gamma exposure rates.

Soil samples and thermoluminescent dosimeter surveys from 10 transects in the Savannah River swamp (from the SRP boundary to Little Hell Landing) were made between 1974 and 1980. Soil cores collected in 1974 show that about 70 percent of the radiocesium was confined to the upper 6 to 7 centimeters but that the radionuclide was detectable at depths of 25 centimeters (Du Pont, 1982a).

Cesium in Savannah River

Turbulence in the Savannah River generally keeps fine soil particles in suspension. These particles are deposited where the river velocity and turbulence are low (such as inside river bends, downstream from obstructions, in oxbow lakes, and on the floodplain), and where flocculation occurs in the estuary below River Mile 40. Riverbed sediments upstream from Savannah River Plant normally have about 1 picocurie per gram or less of radiocesium (Du Pont, 1982a).

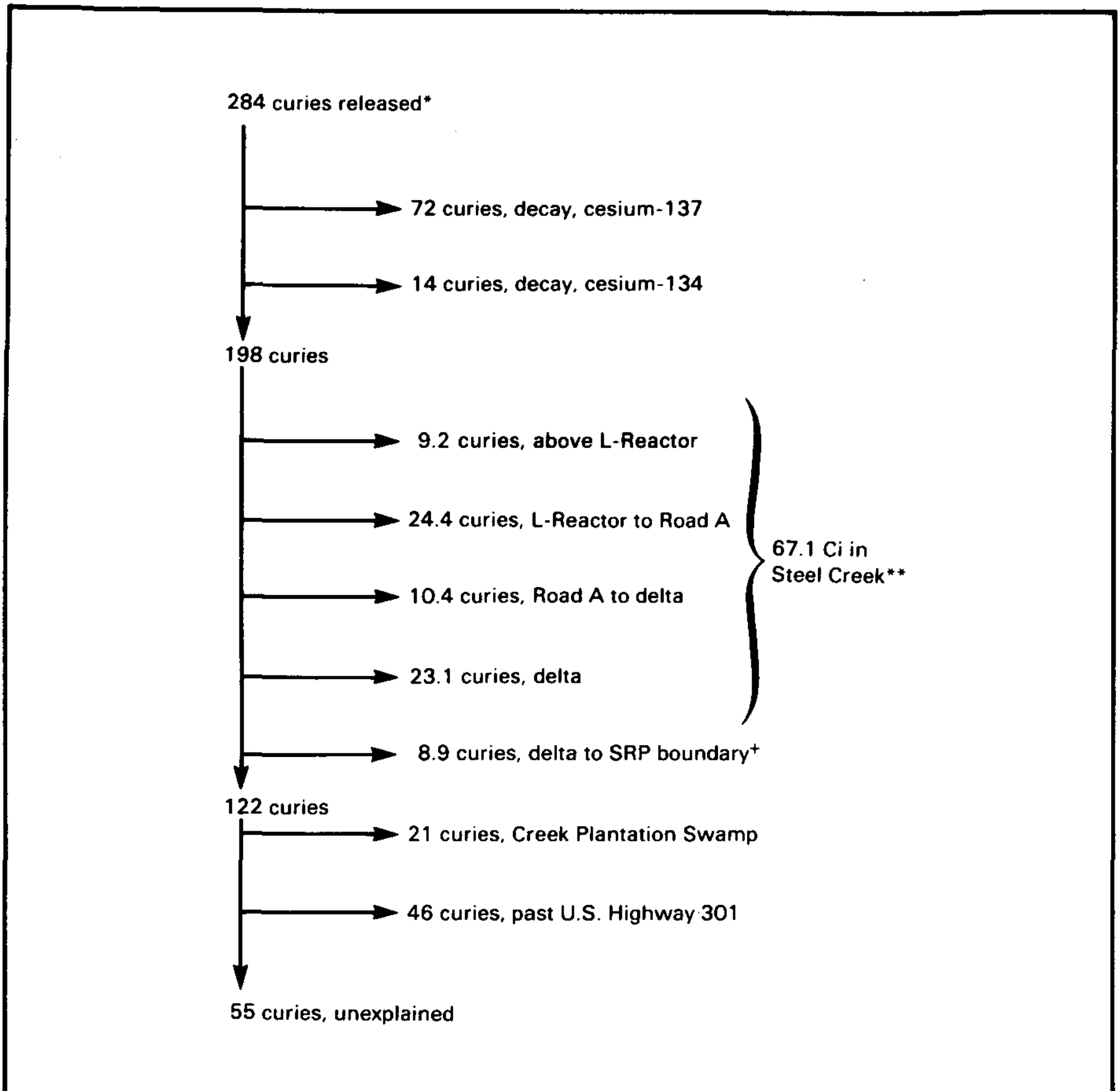
In 1974, riverbed sediments downstream of Savannah River Plant had concentrations of about 2 picocuries per gram near the U.S. Highway 301 bridge and 6.5 picocuries per gram at the South Carolina Highway 119 bridge near Clyo, Georgia. Studies performed in 1978 showed that the radiocesium concentrations were about 0.6 picocurie per gram at the control station above Savannah River Plant and less than 0.8 picocurie per gram at sampling stations between Little Hell Landing and the Highway 301 bridge (Du Pont, 1982a).

Radiocesium inventory

Studies of radiocesium concentration in 1-meter-long soil cores (Smith, Sharitz, and Gladden, 1982a) indicate that about 67 curies of radiocesium currently exist in Steel Creek between the P-Reactor outfall and Steel Creek delta. The distribution of this inventory is shown in Figure 3-14.

Radiocesium was transported, primarily by L-Reactor cooling-water effluent, out of the Steel Creek system to the offsite Creek Plantation swamp and to the Savannah River (Du Pont, 1982a). Approximately 8.9 curies (decay corrected to 1981) are estimated to have been deposited in the area between Steel Creek delta and the SRP boundary, and 21 curies in Creek Plantation swamp between the SRP boundary and Little Hell Landing. Evaluation of the transport in the Savannah River suggests that, given a correction for decay, about 46 curies from Steel Creek were transported past the U.S. Highway 301 bridge near Millhaven, Georgia. Figure 3-14 is a summary diagram of the 1981 radiocesium inventory mass balance. The combination of the known remaining Steel Creek inventory and the inventory in the Savannah River system leaves about 19 percent of the 284 curies of radiocesium released (or 55 curies) unexplained. This fraction of the existing radiocesium inventory could be attributed to the following:

- Less radiocesium released than originally indicated
- A cesium-134-to-cesium-137 ratio greater than 1:20
- Cesium-137 deposited in the river between the mouth of Steel Creek and the Highway 301 bridge
- More cesium-137 from Steel Creek transported past the Highway 301 bridge than indicated by the measurements
- For Steel Creek and Creek Plantation swamp, more cesium-137 below depths of 1 meter



*Released to Steel Creek during 1955-1980.

**Based on soil core measurements.

+Estimated

Figure 3-14. Cesium-137 mass balance in Steel Creek in 1981 based on soil core and river measurements and decay.

Cesium-137 in biota

Vegetation samples were collected at various times from 1970 to 1981 at 10 transects in Steel Creek between the delta and L-Reactor. Samples were also collected at 10 transects in the Savannah River swamp and Creek Plantation swamp. The average radiocesium concentrations in swamp vegetation are generally less than those in vegetation from the creek. The total radiocesium inventory in Steel Creek vegetation is about 0.4 curie (Du Pont, 1982a).

The concentration of radiocesium in wildlife is generally not high in Steel Creek, the Savannah River swamp, and Creek Plantation swamp; concentrations in Savannah River fish are lower than those measured in fish from Steel Creek (Du Pont, 1982a). Additional details are provided in Appendix D.

Cesium-137 in water

Monitoring in the Savannah River by the Savannah River Plant shows that the concentration of radiocesium in river water has been very low in the past several years. From 1979 through 1982 the mean concentration of cesium-137 at the U.S. Highway 301 bridge was 0.08 picocurie per liter and was near the limit of detection at the control station above the Savannah River Plant (Du Pont, 1980b, 1981a, 1982c, 1983a). For the second quarter of 1983, measurements of the radiocesium in the potable (finished) water at the North Augusta, Beaufort-Jasper, and Cherokee Hill water treatment plants averaged 0.006, 0.028, and 0.033 picocurie per liter, respectively. During this monitoring period, the radiocesium concentrations in the potable water were found to vary inversely with river flow (Kantelo and Milham, 1983). In 1982, the monthly average cesium-137 concentration in Steel Creek at the Cypress Bridge (just upstream from the delta; see Figure D-3) was about 3 picocuries per liter; this concentration is about the same as those measured during the previous 5 years.

TC

In November and December 1981, seven water samples from Steel Creek between Road A and the delta were analyzed for their cesium-137 (and potassium) content (Ribble and Smith, 1983). The concentrations ranged from 3.9 to 7.9 picocuries per liter and had a mean value of 5.3 picocuries per liter (with a mean potassium concentration of 1.0 milligram per liter). About 84 percent of this value was associated with the dissolved fraction and 16 percent with the suspended solid fraction. Similarly, Shure and Gottschalk (1976) found that about 20 percent or less of the cesium-137 in water samples from Lower Three Runs Creek was associated with the suspended solid fraction.

More recently, Hayes (1983) reported the results of cesium-137 measurements in Steel Creek made from April through August 1983. During this period, the average transport of cesium-137 was 3.2 ± 1.5 millicuries per week at Cypress Bridge. On this basis, the annual transport would be about 0.17 ± 0.08 curie per year. These measurements indicated that about half the transported cesium-137 was due to remobilization from the creek floodplain system above L-Reactor.

TC

Hayes (1983) also reported that the water that enters Steel Creek from L-Area, from Meyer's Branch (the principal tributary of Steel Creek), and as local rainfall contained cesium-137 concentrations of less than 1 picocurie per liter. However, the measured cesium-137 concentrations at Cypress Bridge averaged about 3.7 ± 0.6 picocuries per liter during the April through August 1983 study period. Hayes contends that the cesium-137 concentrations are governed by a reequilibration process between the water and the cesium in the creekbed and floodplain sediments, because he could find no correlation during this period between cesium concentration and creek flow rate, suspended solid or tritium concentrations in Steel Creek water, or rainfall in the area. Hayes concluded that the creekbed and floodplain sediments could support cesium concentrations as high as about 11 picocuries per liter at equilibrium, and that the lower concentrations (3.7 picocuries per liter) were probably due to insufficient time for equilibration between the water and the cesium-laden sediments. The travel time for water from L-Area to Cypress Bridge is less than 1 day. TC

3.7.2.2 Radiocobalt

Since 1955, 66 curies of radiocobalt (Du Pont, 1983b), formed by neutron activation of stainless steel and dissolved in the fuel element storage basin water, have been discharged to onsite streams. Of this total, approximately 27 curies have been released to Steel Creek. As a result of radioactive decay, a small amount, about 2.1 curies, remains in Steel Creek or Creek Plantation Swamp, or has been transported to the river in a manner similar to radiocesium. Further examination of cobalt has not been performed because the inventories in both Steel Creek and the Savannah River system are significantly less than the bounding cesium inventories (Du Pont, 1983c). Additional details can be found in Appendix D.

3.7.2.3 Radiostrontium

L- and P-Areas have released approximately 0.5 curie of strontium-89 and 40.8 curies of strontium-90 to Steel Creek (Ashley, Zeigler, and Culp, 1982). Because of the short half-life of strontium-89 (50.5 days), no measurable quantities are likely to exist in the creekbed sediments. Strontium-90 has a half-life of about 28 years. About 14.3 curies of strontium-90 have been lost by radioactive decay. According to ERDA (1977) and Marter (1974), another 20.8 curies have been transported to the Savannah River. Thus, about 5.7 curies of strontium-90 might still remain in the sediments of Steel Creek. Soil corings in Steel Creek at Road B and Cypress Bridge and near its mouth have revealed strontium-90 concentrations ranging from 0.11-0.14 picocurie per gram in 1978 to 0.12-0.14 picocurie per gram in 1979. At the SRP control station, strontium-90 concentrations of soil samples were 0.06 picocurie per gram in 1978 and 0.14 picocurie per gram in 1979 (Ashley et al., 1982). These soil coring studies suggest that the inventory might be much less than 5.7 curies. It is not surprising that most of the strontium-90 has been transported from Steel Creek, because the kaolin clay particles of the creekbed sediments have little sorptive capacity for strontium. The distribution coefficient for strontium-90 in SRP kaolinitic soils might be as low as 20 (Oblath et al., 1983), which is at least 35 times less than that for cesium-137. DA-16

Strontium-90 has been detected slightly above background levels in the sediments of Creek Plantation Swamp. This radionuclide has also been detected in composited swamp vegetation samples at concentrations of a few picocuries per gram (Marter, 1974).

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