NOTICE

**CERTAIN DATA
CONTAINED IN THIS
DOCUMENT MAY BE
DIFFICULT TO READ
IN MICROFICHE
PRODUCTS.**

Key Words: Water Resource Planning
Water Management
Hydrology

WATER RESOURCE MANAGEMENT PLANNING GUIDE FOR SAVANNAH RIVER PLANT

by

**J. E. HUBBARD
D. E. STEPHENSON
J. L. STEELE
D. E. GORDON, SRP**

DISCLAIMER

Approved by:

**J. C. Corey, Research Manager
Environmental Sciences Division**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Publication Date: October 1988

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808**

CONTENTS

	<u>Page</u>
List of Tables	iii
List of Figures	iv
Preface	v
Summary	1
Introduction	3
1.0 The Water Cycle and Water Resource Management	3
2.0 SRP Hydrology and Water Resources	3
2.1 Surface Water	3
2.2 Groundwater	6
2.3 Water Budget	10
3.0 Water Resource Use and Demand Trends	10
3.1 Surface Water: Site Uses and Pumping Centers	10
3.2 Groundwater: Site Uses and Pumping Centers	17
3.3 Return Flows	22
4.0 Policy Goals and Objectives	22
5.0 Legal and Regulatory Framework	24
6.0 Water Use Guidelines for Plant Operations	25
References	28
Glossary of Terms	30
Appendix	32

LIST OF TABLES

	<u>Page</u>
1 Savannah River Plant Surface Water Resources	7
2 Aquifers Beneath the Savannah River Plant	8
3 Average Continuous Groundwater Pumpage at the Savannah River Plant	18
4 Average Continuous Groundwater Pumpage for Communities and Industries in the SRP Region	19

LIST OF FIGURES

	<u>Page</u>
1 Water Resource Systems	4
2 The Savannah River Drainage Basin	5
3 Piezometric Surface of Aquifer III	9
4 Piezometric Surface of Aquifer III in the Savannah River Plant Area	11
5 Hypothetical Groundwater Flow Balance at the Savannah River Plant	12
6 Head Difference Between Aquifers III and II	13
7 Normal Annual Precipitation and Runoff in South Carolina	14
8 Water Budget at the Savannah River Plant	15
9 Municipal and Industrial Water Users Within a 20-Mi Radius of the Center of the Savannah River Plant	16
10 Major Groundwater Pumpage on and near the Savannah River Plant	20
11 Schematic Flow Balance at the M-Area Settling Basin	21
12 Schematic Flow Balance in the Separations Areas	23

PREFACE

This document is intended as a guide to suggest goals and objectives that will provide a basis for the development of a water resource plan for SRP. Planning should be flexible rather than rigid, and the plan outlined in this document was prepared to be modified or updated as conditions necessitate.

This guide was drafted while John Hubbard was a Summer Facility Participant in the Environmental Sciences Division of the Savannah River Laboratory. The work was completed with support from D. E. Gordon of the Environment and Energy Department of the Savannah River Plant, J. L. Steele, Research Supervisor of the Geotechnical Group within the Savannah River Laboratory's Environmental Sciences Division, and D. E. Stephenson of the Geotechnical Group.

SUMMARY

The Water Resource Management Planning Guide provides an outline for the development of a Savannah River Plant Water Resource Management Plan (WRMP) to protect, manage, and monitor the site's water resources. The management plan is based on three principle elements: (1) protection of the water quality, (2) management of the water quantity, and (3) monitoring of the water quality and quantity. The plan will assure that changes in water quality and quantity are identified and that corrective action is implemented as needed. In addition, water management activities within and between Savannah River Plant (SRP) organizations and departments will be coordinated to ensure the proper management of water resources.

SRP's water resources management plan must take into account the factors affecting the resources themselves. Surface water and groundwater resources are among the site's least understood natural resources, yet societal demands make them the most used. Groundwater resources are affected by many physical factors, including aquifers leakage, natural variation over distance, and differences in behavior caused by natural and pumpage cycles. In turn, SRP's groundwater use and quality are related to each other as well as to surface water use and quality (with groundwater providing the base flow for streams and discharges to the Savannah River).

The total water resource system is represented by a number of subsystems that, although related, serve different societal functions. It is, therefore, necessary to manage the total water system, not just the areas of interest. Actions at one location will have an effect, even though possibly very minor, on all locations. As described by Domenico (1972), the complex spectrum of interests in the water resource system indicates that elements within the total system may be optimized to the detriment of others. Therefore, the subsystems must complement rather than hinder each other.

The management plan outlined in this report places the emphasis on management activities and coordination of administrative functions. Its intent is not to address functions covered by regulations such as concentration levels, well design, permits, and so forth. Instead, it proposes an approach in which the effect of an activity on the entire hydrologic regime is assessed.

The water resources goals and management objectives for SRP outlined in this report are as follows:

- To have available Savannah River flow at a stage adequate for pumpage for safe SRP reactor operations and for other uses that require surface water.
- To have available groundwater sufficient for pumpage to supply the needs of process operations and domestic use and for other water use requirements.

- To conduct plant operations in a manner that protects public health, preserves and maintains the quality of SRP surface water and groundwater resources, and meets federal and South Carolina regulatory requirements.
- To comply with federal, South Carolina, and Georgia surface water-quality regulations, including the Clean Water Act, the National Environmental Protection Act (NEPA), and regulations pertaining to radiological effluents, spill control, wetlands protection, and in-stream flow requirements.
- To comply with federal and South Carolina regulations, Department of Energy (DOE) orders, and corporate policies for groundwater protection, waste treatment, and waste disposal.
- To understand the natural and operational factors affecting the site hydrology and hydrogeology in order to properly use and protect surface water and groundwater and their environments at and around SRP.
- To manage surface and groundwater use to ensure that natural barriers to contamination are not damaged inadvertently and that uncontaminated waters at and below SRP remain uncontaminated. The head reversal between the deeper and shallower aquifers, which has naturally prevented contamination in plant areas, should be maintained.

This report recommends the following for water management at SRP:

- Communicate to a Savannah River Basin Commission or other future regulator the importance of both the stage range (82.5 to 96.0 ft msl) and discharge range (5,200 cfs) for SRP operations. Suggest SRP representation on any commission.
- Continue pumpage as needed for SRP operations, with particular care in Separations and A/M AMPAs. Determine an upper yield limit for pumpage to meet the needs, possibly not exceeding current use. Consider alternatives of (1) reuse and conservation, (2) alternative groundwater pumping centers, and (3) conjunctive use of surface water and groundwater.
- Conduct plant operations in a manner that protects public health, preserves and maintains the quality of SRP surface water and groundwater environments, and meets federal and state regulatory limits.
- Continue hydrogeologic and hydrologic studies. Continue compliance programs under way for surface water and wetlands, drinking water, land use/wildlife, groundwater, and atmospheric protection as detailed in Du Pont (1988a).
- Maintain the head reversal to reduce the possibility of contamination in the plant area.

INTRODUCTION

This document is a guide for the development of a Water Resources Management Plan (WRMP) for the Savannah River Plant (SRP). The WRMP will outline the steps necessary to protect the quality, manage the quantity, and monitor the quality and quantity of the site's water resources. The plan will coordinate the water management activities of the various SRP operating areas and departments and would assure that changes in the hydrologic system are identified and that corrective action is implemented if necessary. This guide provides a basic understanding of SRP site hydrology and water resources to allow flexible planning for future water use needs and contingencies at SRP.

1.0 THE WATER CYCLE AND WATER RESOURCE MANAGEMENT

The water cycle comprises hydrologic processes that transfer water among the subsurface, surface, and atmospheric zones. Subsurface water includes groundwater in zones of saturation and soil moisture and vadose water above the water table. Streams, lakes, ponds, and wetlands are examples of surface water. Cloud droplets and water vapor constitute atmospheric moisture.

The hydrologic processes that transfer water from one zone to another include the following: precipitation, which transfers water to the land from the atmosphere; surface runoff, which transfers water to streams by overland flow and shallow groundwater discharge; infiltration, which transfers water into soils; evaporation and transpiration, which transfer water from the surface and from vegetated soils to the atmosphere; deep percolation, which recharges groundwater; and slow groundwater flow, which discharges to wells and springs and forms the base flow of streams.

A number of subsystems constitute the water resource system. This system is shown schematically in Figure 1. Because of the close connectivity of the individual elements, it is necessary to manage the total water system and not just specific areas of occurrence or interest.

As described by Domenico (1972), the complex spectrum of interests in the water resource system indicates that elements within the total system may be optimized to the detriment of others. It is necessary that the subsystems complement rather than hinder each other, and this necessity should be accounted for in the development of a management plan.

2.0 SRP HYDROLOGY AND WATER RESOURCES

2.1 Surface Water

The majority of the water used at the Savannah River Plant (SRP) originates offsite. The Savannah River forms the southern boundary of SRP and supplies the plant with approximately 1,320 cfs of surface water. SRP withdraws the water just downstream of the confluence of Upper Three Runs Creek with the river.

More than 8,000 mi² of the large Savannah River drainage basin are upstream of SRP (Figure 2). River flow averages over 10,000 cfs and is regulated by a series of dams. At low flow (5,800 cfs), the river is about

Source: Ackermann (1969).

FIGURE 1. Water Resource Systems

FIGURE 2. The Savannah River Drainage Basin

340 ft wide, from 9 to 16 ft deep, and has an average velocity of about 2 mph. The U.S. Geological Survey (USGS) gages the river at Augusta, GA, and at Jackson, SC, near SRP (Table 1).

The SRP site is drained by several streams tributary to the Savannah River (Table 1). These streams are fed by groundwater discharged from the shallow aquifers. Rainfall produces high stream flows from increased groundwater discharge and overland flow. Groundwater from the deeper aquifers discharges into the Savannah River. Low flows in the Savannah River and site streams normally occur in late summer and autumn; higher flows occur in late winter and spring. Discharges from plant operations cause abnormal flows in streams below several of the SRP reactor and process sites.

2.2 Groundwater

SRP pumps groundwater from deep Coastal Plain aquifers beneath the site. These aquifers are largely recharged in areas north of SRP. A generalized overview of SRP hydrogeology is given in Table 2. Four main aquifers of the Coastal Plain system lie below SRP, numbered sequentially downward from I to IV. Aquifer I is the water-table aquifer and extends through several geologic formations to an aquitard, a leaky layer that confines Aquifer II.

Aquifer II has been called the Congaree aquifer at SRP because it was primarily identified onsite with that geologic formation. Aquifer II extends more than 100 ft in depth to another aquitard, the Ellenton Clay, which largely separates Aquifer II from Aquifers III and IV. Wells in Aquifer II yield small amounts of water for domestic use, generally less than 100 gpm.

Aquifer III is several hundreds of feet in thickness and is located generally within the Pee Dee and Black Creek formations. Aquifer IV is within the Middendorf Formation, below yet another aquitard. Either the relatively impermeable Cape Fear Formation or saprolite on the crystalline bedrock forms the lower boundary of Aquifer IV. Aquifers III and IV have similar lithology and water levels and high transmissivities. They supply the groundwater demands at SRP, with Aquifer IV the preferred aquifer for production wells.

The leakage of water from one aquifer to another through a confining layer often proceeds slowly; therefore, flow within aquifers is often greater than flow between them. Within shallow aquifers, groundwater travels relatively short distances from recharge areas to discharge into local streams. Aquifers I and II are recharged by infiltration of rainfall and percolating water at the site. This groundwater then flows toward nearby streams, where it is discharged. Most fair-weather flow (base flow) of SRP streams is discharged from Aquifers I and II.

As shown in Figure 3, groundwater in Aquifers III and IV can travel large distances over long periods of time, from areas of recharge near the Fall Line to deeply incised river channels or toward Atlantic Coastal areas. Flow is perpendicular to the water level (piezometric surface). Groundwater north of the South Edisto River may take a long arcuate path toward Myrtle Beach, SC. Some of the water from Aquifers III and IV discharges locally to the South Edisto River; but between SRP and the South Edisto River, flow is southward toward the Savannah River.

TABLE 1

Savannah River Plant Surface Water Resources

<u>Stream</u>	<u>Drainage Area (mi²)</u>	<u>Average Dis- charge (cfs)</u>
Savannah River	10,577	
at Augusta Lock and Dam	7,508	10,160
at Jackson	8,160	10,400
Upper Three Runs Creek	205	
at New Ellenton	87	112
at Road C	176	194
at Road A	203	265
Four Mile Creek	35	
at Road A	22	388
Beaver Dam Creek	1	86*
Pen Branch at Road A	22	381*
Steel Creek	34	53
Lower Three Runs Creek	178	
at Snelling	59	84
<u>Impoundment</u>	<u>Surface Area (acres)</u>	<u>Volume (acre-ft)</u>
Par Pond	2,640	47,000
L Lake	1,000	23,000

* These discharges are controlled by plant area operations.

TABLE 2

Aquifers Beneath the Savannah River Plant

<u>Aquifer</u>	<u>Formation</u>	<u>Thick- ness (ft)</u>	<u>Hydraulic Conductivity (ft/day)</u>	<u>Storage Coefficient</u>	<u>Effective Porosity</u>	<u>Groundwater Volume (maf)</u>
I	Barnwell	126	4	0.11	0.15	3.6
II	Congaree	105	38	0.0002	0.20	4.0
III	Pee Dee-	345	33	0.00042	0.30	19.9
	Black Creek					
IV	Middendorf	130	80	0.00045	0.30	7.5

Note: Data are from Du Pont (1988b).

Source: Aucott and Spieran (1985).

FIGURE 3. Piezometric Surface of Aquifer III

Figure 4 shows the piezometric surface of Aquifers III and IV in the SRP region. Maximum recharge occurs north of SRP, where the formations crop out in stream valleys and below surface soils. The major groundwater recharge area for Aquifers III and IV is between SRP and the South Edisto River. As shown in Figure 4, the flow path for water recharged east of Aiken moves below and through SRP toward the Savannah River and the Savannah River Swamp.

2.3 Water Budget

As indicated in Table 2, SRP aquifers contain approximately 35 million acre-feet (maf) of water, the majority of which (27 maf) is contained in Aquifers III and IV. Confined aquifers, however, can yield only a fraction of their volume without additional recharge or aquifer stress, as indicated by their small storage coefficients. An average value of the yield of a confined sandy aquifer is in the range of 0.0001 to 10% of the water stored in the pores. Therefore, even large aquifers have pumpage restrictions.

A flow-net for Aquifers III and IV was constructed to estimate the flow of these aquifers into SRP and their maximum recharge. The flow-net analysis shows that the groundwater flow rate into SRP in Aquifers III and IV is conservatively between 25 and 35 million gallons per day (mgd) and that a maximum possible annual recharge of 6 in. occurs in a small area north of SRP. A USGS Regional Aquifer Analysis Report (Aucott, 1986) shows an area extending north from SRP toward the South Edisto River in which recharge of Aquifers III and IV averages 2 to 4 in. annually. The report indicates that between 1 and 2 in. recharge these deeper aquifers in the northern third of SRP.

Groundwater pressure (head) usually decreases with depth below the land surface, causing water to move downward. A generalized flow balance for SRP is shown in Figure 5, which illustrates the downward movement of groundwater. However, where pressures are greater in the deeper aquifers, groundwater flow paths tend upward. This head reversal is present in about one-fourth of SRP, including F and H Separations Areas. This hydrologic feature provides a natural barrier, preventing contamination of the deeper aquifers. Increased pumpage has diminished the extent of the head reversal, as shown in Figure 6, which indicates that the head reversal in the central burial ground area has been reduced from 20 to 10 ft.

Figure 7 shows the amount of normal annual precipitation and runoff in South Carolina. Figure 8 similarly shows a hypothetical water budget at SRP; a mass balance was used to account for the flow of water in natural catchments.

3.0 WATER RESOURCE USE AND DEMAND TRENDS

3.1 Surface Water: Site Uses and Pumping Centers

SRP operates three pumping stations that withdraw water from the Savannah River to provide cooling water for production reactors, fossil fuel steam and electric generators, and other facilities (Halverson et al., 1987). Normally, 1,320 cfs of Savannah River water are withdrawn at the pumphouses (Figure 9). Two identical 10-pump unit structures (1G and 3G) are located at the end of river intake canals. The third station (5G) operates six smaller pumps on a small inlet cove of the river. Sixteen to 18 pumps in the 1G and

FIGURE 4. Piezometric Surface of Aquifer III in the Savannah River Plant Area

FIGURE 5. Hypothetical Groundwater Flow Balance at the Savannah River Plant

FIGURE 6. Head Difference Between Aquifers III and II

EXPLANATION

- 44— Line of equal average annual precipitation
Interval, in inches, is variable
- 20— Line of equal average annual runoff
Interval, in inches, is variable
- ◆ National Weather Service precipitation
gauge—Monthly data shown in bar
graphs
- ▲ USGS stream-gaging station—Monthly
data shown in bar graphs

SCALE 1:5,000,000

Source: Aucott (1986).

FIGURE 7. Normal Annual Precipitation and Runoff in South Carolina

FIGURE 8. Water Budget at the Savannah River Plant

Source: Christensen and Gordon (1983).

Numerical Key		
1 Aiken	12 Warrenville	29 J. M. Huber Company
2 Jackson	13 Johnstown,	30 Augusta Sand & Gravel
3 Ellenton	Howlandville,	31 Cyprus Mines Corp.
4 Langley	Gloverville	32 Florida Steel Corp.
5 College Acres	14 Belvedere	33 Valchem
6 Bath Water Dist.	15 Barnwell	34 Sandoz Co., Inc.
7 Beech Island	16 Williston	35 E. T. Barwick Ind.
8 Talatha	17 Blackville	36 Barnwell NFP
9 Breezy Hill	18 Hilda	37 A. W. Vogtle NPS
10 Burnettown	19 Elko	38 Girard
11 Montmorenci	28 Graniteville Co.	

FIGURE 9. Municipal and Industrial Water Users Within a 20-Mi Radius of the Center of the Savannah River Plant

3G pumping stations are needed to supply cooling water for C, K, L, and P areas when all four reactors are operating. SRP could remove 1,450 cfs of river water with all 26 pumps in use.

C, K, and L reactors each receive about 400 cfs of cooling water when operating. The coal-fired power plant receives about 100 cfs, and Par Pond receives about 20 cfs to compensate for seepage and evaporation. Most cooling water is returned to streams draining to the Savannah River, although an estimated 120 cfs is lost to evaporation or seepage.

Historically, the U.S. Army Corps of Engineers has attempted to maintain a minimum Savannah River flow of 6,400 cfs at SRP (DOE, 1984), but flow has been reduced during drought periods in the 1980s. To operate three reactors, SRP requires a minimum river stage of 82.0 ft msl and a minimum flow of 4,880 cfs; to operate two reactors, minimums of 81.0 ft msl and 4,130 cfs are required. The minimum operating levels for P Reactor only are 30.4 ft msl and 3,600 cfs. At these minimum levels, only two pumps at the 5G pumphouse can operate, and only the 3G pumphouse can provide for minimum safety reactor core shutdown. A flow of 3,600 is not sufficient to provide necessary thermal mitigation for effluent.

A river stage of 80.0 ft msl and a flow of 3,300 cfs would result in a shutdown of SRP operations. Water intake would be insufficient to run the powerhouses, resulting in no electricity or steam. Because no steam would be available, the Separations Areas would have to be shut down. Reactor operations would be shut down because of the lack of cooling water flow, and the reactors' cores would have to be discharged for safety considerations.

3.2 Groundwater: Site Uses and Pumping Centers

Groundwater pumpage at SRP is approximately one-third the total pumpage reported for South Carolina's Lower Savannah River subbasin; more than 100 wells at various plant locations pump a total of 11 mgd (17 cfs) of groundwater from the aquifers below the site. Major groundwater pumping centers on and near SRP are shown in Figure 9. Average annual pumpage amounts are given in Table 3 for SRP operating areas and in Table 4 for nearby communities and industries. At SRP, about one-half of the site pumpage occurs in F and H Separations Areas, and approximately one-fourth of the total SRP pumpage is withdrawn at A/M Area. Groundwater withdrawals are primarily used for process water; other uses include domestic water and fire protection.

Total groundwater pumpage on the plant has increased about 65% from 6.8 mgd in 1978 to 11 mgd in 1987 (Table 3). SRP use of groundwater has increased because of the convenience afforded by location, the high transmissivity of the deep aquifers, and because of water-quality considerations. Current groundwater pumpage rates at major SRP operating centers and other industries and communities in the SRP region are displayed in Figure 10.

Two SRP locations have been intensively studied as part of a hydrogeologic characterization program: A/M Area and F and H Separations Areas. A flow balance for the area beneath the M-Area Settling Basin is shown in Figure 11 and is expressed in area-inches. The effects of the pumpage, and the

TABLE 3

Average Continuous Groundwater Pumpage by Area at the Severnash River Plant in Gallons Per Minute (GPM)

Area	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
300/700 - N/A	1307	1471	1406	1241	1346	1361	1132	1142	1118	1164	1059	1091	1168	1360	1355	1600	1620	1640	1800	1850	1825
200-F Area	1706	1792	1789	1625	1505	1531	1396	1023	1193	1210	1201	1318	1364	1404	1439	2200	2240	1890	1760	1760	1320
200-H Area	1467	1494	1585	1607	1567	1648	1599	1526	1724	1653	1762	1785	1822	1946	1969	2200	2240	2270	2270	2270	2400
200-S Area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	40
700-B Area	150	150	150	100	100	100	100	100	75	75	75	75	75	75	75	50	50	60	70	75	75
TMX Area	35	35	35	35	35	35	35	35	35	35	35	35	35	160	385	300	280	250	250	220	200
400-D Area	220	210	200	190	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central Shops	70	65	65	65	65	65	90	95	115	150	150	150	150	150	150	200	180	200	200	200	175
100-C Area	0	0	0	0	0	0	0	0	0	0	0	0	0	75	200	300	300	260	200	200	315
100-K Area	0	0	0	0	0	0	0	0	0	0	0	0	0	75	200	250	250	290	650	620	200
100-L Area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	250	250	200	190	150
100-P	0	0	0	0	0	0	0	0	0	0	0	0	0	75	200	350	260	440	670	240	250
Total (GPM)	4820	5217	5233	4863	4798	4740	4327	3916	4240	4252	2282	4454	4614	5320	5995	7700	7770	7550	8070	7640	6890
Total (MGD)	6.94	7.51	7.54	7.00	6.91	6.83	6.23	5.64	6.11	6.12	6.45	6.41	6.64	7.66	8.63	11.09	11.19	10.87	11.62	11.00	9.92

Note: Data from 1968-1983 were compiled by I. V. Marine; data from 1983-1988 were compiled from Water Use Reports provided by R. D. Turner; 1988 values are for the first 6 months of this year.

TABLE 4

Average Continuous Groundwater Pumpage for
Communities and Industries in the SRP Region

<u>Community/Industry</u>	<u>Pumpage (gpm)</u>
Aiken, SC	1,734
Barnwell, SC	1,693
Jackson, SC	150*
New Ellenton, SC	400*
Sandoz, Inc. Martin, SC	1,321
Williston, SC	547

Note: Data are for 1987 and were provided by
the South Carolina Water Resources
Commission.

* These values are estimated.

FIGURE 10. Major Groundwater Pumpage on and near the Savannah River Plant

Source: After Papadopolus (1986).

FIGURE 11. Schematic Flow Balance at the M-Area Settling Basin

consequent draw-down and cone of depression, enhance the vertical migration into Aquifer III and the groundwater inflow from outside the boundary (S. S. Papadopolus, 1986).

Figure 12 presents the flows in the Separations Areas developed from the GeoTrans model (Spalding et al., 1988). At the time this model was developed, the net flow in the deep aquifer was approximately balanced by the pumpage. Using the GeoTrans model to simulate increased pumpage at H Area results in a diminishing of the natural head reversal between Aquifers III and II.

3.3 Return Flows

Return flows of reactor cooling water are discharged to site streams. Separations Areas groundwater pumpage was discharged to Four Mile Creek, but plans for the new Effluent Treatment Facility call for discharge to Upper Three Runs Creek. M-Area effluents are discharged to Tims Branch.

4.0 POLICY GOALS AND OBJECTIVES

The goals of water resource management are to use and protect the quantity and quality of water resources wisely; to conduct all operations so as to make the best use of surface water and groundwater and prevent or minimize degradation of their quality; and if degradation occurs, to restore water quality to its former or potential state.

The Site Operating Contractor, as primary site custodian, is responsible for protecting human health, the environment, and natural resources in full compliance with applicable regulations and corporate philosophy/policy. Site environmental goals must be closely linked to safety, quality, and production goals, and employees must be committed to protecting the environment (Du Pont, 1988a).

The following water resource management supply goal is recommended for the Savannah River Plant Water Resource Management Plan: To ensure that adequate quantities of surface water and groundwater are available for current and future plant operations. The objectives of this goal are two-fold. First, to have available Savannah River flow at a sufficient state adequate for pumpage for safe SRP reactor operations and for other uses that require surface water. Second, to have available at all times groundwater sufficient for pumpage to supply the needs of process operations and domestic use and for other water use requirements.

The following water resource management protection goal is also suggested for consideration under the Savannah River Plant Water Resource Management Plan: To conduct plant operations in a manner that protects public health, preserves and maintains the quality of SRP surface water and groundwater resources, and meets federal and South Carolina regulatory requirements. The objectives of this goal are (1) to comply with federal, South Carolina, and Georgia surface water-quality regulations, including the Clean Water Act and the National Environmental Policy Act (NEPA), regarding radiological effluents, spill control, wetlands protection, and in-stream flow requirements; (2) to comply with federal and South Carolina regulations, Department of Energy (DOE) orders, and corporate policies for groundwater protection, waste treatment, and waste disposal; (3) to understand the natural

Source: After Duffield et al. (1986).

FIGURE 12. Schematic Flow Balance in the Separations Areas

and operational factors affecting the site hydrology and hydrogeology in order to properly use and protect surface water and groundwater and their environments at and around SRP; (4) to manage surface and groundwater use to ensure that natural barriers to contamination (such as the existing head reversal) are not damaged inadvertently and that uncontaminated waters at and below SRP remain uncontaminated (Du Pont, 1988a).

5.0 LEGAL AND REGULATORY FRAMEWORK

South Carolina, Georgia, and the federal government exercise jurisdiction over waters flowing through and around SRP. In South Carolina the doctrine governing surface water use is the riparian reasonable use doctrine (Snyder, 1983). An owner of riparian property has the right to reasonable use of its water, but he cannot unreasonably diminish the water quality or quantity such that it interferes with the rights of another owner of riparian property.

Groundwater rights are also traditionally associated with property ownership. The South Carolina Water Resources Act of 1966 established the South Carolina Water Resources Commission (SCWRC). The South Carolina Ground Water Use Act of 1969 requires SCWRC to establish capacity use areas where the aggregate uses of groundwater may require regulation or impair the replenishment of groundwater. The South Carolina Water Use and Reporting Act of 1982 requires that water use exceeding 100,000 gpd be reported to SCWRC, which can determine and recommend regulation of nonessential water use. SCWRC has identified three capacity-use areas in South Carolina Coastal Plain aquifers: Florence, Myrtle Beach, and Beaufort. The SCWRC is encouraging some of these areas to use Savannah River flow or other surface water to replace the groundwater resources currently in use.

Several water laws, orders, and regulations affect SRP water use. The SRP Environmental Protection Program (Du Pont, 1988a) regulates SRP operations and activities on the SRP reservation. The Federal Water Power Act of 1920 requires the Federal Water Power Commission to issue licenses for construction and operation of power-generating facilities on waterways subject to federal jurisdiction. The Federal Water Pollution Control Act (1972) and Clean Water Act (1977) are administered in South Carolina by the Department of Health and Environmental Control (DHEC), with the Environmental Protection Agency providing oversight and approval activity. The Resource Conservation and Recovery Act (RCRA) includes explicit specifications for groundwater monitoring and cleanup.

U.S. Public Law 98-181 (1983) specified discontinuance of the M-Area Settling Basin and required that DOE-SR develop a plan for groundwater protection. DOE Order 5820.2 (Hazardous and Radioactive Mixed Waste Management) establishes hazardous waste management procedures and requires groundwater monitoring to ensure that groundwater quality is not degraded. The DOE Order governing Radioactive Waste Management includes a waste management plan for radioactive and nonradioactive groundwater monitoring for each facility.

South Carolina DHEC regulations governing water use at SRP include the following:

- o R. 61-61 Solid Waste Regulation (includes post-closure groundwater monitoring wells)
- o R. 61-66 Industrial Solid Waste Disposal Site (includes a permit and observation wells)
- o R. 61-70 South Carolina Landfill Regulation (includes a permit and observation wells)
- o R. 61-71 Well Standards and Regulations (water supply and monitoring well standards)
- o R. 61-79.264 Hazardous Waste Management Facilities Regulation (requires a permit)

Recent periods of regional drought have lead to formation of the Savannah River Basin Drought Coordination Committee. The committee consists of three representatives: one each from the SCWRC, the Georgia Environmental Protection Division, and the U.S. Army Corps of Engineers. Regulation of the Savannah River by the Corps of Engineers is guided by committee recommendations. As water use demands and environmental problems increase within the Savannah River Basin, it is possible that regulation by a Savannah River Basin Commission may occur. River Basin Commissions currently regulate several interstate stream basins in the United States, including the Mississippi, Columbia, and Delaware river basins.

6.0 WATER USE GUIDELINES FOR PLANT OPERATIONS

Water resource planning provides a way of coordinating and evaluating factors that influence water resources. SRP is only one of many entities competing for use of Savannah River water and Coastal Plain groundwater. For example, other current and potential demands for river water include municipal and industrial water supplies for downstream communities; hydropower generation, mostly at upstream localities; recreational demand for the upstream reservoirs; instream flow for thermal mitigation and assimilation of effluents; navigation; and maintenance of ecological communities and spawning anadromous fish.

Competing demands for water resources may result in the formation of a Savannah River Basin Commission, or similar entity, to manage water. River regulators may institute instream flow requirements to determine and maintain the amount of water needed within a stream channel to sustain all relevant instream uses at an acceptable level. These uses include instream flow needs for aquatic biological populations and assimilation of waste materials discharged into the stream. These procedures generally are based upon streamflow equal to or greater than the minimum 7-day average flow rate occurring with an average frequency of once in 10 years (7Q10). Instream flow of less than that rate may not be sufficient to assimilate wasteloads, resulting in water-quality standards violations and impairment of instream and offstream water use.

SRP should be represented on the Savannah River Basin Commission or similar entity that may form and should be prepared to justify its priorities for Savannah River use to the commissions and other water resource users. The

importance of the river stage range (82.5 to 96.0 ft) and discharge range (5,200 cfs) for SRP operations must be made known to the commission or other future regulator. Items as complex as the stewardship of wetlands at SRP need to be considered. For example, the flooding of wetlands at least every 2 or 3 years is beneficial (W. L. Specht, Savannah River Laboratory, personal communication) and can be accomplished at a river stage of 92 ft msl (C. G. Hardin, SRP, personal communication).

Competition for high-quality Coastal Plain groundwater is also expected to increase, with more demands by municipalities, industry, and agriculture. Because much of the surface water flow is dependent upon groundwater discharges that feed the streams, joint consideration of the interdependence of surface water and groundwater is required. Recent droughts have caused surface water supplies to diminish and groundwater levels to fall, bringing increased pressure for water conservation.

A recent publication of the Chemical Manufacturer's Association (1987) recommends that aquifer management plans characterize the groundwater resource: identifying existing and potential beneficial uses, as well as conflicting demands on the resource; identifying sources of contamination; and identifying alternative water resources. The Chemical Manufacturer's Association publication also suggests, where there is a need to protect the resources themselves, that those areas be designated as Aquifer Management Planning Areas (AMPA).

Two SRP areas may require more intense management and qualify as AMPAs because of high demands for groundwater withdrawal or possible contamination of those areas: F and H Separations Areas and A/M Area.

F and H Separations Areas require intensive groundwater pumpage (Figure 4) and waste management activities. Careful resource planning and attention in these areas will serve to avoid unfortunate consequences in the future. An area bounded by Upper Three Runs, Four Mile, and McQueen Branch creeks is suggested as an AMPA.

A/M Area is experiencing rehabilitation of aquifer contamination and intensive groundwater pumpage. An area delineated by the plant boundary, Upper Three Runs Creek, and the Savannah River Swamp is suggested as an AMPA.

General aquifer management guidelines suggest the following for water resources management at SRP:

- Continue to screen new production wells in Aquifer IV, because it is very transmissive and farthest below contamination sources.
- Although cones of depression of production wells in Aquifer IV are not extensive in most areas of SRP, continue to monitor them closely in AMPAs.
- Avoid pumping in locations where the head reversal protection may be lost, and develop alternative sources where the loss of that protection will not be likely to occur.

Pumpage should be continued as needed for SRP operations, although pumpage may need to be limited in F and H Separations Areas (Stephenson and Steele, 1988) and A/M Area AMPAs. Determine an upper yield limit for pumpage to meet the needs, possibly not exceeding current use. Consider reuse and other conservation alternatives, alternative groundwater pumping centers, and conjunctive use of surface water and groundwater.

In order to conduct plant operations in a manner that protects public health, preserves and maintains the quality of SRP surface water and groundwater environments, and meets federal and state regulatory limits, hydrogeologic and hydrologic studies should be continued. Compliance programs under way for surface water and wetlands, drinking water, land use/wildlife, groundwater, and atmospheric protection as detailed in Du Pont (1988a) should continue. Conservation by reducing water use is usually the most economic and conflict-free type of resource management. Water should be used wisely at all times. Wasteful use can diminish the supply of water and increase treatment cost for water and wastewater.

REFERENCES

- Ackermann, W. C., 1969. Scientific Hydrology in the United States, the Progress of Hydrology, 1st Inter. Seminar for Hydrology Professors, Univ. of Illinois, Champaign, IL, pp. 563-71.
- Aucott, W. R., 1986. The Predevelopment and Ground-Water Flow System and Hydrologic Characteristics of the Coastal Plain Aquifers of South Carolina, U.S. Geological Survey, Water Resources Investigations Report 86-4347, Government Printing Office, Washington, DC.
- Aucott, W. R. and G. K. Spieran, 1985. "Ground-Water Flow in the Coastal Plain Aquifers of South Carolina," *Journal of Ground Water* 23:736-745.
- Chemical Manufacturer's Association, 1987. State Groundwater Management Program: A Suggested Approach, Washington, DC.
- Christensen, E. J. and D. E. Gordon, 1983. Technical Summary of Groundwater Quality Protection Program at Savannah River Plant, Vol. I: Site Geohydrology, and Solid and Hazardous Wastes, DPST-83-829, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- DOE, 1984. Environmental Impact Statement. L-Reactor Operation. Savannah River Plant, Aiken, SC, DOE/EIS-0108, Office of Nuclear Materials Production, Washington, DC.
- Domenico, P. A., 1972. Concepts and Models in Groundwater Hydrology, McGraw-Hill, Inc., NY.
- Duffield, G. M., D. R. Buss, R. W. Root, Jr., S. S. Hughes, and J. W. Mercer, 1986. Characterization of Groundwater Flow and Transport in the General Separations Areas, Savannah River Plant: Flow Model Refinement and Particle-Tracking Analysis Report, CORR-86-0031, Report by GeoTrans, Inc., for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Du Pont, 1988a. Draft Environmental Implementation Plan for Savannah River Plant, DPST-87-121, E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC.
- Du Pont, 1988b. Draft Final Safety Analysis Report: Defense Waste Processing Facility, DPSTA-200-10, E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC.
- Halverson, N. V., J. B. Gladden, M. W. Lower, H. E. Mackey, Jr., W. L. Specht, and E. W. Wilde, 1987. Comprehensive Cooling Water Study Final Report, Volume I: Summary of Environmental Effects, DP-1739-1, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC.
- Logan, R. W. and G. M. Euler, 1988. Geology and Ground-Water Resources, Allendale, Bamberg, and Barnwell Counties and Part of Aiken County, South Carolina, South Carolina Water Resources Commission, Report 155, Columbia, SC.

- Papadopoulos, S. S. & Associates, 1986. Hydrogeologic Conditions in the Vicinity of the M-Area Settling Basin and Lost Lake, prepared for E. I. du Pont de Nemours and Company, Aiken, SC.
- Snyder, H. S., 1983. South Carolina State Water Assessment, South Carolina Water Resources Commission, Report 140, South Carolina Water Resources Commission, Columbia, SC.
- Spalding, C. P., G. M. Duffield, and S. T. Shaw, 1988. Characterization of Groundwater Flow and Transport in the General Separations Areas, Savannah River Plant: Effects of Groundwater Withdrawals on the "Tuscaloosa-Congaree" Aquifer Head Reversal in H Area, prepared by GeoTrans, Inc., Herndon, VA, for E. I. du Pont de Nemours and Company.
- Stephenson, D. E. and J. L. Steele, 1988. New Production Wells and Head Reversal in the Separations Areas of the Savannah River Plant (SRP), DPST-88-473, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.

GLOSSARY OF TERMS

Acre-foot: The volume of water required to cover 1 acre of land ($43,560 \text{ ft}^2$) to a depth of 1 ft; equal to 325,851 gal.

Aquiclude: Earth materials incapable of yielding significant quantities of water, but which may act to confine an aquifer.

Aquifer: A geologic formation, group of formations, or part of a formation capable of yielding significant quantities of water to wells, springs, and seeps.

Aquitard: A zone of relatively impermeable earth materials that confines an aquifer and conducts water very slowly.

Base-flow: Sustained or fair-weather streamflow supplied by groundwater.

Confined aquifer: An aquifer that underlies and is under pressure associated with a confining (aquitard) unit; also called an artesian aquifer. A confined aquifer usually is found below an unconfined (water-table) aquifer.

Conjunctive use: Combined use of ground and surface waters.

Consumptive use: Water that is no longer available for reuse because it has been evaporated, transpired, or incorporated into products, crops, or otherwise removed from the water environment.

Cubic ft per second (cfs): A unit of measurement for water discharge; streamflow equivalent to 448.8 gal/min.

Drainage basin: The area of land drained by a particular body of water; also called a catchment or watershed.

Evapotranspiration: A collective term for water discharged to the atmosphere as a result of evaporation from the soil and surface water bodies and by plant transpiration.

Groundwater: Water below the land surface in the saturated zone.

Infiltration: The movement of water into soil or rock.

Maf: Million acre-feet.

Mgd: Million gallons per day.

Normal (meteorol.): The average weather or hydrologic conditions over a specified 30-year period of time (e.g., 1951-1980).

Percolation: Laminar movement of water through porous earth material.

Permeability: The capacity of a rock for transmitting a fluid; for groundwater a permeability coefficient is called the hydraulic conductivity, expressed in units of ft/day.

Porosity: The ratio of the volume of the pore spaces in rock or unconsolidated material to the total volume.

Precipitation: The discharge of water from the atmosphere (i.e., rain, sleet, or hail).

Recharge: The entry of water into the zone of saturation.

Recurrence interval: The average interval of time within which the magnitude of a given event, such as a storm or flood, will be exceeded. Examples include the 100-year flood and the 10-year-7-consecutive-day low flow (7Q10).

Regulation of a stream. Artificial manipulation of a stream, usually involving dam and reservoir operations.

Return flow: The amount of water that reaches a surface or groundwater source after release from the point of use, thus becoming available for further use.

Riparian rights: A concept of water law under which authorization to use water in a stream is based on ownership of the land adjacent to the stream.

Runoff: That part of the precipitation that appears in surface water bodies. It provides the natural streamflow.

Safe yield: Amount of groundwater that can be withdrawn from an aquifer without producing an undesired effect. These can include land subsidence or other result of aquifer stress, salt water intrusion, and "upcoming" of water of poor quality.

Saturated zone: A subsurface zone in which all the pore spaces are filled with water, under greater than atmospheric pressure.

Stage: Height of water surface above an arbitrarily established data point. Used interchangeably with gage height.

Unsaturated zone: The subsurface zone above the water table in which the pore space contains a mixture of air and water held by capillarity.

Water budget: An accounting of the inflow to, outflow from, and storage changes of water in a hydrologic system.

Water table: The upper surface of the saturated zone in an unconfined aquifer. The water levels in wells that penetrate the aquifer mark the position of the water table.

Water year: A continuous 12-month period selected to represent hydrologic data during which a complete hydrologic cycle normally occurs. The water year used by the U.S. Geological Survey runs from October 1 through September 30.

Withdrawal: Water removed from the ground or diverted from a surface water source for use.

APPENDIX

RIVER STAGE AND DISCHARGE REQUIREMENTS FOR SRP OPERATIONS^a

Minimum stage and flow design level:	82.5 ft msl and 5,200 cfs.
Minimum operating level for 3 reactors ^b :	82.0 ft msl and 4,880 cfs.
Minimum operating level for 2 reactors ^c :	81.0 ft msl and 4,130 cfs.
Minimum operating level (P Reactor only) ^d :	80.4 ft msl and 3,600 cfs.
Lowest river level for plant operation ^e :	80.0 ft msl and 3,300 cfs.

Note: SRP personnel observe the stage and discharge at Jackson, SC. Data are available from D. W. Hayes.

^aInformation provided by C. G. Hardin, Jr., POWTEC, SRP.

^bIncreased cavitation (damage) will occur.

^cMinimum level for thermal mitigation (one reactor is always P).

^dAbsolute minimum operating level for D-Area intake. Severe pump cavitation at river system intakes will occur. Restricted 5G flow (2 pumps only) to the D-Area powerhouse will result. Only 3G can provide for minimum safety reactor core shutdown. There will be no flow for thermal mitigation.

^eThe powerhouse will shut down completely (no electricity or steam). The Separations Areas will shut down because of a lack of steam. No reactor operations will be possible because of a lack of cooling water flow. The reactor cores must be discharged for safety.

END

DATE FILMED

01 / 22 / 91