2 BACKGROUND

2.1 Overview of Site Operations

In 1946, Congress created the U.S. Atomic Energy Commission (AEC) to administer the nuclear programs created for the World War II Manhattan Project. AEC needed new production capacity for nuclear weapons materials used in national defense and, in November 1950, AEC selected a location in South Carolina for the Savannah River Plant. Covering about 300 square miles (780 km^2), the site was chosen because of its low population density, large supply of water, freedom from major floods and storms, and other factors (1).

SRS is located about 19 miles (32 km) south of Aiken, South Carolina, and about 22 miles (36 km) southeast of Augusta, Georgia. It borders the Savannah River for about 17 miles and comprises parts of Aiken, Barnwell, and Allendale Counties in southwestern South Carolina. Figure 2-1 shows the general location of SRS.

The Savannah River Plant was designed, constructed, and operated for the AEC by E.I. duPont de Nemours and Company (DuPont). Construction began in 1951 (2). The basic plant was completed within five years and included five nuclear reactors, two chemical separations plants, and numerous laboratories and support facilities. The primary mission was production of ^{239}Pu and tritium. SRS bombarded fuel and targets containing ^{238}U and ^{6}Li with neutrons in the nuclear reactors, and recovered the ^{239}Pu and tritium from the fuel and targets at the separations facilities. DuPont continued operation of the plant until 1989 when operation was taken over by the Westinghouse Savannah River Company. At that time, the site was renamed the Savannah River Site (Phase II).

As production continued, the need for specific materials waned. As a result, site facilities gradually ceased operation until the primary defense-related mission ended in 1992. Since that time, certain activities continue to manage waste, conduct environmental restoration activities, and perform new missions (2).

Table 2-1 summarizes the SRS facilities of main importance for this study, and shows the principal SRS areas and facilities. Most are located in a rough circle in the approximate center of the site.[1] SRS contains two large ponds, Par Pond and L-Lake, and is drained by five major streams feeding into the Savannah River: Upper Three Runs Creek, Four Mile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek. With the exception of Lower Three Runs Creek, all of these streams empty into the Savannah River Swamp bordering the east side of the Savannah River.

[1] SRS facilities are identified by a system, using numbers and letters that reference them to a particular onsite area containing a complex of related or supporting operations. For example, each of the two chemical separations areas is identified by a letter of the alphabet (F and H Areas), and each building or structure within an area is numbered in accordance with a century nomenclature (i.e., the reactor areas are the 100-Areas, the separations areas are the 200-Areas, and so forth). A structure in one of the 100-Areas (reactor areas) is identified by a number in the 100's, a structure in one of the 200-Areas is identified by a number in the 200's, etc.

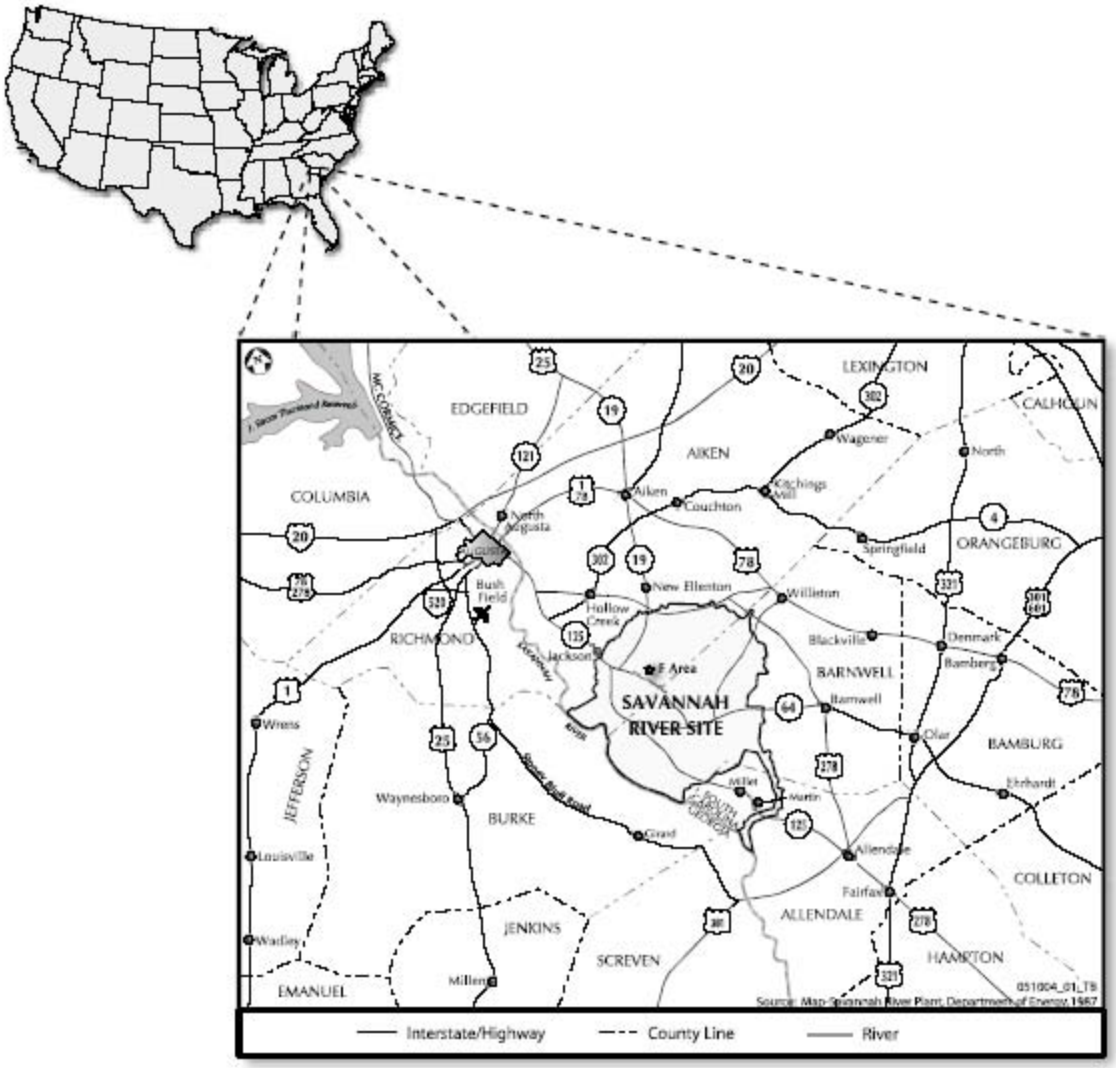

Figure 2-1 General Location of SRS

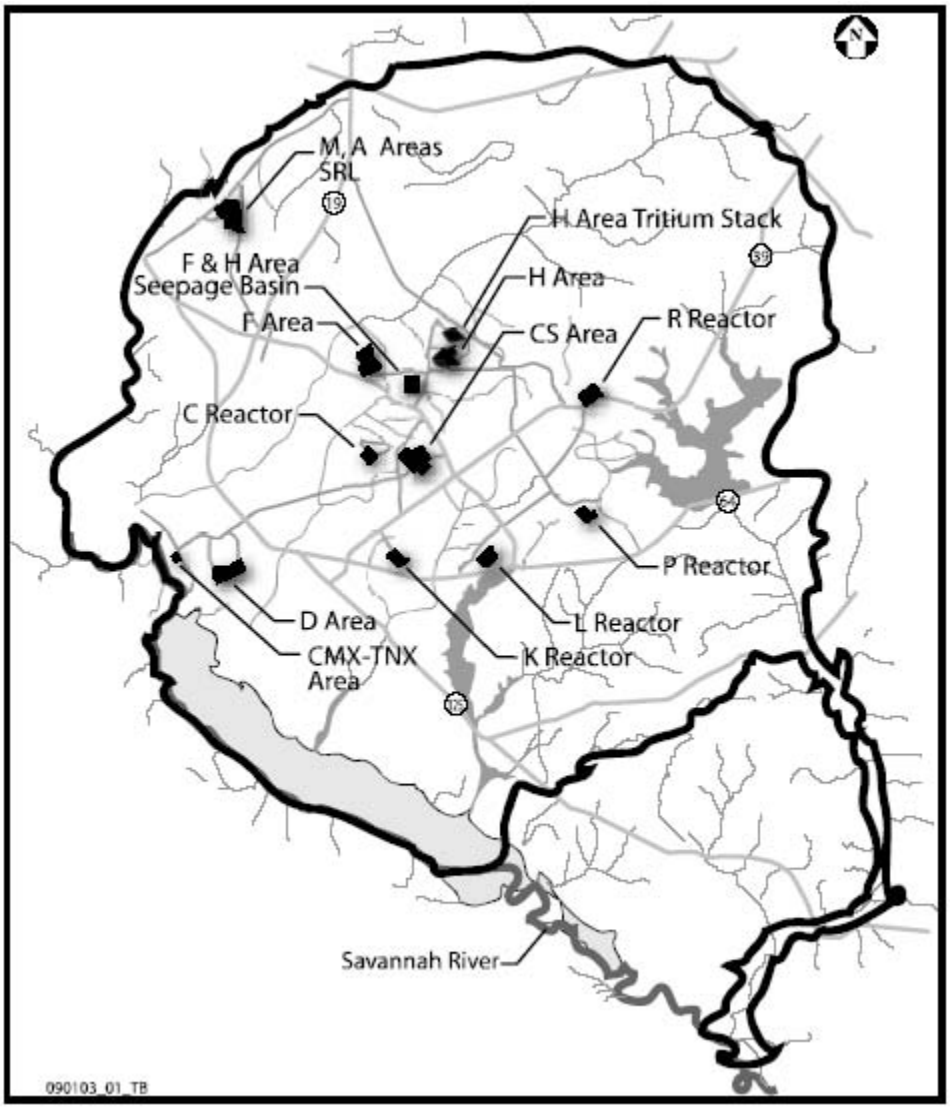

Figure 2-2 Principal SRS Areas and Facilities

Table 2-1 Principal Areas and Facilities

Areas	Facilities	Dates	Notes
100	R-Reactor P-Reactor C-Reactor K-Reactor L-Reactor	1953-1964 1954-1988 1955-1985 1954-1988 1954-1968 1985-1988	Reactors used heavy water as a neutron moderator and primary coolant. L-Reactor operated from 1954 to 1968, and from 1985 to 1988. K-Reactor was the last operating reactor.
200	H-Area Chemical Separations	Completed November 1954	Facilities for chemical separation and purification of plutonium (Pu), tritium (^{3}H), and other products from irradiated targets and fuel. Also used for recovery of tritium from weapons reservoirs.
	F-Area Chemical Separations	Completed July 1955	
300	M-Area Fuel and Target Production	Completed January 1953	Produced reactor fuel and target assemblies for irradiation in reactors.
400	D-Area Heavy Water Plant	First operating by October 1952; full capacity by May 1953	Concentrated heavy water from Savannah River. Reconcentrated heavy water after contamination with light water in reactors.
600	E-Area Waste Management	First disposals in 1953	Burial grounds located in E-Area between F-and H-Areas. Still in use.
	CMX and TNX Facilities	Completed 1953	Technical support, pilot plant development and training. Located near D-Area Heavy Water Plant.
700	A-Area Administration	Opened with site	Administrative offices. Includes Savannah River Technology Center.

Source: (3).

2.1.1 D-Area: Heavy Water Production and Processing

Some of the first facilities to be constructed were those producing heavy water for use in the reactors. The Extraction Plant, which operated until 1981, concentrated heavy water[2] from a natural level in river water (about 0.015 percent) to a concentration sufficient for reactor operations. The Rework Unit and the Distillation Plant removed light water that, over time, would contaminate the heavy water in the production reactors. Additional facilities included a laboratory, a facility to clean drums used for heavy water storage and transportation, and a coal-fired powerplant (3).

[2] Each molecule of water consists of two hydrogen atoms and one oxygen atom. One or both of the hydrogen atoms in heavy water contains a neutron in the nucleus in addition to a proton. A hydrogen atom containing a neutron and a proton in the nucleus is a deuterium (D).

Because tritium[3] is created from deuterium by neutron bombardment, concentrations of tritium in the reactor moderator built up over time. Consequently, the processes used to reclaim reactor moderator discharged tritium into the air and surface water.

The largest source of tritium released to air from D-Area was the Rework Unit, where releases to air occurred from leaks from the Rework Unit pump room and from the exhausts from the area used for storage of recovered heavy water. Releases also occurred from the drum-cleaning facility and the laboratory (1).

The Rework Unit was also responsible for the largest source of tritium released to surface water from D-Area. Typically, waste distillate was collected in tanks before sampling and discharge to cooling water effluent that drained to Beaver Dam Creek (1).[4] The tritium in the waste distillate was normally in concentrations that were too low for practical recovery (1).

2.1.2 M-Area: Reactor Materials

Fuel and target elements for irradiation in the SRS reactors were fabricated in the M-Area. Major facilities located in the M-Area were the Alloy Extrusion Unit, the Uranium Metal Element Fabrication Unit, the Target Extrusion Unit, and the Metallurgical Laboratory. All uranium for fuel and targets was received from offsite sources (1).

Activities generated airborne and liquid effluents containing uranium isotopes. Air treatment procedures differed depending on the operational processes within each M-Area building. Initially, liquids containing uranium were discharged to Tims Branch and pond beds adjacent to M-Area (1).[5] As of 1977, about 50 percent of the discharged uranium had settled in the stream and beds and had "not reached the main stream leading to the river" (1). After late 1976, most liquids were discharged to the M-Area settling basin (1).

2.1.3 Reactor Areas

Table 2-2 summarizes the dates of operation of the five SRS production reactors. All reactors used heavy water as a neutron moderator and primary coolant. All were housed in buildings constructed of heavy concrete to provide radiation shielding to personnel. Reactor systems and auxiliaries included the primary and secondary coolant systems, the component-handling systems, and the disassembly basins (1).

2.1.3.1 Operational Components

<u>Coolant Systems</u>

The primary coolant system consisted of heavy water circulating through the reactor core. In each system, coolant entered a plenum and then flowed through the reactor core. Heated coolant then passed through heat-exchangers where heat from the fission process was transferred to a secondary coolant system (1).

[3] A tritium (T) atom is a radioactive atom of hydrogen containing two neutrons and a proton in the nucleus.
[4] This creek flows to the Savannah River Swamp and then follows a meandering route through the swamp to the river, mixing with a portion of the flow from Four Mile Branch.
[5] Tim's Branch empties into Steeds Pond about 1-1/2 miles from the 300-Area. Overflow from Steeds Pond drains into Upper Three Runs Creek, which empties into the Savannah River.

At each reactor, water bled from the primary coolant system was circulated through a water-treatment system to maintain ionic purity of the coolant and to reduce radiation exposures to personnel.[6] Typical water treatment equipment included filters, deionizers, and evaporators. An offshoot from the deionizer effluent passed through a distillation unit that removed light-water impurities from the heavy-water coolant (1).[7]

Table 2-2 Summary of Reactor Operations

Reactor	Dates of Operation	Comments
C	1955-1985	Shut down in 1985.
K	1954-1988	Shut down in 1988, but operated briefly in 1992. In 1993, it was put in cold standby as the Nation's tritium source. Shut down permanently in 1996.
L	1954-1968 1985-1988	Shut down for upgrades in 1968. Restarted in 1985. Shut down in 1988.
P	1954-1988	Shut down in 1988.
R	1953-1964	Shut down in 1964.

Source: (2).

The secondary coolant system consisted of water from the Savannah River. River water was pumped to reservoirs located in the reactor areas, and from the reservoirs passed through the reactor heat exchangers. As reactor thermal power gradually increased from 1954 to 1962,[8] additional secondary cooling capacity was achieved by measures such as doubling the number of heat exchangers used in the secondary coolant system, by increasing river-pump capacity, and by the construction of Par Pond in 1958 (3).

Par Pond is a 2,700-acre reservoir formed by damming Lower Three Runs Creek. Pond water pumped to the P- and R-Reactors was returned to Par Pond,[9] allowing increased delivery of river water to the L-, P-, and C-Reactor secondary cooling systems. Until 1985 and 1988, respectively, effluent cooling water from C- and K-Reactor heat exchangers flowed back to the river via onsite streams. Until 1988, cooling water from P-Reactor continued to flow to Par Pond. In 1985, SRS formed L-Lake by damming Steel Creek. SRS used L-Lake as a heat sink for L-Reactor when it operated from 1985 through 1988 (3).

Component-Handling System

The component-assembly area of a reactor building was used to receive fresh fuel from the 300-M Area and to discharge irradiated fuel from the reactor[10] to a reactor disassembly basin (1).[11]

Disassembly Basin

[6]Operation of the reactor resulted in contamination of the coolant with radionuclides due to neutron activation of coolant, cladding, and reactor components; corrosion of cladding and components; and leakage of fission products from fuel.
[7]Buildup of light water in the primary coolant system primarily resulted from exposure of the coolant to humid air within the system.
[8] The reactor thermal power, or heat output, is proportional to the rate of fission and the creation of fission products in the fuel. With higher rates of fission, higher reactor core densities of neutrons were achieved resulting in larger rates of production of tritium and other products.
[9] Before construction of Par Pond, cooling water from the heat exchangers was discharged directly into onsite streams.
[10] Control rods and other components were similarly charged into the reactor and discharged as needed.
[11] Also called a fuel and target storage basin or a fuel pool.

A disassembly basin is a deep pool of water used to temporarily store fuel and miscellaneous reactor components removed from the reactor. During the 1950's and 1960's, irradiated material stayed in the disassembly basins for less than nine months. In later years, the storage period was longer (3).

2.1.3.2 Air and Water Treatment and Effluent

Releases of radionuclides to air and water varied over time depending on modifications to reactor operations, reactor equipment, and air- and water-treatment systems. Releases to air and water also resulted from occasional problems with equipment.

Air

Principal sources of airborne release at reactor areas included the reactor building, disassembly basins, and seepage basins (3).

Exhaust from each of the process areas in a nuclear reactor was routed through an air treatment system consisting of moisture separators, filters, and charcoal beds to remove elemental iodine vapor and gaseous iodine compounds.[12] Exhaust was discharged from a 200-foot stack (1). Radionuclides released from the reactor building included tritium and fission and activation products, including iodine isotopes and ^{41}Ar. Tritium was released mainly from evaporation of the moderator (3).[13]

Exhaust from the disassembly basin area was discharged to the air from a roof vent. Releases mainly consisted of tritium in water evaporating from the pool surface. Ground-level release of tritium occurred from evaporation of seepage basin water (3).

Water

Table 2-3 summarizes liquid effluent procedures for each reactor. During operation, some of the radionuclides contaminating the reactor coolant were transferred to secondary coolant water from leakage of the heat exchangers. Thus, coolant water discharged to surface waters contained tritium and other radionuclides.

The disassembly basins were additional sources of contaminated liquid effluent. To ensure visual clarity and maintain personnel exposure levels at acceptable levels, the basins were purged with river water. Until the mid 1960's, basin purge water was continuously discharged to site streams along with secondary cooling water. Sand filters were added to the disassembly basins in the early 1970's, and continuous purging to site streams ceased although periodic purging continued from 1970 to 1977. In 1978, SRS began to discharge water from periodic purges to reactor seepage basins. These seepage basins were constructed at all reactor basins during the second half of 1957 primarily for disposal of water generated from vacuum-cleaning the disassembly basins (3).

2.1.4 F- and H-Separations Areas

Chemical separations facilities at SRS consist of two main complexes: F- Area and H-Area. Each complex contains a shielded separations building divided into two parallel "canyons" as well as auxiliary facilities that include a waste concentration and storage system, seepage basins, powerhouses, and service facilities. F-Area contains a laboratory, the plutonium metallurgical building, and the Plutonium Fuel

[12] This equipment was typical by the end of 1963 when all reactor ventilation systems had been fitted with charcoal beds and high-efficiency particulate filters. This air-treatment system was installed in R-, P-, and K-Reactors in 1962, and in the remaining two reactors the following year.

[13] Tritium built up due to neutron capture by deuterium and primarily released as either T_2O or DTO.

Form Facility (PuFF). H-Area contains the tritium process buildings, the Receiving Basin for Offsite Fuels (RBOF), and the Resin Regeneration Facility (RRF).

Table 2-3 Summary of Liquid Discharge Procedures at SRS Reactors

Reactor	Operation	Liquid Effluents
R	1953-1964	To Lower Three Runs Creek, Par Pond, and one seepage basin
P	1954-1988	To Steel Creek, Par Pond, and three seepage basins
C	1955-1985	To Four Mile Creek and three seepage basins
K	1954-1988	To Pen Branch and two seepage basins
L	1954-1968 1985-1988	To Steel Creek, L Lake (built in early 1980's by damming Steel Creek), and a seepage basin

Source: (3).

2.1.4.1 Operational Components

Separations

Operations at either of the two separations facilities typically began with dissolution of the cladding from the irradiated fuel or targets, followed by dissolution of the declad materials, generally in nitric acid. This process evolved volatile fission products such as iodine isotopes. The solution was then sent through a series of solvent extraction cycles. The first solvent extraction cycle stripped the product (e.g., plutonium and uranium) from the fission products. The product was then purified in subsequent chemical processes. Fission products (and some residual plutonium and uranium) from the first solvent extraction cycle were routed to the high-level waste tanks (3).

Tritium Recovery

The tritium facilities in the H-Area consist of three buildings (i.e., 232-H, 234-H, and 238-H) where tritium was separated from irradiated lithium-aluminum targets, further purified, and packaged (1).

Receiving Basin for Offsite Fuels

This H-Area building houses fuels from offsite reactors. Fuels are received and either stored or cut and packaged for reprocessing. In addition, the RBOF received special nuclear fuels from SRS and offsite research reactors. It is now shut down (1, 3).

Resin Regeneration Facility

This H-Area facility received ion-exchange resin beds and filters from reactor areas for regeneration (1).

Metallurgical Building

This F-Area facility was used to fabricate components for uranium, neptunium, and plutonium reactor elements (1).

Plutonium Fuel Form Facility

This F-Area facility manufactured Pu-238 heat source fuel forms (3).

Analytical Laboratory

This F-Area facility supplied radioanalytical services to the entire plant except for the Savannah River Laboratory (1).

Waste Concentration and Storage

High-activity waste liquids from separations operations were concentrated and stored in tanks. Most notably, high-level liquid wastes from the solvent extraction process were pumped to large underground tanks located in "farms" in each separations area. As of 2002, 37 million gallons of waste remained stored in 49 tanks in 2 tank farms (4).

2.1.4.2 Air and Water Treatment and Effluents

Air

Both separations buildings were ventilated by systems that directed air from clean areas to areas that were contaminated. Ventilation air was passed through filters before discharge to stacks. The main stacks for both separations areas were 200 feet tall. The F-Area Canyon was also equipped with an auxiliary stack for dissolver off-gas as well as a 160-foot stack for air ducted from the plutonium processing areas (1).

Air from the three tritium facilities (232-H, 234-H, and 238H) was discharged through tall stacks (1)

Off-gas from the RBOF building was filtered and discharged to air through 53-foot stacks. In addition, gases collected from fuel-cask opening or fuel-cutting operations were passed through charcoal and HEPA filters before discharge (1).

Water

Radioactive contamination released to surface water mainly came from two sources: coolant water for the separations process vessels and seepage basins. One coolant-water system, used for areas that were unlikely to become contaminated, recirculated coolant water through a cooling tower. A second system was a once-through system: water was normally discharged to Four Mile Creek if measured levels of contamination were sufficiently low. If water from either system contained contamination above prescribed limits, the water was diverted to seepage basins constructed in each of the two separations areas. If seepage basin limits were exceeded, the water was sent to retention basins for storage pending treatment (1).

Three seepage basins were used at each separations area. Liquid discharged into the seepage basins seeped through the ground until it discharged to a seepline draining to Four Mile Creek. After 1988, when the Effluent Treatment Facility for the separations areas became operational, the F- and H-Area seepage basins were not used (3).

2.1.5 Waste Management Areas

Activities at SRS have generated large quantities of radioactive wastes, most of which were either disposed or stored onsite. Disposal of radioactive wastes has occurred at 20 locations within SRS. The high-level waste is stored in several underground tanks located in the F- and H-Areas (3). These wastes are not of particular interest to this study due to the low levels of radionuclide release from waste storage and disposal operations to air and surface water. However, liquid effluents that have been released to seepage basins are of interest. Seepage basins have been discussed above.

2.1.6 Additional SRS Facilities

Several additional facilities and support areas exist on the SRS and provide small to negligible discharge of radionuclides to water or air.

2.1.6.1 A-Area: Administrative Area

The Administrative Area contains organizations and facilities that support SRS operations. The only facility that historically contributed radionuclides to air and water was the Savannah River Technology Center (SRTC), which was established in 1951 as the Savannah River Laboratory. For its first few decades of operation, the SRTC fabricated fuel-element prototypes, targets containing radioactive oxides, and sealed radioactive sources. It also performed research and development of separations processes. Airflow through contaminated areas was filtered and vented through either a 100-foot or a 160-foot stack. If within prescribed concentration limits, low-activity contaminated liquids were transferred to laboratory seepage basins; otherwise, they were transported to F-Area for treatment. High-activity-level liquids were transferred to F-Area for storage (1, 3).

Other facilities in the A-Area include the U.S. Department of Energy site office and the Savannah River Ecology Laboratory.

2.1.6.2 TNX and CMX Semiworks

Although considered part of the SRTC, the TNX and CMX Semiworks are located near the Savannah River next to the 400-D Area. The TNX facilities were used to study chemical-processing problems and test production-scale equipment. Tests were conducted using natural uranium or other surrogates. In later years, the facility researched and developed waste treatment processes. The CMX facility conducted non-nuclear tests of the hydraulic systems of the SRS reactors until it shut down in 1984 (3).

2.2 Principal Radionuclides Released During SRS Operations

During 39 years of operation, SRS released a variety of radionuclides into air and surface water. For the SRS dose reconstruction effort, the Phase II report provides estimates of the release of those radionuclides determined to be most significant for public health concerns (3).

Challenges faced in the Phase II study included incomplete records of radionuclide release, gaps in monitoring data, and questions about early radiation detection and analysis equipment. Releases of radionuclides from times when data were available were scaled in Phase II to times when data were not available based on knowledge of the processes that resulted in the release. SRS procedures for monitoring releases from plant operations were reviewed as was the SRS environmental monitoring program. Estimates of release for some radionuclides were adjusted from those reported by SRS (3).

To focus the effort, a two-step screening analysis was performed using a screening process set forth by the National Council on Radiation Protection and Measurements (5). From the first step of the screening process, the Phase II study identified a list of key radionuclides that had been released into the air and water from SRS operations. The key radionuclides released to air were ^{241}Am, ^{41}Ar, ^{14}C, ^{137}Cs, ^{3}H, ^{129}I, ^{131}I, ^{238}Pu, ^{239,240}Pu, ^{103,106}Ru, ^{89,90}Sr, and uranium. The key radionuclides released to surface water were ^{137}Cs, ^{60}Co, ^{3}H, ^{129}I, ^{131}I, ^{32}P, ^{238}Pu, ^{239,240}Pu, ^{89,90}Sr, ^{35}S, ^{99}Tc, uranium, ^{91}Y, ^{65}Zn, and ^{95}Zr/Nb. From the second step of the screening process, which considered possible exposure pathways in more detail, the Phase II study identified two smaller sets of radionuclides released to the air and water for further detailed analysis. These radionuclides consisted of ^{131}I, ^{3}H, ^{41}Ar, ^{129}I, ^{239,240}Pu, and uranium released to air, and ^{137}Cs, ^{3}H, ^{89,90}Sr, ^{60}Co, ^{32}P, ^{131}I, and uranium released to water (3).

For the Phase III effort, the source term provided in the Phase II report was closely reviewed and refined. Chapters 5 and 7 discuss these adjustments in detail. The radionuclide release data presented in the Phase II report could not be used directly in the Phase III effort due to the following three major concerns:

1. The Phase II report did not provide annual release estimates for all key radionuclides. For some radionuclides, the report provided a 36-year total source term.

2. The Phase II report did not provide release estimates for many radionuclides for the years 1990 through 1992.

3. The Phase II report included estimates for some radionuclides as aggregated quantities (e.g., ^{89,90}Sr, uranium). However, some aggregated radionuclides were disaggregated into separate isotopes to provide a more refined treatment of health effects.

The estimates provided in the Phase II report were refined to determine annual release estimates of each of the key radionuclides for all 39 years of the study[14]. To do so, data in SRS reports (6) was examined. For key radionuclides cited in the Phase II report as aggregated isotopes (e.g., ^{89,90}Sr, uranium), the radionuclides were separated into their isotopic constituents based on an understanding of the processes that generated the isotopes.[15] In addition, some of the data in SRS reports were presented in terms of undifferentiated activity (i.e., unidentified [gross] alpha and unidentified [gross] beta-gamma activity). For these data, ^{239}Pu was assumed for reported unidentified alpha activity and ^{90}Sr was assumed for reported unidentified beta-gamma activity. Finally, information was reviewed about the likely chemical forms of the released radionuclides, a consideration needed for certain portions of the analysis. See Chapters 5 and 7, and Appendix B, for additional information about partitioning assumptions and procedures.

2.2.1 F- and H-Separations Areas

Table 2-4 lists the radionuclides considered in Phase III and whether they were released via the air or surface water pathway. Some radionuclides considered in Phase III for water release are not considered for air release, even though releases of these radionuclides to air did occur. One reason is that the quantities of radionuclides release to air may have been much less than the quantities released to water; consequently the doses from the air releases were not significant. In addition, because the Phase II screening methodology considered generic environmental pathways for the radionuclides, some radionuclides produce a larger dose impact when released to water than when released to air. Thus, ^{134}Cs is considered separately from ^{137}Cs for water releases, but ^{134}Cs released to air was screened out in Phase II. Appendix B provides lists of the quantities of each radionuclide released through air and water pathways as a function of year.

[14] ^{106}Ru, ^{144}Ce, and ^{134}Cs were added to the list of isotopes considered in Phase III for release to surface water. ^{91}Y was deleted for release to surface water. Although ^{91}Y was listed as a key radionuclide in the Phase II report, it actually did not pass the screening criteria used for either step of the Phase II screening analysis.

[15] In this report, ^{89,90}Sr was partitioned into ^{89}Sr and ^{90}Sr, ^{95}Zr/Nb was partitioned into ^{95}Zr and ^{95}Nb, and uranium was partitioned into ^{234}U, ^{235}U, ^{236}U, and ^{238}U. It was assumed that activity identified as ^{239,240}Pu was all ^{239}Pu, activity identified as ^{103,106}Ru was all ^{106}Ru, and activity identified as ^{141,144}Ce was all ^{144}Ce.

Table 2-4 Radionuclide Release Pathways

Radionuclide	Released to Air	Released to Surface Water
^{3}H (tritium)	X	X
^{14}C	X	
^{32}P		X
^{35}S		X
^{41}Ar	X	
^{60}Co		X
^{65}Zn		X
^{89}Sr	X	X
^{90}Sr	X	X
^{95}Zr		X
^{95}Nb		X
^{99}Tc		X
^{106}Ru	X	X
^{129}I	X	X
^{131}I	X	X
^{134}Cs		X
^{137}Cs	X	X
^{144}Ce		X
^{234}U	X	X
^{235}U	X	X
^{236}U	X	X
^{238}U	X	X
^{238}Pu	X	X
^{239}Pu	X	X
^{241}Am	X	

2.2.1.1 Iodine and other Beta-Gamma-Emitting Particles

Radioactive iodine and other beta-emitting-radionuclides were released mainly from the separations areas. In particular, iodine and other volatile isotopes evolved from dissolution of reactor fuels and targets.

Iodine releases included elemental iodine (I_2) and organic iodides (e.g., CH_3I). The Phase II report observed that releases if iodine for the early years of operation (through about 1961) contained significant uncertainties. The Phase II estimates of ^{131}I release included a significant correction to release estimates provided by SRS (3).

Release of other beta-gamma-emitting isotopes also occurred, mainly from the F- and H-Areas. These isotopes included $^{89,90}Sr$, $^{95}Zr/Nb$, $^{103,106}Ru$, ^{137}Cs, and $^{141,144}Ce$ (3).

2.2.1.2 Activation Products

Activation products are generated when neutrons produced during fission interact with reactor materials such as control rods and structural members, with fuel and target cladding, with air within the reactor, and with impurities and anti-corrosion chemicals in the moderator. Table 2-5 lists the principal activation products generated in SRS reactors (3). The principal activation product of concern for release into the air is ^{41}Ar. Because argon is a noble gas, it was released from SRS facilities (primarily reactors) without capture by the air treatment and filtration systems.

Table 2-5 Characteristics of Activation Products

Radionuclide	Primarily Produced From	Half-Life
^{32}P	^{31}P	14.3 days
^{35}S	^{35}Cl	87.3 days
^{41}Ar	^{40}Ar	1.83 hours
^{51}Cr	^{50}Cr	27.7 days
^{60}Co	^{59}Co	5.27 years
^{65}Zn	^{64}Zn	244 days

Source: (3).

2.2.1.3 Alpha-Emitting Radionuclides

Alpha-emitting radionuclides—principally isotopes of uranium and plutonium—were released to air at SRS primarily from the M-Area, the reactors, and the separations facilities. Measured releases were small from M- Area and the reactors, and larger from the separations facilities. Most plutonium emissions occurred from 1955 to 1969 from F- and H-Area stacks. Uranium releases were largest during 1955, 1968, and 1969 from H-Area stacks; and during 1955, 1956 and throughout the 1960s from F-Area stacks (3).

2.2.2 Release of Radionuclides to Surface Water

2.2.2.1 Tritium

The major sources of tritium released to surface water were reactor and separations area effluents discharged to streams and seepage basins. Lesser quantities of tritium were released to surface water from the D-Area (3).

2.2.2.2 Iodine and other Beta-Gamma-Emitting Particles

The major sources of iodine, ^{137}Cs, and other beta-gamma-emitting particles released to surface water were reactor and separations area effluents discharged to streams and seepage basins (3).

2.2.2.3 Activation Products

The major sources of activation products released to surface water were reactor and separations area effluents discharged to streams and seepage basins (3).

2.2.2.4 Alpha-Emitting Radionuclides

Alpha-emitting radionuclides released to surface water included isotopes of uranium and plutonium. Uranium isotopes were released from M-Area and the separations areas. Plutonium releases to surface water came mainly from the separations areas (3).

2.3 SRS Environmental Setting

This section provides a background discussion of human and environmental factors within the vicinity of SRS that are of interest to this study. Primary references are (1), (3), (4), (7), and (8).

2.3.1 Population and Land Use

The area was sparsely populated when SRS was created. Although the only towns on the plant site were Ellenton (population 600) and Dunbarton (population 251), the communities of Leigh, Hawthorn, Robbins, and Meyers contained isolated groups of families (1). About 6,000 persons comprising 1,500 families (8) were relocated. Some moved to New Ellenton, which was established north of the SRS boundary to replace Ellenton (4).

Construction of SRS employed a peak force of 38,500 workers (4). The operating work force initially numbered 5,000 workers (1), climbed to 7,500 by 1980, and totaled nearly 26,000 by 1992 (4). As of 2000, it numbered 14,000 (4).

When SRS was sited, about 67 percent of the land was forested and about 33 percent was pasture and cropland. The main crops were cotton and corn (1). Abandoned fields gradually became pine forests. Current land use on SRS is about 56 percent pine forest, 35 percent hardwood, 7 percent in SRS facilities and open fields, and 2 percent water (8). Except for three roads and a rail line near the edge of the site, public access to SRS is restricted to environmental studies, guided tours, and controlled deer hunts (8). Adjacent to SRS, about 21 percent of the land is devoted to agriculture and about 70 percent comprises forests, wetlands, water bodies, and unclassified, predominately rural lands. Less than 8 percent is urban or built-up (8).

2.3.2 Environmental Characteristics

2.3.2.1 Meteorology and Climatology

The climate in the region of SRS is subtropical, characterized by long, warm, and humid summers and short, mild winters. The average annual temperature at SRS is 64.7°F and the average precipitation is 49.5 inches. The driest season is fall, with an average monthly rainfall of 3.3 inches; the wettest season is summer, with an average monthly rainfall of 5.2 inches. The average annual relative humidity is 70 percent. The average daily maximum relative humidity is 91 percent, and the average daily minimum is 45 percent. Winds currently blow most frequently from the northeast and southwest. Current SRS atmospheric conditions have been classified as unstable about 56 percent of the time (8).[16]

[16] More detailed historical information about wind speeds, directions, and stability classes are more difficult to obtain. Of interest to this report would be detailed meteorological data from the mid 1950's to the 1990's. SRS lacked a formal meteorological program until the early 1970's, leaving a gap of about 20 years in SRS-specific meteorological data.

2.3.2.2 Geology and Hydrology

Regional Geology

SRS is located on the Upper Atlantic Coastal Plain. Most soils at SRS are sandy over loamy or clayey subsoil. Annual erosion rates for regional soils, including cropland, range from 1.5 to 2.0 kg/m^2/yr. Two soil profile horizons are commonly noticed. The upper horizon (A Horizon) typically consists of structureless fine- to medium-grain quartz sand up to 3 meters thick. The lower horizon (B Horizon) contains iron and aluminum compounds and may range in thickness from 0.6 to 3 meters (8).

Ground Water Hydrology

The shallow ground water on the site is contained within the Floridian Aquifer System, comprising the lowermost Gordon aquifer unit, the Gordon confining unit, and the uppermost Upper Three Runs aquifer unit that contains the water table (4, 8). The water table varies from ground surface to a depth of about 100 feet. In F- and H-Areas, the ground-water velocity ranges from a few hundredths of a foot per day to one foot per day near streams (1).

The shallow aquifers beneath the industrial areas that make up about to 10 percent of the SRS have been contaminated with industrial solvents, metals, tritium, and other constituents used or generated at SRS. In general, DOE does not use these aquifers for SRS process operations although there are a few low-yield wells in the Gordon Aquifer and the lower zone of the Upper Three Runs Aquifer. The shallow aquifer units of the Floridian System discharge to SRS streams and eventually the Savannah River (4).

Despite the contamination in some of the shallow aquifers on the site, "there is no data available to suggest that groundwater containing radionuclides has migrated off the SRS to the surrounding communities" (9). Rather, as stated above, localized contaminated ground water on the SRS discharges into onsite streams that ultimately discharge to the Savannah River (9).[17]

Surface Water Hydrology

Operations at SRS caused large withdrawals of cooling water from the Savannah River as well as discharge of heated water to onsite streams. Thermal discharges were reduced after construction of a cooling tower to support K-Reactor operation and L-Lake to support L-Reactor operation (3).

Five major tributaries to the Savannah River drain SRS: Upper Three Runs Creek, Four Mile Branch, Beaver Dam Creek, Steel Creek, and Lower Three Runs Creek. Figure 2-3 shows the major river and stream system at SRS. These streams meander for several miles through SRS and—except for Lower Three Runs Creek— through the Savannah River Swamp before emptying into the river. A sixth stream, Pen Branch, joins Steel Creek in the Savannah River Swamp. One stream in the northeast area of SRS drains to the Salkehatchie River. The natural flow of SRS streams ranges from about 10 cubic feet per second (cfs) in smaller streams to 245 cfs in Upper Three Runs Creek (4). For several years, coolant and effluent discharges greatly increased flow in these streams above their natural rates. Savannah River flow in 1995 averaged about 10,000 cubic feet per second at SRS (4).

F- and H-Areas are situated on a divide that separates drainage into Upper Three Runs Creek and Four Mile Branch. About half of each area drains into each stream. The F- and H-Areas are drained by Upper Three Runs Creek to the north and west and by Four Mile Branch to the west. The surface aquifer for

[17]The Phase II report concludes, in Appendix J, that "although groundwater contamination from SRS releases may be a potential exposure pathway for the future, the evidence suggests that it did not impact offsite residents before 1992" (3).

both F- and H-Areas discharges at seeplines along both Four Mile Branch and Upper Three Runs Creek (3,4).

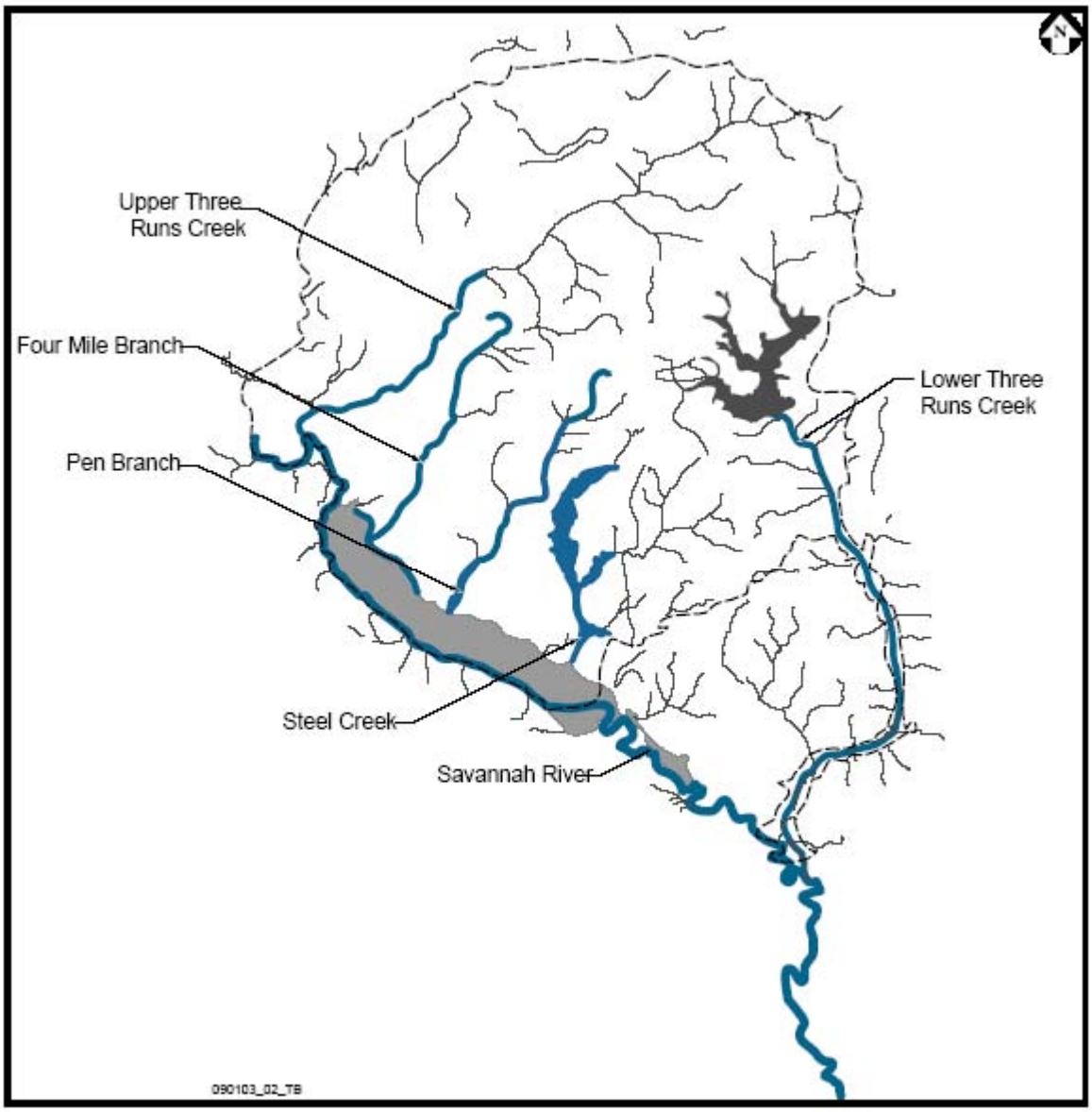

Figure 2-3 Major River and Stream Systems at SRS

Upper Three Runs Creek is the only major tributary on SRS that has not received thermal discharges (4). One of Upper Three Run Creek's tributaries—Tim's Branch—received (at Road C) effluents from A-Area and M-Area. Steed's Pond, located on Tim's Branch just north of Road 2, was a mixing and settling pond for A-Area and M-Area wastes (3, 4).

Four Mile Branch originates near the center of SRS and flows southwest before emptying into the Savannah River (4). It drains much of the F-, H-, and C-Areas and received C-Reactor cooling water about 0.5 miles south of Road 3. It flows parallel to the Savannah River behind natural levees and enters

the river through a breach downriver from Beaver Dam Creek. In its lower reaches, Four Mile Branch broadens and flows via braided channels through a delta formed by the deposition of sediments. Downstream from the delta, the channels rejoin into one main channel (3, 4).

Steel Creek and Lower Three Runs Creek both received significant quantities of reactor effluents. Steel Creek received discharges from the L- and P-Reactor Areas before Par Pond was built in 1958. K-Reactor effluent from Pen Branch was discharged to Steel Creek via the swamp through one major and one or more minor streams about a half mile above Steel Creek's mouth (3). Lower Three Runs Creek received some discharge from the R-Reactor area before 1958. Overflow from Par Pond carried runoff from the northeast portion of the plant and any contaminants leaking to the reactor secondary cooling water system (3).

The mouths of Steel Creek, Pen Branch, and Four Mile Branch have built sedimentation deltas from erosion of stream banks caused by stream channels carrying many times their natural flows. In the late 1950's and early 1960's, L- and P-Reactor effluents increased the flow in Steel Creek from its natural level of 35 cfs to 250-400 cfs (3).

The Savannah River Swamp borders the river for about 10 miles (16 km) and has an average width of about 2.4 km (1.5 miles). From 1958 to 1967, the swamp flooded about 74 days per year. The river historically overflowed its channels when flows were equal to or exceeded 438 cubic meters per second. The highest levels in the Savannah River typically occur in summer and spring, and the lowest levels occur in fall and winter (3).

2.3.3 Ecology

Because public use of the Savannah River Site was restricted, and because the production and support facilities occupy only a fraction of the total site area, SRS is a natural preserve for biota typical of the southeastern Coastal Plain.

2.3.3.1 Vegetation

The site is about evenly divided between the Aiken Plateau and three Coastal terraces: Brandywine, Sunderland, and Wicomico. The Aiken Plateau is hilly and deeply dissected by streams and contains extensive growths of scrub oak and longleaf pine. Soils are sandy in the Aiken Plateau and sandy loam in the terraces (1).

Little timber management occurred before Federal acquisition of the site. Generations of logging had depleted stands of timber except for floodplain hardwoods, which were not generally exploited. Much of the site consists of managed pine forests. Dry, sandy areas of the site are typically covered with scrub oak and contain longleaf pine, turkey oak, blue jack oak, black jack oak, dwarf post oak, and huckleberry. Trees available in moister soils along streams and on old floodplains include tulip poplar, beech, sweetgum, willow oak, swamp chestnut oak, water oak, loblolly pine, and ash. Bald cypress and tupelo gum are dominant trees in the Savannah River Swamp (1).

2.3.3.2 Mammals

Mammal populations—particularly deer—increased rapidly after closure of the site to the public on December 14, 1952. By the mid 1970's the deer population grew to more than 20 deer per square mile or about 5,000 to 8,000 deer on the plant site. Controlled hunts open to the public were begun in 1965. Thousands of deer have been taken in public hunts. In addition, feral hogs are present. These were

domestic animals that reverted to a semiwild state after abandonment in 1952. Similar to deer, the hogs grew sufficient in number to warrant hunts. About 125 were taken between 1969 and the mid 1970's (1).

Additional wild mammals common to the site include mice, rats, shrews, gray and red foxes, raccoons, wildcats, striped skunks, opossums, fox squirrels, and beavers (1).

2.3.3.3 Birds

Biologists have identified more than 200 species of birds on the plant site. Of note is the wild turkey population, which was small at the time the site opened. However, wild turkey populations have increased as the result of a program initiated in 1972 that used the site as a breeding ground for stocking other parts of the States. In addition, large numbers of coots and ducks spend winters on and near the site (1).

2.3.3.4 Aquatic Animals

Diverse populations of reptiles and amphibians exist onsite, including numerous species of turtles, lizards, snakes, salamanders, frogs, and toads. Alligators have been seen in ponds and streams. Onsite fish species include largemouth bass, black crappie, bluegill, redbreasted sunfish, flat bullhead, and blueback herring (1).

Hundreds of species of aquatic insects have been identified on SRS (e.g., a study conducted from 1976 to 1977 identified 551 species in the Upper Three Runs Creek system including species and genera that were new to science). Otherwise, populations of fish and aquatic insects in some of the onsite streams were adversely affected during SRS's nuclear production period due to thermal loadings, principally from reactor discharge of heated cooling water. But as operational changes (e.g., reactor shutdown) reduced the volumes of heated water discharged to onsite streams, the fish and aquatic insects have returned (4). For example, since C-Reactor was shut down in 1985, macroinvertebrate communities have recovered in Four Mile Branch and, in some parts of the stream; have resembled those in other nonimpacted SRS streams. Macroinvertebrate communities of Four Mile Branch currently tend to show more diversity in downstream than in upstream reaches (4).

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