Environmental Summary of the F- and H-Area Seepage Basins Groundwater Remediation Project, Savannah River Site

by

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Executive Summary

From 1955 to 1988, the F- and H-Area facilities discharged hazardous and radioactive chemicals into seven seepage basins, contaminating the underlying soils and upper aquifers. These radioactive and chemical contaminants continue to migrate via the groundwater, eventually surfacing in the wetlands of Fourmile Branch, a tributary of the Savannah River. The basins were certified closed in 1991 in accordance with RCRA regulations which also stipulated continued monitoring of the groundwater. In 1992, the State of South Carolina Department of Health and Environmental Control (SCDHEC) issued a RCRA Part B postclosure care permit that required a corrective action plan to remediate groundwater contamination. The remedial action seeks to remove the contamination by extracting groundwater using extraction wells, treating the water using reverse osmosis technology, and injecting the treated water back into the aquifer. This report summarizes the results of nearly 70 investigations of the baseline environment, describes the remedial action, and identifies constituents of interest that pose potential risk to human health and the environment. It also proposes an approach for evaluating the effectiveness of the remedial action.

Characterization of the Baseline Environment

Abiotic Investigations

Abiotic investigations have included sampling and analyses of soil, sediment, and surface waters. Studies of soil and sediment in the vicinity of the F- and H-Areas have been performed primarily as part of the routine monitoring and surveillance efforts reported in annual SRS environmental reports. In soil, elevated concentrations of antimony and zinc were reported. Radioisotopes of cesium, plutonium, and strontium were also found in soils. The maximum radioactivity was 1.01 pCi/g of Cs-137 near H-Area in 1994 and 1995. The most recent and comprehensive sampling and analyses of sediment near the seepage basins occurred in 1995. The majority of non-radiological constituents had concentrations that exceeded background levels. Fourmile Branch had four constituents whose 95% upper confidence intervals exceeded EPA thresholds. Arsenic was the only constituent that exceeded threshold levels at both seepines and Fourmile Branch. Although no radiological screening values have been issued by EPA, tritium had the highest radioactivity of the constituents that were measured. The mean tritium activity ranged from 82 pCi/g at the H-Area seepine to 289 pCi/g in Fourmile Branch.

Surface water in the vicinity of the seepage basins consists primarily of the waters of Fourmile Branch and shallow pools associated with the seepines. The average flow of Fourmile Branch from 1977 to 1991 at Road A-12 was 5.9 m³/s (208 ft³/s). Surface water associated with the seepines varies seasonally and is influenced by precipitation and water elevation of the Savannah River. Three programs were initiated in the 1990's to examine surface water chemistry: (1) semi-annual sampling of the F- and H-Area seepines and Fourmile Branch for metals, radionuclides, volatile compounds, inorganic constituents and physical parameters, (2) quarterly surveys of tritium, pH, and specific electrical conductance at both seepines, and (3) quarterly sampling of wetland surface waters along the old F-Area effluent ditch for tritium and volatile organic compounds.

Semi-Annual Program - Results of the semi-annual sampling program indicated that surface waters at the F- and H-Area seepines and Fourmile Branch contained contaminants associated with the seepage basins. Analytical results from the 1996 sampling program are incomplete. However, based on the results of the 1995 sampling effort, 25 non-radiological constituents had concentrations that exceeded both human health and ecological benchmarks. Radioisotopes whose activity levels exceeded drinking water standards or maximum concentration levels were Cs-137, I-129, Np-237, Ra-228, Sr-90, tritium, and U-238.

Tritium Program - Tritium, pH, and specific electrical conductance were measured in surface water at both seepines in 1989 and also from 1992 to 1996. Water samples were taken from Fourmile Branch since 1992. Tritium levels at both seepines and Fourmile Branch have declined since the initial sampling events. The mean radioactivity of tritium at the F-Area seepine declined from 3357 pCi/mL in 1989 to 1484 pCi/mL in 1996. Mean radioactivity of tritium at the H-Area seepine declined from 8402 pCi/mL in 1989 to 994 pCi/

mL in 1996. From 1992 to 1996, the mean radioactivity of tritium in Fourmile Branch ranged from 853 pCi/mL in 1992 to 145 pCi/mL in 1996. Since 1989, the radioactivity of tritium at both seepines and Fourmile Branch markedly exceeded the drinking water standard of 20 pCi/mL; levels were highest at the H-Area seepine, intermediate at the F-Area seepine, and lowest in Fourmile Branch. The pH of surface water at the seepines and Fourmile Branch ranged between 2.9 and 7.0 from 1989 to 1996. This compares to a range of between 6.0 and 8.5 for groundwater within the United States and 4.9 to 7.7 for the coastal plain of South Carolina. Median pH values were lowest at the F-Area seepine, intermediate at the H-Area seepine, and highest in Fourmile Branch. Specific electrical conductance provides an indication of ion concentration and has been used as a general indicator of plume differentiation between the seepage basins and the burial ground at SRS. From 1989 to 1996, the mean conductivity ranged from 65 μ S/cm in Fourmile Branch to 354 μ S/cm at the F-Area seepine. Conductivity and tritium radioactivity were correlated at both seepines.

Old F-Area Ditch - Results of surface water sampling showed that tritium and volatile organic compounds, presumably from the old burial ground, had migrated to the wetlands along the old F-Area ditch. In addition to tritium, 1,2-dichloroethylene, tetrachloroethylene, trichloroethylene, and vinyl chloride had concentrations that exceeded primary drinking water standards or maximum contaminant levels from 1994 to 1996.

Piezometers - To further characterize the baseline environment, a network of 20 piezometers (12 in F-Area and 8 in H-Area) was installed in January and May 1996. The objective of this program was to establish baseline hydraulic head data and to permit the monitoring of water table elevations before, during, and after remedial action. From January to August 1996, water table levels were relatively stable. Additional piezometers will be established in a reference area in 1997 so that changes in water table behavior attributable to natural processes can be distinguished from those that might be attributable to the extraction wells.

Biotic Investigations

Biotic investigations have included studies of the flora, fauna, and aquatic toxicity near the seepage basins and Fourmile Branch. In the spring of 1993, the jurisdictional wetlands downgradient from the seepage basins and north of Fourmile Branch were delineated and mapped in accordance with U.S. Army Corps of Engineers protocol. In addition to being ecologically and hydrologically important, wetlands are protected by several regulations and executive orders. There is a policy of "not net loss" of wetlands at the SRS.

Vegetative stress and mortality of bottomland hardwood forest in the wetlands was observed in 1988, and appears to be a result of chemical contaminants in the substrate, altered hydrology, and drought. A series of studies, including seed germination and revegetation investigations, was initiated to assess vegetative conditions and potential impacts to the wetlands along Fourmile Branch. Seed germination studies of toxicity in seepine soil leachates showed reduced effects over time on lettuce seed germination and growth as compared to control samples from an uncontaminated site. This implies that natural water transport reduced soil toxicity, and that further reductions in contaminant concentrations are possible with subsequent hydrological events. Revegetation of stressed areas by natural succession has been poor or marginal in both F- and H-Areas. An effort to test the ability of the impacted wetlands to sustain growth of the native tree species was initiated in 1994. In an effort to reestablish the climax species of the area, swamp tupelo seedlings were planted in four areas along the seepine. Percent survival of tupelo seedlings generally declined in three areas from 1994 to 1996.

Studies of macroinvertebrates in 1993 indicated stressed environmental conditions in Fourmile Branch. These were due to low dissolved oxygen concentrations rather than discharges from the seepage basins. In 1995, macroinvertebrate communities in Fourmile Branch near Road C were perturbed compared to other SRS streams even though oxygen levels were near acceptable limits. Species diversity of fish in Fourmile Branch was similar to other SRS sites, but analysis of fish tissue contained metals including aluminum, chromium, mercury, selenium, and zinc. Comprehensive studies are scheduled for 1997. Body burdens of constituents in shrews captured in 1995 were generally higher in the vicinity of the basins than at background locations.

Since 1990, a series of aquatic toxicity studies was performed at 11 seepine locations and five locations in

Fourmile Branch. In addition, surface water from five reference locations was also tested. Of the eleven seepage locations that were sampled in 1993 and 1994, only two showed no evidence of toxicity. The remaining seepage locations showed toxic responses on at least one occasion. Notably, the degree of toxicity appeared to vary temporally, likely as a result of rainfall which would dilute the concentrations of toxic constituents at the seepage. Concurrent sampling of reference seepage locations that were not influenced by any known source of contamination also showed a high percentage of toxic responses, thus indicating that unimpacted groundwater in portions of the SRS is toxic to the standard test organism. However, the reference locations were generally less toxic than the F- and H-Area seepages. Of the tests conducted between 1990 and 1994, only a single test conducted on Fourmile Branch showed evidence of toxicity. This indicated that the groundwater discharging into the wetlands down gradient from the F- and H-Area seepage basins was not producing toxic responses in the receiving stream, Fourmile Branch.

Toxicity Identification Evaluations- The toxicity testing conducted at the seepages from 1990 through 1994 produced reasonably consistent results indicating that some component of the groundwater in both this region of the SRS, and at reference locations, was causing toxic responses. In 1995, the SRS performed a Toxicity Identification and Evaluation (TIE) at the seepage to determine which constituents were causing the observed responses. The results of the testing for the F-Area seepage indicated that aluminum and cadmium were the most likely contributors to the toxic response, with naturally occurring iron as an additional potential contributor. At the H-Area seepage, the results of the TIE were inconclusive, but the results suggested the presence of a volatile toxicant. Testing further indicated that toxicity at the H-Area seepage had declined over time. Testing at a reference seepage location and Fourmile Branch indicated that naturally high levels of iron in groundwater were responsible for the toxicity at both locations. Elevated aluminum and cadmium concentrations at the F-Area seepage are either a result of historic discharges to the basin or, more likely, a result of leaching of these constituents from the soil matrix by the acidic groundwater conditions under the basins. The nature and source of the volatile constituent in the H-Area seepage waters is unresolved, but might be due to elevated concentrations of ammonia.

Constituents of Interest

Because this report summarizes several investigations that have used different screening protocols, chemicals potentially posing risk to the environment were broadly categorized as "constituents of interest." These included constituents that met the following criteria: (1) they were identified as a constituent of potential concern in the screening level risk assessment for the F- and H-Area groundwater unit, (2) they were identified as being of concern by an independent peer review, or (3) concentrations exceeded a regulatory threshold value such as the primary and secondary drinking water standards, EPA Region III risk-based concentrations, or an ecological screening value issued by EPA Region IV. Non-radiological constituents of interest to human health or the environment in surface water included aluminum, antimony, arsenic, beryllium, cadmium, chloride, copper, iron, manganese, mercury, nitrate, nitrite, silver, and thallium. Radiological constituents of interest to human health or the environment in surface water included americium-241, carbon-14, cesium-137, curium-243, iodine-129, radium-226, radium-228, strontium-90, technetium-99, tritium, and uranium-238. Ecological constituents of interest in sediment were arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and silver. Because screening levels for sediment have not been issued for human health, sediment constituents of interest could not be identified. The concentrations of all constituents varied by area and by year. The constituents listed above are comprehensive based on studies to date and should receive consideration for future monitoring studies and risk assessment.

Remedial Action

The remedial action that is proposed for the F- and H-Areas consists of a pump-and-treat technology that utilizes reverse osmosis. Under this scenario, extraction wells would pump contaminated groundwater to the surface for treatment. The treatment system will reduce heavy metals, nitrates, and some radionuclides to groundwater protection standards. Although tritium cannot be removed by this approach, the well system is designed to control seepage into the wetlands by the groundwater. The treated water, which would retain radioactive tritium, would be reinjected into the aquifer until the tritium decays naturally to acceptable levels. Potential effects associated with this remedial action include alteration of wetland and aquatic habitat.

1.0 Introduction

With the ending of the cold war, the mission of the Savannah River Site (SRS) changed from one of producing nuclear defense materials to facility decontamination, environmental restoration, and waste management. In response to the Resource Conservation and Recovery Act (RCRA) and Superfund Reauthorization Act (SARA), environmental restoration became one of the principal programs at SRS. Its goal is to safely and cost-effectively remediate inactive waste and groundwater units while managing risk and protecting human health and the environment.

Radiological and non-radiological materials have been used at facilities and laboratories throughout the SRS. Perhaps the most important was the General Separations Area (GSA), an industrial complex comprised of F-Area, H-Area, and the Burial Ground Complex. The F- and H-Area facilities discharged hazardous and radioactive materials into seven seepage basins from 1955 to 1988, contaminating the underlying soils and aquifers. Although the seepage basins are currently inactive, radioactive and chemical contaminants migrate via the groundwater, eventually reaching the surface in the wetlands of Fourmile Branch, a tributary of the Savannah River. This report summarizes what is known about the baseline environment, describes the remedial action, and identifies constituents that pose potential risk to human health and the environment.

1.1 Background

Environmental studies have been conducted in the vicinity of the F- and H-Area Seepage Basins (FHSB) since the 1960's. The basins were certified closed in 1991 in accordance with RCRA regulations which also stipulated continued monitoring of the groundwater. In 1992, the State of South Carolina Department of Health and Environmental Control (SCDHEC) issued a RCRA Part B postclosure care permit that required a corrective action plan to remediate groundwater contamination. The remedial action seeks to remove the contamination by extracting groundwater using extraction wells, treating the water using reverse osmosis technology, and injecting the treated water back into the aquifer.

1.2 Objectives

The principal goal of this report is to summarize existing information pertaining to the baseline environment at FHSB. Characterization of the baseline environment is based on data and information collected in the 1990's. Specific objectives include the following:

- comprehensively identify existing environmental data and characterize the baseline environment
- summarize the results of abiotic and biotic investigations that have been conducted to date
- identify constituents of potential interest
- describe potential impacts to the environment from the proposed remedial action
- identify performance measures that can be used to gauge the effectiveness of remedial action

2.0 Site Description

2.1 F- and H-Area Seepage Basins and History of Operations

The FHSB consists of seven seepage basins located within the General Separations Area of the SRS (Figure 1). The basins, which occupy approximately 9 ha (23 acres), have been covered with impermeable clay caps and closed under RCRA authority. The nearest stream, Fourmile Branch, is located approximately 400 m (1300 ft) from the H-Area Basins and approximately 600 m (1970 ft) from the F-Area Basins. The Savannah River is located approximately 13 km (8 miles) from the FHSB.

FIGURE 1. General Site Map of the F- and H-Area and Fourmile Branch, Savannah River Site.

The FHSB consists of two principal areas: (1) the western area which contains the three F-Area Seepage Basins and (2) the eastern area which contains four H-Area Seepage Basins. The F-Area basins cover approximately 7 acres whereas the H-Area basins cover approximately 16 acres.

The F- and H-Area Seepage Basins were constructed and began operations in 1955. The F-Area Seepage Basins consisted of three unlined basins that were hydraulically connected by vitrified clay process sewers. The seepage basins received process waste water from the F-Area Separations Facilities for a period of 33 years. The major sources of waste were cooling water from tritium facilities, nitric acid recovery overheads, general purpose evaporator overheads, and retention basin transfers (Killian et al., 1987a). Discharges to the basins ceased in November 1988, and closure caps were placed over the basins to minimize infiltration through the basin sediments in 1990.

The H-Area Seepage Basins also consisted of three unlined basins that were constructed in 1955. In 1962, however, one basin was made inactive and replaced by a fourth basin. The basins received process waste water from the H-Area Separations Facilities until 1988. The main sources of waste water included those listed for the F-Area Seepage Basins, overheads from the two H-Area Tank Farm evaporators, and liquids from the Receiving Basin for Offsite Fuels Facility (Killian et al., 1987b). Discharges to the basins terminated in November 1988. Closure caps were placed over the seepage basins in 1991 to minimize infiltration through the basin sediments.

2.2 Description of the Environment

The F- and H-Area occupies approximately 194 acres on a nearly flat divide between Upper Three Runs Creek to the north and Fourmile Branch to the south. Ground surface elevations range from approximately 270 feet above mean sea level (MSL) to approximately 300 feet above MSL. The surface topography generally slopes to the south. Engineered ditches send surface runoff to Fourmile Branch. The bed of Upper Three Runs Creek is about 140 feet below the divide surface; the channel of Fourmile Branch is about 90 feet below the divide surface. A mixture of brushland, sparse forest, and grassland occupies areas to the east, north, and west of the F/H Area. The environment in the vicinity of the FHSB provides habitat for a diverse flora and fauna. Immediately downslope from the basins is old field herbaceous/scrub brush habitat which transitions into upland forest. The upland forest integrates into lowland forest vegetation at the seepline where the groundwater surfaces and flows into the wetlands. The wetland habitat also includes the Fourmile Branch stream community.

Fourmile Branch, a second order blackwater stream, forms the southern boundary of the FHSB environment. From 1955 through 1985, it received cooling water discharge from C Reactor which modified and reduced the original bottomland forest. The waters of Fourmile Branch at SRS Road A-7 (downstream of the point at which constituents from the F- and H-Areas discharge, yet upstream of thermal effluents from C-Reactor) have low alkalinity, suspended solids, and chemical oxygen demand. Concentrations of nutrients in the stream, particularly nitrates (as nitrogen) are generally an order of magnitude higher than in all other SRS streams. These elevated levels of nitrates have been attributed to outcropping of nitrates from shallow groundwater south of the F- and H-Area Seepage Basins.

3.0 Baseline Environment Overview

Baseline refers to existing conditions in the absence of any remedial action. Environmental studies in the vicinity of the FHSB have included sampling and analyses of the abiotic and biotic media. These investigations, which began in the 1950's and continue to date, were summarized by Rogers and Associates (RAEC 1995) in the Five Year Ecological Monitoring Plan. To comprehensively and thoroughly characterize the environment, data should be relatively recent and include both abiotic and biotic components. This section characterizes the baseline environment using existing information and emphasizes data collected since 1990.

3.1 Abiotic Investigations

Abiotic investigations include studies of the physical, non-living environment. Numerous samples of soil, sediment, groundwater, surface water, and air have been collected and analyzed at the SRS. With the exception of air and groundwater, the following sections summarize the more recent investigations near F- and H-Areas.

3.1.1 Soil

Surface and subsurface soil have been sampled and analyzed as part of several independent studies within the Fourmile Branch watershed. Rogers (1990) classified and mapped the soils of the SRS including the FHSB area. Haselow et al. (1990) collected soil cores along the Fourmile Branch seepage line bordering the F- and H-Areas in 1988 and 1989. These were analyzed for metals, inorganics, and radionuclides. The concentrations of all inorganics and most metals were below the maximum background concentration (RAEC 1995). Haselow et al. (1990) concluded that Am-241, Cm-241, Co-60, I-129, Ra-226, and Pu-238 may exceed background concentrations (RAEC 1995).

In spring 1990, soil from the Fourmile Branch corridor was analyzed for gamma-emitting radionuclides as part of the SRS monitoring program (WSRC 1991a). Additional samples were subsequently taken in support of the F-Area and H-Area Retention Basin work plans (RAEC 1995). Soil samples in the vicinity of F- and H-Areas were also collected under the radiological monitoring program at the SRS and analyzed for gamma-emitting radioisotopes such as cesium, plutonium, and strontium. In 1994, the highest concentration of Cs-137 detected on-site (n=24 locations) was 1.01 pCi/g from a sample taken near H-Area (WSRC 1995a). Pu-238 was detected at single locations at F-Area and at the Burial Ground (WSRC 1995a). Strontium in soil exceeded the lower limit of detection at a single location in 1994.

In March 1994, Dixon (1994) collected four surficial soil samples from the wetlands at the old F-Area effluent ditch. Samples were analyzed for metals, volatile organic compounds, and gross radiological indicators. Barium, beryllium, and zinc were detected in each sample whereas antimony was detected in three samples. Concentrations of barium and beryllium were within expected ranges. Concentrations of zinc and antimony, however, were elevated. Five volatile organic compounds were detected. Tritium, the only radionuclide that was detected in significant quantities, was present in all four samples.

In 1995, soil samples were collected from 18 locations including F- and H-Areas and two reference sites 100 miles from SRS (WSRC 1996). Samples were analyzed for gamma-emitting radioisotopes, Sr-89, Sr-90, Pu-238, and Pu-239. The highest concentration of Cs-137 detected on the SRS was 1.01 pCi/g near H-Area (Table 1). This equaled the maximum concentration detected in 1994 (WSRC 1995a). Concentrations of Cs-137 in 1995 ranged from 0.25 pCi/g to 0.42 pCi/g at the site perimeter, and from 0.29 pCi/g to 0.35 pCi/g at the 100 mile radius locations (WSRC 1996). Radioactivity of cesium, strontium, and plutonium in soil at a depth of 0-8 cm for F-Area, H-Area, and two control sites in 1995 are shown in Table 1.

TABLE 1. Radioactivity (pCi/g dry wt) in surficial soil (0-8 cm depth) at F- and H-Areas, 1995 (WSRC 1996).

Location	Sr-89,90	Cs-137	Pu-238	Pu-239
F-Area				
2000 feet east	3.43E-02	9.74E-01	6.76E-02	6.16E-01
2000 feet north	0.26E-02	1.14E-01	4.23E-02	1.04E-01
2000 feet south	0.67E-02	1.56E-01	8.81E-03	1.26E-02
2000 feet west	0.68E-02	6.83E-01	6.64E-02	8.83E-02
H-Area				
2000 feet east	1.31E-02	4.6E-01	6.31E-03	1.77E-02
2000 feet north	0.70E-02	1.01E+00	2.86E-02	9.23E-02
2000 feet south	2.35E-02	7.8E-01	8.14E-03	4.33E-02
2000 feet west	2.9E-02	2.96E-01	6.8E-03	3.31E-02
100-Mile Radius				
Clinton, SC	7.41E-02	2.92E-01	5.78E-04	6.81E-03
Savannah, GA	1.94E-02	3.55E-01	4.18E-04	6.29E-03

3.1.2 Sediment

Sediment is the fine, inundated material that lies at the bottom of impoundments, streams, and rivers. It occurs at both seep lines where shallow pools and saturated conditions exist and also in Fourmile Branch. Radionuclides and certain chemicals typically concentrate in the uppermost strata of sediment, posing potential exposure to invertebrates, other aquatic organisms, and vertebrates such as fish which occupy higher trophic levels.

Sediment in Fourmile Branch was collected in 1987 at five locations and analyzed for metals, organics, pesticides, and polychlorinated biphenyls (E.I. du Pont 1988). These locations and three additional samples were also analyzed for radionuclides. In 1989, Haselow (1990) sampled streambed sediments at six locations in Fourmile Branch to support the preparation of the Part B Postclosure Care Permit for the F- and H-Area Seepage Basins. This study showed that downstream sampling locations had higher concentrations than upstream locations because of particulate transport by Fourmile Branch. Comparisons of sediment concentrations to background soils showed that cadmium and copper exceeded maximum background values.

Sediment from the streambed of Fourmile Branch was collected from three locations in 1994 (WSRC 1995a). Of the 22 sampling locations that were used in the SRS environmental monitoring program, Fourmile Branch had the highest concentration of Pu-238, Pu-239, Sr-89, and Sr-90. Co-60 was also detected in sediment from Fourmile Branch.

In 1995, the maximum strontium-89,90 concentration measured at SRS was in Fourmile Branch (WSRC 1996). This level, however, was lower than the concentration found in 1994. Between May and September 1995, RUST Environment & Infrastructure collected sediment samples (Figure 2) from the F- and H-Area seep lines, Fourmile Branch, and background locations (WSRC 1995b). Coordinates for the sediment sampling locations are given in Appendix A, Table A-1. Samples were analyzed by General Engineering Laboratories and data validation was performed by BAT Associates, Inc. (WSRC 1995b). The mean and upper 95% confidence intervals for non-radiological and radiological constituents in sediment collected in 1995 from these four areas are presented in Appendix B, Tables B-1 and B-2, respectively.

FIGURE 2. Distribution of sediment and surface water sampling locations, 1995 (WSRC 1995b).

The majority of non-radiological constituents in sediment collected in 1995 had 95% upper confidence intervals that exceeded background concentrations (Table 2). When compared to EPA Region IV ecological sediment screening values (EPA 1995), Fourmile Branch had seven constituents whose 95% upper confidence intervals exceeded EPA threshold values. The F-Area seepine had three constituents (arsenic, cadmium, and silver) that exceeded threshold values whereas the H-Area seepine had two (arsenic and copper). Arsenic was the only constituent that exceeded the sediment screening level at all three areas. The concentration of copper, nickel, and zinc did not exceed ecological screening values at the seepines but did so in Fourmile Branch.

Although radiological sediment screening values for human health and ecology have not been issued by EPA, activity levels for 44 radioisotopes, gross alpha, and non-volatile beta were reported for 1995 (Table B-2). Of these, tritium contributed the highest radioactivity of the constituents measured in sediment. The mean radioactivity of tritium ranged from -0.45 pCi/g at background locations to 289 pCi/g at Fourmile Branch. Other radioisotopes having activity levels higher than 10 pCi/g in 1995 included Tc-99, Cs-137, Ni-63, Sr-90.

TABLE 2. List of constituents in sediment that exceeded background and ecological (EPA 1995) screening values, 1995.

Constituent	95% UCI Exceeded Background			95% UCI Exceeded Ecological		
	F-Area Seepine	H-Area Seepine	Fourmile Branch	F-Area Seepine	H-Area Seepine	Fourmile Branch
Aluminum	•	•	•	*	*	*
Ammonia as N	•	•	•	*	*	*
Antimony	•	•	•	*	*	*
Arsenic		•	•	•	•	•
Barium	•	•	•	*	*	*
Beryllium	•	•	•	*	*	*
Cadmium	•	•	•	•		•
Calcium	•	•	•	*	*	*
Chloride	•	•	•	*	*	*
Chromium			•			
Cobalt	•	•	•	*	*	*
Copper	•	•	•			•
Cyanide	•	•	•	*	*	*
Iron			•	*	*	*
Lead	•	•	•	*		
Magnesium	•	•	•	*	*	*
Manganese	•	•	•	*	*	*
Mercury		•	•		•	•
Nickel	•	•	•	*		•
Nitrate	•	•	•	*	*	*
Nitrate/Nitrite	•	•	•	*	*	*
Potassium	•	•	•	*	*	*
Selenium	•	•	•	*	*	*
Silver	•	•	•	•		•
Sodium	•	•		*	*	*
Thallium	•	•	•	*	*	*
Tin	•	•	•	*	*	*
Vanadium			•	*	*	*
Zinc	•	•	•			•

* - EPA has not issued a screening value for this constituent.

3.1.3 Surface Water

Surface water in the vicinity of the FHSB consists primarily of the waters of Fourmile Branch and shallow pools associated with the seep lines. Fourmile Branch (Figure 3) originates near the center of SRS and flows southwesterly for approximately 24 km (Wike et al. 1994). The Fourmile Branch watershed covers approximately 57 km² and drains several facilities including C-Area, F-and H-Areas, and the Solid Waste Disposal Facility. The headwaters of Fourmile Branch is a small blackwater stream that has been relatively unimpacted by SRS operations (Specht 1987). In its lower reaches, Fourmile Branch broadens and flows through a delta that was formed by the deposition of sediments. Downstream of the delta Fourmile Branch becomes one main channel that flows primarily into the Savannah River. Some water, however, flows west and enters Beaver Dam Creek. When the Savannah River floods, water from Fourmile Branch flows along the northern boundary of the floodplain swamp and joins with Steel Creek and Pen Branch instead of flowing directly into the Savannah River (Specht 1987).

FIGURE 3. The Savannah River Site showing the location of Fourmile Branch.

3.1.3.1 Flow Measurements

The U. S. Geological Survey measured SRS stream flow at two locations on Fourmile Branch (Figure 4). Records for the most downstream station (Fourmile Branch at Road A-12.2) date back to November 1976. In water year 1991, the mean flow of Fourmile Branch at Road A-12.2 was 1.8 m³/s (63.1 ft³/s). Over the period of record (water years 1977-1991) at Road A-12.2, the mean flow was 5.9 m³/s (208 ft³/s), the 7-day low flow was 0.22 m³/s (7.6 ft³/s), and the 7Q10 was 0.31 m³/s (11.1 ft³/s). The maximum, minimum, and mean daily flows for the periods of record at both locations are shown in Figures 5 and 6.

FIGURE 4. Flow Measurement Stations 01 and 02, Fourmile Branch (Wike et al. 1994).

FIGURE 5. Maximum, mean, and minimum flow measurements at Station 01 (Wike et al. 1994).

FIGURE 6. Maximum, mean, and minimum flow measurements at Station 02 (Wike et al. 1994).

3.1.3.2 Surface Water Chemistry

Numerous studies have examined surface water chemistry of the F-and H-Area seepines and Fourmile Branch. These investigations have ranged from routine monitoring of radionuclides and chemicals to special studies designed to more fully characterize specific areas. In the late 1980's, several investigators examined surface water chemistry in the vicinity of the FHSB (Looney 1988, Haselow et al. 1990). In the 1990's, three programs were implemented in the vicinity of F-and H-Areas: (1) semi-annual sampling of the F-and H-Area Seepines and Fourmile Branch, (2) quarterly tritium surveys of the F-and H-Area seepines, and (3) quarterly sampling of wetland surface waters along the old F-Area effluent ditch. These programs are summarized below.

Semi-Annual Sampling Program (1992-1996)

A semi-annual sampling program was initiated in 1992 to examine the presence and concentration of contaminants associated with the seepage basins in surface water at the F-and H-Area seepines and Fourmile Branch. Beginning in 1994, however, sampling was done annually through 1996. Surface water investigations that were conducted during this period are described below. Sampling locations (Figure 7) were relatively consistent each year, but sometimes varied depending on environmental conditions (Table 3).

In July 1992, Dixon and Rogers (1993) began examining surface water from the F-and H-Area seepines and Fourmile Branch as the first of three semi-annual sampling events designed to characterize the surface water in the vicinity of the FHSB. Samples were collected in July 1992 by Normandeau Associates, Inc. under a subcontract to Metcalf and Eddy, Inc. The samples were analyzed for RCRA Appendix IX metals, radionuclides, volatile compounds, and inorganic constituents and physical parameters. Concentrations of constituents were compared to primary drinking water standards (PDWS), secondary drinking water standards (SDWS), and maximum contaminant levels (MCLs). Statistical comparisons to background concentrations were also performed. In order to evaluate trending, comparisons were also made with the 1989 results reported by Haselow et al., 1990. Results indicated that most of the non-radiological constituents, particularly sodium and aluminum, had declined at the seepines and in Fourmile Branch. The concentrations of some radionuclides were unchanged from levels reported earlier.

FIGURE 7: Distribution of surface water sampling locations, 1989-1996.

The semi-annual sampling program continued in 1993 (Chappell et al. 1996). Normandeau Associates, Inc. collected samples between 25 January and 4 February 1993, and also between 19-22 July 1993 (Metcalf and Eddy 1993 a,b). In 1994, semi-annual sampling was discontinued, and a single sampling effort was conducted between 11-21 April (Metcalf and Eddy 1994). Samples collected in 1993 and 1994 were analyzed for Appendix IX metals, radionuclides, selected volatile organic compounds, and inorganic constituents and parameters. Chappell et al. (1995) reported that the F- and H-Area seepines and Fourmile Branch continued to be influenced by contaminants migrating from the F- and H-Area seepage basins. Concentrations of many constituents, however, had declined from 1989 levels reported by Haselow et al. (1990).

In 1995, RUST Environment & Infrastructure, under subcontract to the Environmental Monitoring Section of WSRC, collected surface water samples (Figure 2) near the F- and H-Area seepines (WSRC 1995b). This sampling event was in addition to that done under the semi-annual sampling program. Laboratory analyses and data validation were performed by General Engineering Laboratories and BAT Associates, Inc., respectively (WSRC 1995b). Samples were analyzed for metals, radionuclides, inorganic constituents, and other parameters (Appendix B, Tables B3 and B4). Table 4 compares 95% upper confidence intervals for non-radiological constituents in surface water with background, ecological, and human health benchmarks. Ecological benchmarks were chronic ambient water quality criteria issued by EPA Region IV (EPA 1995). Human health benchmarks included risk-based concentrations (EPA 1997), maximum contaminants levels (MCLs), primary drinking water standards (PDWS), and secondary drinking water standards (SDWS). Based on the results of the 1995 data, 17 non-radiological constituents had concentrations that exceeded ecological and human health benchmarks (Table 4). Radiological constituents in surface water that exceeded PDWS, MCLs, and SDWS standards in 1995 were Am-241, Cs-134, Cs-137, Co-57, Co-60, Eu-154, I-129, Na-22, Np-237, Ra-226, Ra-228, Ru-106, Sb-125, Sr-90, Th-228, Th-230, Th-232, tritium, U-235, and U-238 (Table B-4).

TABLE 3. Semi-annual sampling locations for surface water, 1989-1996.

Location	1989	1992	1993	1994	1995	1996
BG001		•	•	•	•	•
BG002		•	•	•	•	•
BG003		•	•	•	•	•
BG004				•	•	•
FMC001F		•	•	•	•	•
FMC001H	•	•	•	•	•	•
FMC002H	•	•	•	•	•	•
T4/1108					•	
FSP012	•	•	•	•	•	•
FSP019					•	
FSP026					•	
FSP032	•	•	•	•	•	•
FSP035					•	
FSP047	•	•	•	•	•	•
FSP204	•	•	•	•	•	•
FSP290		•	•	•	•	•
HSP008		•	•	•	•	•
HSP025					•	
HSP029		•	•	•	•	•
HSP043	•	•	•		•	•
HSP052					•	
HSP060		•	•	•	•	•
HSP092		•	•	•	•	•

In April 1996, organic and inorganic analyses were discontinued because none of the constituents exceeded primary drinking water standards (PDWS), secondary drinking water standards (SDWS), or maximum contaminant levels (MCLs). The analytical results for the 1996 sampling and analyses program have not been completed. Preliminary results for non-radiological and radiological constituents are presented in Appendix B, Tables B-5 and B-6.

Old F-Area Ditch

The old F-Area ditch is a natural drainage pathway that historically received discharges and surface runoff from F- and H-Areas. In 1994, a quarterly sampling program was initiated to examine tritium and volatile organic compounds (VOCs) in water collected from a series of shallow wells located along the old F-Area effluent ditch (Figure 1). In 1995, sampling was reduced to a single event in September. Sampling was also conducted in March and October, 1996. A summary of these investigations is given below.

In March 1994, Dixon et al. (1994a) collected samples from seven locations in the wetlands along the old F-Area effluent ditch and also at two background locations in the vicinity of Upper Three Runs Creek. Both shallow wells and buckets were used. Results indicated that tritium and volatile organic compounds, presumably originating from the old burial ground (643-E), had reached the wetlands. These findings are consistent

TABLE 4. Constituents in surface water whose 95% UCI exceeded background, ecological, and human health benchmarks at Fourmile Branch (FMB) and the F-and H-Area seep lines, 1995.

Constituent	Exceeded Background			Exceeded Human Health			Exceeded Ecological		
	FMB	FSP	HSP	FMB	FSP	HSP	FMB	FSP	HSP
Aluminum		•	•	•	•	•	•	•	•
Ammonia as N		•		•			*	*	*
Antimony	•		•			•			
Arsenic			•						
Barium	•	•	•				*	*	*
Beryllium			•	•	•	•		•	•
Cadmium	•	•	•	•	•		•	•	•
Calcium	•	•	•	*	*	*	*	*	*
Chloride		•	•						
Chromium			•					•	•
Cobalt	•	•	•				*	*	*
Copper			•					•	•
Cyanide	•		•				•	•	•
Iron	•		•	•	•	•	•	•	•
Lead		•	•				•	•	•
Magnesium	•	•	•	*	*	*	*	*	*
Manganese	•	•	•	•	•	•	*	*	*
Mercury	•	•	•				•	•	•
Nickel	•	•	•						
Nitrate	•	•		•			*	*	*
Nitrate/Nitrite		•		*	*	*	*	*	*
Potassium		•	•	*	*	*	*	*	*
Selenium	•	•	•				•		•
Silver			•				•	•	•
Sodium		•	•	*	*	*	*	*	*
Thallium	•			•	•	•	•		
Tin							*	*	*
Vanadium			•				*	*	*
Zinc	•	•	•					•	•

* EPA has not issued a screening value for this constituent.

with results from monitoring wells in the vicinity of 643-E. Dixon et al. (1994a) also compared tritium concentrations in shallow wells with buckets and concluded that the sampling devices had intercepted different groundwater flow paths.

Results from sampling in May (Dixon and Cummins 1994), August (Cummins and Dixon 1994), and November (Cummins and Dixon 1995) were consistent with the March 1994 findings with the exception of detecting

additional constituents. Because the use of both buckets and point wells to collect samples was not providing significantly different information and to maximize cost savings, buckets were discontinued beginning in November 1994. Sampling continued in September 1995, March 1996, and October 1996 (Dixon 1996a, Dunn and Dixon 1996). Although additional constituents were detected, the findings were consistent with previous reports.

Constituents that exceeded PDWS or MCLs at a minimum of one location between March 1994 and November 1996 are listed in Table 5. Concentrations of tetrachloroethylene, trichloroethylene, and tritium exceeded these benchmarks for all of the seven sampling events. Constituents that did not exceed these benchmarks but were detected included acetone, methyl ethyl ketone, chloromethane, toluene, methyl chloride, and trans-1,2-dichloroethylene.

TABLE 5. Constituents in surface water along the Old F-Area Effluent Ditch that exceeded Primary Drinking Water Standards or Maximum Contaminant Levels, 1994-1996 (Dixon et al. 1994, Dixon and Cummins 1994, Cummins and Dixon 1994, 1995, Dixon 1996a).

Constituent	1994	1995	1996
1,2-Dichloroethylene	•		
cis,-1,2-Dichloroethylene	•		
Tetrachloroethylene	•	•	•
Trichloroethylene	•	•	•
Tritium	•	•	•
Vinyl Chloride	•	•	

Tritium Program (1992-1996)

Looney et al. (1988) collected surface water from the seepines and Fourmile Branch in 1987 and reported that sodium, nitrate, and hydrogen ions had migrated from the seepage basins to the seepines. It was also reported that several metals were leaching from the subsurface due to low pH. Concentrations of all constituents were below PDWS standards (Looney et al. 1988). Haselow et al. (1990) also collected surface water along the seepines and Fourmile Branch in 1989. With the exception of cadmium at the F-Area seepine, concentrations of metals were below the PDWS. However, elevated levels of aluminum and sodium were noted. Six radioisotopes, including tritium, had activity levels at the seepines that were greater than proposed or established drinking water standards. The concentration of nitrate also exceeded the PDWS at the seepines. In Fourmile Branch, Haselow et al. (1990) reported that gross beta and tritium exceeded drinking water standards at least one location. Concentrations of nitrate exceeded drinking water standards at both seepines but not in Fourmile Branch (Haselow et al. 1990).

In May 1992, a quarterly sampling and analysis program was initiated to examine tritium, pH, and specific electrical conductance (i.e., conductivity) in surface waters at the seepines and in Fourmile Branch. Quarterly sampling continued through 1995. In 1996, semi-annual sampling began. Results of these investigations have been reported by Koch and Dixon (1994, 1995, 1996 a,b), Dixon and Rogers (1992, 1993 a,b, c, d, e; 1994 a,b), Dixon et al. (1993, 1994 a,b) and Rogers et al. (1994 a,b).

Tritium

The mean radioactivity of tritium at both seepines and Fourmile Branch has declined annually since 1989 (Table 6). At the F-Area seepine, mean activities ranged from 3357 pCi/mL in 1989 to 1484 pCi/mL in 1996 (Figure 8). Based on a Kruskal-Wallis nonparametric analysis of variance, radioactivity at the F-Area seepine was not significantly different ($P>0.05$) between years. Tritium levels at the H-Area seepine have also declined each year since 1989 (Table 6). At the H-Area seepine, radioactivity of tritium ranged from

8402 pCi/mL in 1989 to 994 pCi/mL in 1996 (Figure 9). The mean radioactivity of tritium for 1989 was significantly higher ($P < 0.05$) than levels for 1992 through 1996. Significant differences were also found between 1996 and 1992 and also between 1996 and 1993. Levels of tritium from the 1995 RUST survey (WSRC 1995b) were higher than those reported by the quarterly tritium program. The mean radioactivity for F- and H-Area seepines was 4000 and 2100 pCi/mL, respectively (Table B-4). Tritium radioactivity in Fourmile Branch was 958 pCi/mL in 1995 (WSRC 1995b).

Boxplots of tritium radioactivity at both seepines and Fourmile Branch from 1989 to 1996 are shown in Figure 10. The top and bottom of the box represent the 75th and 25th percentiles, respectively. Thus, half of the observed values are contained within the box. Median values are represented by horizontal lines approximately mid-way in the box. The largest and smallest observed values that are not outliers are identified by the lines that extend above and below the boxes. Generally, tritium radioactivity is highest at the H-Area seepine, intermediate at the F-Area seepine, and lowest in Fourmile Branch. There has a marked annual decline of tritium radioactivity at each location since 1989 (Figure 10).

TABLE 6. Mean radioactivity (pCi/mL) and 95% upper confidence intervals (UCI) of tritium at the F- and H-Area Seepines and Fourmile Branch, 1989-1996.

Year	F-Area Seepine			H-Area Seepine			Fourmile Branch		
	N	Mean	95% UCI	N	Mean	95% UCI	N	Mean	95% UCI
1989	22	3357	5326	22	8402	11621	-	-	-
1992	66	1916	2625	66	3345	4235	3	853	3475
1993	87	1892	2563	87	2667	3326	9	219	385
1994	87	1671	2210	83	2163	2941	12	179	289
1995	21	1634	2556	18	1547	2877	3	268	1076
1996	43	1484	2118	39	994	1404	6	145	342

FIGURE 8. Mean radioactivity (pCi/mL) and 95% confidence intervals of tritium at the F-Area Seepage Basins, 1989-1996.

FIGURE 9. Mean radioactivity (pCi/mL) and 95% confidence intervals of tritium at the H-Area Seepage Basins, 1989-1996.

FIGURE 10. Tritium radioactivity (pCi/mL) at the F-and H-Area Seepines and Fourmile Branch, 1989-1996.

Hydrogen Ion Activity (pH)

The activity of hydrogen ions in water is typically expressed in logarithmic units, and the abbreviation "pH" represents the negative base-10 log of the hydrogen-ion activity in moles per liter (Hem 1989). The pH of pure water at 25 °C is 7.00, and most groundwater in the United States ranges between 6.0 and 8.5 (Hem 1989). Strom and Kaback (1992) reported a range of 4.9 to 7.7 for the coastal plain of South Carolina whereas Railsback et al. (1996) gave a range of 6.3 to 7.7 in the coastal plain of Georgia. The pH of groundwater and surface water in the vicinity of the FHSB is important because it can influence the availability and mobility of metals, which in turn, can affect human health and the environment.

Boxplots of pH values at the seepines and at Fourmile Branch are shown in Figure 11. From 1989 to 1996, the pH ranged between 2.9 and 7.0. Median values were lowest at the F-Area seepage, intermediate at the H-Area seepage, and highest in Fourmile Branch. These results may be associated with greater releases of nitrates in F-Area as compared to H-Area, and also due to greater dilution in Fourmile Branch.

FIGURE 11. Boxplots for pH at the F-and H-Area Seepines and Fourmile Branch, 1989-1996.

Conductivity

Electrical conductance (i.e., conductivity), which refers to the ability of water to conduct an electric current, is measured in microsiemens per centimeter (Hem 1989). When measured at a specified temperature, conductivity is called specific electrical conductance. SRS conductivity data are based on a temperature of 25 °C. Conductance measurement provides an indication of ion concentration and has been used as a general indicator of plume differentiation between the FHSB and the burial ground. From 1989 to 1996, the mean conductivity ranged from 65 $\mu\text{S}/\text{cm}$ in Fourmile Branch to 354 $\mu\text{S}/\text{cm}$ at the F-Area seepine (Table 7). For both the F-Area and H-Area seepines, there was a correlation between conductivity and tritium. Spearman correlation coefficients were 0.92 ($P < 0.01$) for F-Area 0.76 ($P < 0.01$) for H-Area. Conductivity at the F-Area seepine was relatively consistent from 1989 to 1996 (Figure 12). At the H-Area seepine, however, conductivity has steadily declined since 1989 (Figure 13).

TABLE 7. Mean conductivity ($\mu\text{S}/\text{cm}$) and 95% upper confidence intervals (UCI) at the F-and H-Area Seepines and Fourmile Branch, 1989-1996.

Location	n	Mean	95% UCI
F-Area Seepine	327	354	403
H-Area Seepine	314	168	182
Fourmile Branch	33	65	74

FIGURE 12. Mean and 95% confidence interval of conductivity (μS/cm) at the F-Area Seepage line, 1989-1996.

FIGURE 13. Mean and 95% Confidence Intervals (95%) of conductivity (μS/cm) at the H-Area Seepage line, 1989-1996.

3.1.4 Water Table Monitoring

The proposed remedial action at the FHSB could alter the existing hydrology. In some areas, this could reduce soil moisture within the root zones of vascular flora. This could affect vegetative structure and the availability of wildlife habitat. In order to assess possible impacts to the wetlands, a network of 20 piezometers (12 in F-Area and 8 in H-Area) was installed in January and May 1996 (Figure 13). The objective of this program was to establish baseline hydraulic head data and to permit the monitoring of water table elevations after remedial actions commence. From January to August 1996, water table levels have been relatively stable (Dixon 1996b).

FIGURE 14. Distribution of piezometers at the F-and H-Area Seepages.

3.1.5 Remote Sensing

The existing remote sensing data base for the F-and H-Areas consists of various applications dating back to 1938. Airborne gamma surveys, which are used to monitor low-level contamination patterns, were conducted for 1974, 1979, 1982, and 1991. Multispectral scanner data, which are useful in examining vegetative stress patterns, exists for 1981 and for the period 1983-1996. Historic aerial photography includes three years (1938, 1943, and 1951) before the SRS was constructed. Post-SRS black and white imagery exists for 1956, 1961, 1966, 1973, and 1974. False color infrared and normal color aerial photography was taken from 1978 to 1996. Aerial obliques, video, and satellite (SPOT) information are also available for the 1980s and 1990s. Remote sensing information can be used to reconstruct historical events and examine former waste management practices. It is also useful for monitoring vegetative change, particularly canopy mortality and succession, over time.

3.2 Biotic Investigations

3.2.1 Vegetation

Observations of arboreal mortality in bottomland hardwoods between the FHSB and Fourmile Branch have been documented by Mackey (1988), LeBlanc and Loehle (1990), Greenwood et al. (1990), Lohle (1990 a,b,c), Parker et al. (1990) and others. In spring 1990, a survey of Fourmile Branch was conducted to characterize the radiological condition of the stream and stream valley (WSRC 1991a). Ferns and timber were analyzed for levels of gross alpha, gross beta, cesium, cobalt, strontium, and tritium.

Loehle (1990a) sampled areas exhibiting canopy mortality near the FHSB and also conducted toxicity tests using lettuce seedlings on leachate from seepage soils. Although Loehle (1990a) found soil leachate to be toxic, he concluded that continued leaching improved soil quality.

Greenwood et al. (1990) reviewed SRS data and information in the open literature on contaminant chemistry and toxicology in trees in an attempt to determine the cause of tree mortality observed in the F- and H-Areas. The study focused on three possible causes of stress, namely altered hydrology, hazardous chemicals, and nonhazardous chemicals. Greenwood et al. (1990) concluded that severe drought in 1977 played a role in the observed tree stress. Dry conditions may have exacerbated stress caused by chemicals present in the soils by concentrating them further. Salt and heavy metal concentrations were elevated in soil at each impacted site. Aluminum was identified as probably the most toxic metal at F-Area. However, cadmium, manganese, and zinc were present at concentrations high enough to be considered possible causes of tree mortality. Aluminum was thought to be the most likely cause of tree mortality at H-Area.

LeBlanc and Loehle (1990) analyzed tree-rings to determine causes of vegetative stress at FHSB. Chemical analyses of the cores failed to provide conclusive evidence of temporal changes in the soil chemical environment associated with groundwater contamination. Observed increases in aluminum concentrations during the 1978-1987 period were consistent with the expected effects of acidic contaminants on soil solution chemistry. However, this effect was not corroborated by increases of manganese, also expected as a result of soil acidification. Tree ring analysis indicated that severe droughts occurred in 1977 and 1986.

Dames and Moore (1991) characterized wetland vegetation near Fourmile Branch using stratified plots, but this study did not include the tree-kill areas in the vicinity of FHSB. Loehle (1990c) performed a cluster analysis using the Dames and Moore (1991) data but failed to identify any contamination patterns. Vegetative stress and low species richness, however, were reported.

In the spring of 1993, V.A. Rogers (unpublished) delineated the jurisdictional wetlands north of Fourmile Creek (Figure 15) in accordance with U.S. Army Corps of Engineers protocol (USACOE 1987). For an area to be declared a jurisdictional wetland, hydrophytic vegetation, hydric soils, and wetland hydrology must be present. Survey flags were placed along the boundary of the wetlands and these locations were subsequently surveyed. The jurisdictional wetlands (Figure 15) were delineated using coordinates (Appendix A) from the survey.

Seed Germination Studies

Eaton and Murphy (1993) also tested the toxicity of F-Area seepage soil leachate using lettuce seedlings. Their study, which was designed to evaluate changes in toxicity from those reported by Loehle (1990a), revealed no significant differences in germination between the treatments but radicle length was markedly reduced by the first extraction from seepage soils. Continued seed germination studies have shown that extracts of wetland soils generally reduce seed vigor.

In a subsequent study by Nelson and Westbury (1994), the growth response, as measured by seed germination and root elongation, to leachates (first and sixth water washings) from the impacted soils of F-Area were compared to uncontaminated wetland soils and distilled water. This study measured both the number of seeds that

FIGURE 15. Distribution of jurisdictional wetlands below the F and H-Areas as determined by field surveys in 1993.

germinated and the elongation of the root and hypocotyl during the 72 hour test. Statistical differences in germination rates due to water samples in this study were not significant at the 95% confidence level. Germination of seeds from the control, blank, and sixth wash of the F-Area samples were similar in 1994 to the results from 1990. Germination order among the treatments were similar over the three years tested. De-ionized water generally produced the greatest germination values, with sixth wash values of the F-Area being nearly equal. First wash treatments were generally lower, especially for the F-Area in previous studies. Much of the toxic effect on seed germination of this sample has been reduced over the years.

The analysis of the variation in root elongation found significant differences between treatments. A Tukey multiple comparison analysis found that the first wash treatments from the F-Area and the control area were different from the de-ionized water blank. No other differences were significant at the 95% confidence level, including between F-Area first wash and the control.

First washes of these wetland soils have generally reduced root elongation in each of the years tested (Table 8). It is possible that these wetland soils possess a component that naturally suppresses lettuce seed germination, above and beyond the chemical toxicity of the impacted soils tested. The sixth wash of the impacted soil generally produced higher germination and greater elongation than the first wash of the control soil and nearly as good as the de-ionized water sample.

This study showed a greatly reduced toxic effect of the leachate from F-Area seepage soil samples over time on lettuce seed germination and growth as compared to control samples from an uncontaminated site. This

TABLE 8. Germination (%) and root elongation (mm) results, 1990-1994.

Treatment	Germination (%)			Root Elongation (mm)		
	1990	1993	1994	1990	1993	1994
First Wash (F-Area)	44	90	84	7.6	4.1	8.8
Sixth Wash (F-Area)	85	98	86	10.3	9.6	11.2
Control	75	94	75	11.8	6.0	9.2
Deionized Water	95	94	91	12.2	11.3	11.7

Continuation of the testing work has led to the development of an on-site root elongation technique that does not require removal of materials for testing. This results in a test of the natural site condition in place and avoids the laboratory testing phase. This allows the larger scale testing of the entire tree-kill areas in the field. As part of this effort, additional water chemistry collection has shown that the seepage water coming into the tree-kill areas is less toxic than the water within the area but is more toxic than the background wetland area. This indicates that there are some residual affect within the tree-kill zones that have not been completely reduced, as well as affect from continuing inputs from the seepage into the system.

Revegetation Studies

Vegetation of two wetland areas (one in F-Area and one in H-Area) previously adversely affected by outcropping groundwater were characterized to evaluate the type and extent of revegetation (Nelson and Irwin 1994). The two areas examined in 1993 were the most severely affected ones in the F-Area and the H-Area. These areas are among those previously described and sampled in the 1980's. Prior to damage the sites were pure swamp tupelo (*Nyssa sylvatica* var. *biflora*) stands. All mature individuals were killed by the stress that occurred in the wetland areas. No overstory, other than a few widely scattered individuals, remained in either location.

A series of permanent vegetation characterization plots were installed to quantify the recovery. These plots were circular milacre plots (43.56 sq. ft/plot, 4.05 sq. m/plot) installed at uniform intervals along transects in the two areas. Within each plot, all individuals were identified to species, where possible. Initial sampling took place in August and September 1993. Forty plots were examined in the F-Area along 4 parallel transects and 56 plots were examined in the H-Area along a single transect. Plot data were summarized to indicate qualitative and quantitative information about the current status of the two tree-kill areas sampled.

The substrate within the F-Area tree-kill location consisted of thick, flocculent, deep, muck with water flowing through it; algae grew on its surface. Vegetation within the F-Area tree-kill area was sparse. The canopy had been almost totally destroyed; only a few live trees remained. Some standing dead trunks and many fallen trunks were scattered throughout the area. Most of the existing understory vegetation was growing in widely scattered clumps on stumps, fallen logs, and accumulated debris. An occasional herbaceous wetland plant was noted growing in the muck near the upland edge of the tree-kill area. Twenty six species were encountered in the first sampling. Of the 40 plots sampled, seven (17.5%) were totally devoid of vegetation. Transect 1, closest to the source of the groundwater discharge and farthest from the surrounding forest, contained the fewest species (11), and the least number of individuals in all vegetation layers. Transects 2, 3 and 4 contained approximately the same number of species. Transect 4, which was closest to the adjacent forest and Fourmile Branch, contained the highest number of tree seedlings (69 individuals versus 22 or less in each of the other transects).

Soil in the H-Area tree-kill zone was much more consolidated than the soil in the F-Area site. Much of the area had standing water at the surface. Depth increased as the plot number increased along the transect. Very few canopy trees were still alive. Some standing dead trees were evident and many logs were on the ground throughout the area. A total of 40 species was identified in the H-Area sampling location. The affected area

had two distinct characterizations. Plots 1 through 15 were less wet and showed evidence of revegetation by woody species. The plots were clearly impacted previously, but were recovering much faster than plots 16 through 56. Plots 16 through 56 were much wetter and dominated by cattails (*Typha* sp.) and cut grass (*Leersia oryzoides*).

The sparse vegetation of the F- and H-Area tree-kill areas was in stark contrast to the adjacent forest. The species composition was similar, but the structure was very different. Unlike a relatively undisturbed forest, the tree-kill areas were not stratified. The species normally associated with canopy, subcanopy, and shrub layer were present in the F-Area, but as sickly seedlings perched above the substrate on stumps, logs, and piles of debris. None of the species can survive continuous deep flooding that is typical of these areas. Therefore, without the stumps, logs, and debris, the vegetation could not exist. The adjacent forest, however, was characterized by a closed canopy of mature mixed hardwoods and loblolly pine (*Pinus taeda*). The subcanopy and shrub layers were intact and well defined; the plants were growing on a consolidated soil more characteristic of these wetland areas.

The composition of the first 15 plots of the H-Area tree-kill area indicated that the section was beginning to re-establish itself as a bottomland hardwood forest. Many years will be needed to allow the canopy to form a self-perpetuating forest. The hydrology of the remainder of the H-Area tree-kill area and the lack of tree and shrubs indicated that the area was not suitable for natural regeneration of the bottomland hardwood forest.

The vegetation characterization plots were reassessed in June of 1994 to determine if any improvement had occurred in the additional year (Westbury and Nelson 1994). The F-Area site exhibited minimal plant community development. Most of the vegetation was growing on or near woody structured and elevated areas where the roots were above the saturated sediments. Thirty plant species were identified in 1994 in the F-Area plots, and were similar in composition to the 26 species found in 1993. Between 1993 and 1994, the number of woody plants increased three-fold. This increase was especially pronounced in plots on Transect 4. This transect accounted for over half of the woody plants found in the area, as was the case in 1993. Red maple seedlings (*Acer rubrum*) accounted for the largest increase in numbers of individuals. If the survival rate of these seedlings is good and they can establish roots in the saturated sediments, the substrate could become more consolidated and amenable to colonization by wetland plants. In general, this site was devoid of flora, with only 8% herbaceous cover and very small tree and shrub seedlings confined to dryer locations. There was no evidence of the development of a herbaceous wetland plant community, which would indicate a reduction of the toxicity of the sediments in the tree-kill zone. Virtually all plants growing within the F-Area tree-kill zone were rooted out of the saturated sediments.

The H-Area tree-kill site substrate was again found to be much more densely vegetated with more consolidated sediments of a higher organic content than the F-Area site in the 1994 characterization. Extensive development of a herbaceous wetland plant community indicated that the toxicity of the sediments had been reduced considerably. The general character of the plants in the area did not show signs of stress and the high percent coverage indicated minimal impairment of plant establishment and growth. In 1994, 50 plant species were identified in the study plots, as compared to 40 in 1993. Species composition was similar in both studies, with most of the increase due to the difference in the sample dates with respect to season. The total herbaceous cover of the H-Area plots decreased from 93% in 1993 to 77% in 1994. The largest decrease was with the two most frequent and dominant species; cattail decreased from 54% in 1993 to 40% in 1994, whereas cutgrass decreased from 30% in 1993 to 18% in 1994. The decrease in percent cover of these two species was probably due to the 1994 sample being taken earlier in the growing season (June) than in 1993 (September). Ten additional plant species were measured in 1994. Most of these additions were also attributed to the earlier sample date because the plants were in flower and could be identified to species, or, as with bishop-weed (*Ptilimnium capillaceum*) the plant flowers and senesces early in the season. The increase in herbaceous plant species numbers was insignificant.

The H-Area tree-kill site had developed an extensive post-disturbance plant community dominated by herbaceous wetland plants. After the swamp tupelo canopy was removed by the initial impact, wetland herbaceous species should colonize the saturated sediments as soon as the toxicity of the sediments became sub-lethal.

With time, shrub and tree species would become dominant, eventually returning to the pre-disturbance composition. The northern portion of the zone (plots 1-20) had developed a sub-canopy of shrubs and saplings indicating a more advanced successional stage than the remainder of the zone. The principal tree species present was red maple, an early successional invader. The intermediate section (plots 21-35) was dominated by southern cattail as opposed to broad-leaf cattail in the more open western section (plots 36-56). This abrupt shift in species composition may be due to variations in hydrology, light availability, or pH.

General conditions at both tree-kill zones were unchanged between the 1993 and 1994 studies. Differences due to sampling date were observed. Future characterization should be on a standardized date to reduce this variability. The F-Area site exhibited toxicity in the saturated sediments, and was largely devoid of vegetation with only 8% herbaceous cover. The typically three-fold increase in tree, shrub, and vine seedlings was a positive sign, although general vigor and health of the new individuals was poor. If the survival rate of these seedlings is good and they are able to send roots into the saturated sediments, then the substrate could become more consolidated and amenable to colonization by wetland plants.

The H-Area site exhibited far greater plant community development and successional recovery than the F-Area site. The presence of a shrub sub-canopy in the northern and middle portions of the zone, and the generally high percent cover (77-93%) of herbaceous wetland plants, indicate lowered toxicity of the substrate to germination and establishment of vegetation.

In 1994, Nelson and Rogers (1995) initiated efforts to re-establish native vegetation in several of the tree kill areas. In an effort to reestablish the climax species of the area, swamp tupelo (*Nyssa sylvatica* var. *biflora*) seedlings were planted in four of the impacted areas. The four areas were named for the seepage water sampling point nearest to them. The areas represented a gradient of impact level to the vegetation, with F14 and F47 being most severely damaged, F204 the least damaged, and H38 as intermediate. Natural revegetation of the areas reflects the original damage level, with little revegetation at F14 and F47, early successional species invasion of H38, and a moderate shrub and herbaceous layer occurring in F204. Each of the study areas was planted with swamp tupelo seedlings in early February 1994. An initial survival tally of the seedlings was taken on June 7, 1994, and indicated that healthy seedlings had been planted into the areas. Seedlings were placed into categories ranging from 1 for a healthy seedling to 4 for a dead seedling. A late season tally of the seedlings was conducted September 13, 1994 using the same classes of seedling condition. This tally was used to determine how well the seedlings had performed in their new environment. Subsequent tallies have been made each spring and fall to track the performance of the seedlings.

Survival of swamp tupelo seedlings after the first field growing season was excellent on all four of the affected sites examined. The first year after planting is characteristically spent by the seedling establishing contact with its new environment.

During the second growing season, the two sites which had less severe original impacts, F204 and H38, still showed good survival and general condition of the seedlings. The two sites which experienced the greatest original tree-kill, F14 and F47, also had good over-winter survival. The percentage of trees that appeared stressed, however, had increased from the tally at the end of the first growing season for these two sites. Subsequent observations of F14 and F47 sites during the growing season indicated that seedling condition was deteriorating. Observations at the start of the third season of growth clearly confirmed this. The two sites which had less severe original impacts, F204 and H38, still showed good survival and general condition of the seedlings. The two sites which experienced the greatest original tree-kill, F14 and F47, continued to show the effects of the environment which were noted during the middle of the second growing season. Both of these areas experienced a greater than 20 percent decline in survival between the second and third growing seasons, as was anticipated after the mid-season evaluation. This continued decline is seen in Figure 16, which indicates the percent survival of the tupelo seedlings at the beginning of the first, second, and third growing seasons.

FIGURE 16. Percent survival of seedlings in four wetland areas, 1994-1996.

3.2.2 Macroinvertebrates

Macroinvertebrates include immature, aquatic insects such as mayflies, stoneflies, and caddisflies. These species spend the first part of their lives under water, breathing oxygen via gills and burrowing into the sediment. Macroinvertebrates are excellent indicators of environmental health and are not commonly found where contamination prevails. Numerous investigations of macroinvertebrates have been conducted on the SRS.

Firth et al. (1986) sampled macroinvertebrates monthly at 29 sites in the SRS stream and swamp areas using Hester-Dendy multiplate samplers placed in the streams. Species richness, density, and biomass were recorded for each sample, and invertebrates were sorted into functional feeding groups. Density and species diversity of macroinvertebrates at Fourmile Branch were either the highest or among the highest observed at the nonthermal stream sites. The Fourmile Branch location also exhibited the highest biomass of collector-filterer organisms and a relatively low biomass of predators. The dominance of collector-filterer organisms in Fourmile Branch indicated that the trophic structure in the stream was supported by fine particulate organic detritus, possibly related to the presence of beaver ponds throughout the drainage (Gladden 1988). A high degree of biological processing of this organic matter is considered a desirable feature. The reason behind the relative absence of predators in Fourmile Branch was not clear. Gladden (1988) concluded that the macroinvertebrate community in Fourmile Branch was similar to the trophic structure of macroinvertebrate communities in upper Pen Branch and Meyers Branch, both of which have not been adversely affected by SRS operations.

Lauritsen et al. (1989) examined macroinvertebrates in Fourmile Branch between June 1985 and September 1987 as part of a larger study of SRS streams. They found that following the shut down of C-Reactor, recolonization of the stream by macroinvertebrates began within a month and proceeded rapidly. It was also noted that this phenomenon occurred in summer, the peak reproductive period for macroinvertebrates.

Specht (1994) examined macroinvertebrates at six locations in Fourmile Branch during the summer of 1993. The diversity and abundance of macroinvertebrates in Fourmile Branch at Road C indicated stressed conditions. It was concluded that these conditions were attributable to low dissolved oxygen concentrations (4.0 mg/L) rather than discharges from FHSB. The 1993 study showed longitudinal trends with respect to most of the parameters that were measured. In general, environmental stream quality appeared to improve in a downstream direction.

Specht and Paller (1995) sampled 16 SRS streams including Fourmile Branch at Road C for macroinvertebrates in September 1994. Although dissolved oxygen at this location was 4.9 mg/L and species richness and biomass (g/m²) ranked third and 13th, respectively, Fourmile Branch in the vicinity of Road C was perturbed compared to other SRS streams.

3.2.3 Fish

The principal aquatic habitat for fish in the vicinity of FHSB is Fourmile Branch and its tributaries. Aquatic habitat associated with the seep lines are generally unsuited for fish, except during periods of flooding. Several studies have examined fisheries resources in the general area. Gladden (1988) summarized two fishery studies conducted by Environmental & Chemical Sciences (ECS, unpublished) and Aho et al. (1986). Fish samples were collected in Fourmile Branch by ECS between December 1984 and August 1985 whereas Aho et al. (1986) sampled nine nonthermal streams from March 1984 to December 1985. Both studies used electroshocking equipment to collect samples. All but one of the stream sites were dominated by minnows, with the degree of dominance at these sites ranging from 41 to 63 percent. Fourmile Branch ranked at the lower end of this scale.

Because species richness of fish in Fourmile Branch was similar to other SRS sites, Gladden (1988) concluded that the fish communities in nonthermal reaches of Fourmile Branch had not been affected by effluent discharges. However, there was evidence that seepage and stream water have been occasionally toxic. Several metals have been commonly detected in the tissue of fish inhabiting Fourmile Branch. However, the concentrations of most of these chemicals have not been correlated to seepage basin discharges. Results of fish community structure analyses do not indicate that fish in Fourmile Branch have been adversely affected.

Paller and Story (1990) examined the abundance, distribution, and tissue of fish in Fourmile Branch upstream and downstream of the FHSB. They reported that species richness and catch per unit effort below the contaminant discharge zone were higher than locations above the zone. Total catch per unit effort in Fourmile Branch was similar to results from Pen Branch.

Loehle and Paller (1990) analyzed the tissues from fish collected by Paller and Story (1990) to assess the bioaccumulation of metals from the seepage basins. Of the nine metals that were analyzed, only aluminum, chromium, mercury, selenium, and zinc were detected. In 1992, Paller et al. (1995) used rapid bioassessment methods to collect fishes in Fourmile Branch and reported evidence of degradation. To better understand the fisheries of Fourmile Branch, comprehensive studies are scheduled for 1997 to support the Integrator Operable Unit (IOU) evaluation. These studies will include: (1) characterization of community structure using rapid bioassessment techniques, (2) tissue analysis for radioisotopes, metals, and volatile chemicals, and (3) necropsies for assessing ecological stressors.

3.2.4 Herpetofauna and Small Mammals

Friday et al. (1994) examined the diversity and relative abundance of amphibians, reptiles, and small mammals in the vicinity of F- and H Areas in 1994. Amphibians were markedly more common than reptiles based on observation, frequency of capture, and auditory surveys. Eight of the thirteen species of amphibians that were captured or observed were identified near the F-Area canal. Reptiles inhabiting the area included the box turtle, rat snake, and four species of lizards (green anole, six-lined racerunner, five-lined skink, and ground skink).

Mammalian species richness was relatively low; the short-tailed shrew and cotton rat were the most frequently captured small mammal. Composite tissue samples from short-tailed shrews captured from two reference locations, the old F-Area effluent ditch, and the H-Area seepage line were analyzed for radioisotopes and metals (WSRC 1995c). Concentrations of the five composite samples are given in Table 9. Body burdens of 22 constituents in shrews from the F-Area ditch exceeded background levels compared to 12 constituents analyzed from shrews at the H-Area seepage line.

TABLE 9. Body burdens of selected constituents in shrews (*Blarina carolinensis*) in the vicinity of the FHSB, 1995 (WSRC 1995c).

Constituent	Background	F-Area Effluent	H-Area	Units
		Ditch (N=2)	Seepline (N=2)	
Non-radiological				
Silver	1,260	3,880	1,190	µg/kg
Aluminum	6,400	13,355	13,975	µg/kg
Arsenic	15,200	46,600	14,300	µg/kg
Barium	59,900	43,700	58,600	µg/kg
Beryllium	505	1551	476	µg/kg
Calcium	3.97E+07	4.35E+07	4.74E+07	µg/kg
Cadmium	253	778	238.5	µg/kg
Cobalt	936	1220	1145	µg/kg
Chromium	1920	4600	1690	µg/kg
Copper	8910	12100	10150	µg/kg
Iron	2.59E+05	5.26E+05	2.58E+05	µg/kg
Potassium	8.91E+06	9.14E+06	9.15E+06	µg/kg
Magnesium	1.13E+06	1.28E+06	1.34E+06	µg/kg
Manganese	5030	6790	7070	µg/kg
Sodium	3.93E+06	4.00E+06	4.05E+06	µg/kg
Nickel	3,870	53,265	5,650	µg/kg
Lead	5,050	15,510	4,760	µg/kg
Antimony	5,050	15,510	4,760	µg/kg
Selenium	15,200	46,600	11,320	µg/kg
Thallium	15,200	46,600	14,300	µg/kg
Vanadium	505	1,551	476	µg/kg
Zinc	68,300	77,600	75,500	µg/kg
Radiological				
Gross Alpha	238	471.5	-543	pCi/g
Nonvolatile Beta	9,640	20,050	25,950	pCi/g
Cesium-137	5,010	7,985	4,595	pCi/g
Radium-226	-	1.635	-	pCi/g
Radium-228	-	1.052	-	pCi/g

3.2.5 Aquatic Toxicology

Toxicity testing is the process of exposing test organisms to a medium (water, soil, sediment, or air) and evaluating the lethal or sublethal effects of contamination on the survival, growth, reproduction, or other biological functions. Toxicity tests can be acute or chronic. Acute toxicity tests are short-term tests that measure the effects of exposure to relatively high concentrations of chemicals. Chronic toxicity test are longer-term test that measure the effects of exposure to relatively lower, less toxic concentrations. Toxicity testing can usually confirm the presence of a toxicant, but it typically cannot identify the specific chemical. This can be accom-

plished by a subsequent investigation, the toxicity identification evaluation (TIE). The principal objective of aquatic toxicology studies at SRS was to evaluate the effect of contaminated groundwater that surfaces at the F- and H-Area seepines, flows through the wetlands, and enters Fourmile Branch.

3.2.5.1 Chronic Aquatic Toxicity

Chronic toxicity tests using EPA protocol were performed on surface water samples collected from 11 seepine locations and five locations in Fourmile Branch between May 1990 and July 1994 (Figure 17). In addition, surface water from five uncontaminated background locations was also tested. The distribution of sampling locations by year is summarized in Table 10. Locations denoted as FSP and HSP represent F- and

TABLE 10. Distribution of aquatic toxicity sampling locations, 1990-1994 (Specht 1996).

Location	1990	1991	1993	1994
FSP-012	•		•	•
FSP-032	•		•	
FSP-047			•	
FSP-204			•	•
FSP-256			•	
HSP-008			•	•
HSP-020			•	
HSP-043	•			
HSP-060			•	
HSP-103			•	•
H-6	•			
FMB Road 4			•	
FMB Road C	•		•	
FMB Road C-4	•		•	
FMB SCE&G				•
FMB Road A-7	•	•	•	
UTR-022				•
UTR-029				•
UTR-116				•
BGW-045				•
UTR RR Bridge				•

H-Area seepine sites, respectively. Sampling locations in Fourmile Branch are designated as FMB. The four background seepine locations include UTR and BGW sites. A background stream location, Upper Three Runs Creek (UTR) at the railroad bridge, was also sampled.

Definitive chronic toxicity tests were conducted on the water flea, *Ceriodaphnia dubia*, using EPA methods (Weber et al. 1989). Toxicity tests were performed on a series of dilutions, (generally 0, 6.3%, 13%, 25%, 50%, and 100% sample water), using 10 test organisms per concentration. At the end of the 7-day test the reproductive success (number of young produced) of organisms exposed to each dilution was compared statistically to that the control group (0%) in order to determine if reproduction was impaired. The results of the tests were reported as NOEC's (No Observed Effect Concentration), which represent the highest concentration that did not significantly reduce reproduction. A NOEC value of 100% means that no reproductive impairment was observed in the undiluted sample. In addition, any mortality that occurred during the test was

FIGURE 17. Distribution of toxicity sampling locations, 1990-1994.

also recorded. Water quality parameters routinely measured during the toxicity tests included temperature, pH, hardness, alkalinity and specific conductance.

Toxicity tests were initially conducted in May and June, 1990. Six representative sampling locations were selected based on water chemistry analyses conducted by Haselow et al. (1990): (a) two at the F-Area seepine, (b) two at the H-Area seepine, and (c) two locations in Fourmile Branch (Table 10). Fourmile Branch at Road C was selected because it occurs downstream from the H-Area seepines, yet upstream from the F-Area seepine. Fourmile Branch at Road C-4 was selected because it lies downstream from both seepines. In November and December 1990, samples were collected at the same locations except for Fourmile Branch which was sampled at Road A-7 rather than at Road C-4 (Korthals 1991). The location at Road A-7 lies downstream from both the F and H-Area seepage areas (Figure 1). The results of the 1990 testing indicated the presence of toxicity at both seepines and also in Fourmile Branch at Road A-7 (Table 11).

In July 1991, a second toxicity test was conducted on surface water collected from Fourmile Branch at Road A-7. These results, however, showed no evidence of toxicity in the stream (Table 11). Toxicity testing was not conducted for the F- and H-Area seepines in 1991 nor was toxicity testing performed in 1992.

In September 1993, toxicity tests were conducted at five F-Area seepine locations, four H-Area seepine locations, and four locations in Fourmile Branch (Table 11). The seepine locations were selected based on

water chemistry results of Dixon et al. (1993), and included several locations that were tested in 1990. The creek locations were selected to be upstream of the F- and H-Area seeps (Road 4), between the F- and H-Area seeps (Road C), immediately downstream of most of the seeps (Road C-4), and downstream of all seeps (Road A-7). Except for a single location in H-Area, all seepage locations were toxic in 1993 (Table 11). No toxicity was detected in Fourmile Branch.

Toxicity testing was continued in 1994 at 10 locations: (1) two seepage sites in F-Area, (2) two seepage sites in H-Area, (3) one location in Fourmile Branch at the SCE&G power line, (4) four background seepage sites, and (5) one background location in Upper Three Runs Creek. The results of these analyses indicated that seepage waters at F- and H-Area were toxic, background seepage locations were slightly toxic, and Fourmile Branch and reference streams were not toxic. Compared to earlier observations, toxicity at some seepage locations appeared to decline.

Aquatic toxicity varied by location and year (Table 11). Toxicity results for background, seepage, and Fourmile Branch locations are summarized below.

Background Locations- Three of the four background seepage locations that were sampled in 1994 were toxic (NOEC values of 50%). One seepage location and the single stream location in Upper Three Run Creek at the rail road bridge were not toxic. These results indicate that some seepage locations on the SRS, even though they are not influenced by the F- and H-Area seepage basins, can be toxic to *Ceriodaphnia dubia*.

Seepage Locations- Toxicity tests conducted on seepage locations downgradient from the F- and H-Area Seepage Basins had NOEC's ranging from 3% to 100% (Table 11). Of the eleven seepage locations that were sampled in 1993 and 1994, only two showed no evidence of toxicity (HSP-008 and H-6). The remaining locations were toxic on at least one occasion. The degree of toxicity at the seepages appears to vary temporally. The variation is probably related to the amount of rainfall in the week or two prior to sample collection. Rainfall can dilute the seepage surface water directly and can also infiltrate the shallow groundwater, causing further dilution.

Fourmile Branch- Between 1990 and 1994, surface water from five locations in Fourmile Branch was tested (Table 11). Of the ten toxicity tests that were performed, only Fourmile Branch at Road A-7 in winter 1990 showed evidence of toxicity (NOEC = 60%). It cannot be determined if this toxicity was due to naturally occurring conditions or to contamination associated with the F-Area seepage. However, no toxicity has been observed in Fourmile Branch below the F- or H-Area seepages since 1990. This suggests that the seepages were not toxic to Fourmile Branch.

3.2.5.2 Toxicity Identification Evaluations

In order to determine the cause of observed toxicity, Toxicity Identification Evaluations (TIE's) were performed on three representative seepage locations: (1) FSP-204, which is downgradient from the F-Area Seepage Basins, (2) HSP-103, which is downgradient from the H-Area Seepage Basins, and (3) UTR-029, which is uninfluenced by F- and H-Areas. In addition, as part of another study, a TIE was performed on water collected from Fourmile Branch at Road F, which is upstream from all SRS discharges.

F-Area Seepage Toxicity testing in September 1993 and June 1994 on seepage location FSP-204 demonstrated that the surface water was toxic. In November 1994 and July 1995, surface water from this location was analyzed for the presence of metals. Results indicated that potentially toxic concentrations of aluminum, cadmium, iron, lead, and zinc were present. In January 1995, a Phase I TIE was initiated. Although most treatments were ineffective in removing toxicity, adjusting the pH to 10, aeration at pH 3 and pH 6, filtration, and filtration with a C-18 Solid Phase Extraction (SPE) column all reduced toxicity. The seepage water was also

TABLE 11. No Observed Effect Concentrations (NOECs) for Toxicity Testing Locations, 1990-1994 (Specht 1996).

Location	May-June 1990	Nov-Dec 1990	July 1991	September 1993	April-June 1994
FSP-012	60%	60%		10%	100%
FSP-032	100%			30%	
FSP-047				30%	
FSP-204				30%	25%
FSP-256				30%	
HSP-008				100%	100%
HSP-020				3%	
HSP-043	60%	60%			
HSP-060				10%	
HSP-103				3%	13%
H-6	100%	100%			
FMB Rd. 4				100%	
FMB Road C	100%	100%		100%	
FMB Road C-4	100%			100%	
FMBSCE&G					100%
FMB Road A-7		60%	100%	100%	
UTR-022					50%
UTR-029					50%
UTR-116					50%
BGW-045					100%
UTR RR Bridge					100%

found to be less toxic at pH 8.5 than at pH 6.0. EDTA chelation, which is effective in removing many cationic metals (including Cd, Cu, Fe, Pb, Mn, and Zn) was ineffective in reducing toxicity. Based on the results of the initial Phase I TIE studies, potential toxicants include the following: cationic metals not chelatable by EDTA, hydrogen sulfide, total dissolved solids, and non-polar organics (which are removed by a C-18 SPE column).

In March 1995, a methanol elution was performed to distinguish between the removal of non-polar organics (which can typically be eluted by methanol) and cationic metals. The results indicated that the toxicants were not eluted by the methanol, suggesting that the toxicity was not attributable to non-polar organics.

Additional Phase I testing was conducted in July 1995 to confirm the results of the January 1995 Phase I tests, and to evaluate alternative treatments. Based on the results, a volatile compound (hydrogen sulfide) and particulate contaminants were eliminated from further consideration. The anionic exchange resin failed to significantly reduce toxicity; the cationic resin, however, removed all of the toxicity. This implies that most of the toxicity was due to a cation. The graduated pH test indicated that the seep water was considerably less toxic at pH 8.0 than at 6.5, which would suggest one or more of the following toxicants: aluminum, copper, hydrogen sulfide or lead. Because copper and lead are chelatable by EDTA and EDTA did not reduce toxicity in the first round of Phase I tests, the results suggest that cationic metals not chelatable by EDTA (probably

aluminum) were the primary toxicants. However, some residual toxicity remained with most of the treatments that reduced toxicity. The presence of residual toxicity indicated that other toxicants, with different characteristics, also contributed to the toxicity.

H-Area Seepage Surface water collected from the H-Area seepage (HSP-103) in September 1993 and June 1994 was toxic to *Ceriodaphnia dubia*, with NOEC's of 3% and 12.5%, respectively. In January 1995, a full TIE was initiated for this location. Aeration at pH 3 was the only treatment that removed toxicity, suggesting that the toxicant was either volatilized or oxidized to a less toxic form at an acidic pH. Therefore, potential toxicants include sulfide/hydrogen sulfide, and possibly cationic metals and/or acid volatile organics.

In May 1995, additional TIE tests that included aeration and nitrogen sparging were conducted on surface water collected from HSP-103. The only treatment that removed the toxicity was nitrogen sparging at the initial pH; however, all of the aeration and sparging treatments reduced toxicity to some extent. These results suggest that the toxicant was a volatile compound. However, it is unlikely that hydrogen sulfide was the toxicant because its toxicity would be reduced more by aeration than by sparging. Because toxic concentrations of volatile organic compounds have not been found in the HSP seepage and because the toxicity was not removed by a C-18 SPE column, the toxicant is unlikely to be a volatile organic compound.

High concentrations of nitrate in the seepage water may be reduced to ammonia under anoxic conditions. Ammonia toxicity is pH and temperature dependent. Toxicity would be expected at approximately 2 mg/L under the pH and temperature conditions that were present at HSP-103. However, Chapell et al. (1995) did not report ammonia concentrations at H-Area seeps that approached 2 mg/l. No other source of volatile toxicants is known for the H-Area seepage.

Samples were collected twice from HSP-103 during the summer of 1995. However, neither sample was toxic when a baseline toxicity test was initiated prior to beginning additional TIE tests. Therefore, it was not possible to clearly identify the source of the toxicity at HSP-103. However, it appears that the source of the toxicity has been reduced or eliminated over time. In September 1993, the NOEC was 3%, in June 1994, the NOEC was 12.5%, in January 1995, when the TIE was initiated the NOEC was 60%, and by the late summer 1995, the water was no longer toxic. These results suggest that the toxicity was due to constituents from the H-Area basins that have been reduced or eliminated by the capping of the basins.

Fourmile Branch In 1994, water samples from Fourmile Branch were used to culture *Ceriodaphnia dubia* as part of another investigation. Results indicated that water from Fourmile Branch was usually chronically toxic. Acute toxicity was also noted on an intermittent basis. To determine the cause of the toxicity, a TIE was initiated in June 1995 on water collected from Fourmile Branch at Road F. This location is near the headwaters of the stream and is upstream from all SRS discharges to the stream. Treatments that effectively reduced or removed toxicity were filtration, C-18 column, sodium thiosulfate addition at 1 mg/l, and EDTA addition at ≥ 5 mg/l. With the exception of filtration at neutral pH, all treatments were effective in removing cationic metals. Therefore, the toxicity in Fourmile Branch was probably attributable to a metal.

Phase II TIE studies were initiated in July 1995 to identify and confirm the source of toxicity in Fourmile Branch. The results of the Phase II investigations confirmed that the untreated sample was toxic and that adjustment to pH 9.0 and filtration removed the toxicity. When iron was spiked back into the sample at concentrations exceeding 2 mg/l, toxicity was again observed. These results confirmed that iron was the source of the toxicity in water collected from Fourmile Branch. Because the sample was collected upstream from all SRS discharges to the stream, it appeared that the toxicity was due to naturally occurring iron. The iron was probably leached from surrounding soil by the low pH resulting from naturally occurring humic and fulvic acids that are characteristic of blackwater streams.

Background Seepage

In April 1993, background seepage location UTR-029 was sampled and analyzed for organic and inorganic constituents (Dixon and Cummins 1994). Analytical results indicated elevated levels of total aluminum (5.93

mg/L), iron (17.7 mg/L), manganese (1.9 mg/L), zinc (32.5 mg/L) and total suspended solids (308 mg/L), and a moderately high hardness (59 mg/L). No organic compounds were detected at levels above background concentrations. In April 1994, a chronic toxicity test for this location indicated that it was acutely toxic to *Ceriodaphnia dubia*.

A partial Phase I TIE was conducted in November 1994 to determine if the toxicity was caused by a metal or metals. Four treatments known to be effective in removing toxicity were used. Each test, except the graduated pH test, was effective at removing chronic toxicity. These results were consistent with the responses that would be expected if the toxicant were a metal. The orange precipitate that resulted when the pH was adjusted to 10 and filtered suggests that the toxicity was due to iron.

Following the Phase I partial TIE for cationic metals, Phase II TIE studies were initiated on a water sample collected from UTR-029 on January 5, 1995 (ETT 1995). In the Phase II studies, water from the seep was adjusted to pH 10 and filtered to remove cationic metals. Samples of the treated water were then spiked with iron (2.1 mg/L), with zinc (17 mg/L), and with iron (2.1 mg/L), zinc (17 mg/L) and manganese (0.71 mg/L). These spiked samples were then subjected to the same treatments that removed toxicity in the Phase I tests (filtration at pH 10, sodium thiosulfate addition, and EDTA chelation).

The results indicated that 2.1 mg/L of iron produces a chronic toxic effect of similar magnitude to that observed in the seep sample (Table 11). The addition of zinc to a concentration of 17 mg/L did not increase the toxicity, which suggests that the amount of zinc present in the UTR-029 seep water was not great enough to produce toxicity. Similarly, the addition of manganese and zinc to the sample that had been spiked with iron did not increase the toxicity. The results of the Phase II TIE therefore confirmed that the observed toxicity of UTR-029 was due to iron. Because this background location has not been impacted by SRS operations, it is concluded that the iron is naturally occurring, and has probably been leached from the soil because of the relatively low pH (5.49) of the groundwater.

4.0 Constituents of Interest

One of the principal tasks associated with site characterization and risk assessment is to identify analytes, chemical compounds, and radioisotopes that have the potential to cause adverse effects on human health and the environment. This is typically achieved using a screening protocol tailored to the existing data, affected media, availability of benchmark values, and other factors. When performed as part of a baseline risk assessment, constituents that are potentially unit-related and are present at concentrations that may impact human health and the environment are referred to as constituents of potential concern (COPCs). COPCs are generally identified as part of a data screening process involving validation, statistical analyses, and other investigative procedures. Because this report seeks to identify constituents from several investigations that have used different screening protocols, constituents are broadly categorized herein as "constituents of interest." These include constituents that meet the following criteria: (1) they were identified as a COPC in a screening level risk assessment (WSRC 1995d) for the F- and H-Area groundwater unit, (2) they were identified as being of concern by an independent peer review (Babich et al. 1995), or (3) concentrations exceeded a regulatory threshold value such as the primary and secondary drinking water standards, EPA Region III risk-based concentrations (EPA 1997), or an ecological screening value issued by EPA Region IV (EPA 1995). Constituents of interest for human health and ecological are listed in Tables 12 and 13, respectively.

4.1 Human Health

Constituents of interest in water pertaining to human health varied by screening protocol (Babich et al. 1995, Dixon and Rogers 1993 b,c; 1994 a, EPA 1997, WSRC 1995d,) and included radiological and non-radiological categories (Table 12). The independent site peer review (Babich et al. 1995) identified cadmium, mercury, nitrate and nitrite as non-radiological constituents of interest. Radium-228, strontium-90, technetium-99, and tritium were listed as radiological constituents of interest (Babich et al. 1995). The human health component of the screening level risk assessment (WSRC 1995d) considered two risk scenarios: (1) a current worker who sampled groundwater monitoring wells, and (2) a hypothetical, future on-site resident. For a current worker in F-Area, risk from exposure to chemicals was below the $1.0\text{E-}06$ threshold of concern whereas risk from radionuclides marginally exceeded the threshold. For a current worker in H-Area, risk from chemicals and radionuclides was below the $1.0\text{E-}06$ threshold level.

For a hypothetical, future on-site resident who drank water contaminated with tritium from Fourmile Branch, a cancer risk ($P > 1.0\text{E-}04$) would result. Once this water reached the Savannah River, risk marginally exceeded the $1.0\text{E-}06$ threshold level. A hypothetical future on-site resident who consumed water from a well would be at risk from chemicals and radionuclides in F-Area. In H-Area, risk from chemicals was above the threshold level whereas risk from radionuclides was below the threshold level.

Based on the two risk scenarios, the screening level risk assessment identified seven non-radiological constituents of interest to human health. Non-radiological constituents of interest that were identified for human health included aluminum, beryllium, cadmium, manganese, mercury, nitrite, and nitrate. Eight radiological constituents of interest were identified (Table 12). Eleven additional constituents had concentrations that exceeded primary or secondary drinking water standards, maximum contaminant levels, or risk-based concentrations (Table 12). Cadmium, nitrate, and radium-228 were the only constituents of interest to human health that were identified by all three screening protocols.

4.2 Ecological

Ecological constituents of interest were identified for both sediment and surface water (Table 13). Based on a comparison of the 1995 analytical results (WSRC 1995b) with EPA Region IV screening levels (EPA 1995), eleven non-radiological constituents of interest were identified in sediment. Ten constituents in sediment at the seep lines had 95% upper confidence intervals that exceeded ecological screening values (Table 13). These included antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and silver. The concentration of zinc in the sediment of Fourmile Branch exceeded the ecological screening value but the seep line sediments did not. Concentrations of arsenic, chromium, and silver exceeded EPA sediment screening values, but were not identified as constituents of interest in surface water.

TABLE 12. Constituents of interest to human health in water as identified from three screening protocols (Babich et al. 1995, WSRC 1995d, Dixon and Rogers 1993 b, c; 1994 a).

Constituent of Interest	Independent Site Peer Review	Screening Level Risk Assessment	Regulatory ^a
Non-Radiological			
Aluminum		•	•
Antimony			•
Arsenic			•
Beryllium		•	•
Cadmium	•	•	•
Chloride			•
Copper			•
Iron			•
Manganese		•	•
Mercury	•	•	
Nitrate	•	•	•
Nitrite	•	•	
Silver			•
Thallium			•
Radiological			
Americium-241		•	
Carbon-14		•	
Cesium-137		•	
Curium-243		•	
Gross Alpha			•
Iodine-129			•
Nonvolatile Beta			•
Radium-226			•
Radium-228	•	•	•
Strontium-90	•	•	
Technetium-99	•		
Tritium	•	•	•
Uranium-238		•	

^a Concentration of constituent exceeded primary or secondary drinking water standards, maximum contaminant levels (MCLs), or EPA Region III risk-based concentrations for the period 1992-1996.

For surface water, the ecological component of the screening level risk assessment (WSRC 1995d) identified metals as the greatest risk to the environment (Table 13). Aluminum, cadmium, iron, lead, mercury, and zinc were identified as COPCs in surface water. No radiological COPCs were identified in surface water. COPCs identified as having the potential to pose ecological risk to assessment endpoint in groundwater from F-Area included aluminum, beryllium, cadmium, iron, lead, mercury, and nickel. COPCs in H-area were aluminum,

copper, iron, lead, and mercury. Although not identified as COPCs, both pH and specific electrical conductance influence the distribution and availability of constituents and therefore should be monitored. Other constituents whose concentrations exceeded EPA Region IV screening values included antimony, arsenic, beryllium, chromium, copper, silver, and thallium. Cyanide, nitrate, and 14 metals represent the constituents of interest based on the various screening protocols (Table 13).

TABLE 13. Ecological constituents of interest in sediment and surface water.

Constituent of Interest	Sediment	Surface Water
Aluminum		•
Antimony	•	•
Arsenic	•	•
Beryllium		•
Cadmium	•	•
Chromium	•	•
Copper	•	•
Iron	•	•
Lead	•	•
Mercury	•	•
Nickel	•	•
Nitrate		•
Selenium		•
Silver	•	•
Thallium		•
Zinc	•	•

5.0 Remedial Action

5.1 General Description

The objective of the remedial action is to reduce the concentration of contaminants in groundwater to levels that comply with the standards identified in the RCRA post-closure permit. Contaminated groundwater will be extracted, treated, and injected hydraulically upgradient from the extraction point. The treatment system will reduce heavy metals, nitrates and some radionuclides to groundwater protection standards. To adequately provide hydraulic control of the contaminated groundwater plumes beneath and downgradient of the seepage basins, the project components will be designed for the extraction, treatment, and injection of affected groundwater at an optimum flow rate, plus 15% contingency, of approximately 410 gpm total from both areas. Each area (F and H Seepage Basins Areas) will have its own independent modular remediation system. The major components for each remediation system will include: (1) groundwater extraction and collection system, (2) modular groundwater and secondary waste treatment system, (3) treated water distribution and injection system, and (4) secondary waste collection and packaging system. Each component will be equipped with all the necessary accessories required for flow control, treatment, and safety alarms. This will allow the processes for both F-and H-Areas to be monitored and controlled.

The Groundwater Extraction and Collection System will provide adequate hydraulic control of the contaminated groundwater plumes delineated by the 10,000 pCi/ml tritium and the 2 µg/L mercury isoconcentration contours. This action will prevent these plumes from reaching and/or further discharging to Fourmile Branch. The contours are based on the second quarter 1992 groundwater monitoring data, the most current and complete at the start of the project. The extraction and collection system will allow flexibility in its operation for pumping rates to be adjusted over a fixed range. Each extraction well (Figures 18 and 19) will be equipped with a submersible pump and a control valve to regulate flow so it can be placed in or out of service as required. Wells will have ports connected to a water collection system at the ground surface for sampling. The collection system in each area will transport the groundwater from the well to the mixing tank(s) in each area.

The Modular Groundwater Treatment System will meet the requirements of both the Industrial Wastewater Treatment (IWT) permit for above ground water treatment and the Underground Injection Control (UIC) permit for the injection of the treated water. The modular treatment facilities will remediate the extracted groundwater by a surface treatment system (1) to meet the regulatory criteria for the Phase I treatment standards specified in the RCRA post-closure permit for the concentrations of the contaminants of concern, and (2) to meet engineering criteria for physical, chemical, and biological characteristics, making the water suitable for injection. Tritium and nitrate removal is not included in the Phase I treatment process. The modular treatment facilities will consist of process equipment only. At the location of the modular equipment, storm water accumulation will be minimized with rain covers, and spills will be confined with concrete pads with curbing.

The Treated Water Distribution and Injection System will transfer the treated water through an injectate tank(s) and piping network to the injection wells. The treated water will be injected hydraulically upgradient into the aquifers from which it was extracted. The injection wells will probably be fully penetrating and fully screened in the appropriate aquifer. Each well will have a valve so any individual injection well can be placed in or out of service or have its flow rate adjusted without impacting other injection wells.

The Secondary Waste Collection and Packaging System will prepare the secondary waste generated by the treatment processes for disposal in the E-Area Solid Waste Disposal Facility (SWDF), if as expected the waste is classified as low-level radioactive waste.

The proposed remedial action will utilize a reverse osmosis design combined with pre-filtration and secondary waste stream treatment using coagulation, precipitation and encapsulation to achieve acceptable TCLP (Toxicity Characteristic Leachate Procedure) results for the filter cake. The resultant liquid stream will be polished and combined with the reverse osmosis permeate into the effluent stream. The individual unit processes include: (1) sand filtration, (2) reverse osmosis, (3) chemical treatment precipitation, (4) clarification, (5) sludge dewatering and drying, and (6) effluent polishing.

FIGURE 18. Distribution of extraction and injection wells for F-Area.

5.2 Potential Environmental Effects

Potential environmental effects associated with the proposed remedial action are considered to be temporary. The pumping of water from the aquifer could produce cones of depression within the wetlands. Although localized and relatively small, the lowering of the water table could affect soil moisture. Changes in soil moisture could be detrimental to wetland flora which in turn could affect vegetative structure and wildlife habitat. Until vegetation can become re-established, surface water runoff could foster soil erosion and siltation of Fourmile Branch. When the pump and treat remedial action is completed, however, the process of natural succession should revegetate these areas.

5.3 Evaluating the Remedial Action

One of the basic questions associated with any remedial action is "how does one determine when the remedial action goal has been achieved?" To answer this, some measure of performance must be identified and monitored. One approach is the use of control charts (Gilbert 1987). Control charts are widely used in industry and research and development laboratories to evaluate performance and specification compliance. From the population distribution of a given parameter, such as the concentration of a metal in surface or groundwater, repeated samples are taken over time. Means or individual values are then plotted against an upper and lower predetermined limits. If data points fall outside the boundaries, the process is declared to be "out of control". Otherwise the process is declared to be "within control". The advantage of control charts or modifications thereof is that they are fairly easy to construct and they provide a quick visual evaluation of performance.

FIGURE 19. Distribution of extraction and injection wells for H-Area.

There are two standards or criteria against which comparisons can be made—background and regulatory compliance benchmarks. For a constituent of interest within a matrix, control charts using background data would require an estimate of the pre-operational arithmetic mean and standard deviation. Individual values are then plotted against the operating background level (mean plus standard deviation) and an action level (operating background level plus 1.5 times the standard deviation). Control charts can also be simplified to using regulatory compliance benchmarks as control limits. For example, chronic ambient water quality criteria and primary drinking water standards could be established as the limits of control. Values such as individual observations, means, or 95% upper confidence intervals could be plotted against these to determine environmental compliance or lack thereof. An example of a control chart using individual tritium values is shown in Figure 20.

Parametric and non-parametric statistical analyses can also be used to detect significant differences in concentrations between populations (e.g. years). One-tailed tests are appropriate when the direction (i.e., greater than or less than) is important. It should be noted, however, that each of the approaches discussed above must be applied individually by matrix to the constituents of interest. Although the use of these methods can serve as a performance measurement for abiotic data, other approaches must be used for evaluating terrestrial and aquatic ecosystems. In the vicinity of the FHSSB, the majority of existing ecological data is associated with Fourmile Branch and its wetlands. Gauging the effectiveness of remedial action could be attained by monitoring the floristic diversity and revegetation of stressed areas within the wetlands and also by continued monitoring of fishes and macroinvertebrates in Fourmile Branch. Color infrared aerial imagery could be used to detect significant changes in the arboreal canopy of the wetlands. Sampling and analyses would be required, however, in Fourmile Branch.

FIGURE 20. Example of a control chart for tritium (pCi/mL).

6.0 Summary and Conclusions

From 1955 until 1988, the F-and H-Area facilities annually discharged approximately 80 million gallons of wastewater into seven, unlined seepage basins. The wastewater, which contained radioactive and non-radioactive constituents, seeped into the underlying soil and groundwater, eventually reaching Fourmile Branch and the Savannah River. Environmental monitoring studies have detected concentrations that pose potential risk to human health and the environment. In 1991, the basins were certified closed by the South Carolina Department of Health and Environmental Control. The RCRA Part B permit required a corrective action plan to remediate contaminated groundwater.

Since the basins were closed, numerous investigations have been conducted to better understand the baseline environment, monitor concentrations and radioactivity of constituents, evaluate the mobility and transfer of contaminants, and to identify a remedial action that can reduce or eliminate contaminants. The objectives of this report are to summarize the results of these investigations, identify constituents of interest, describe the remedial action and its potential effects, and identify an approach that can evaluate the effectiveness of the remedial action.

6.1 Baseline Environment

Environmental studies in the vicinity of the F-and H-Area seepage basins have included both abiotic and biotic components. Several investigators have examined surficial soils on the SRS but the number of samples was small and sample locations were not specific to the FHSB. The most recent and comprehensive study of soils was done in 1995 at the F-and H-Area facilities as part of the site-wide monitoring program. Mean radioactivity of Cs-137, Pu-238, and Pu-239 were higher than the two control sites 100 miles away. The mean activity of strontium, however, was higher at the control sites than the FHSB. Relatively little information is available for non-radiological constituents in surficial soils in the vicinity of the FHSB.

Preliminary investigations of sediment identified elevated concentrations of metals and radionuclides. The most extensive examination of sediments was conducted during 1995 in both seepage areas. The majority of non-radiological constituents in sediment had 95% upper confidence intervals that exceeded background and ecological screening values. There are no human health screening values for sediment. Radioisotopes that exceeded background levels included Cs-137, Ni-63, Ra-226, Th-232, and others. Radioactivity of tritium in sediment was markedly above background level (38 pCi/g), ranging from 3833 pCi/g at the F-Area seepage to 616 pCi/g in Fourmile Branch. Because the analytical data for sediment is limited to a single year, it was not possible to identify trends.

In the 1990's, three programs were initiated to investigate surface water chemistry in the vicinity of the F-and H-Areas: (1) semi-annual sampling of the F-and H-Area seepages and Fourmile Branch, (2) quarterly tritium surveys of both seepages, and (3) quarterly sampling of the old F-Area effluent ditch. From 1992 to 1997, surface water at the seepages and Fourmile Branch were analyzed for metals, organic compounds, radionuclides, and other variables. The concentrations of several metals and radioisotopes exceed background, human health, and ecological threshold values. These are identified below as constituents of interest.

From 1994 to 1996, surface water samples were also collected along the old F-Area ditch and analyzed for tritium and volatile organic compounds. Concentrations of tritium, tetrachloroethylene, trichloroethylene, dichloroethylene, and vinyl chloride exceeded primary drinking water standards or maximum contaminant levels. Vinyl chloride, a common laboratory chemical, is not considered a constituent of interest. Studies along the old F-Area effluent ditch indicated that two different groundwater flow paths existed. These studies have also confirmed that tritium and volatile organic compounds, presumably from the old burial ground, have migrated to the wetlands along the effluent ditch.

Surveys of tritium in surface water have been conducted since 1989. In 1992, a sampling program was begun at both seepages and Fourmile Branch. Since the initial survey, the mean radioactivity of tritium has declined

annually at each location. Prior to 1995, mean levels of tritium were highest at the H-Area seepage line, ranging between 8402 and 2667 pCi/mL. In 1995 and 1996, however, tritium radioactivity was higher at the F-Area seepage line than the H-Area seepage line. Tritium radioactivity in Fourmile Branch has consistently been the lowest of the three locations, and has also declined annually since 1992. The grand means (1989, 1992-1996) of tritium at the F-Area and H-Area seepage lines were 1992 and 3186 pCi/mL, respectively. The grand mean of tritium in Fourmile Branch (1992 to 1996) was 333 pCi/mL. The maximum concentration level for tritium is 20 pCi/mL.

The median pH in seepage surface water was lowest at the F-Area, intermediate at H-Area, and highest in Fourmile Branch. Seepage pH values may be associated with past operations of the basins. The mean specific electrical conductance, which was two times higher in F-Area than H-Area from 1989 to 1996, was used to differentiate plumes in the burial ground from FHSB. Studies have also shown an association between tritium and conductivity at both seepage lines.

Vegetation studies in the vicinity of the F- and H-Areas has included wetland mapping and characterization efforts, revegetation assessment, and seed germination studies. Jurisdictional wetlands have been identified and mapped between Fourmile Branch and the F- and H-Areas. Canopy mortality covering approximately eight acres in the wetlands has resulted from toxicants associated with the seepage basins. Natural revegetation of these areas has been poor. The survival of planted tupelo seedlings has also been marginal, declining annually from 1994 to 1996. Seed germination studies have shown that wetland soils are not optimal for plants, generally reducing seed vigor. These studies also showed that toxicity was reduced with a series of soil washings, indicating that natural water transport of soluble contaminants had occurred. This implies that soil toxicity could be reduced naturally over time as contaminants are removed by leaching and surface runoff.

Faunal studies in the vicinity of the FHSB have included macroinvertebrates, fish, herpetofauna, and small mammals. Macroinvertebrates inhabiting Fourmile Branch in the 1980's were reported to be similar to those found in other SRS streams. In 1994, however, Fourmile Branch near Road C was found to be perturbed compared to other SRS streams. Low dissolved oxygen, rather than discharges from the FHSB, was identified as the causal factor. Species richness of fish in Fourmile Branch was found to be similar to other SRS streams. Nonthermal reaches of Fourmile Branch do not appear to have been impacted by effluent discharges. Preliminary studies of fish tissue, however, revealed the presence of several metals but it is not clear where the points of exposure occurred. Comprehensive studies of fish in Fourmile Branch are planned for 1997. These will provide a better understanding of community structure and the effects of ecological stressors.

Chronic aquatic toxicity testing was conducted beginning in 1990 at both seepage lines, Fourmile Branch, and at control sites. Surface water at the seepage lines was toxic at nine of eleven locations; control sites were slightly toxic. Toxicity at the seepage lines varied temporally, and was perhaps associated with precipitation which can dilute the concentration of the toxicant. Toxicity has not been observed in Fourmile Branch since 1990, suggesting that the seepage lines do not affect the stream's water chemistry. To identify the specific toxicant, toxicity identification evaluations were conducted. At the F-Area seepage line, aluminum and cadmium were identified as the primary toxicants. Residual toxicity, however, indicated that other toxicants, possibly iron, also contributed to the observed toxicity. Toxicity identification evaluations at the H-Area seepage line were inconclusive, but the results suggested the presence of a volatile organic compound. It furthermore appeared that some toxicants associated with the H-Area seepage basin have been reduced or eliminated by the capping of the basins. Toxicity at control sites and Fourmile Branch were due to naturally occurring iron.

6.2 Constituents of Interest

Constituents of interest that pose potential risk to human health and the environment were identified from three screening protocols. These included a screening level risk assessment, an independent peer review, and comparisons to regulatory threshold values. For a hypothetical, future on-site resident who drinks water from Fourmile Branch, a cancer risk ($P > 1.0E-04$) would result from tritium. In the Savannah River, however, risk marginally exceeds the $1.0E-06$ threshold level. Other radioisotopes of interest include radium, strontium, and technetium. Non-radiological constituents of interest to human health included beryllium, cadmium, lead,

manganese, mercury, nitrite, and nitrate.

Ecological constituents of interest in surface water included the metals aluminum, beryllium, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, thallium, and zinc. No radiological constituents of interest were identified. Constituents of interest in sediment were arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and silver.

6.3 Remedial Action

The remedial action that is proposed for the F-and H-Areas consists of a pump-and-treat technology that utilizes reverse osmosis. Under this scenario, a series of extraction wells would pump contaminated groundwater to the surface for treatment. The treatment system will reduce heavy metals, nitrates, and some radionuclides to groundwater protection standards. Although tritium cannot be removed by this approach, the well system is designed to control seepage into the wetlands by the groundwater. The treated water, which would retain radioactive tritium, would be reinjected into the aquifer until the tritium decays naturally to acceptable levels. Potential effects associated with this remedial action include alteration of wetland and aquatic habitat. Zones of depression from pumping could reduce soil moisture to levels that no longer support wetland flora. In turn, wildlife habitat could be adversely impacted. These affects would be short-term; cessation of pumping would permit the re-establishment of wetland flora within a few years. Positive affects associated with the remedial action would be a reduction of toxicant concentrations. Continued monitoring of sediment and surface water chemistry, particularly constituents of interest, combined with the use of control charts can be used to evaluate the effectiveness of the remedial action.

7.0 References

Aho, J.M., C.S. Anderson, K.B. Floyd, and M.T. Negus. 1986. Patterns of Fish Assemblage Structure and Dynamics in Waters of the Savannah River Plant, Comprehensive Cooling Water Study Final Report SREL-27, Savannah River Ecology laboratory, Aiken, SC.

Babich, A., M.M. Benjamin, J.D. Bredehoeft, W.E. Cooper, G.L. Culp, R.D. Kimbrough, J.W. Massmann, and S.E. Parent. October 19, 1995. Independent Scientific Peer Review of Groundwater Remediation Technologies-Evaluation of Proposed Groundwater Corrective Actions F- and H-Area Seepage Basins Savannah River Site. ISPR Final Report.

Chappell, R.W., F.P. Winslow, K.Y. McCluskey, K.L. Dixon, J.W. Koch, and V.A. Rogers. 1996. Semi-Annual Sampling of Fourmile Branch and Its Seepines in the F and H Areas of SRS: February 1993, July 1993, and April 1994. Westinghouse Savannah River Company, WSRC-TR-94-0454.

Cummins, C.L. and K. L. Dixon. 1995. Quarterly Sampling of the Wetlands Along the Old F-Area Effluent Ditch: November 1994. Westinghouse Savannah River Company, WSRC-TR-95-0117.

Cummins, C.L. and K.L. Dixon. 1994. Quarterly Sampling of the Wetlands Along the Old F-Area Effluent Ditch: August 1994. Westinghouse Savannah River Company, WSRC-TR-94-0543, Rev 1.

Dames and Moore, Inc. 1991. Vegetation Survey of Pen Branch and Four Mile Creek. Westinghouse Savannah River Company, WSRC-RP-92-482.

Dixon, K.L. September 1996a. Sampling of the Wetlands Along the Old F-Area Effluent Ditch: September 1995 and March 1996. Westinghouse Savannah River Company, WSRC-TR-96-0288.

Dixon, K.L. September 1996b. Monitoring of the Water Levels in the Wetlands of Fourmile Branch Near the F- and H-Areas of SRS. Westinghouse Savannah River Company, WSRC-TR-96-0289.

Dixon, K.L. 1994. Sampling and Analysis of Soil from the Old F-Area Effluent Ditch and its Surrounding Wetlands. Westinghouse Savannah River Company, WSRC-TR-94-0311.

Dixon, K.L. and C.L. Cummins. 1994. Quarterly Sampling of Wetlands Along the Old F-Area Effluent Ditch: May 1994. Westinghouse Savannah River Company, WSRC-TR-94-0365, Rev 1.

Dixon, K.L. and V.A. Rogers. 1994a. Semi-Annual Sampling of Fourmile Branch and Its Seepines in the F and H Areas of SRS: July 1992. Westinghouse Savannah River Company, WSRC-TR-93-289, Rev 0.

Dixon, K.L. and V.A. Rogers. 1994b. Results of the Quarterly Tritium Survey of the Four Mile Creek and its Seepines in the F- and H-Areas of SRS: June 1993. Westinghouse Savannah River Company, WSRC-TR-93-656 Rev 0.

Dixon, K.L. and V.A. Rogers. 1993a. Results of the Fourth Quarter Tritium Survey of the F- and H-Area Seepines: March 1993. Westinghouse Savannah River Company, WSRC-TR-93-526, Rev 0.

Dixon, K.L. and V.A. Rogers. 1993b. Semi-Annual Sampling of Fourmile Branch and Its Seepines in the F and H Areas of SRS. Westinghouse Savannah River Company, WSRC-TR-93-293.

Dixon, K.L. and V.A. Rogers. 1993c. Semi-annual Sampling of Fourmile Branch and Its Seepines in the F- and H-Areas of SRS: July 1992. WSRC-TR-93-289, Westinghouse Savannah River Company, Savannah River Technology Center, Aiken, SC.

Dixon, K.L. and V.A. Rogers. 1993d. Results of the Third Quarter Tritium Survey of the F- and H-Area Seepines: December 1992. Westinghouse Savannah River Company, WSRC-TR-93-284, Rev 1.

Dixon, K.L. and V.A. Rogers. 1993e. Results of the Second Quarter Tritium Survey of the F- and H-Area Seepines: September 1992. Westinghouse Savannah River Company, WSRC-TR-93-129.

Dixon K.L. and V.A. Rogers. 1992. Results of the First Quarter Tritium Survey of the F- and H-Area Seepines: May 1992. Westinghouse Savannah River Company, WSRC-TR-92-304.

Dixon, K.L., C.L. Cummins, and V.A. Rogers. 1994a. Quarterly Sampling of the Wetlands Along the Old F-Area Effluent Ditch: March 1994. Westinghouse Savannah River Company, WSRC-TR-94-0225.

Dixon, K.L., V.A. Rogers, and B.B. Looney. 1994b. Results of the Quarterly Tritium Survey of Fourmile Branch and its Seepines in the F- and H-Areas of SRS: September 1993. Westinghouse Savannah River Company, WSRC-TR-94-0286, Rev 1.

Dixon, K.L., V.A. Rogers, and B.B. Looney. 1993. Results of the Quarterly Tritium Survey of Four Mile Creek and its seepines in the F- and H-Areas of SRS: September 1993. Westinghouse Savannah River Company, WSRC-TR-93-286-ESS, Rev. 1, Aiken, SC.

Dunn, D.L. and K.L. Dixon. 1996. Sampling of the Wetlands Along the Old F-Area Effluent Ditch: October 1996. Westinghouse Savannah River Company, WSRC-TR-97-0050.

Eaton, D., and C.E. Murphy. 1993. Toxicity Test of the F-Area Seep Soils by Laboratory Lettuce Seed Germination and Seedling Growth. Westinghouse Savannah River Company, WSRC-TR-93-669.

E.I. du Pont de Nemours and Co. 1988. U.S. Department of Energy, Savannah River Plant Environmental Report for 1987. DPSPU-88-30-1.

ETT Environmental, Inc. 1995. Chronic Toxicity Identification Evaluation Phase II, UTR-029 Seep at the Savannah River Site, January 1995. ETT Environmental, Greenville, SC 29606.

Firth, P., J.R. O'Hop, B. Coler, and R.A. Green. 1986. Lotic aquatic ecosystems of the Savannah River Plant: Impact evaluation, habitat analyses, and the lower food chain communities, Vol. I. E.I. du Pont de Nemours and Co., DPST-86-797.

Friday, G.P., G.D. Hartman, H.E. Mackey, R.S. Riley, J.L. Roach, W.L. Specht, H.M. Westbury, and L.D. Wike. 1994. A Summary of Ecological Investigations at the Burial Ground Complex, Savannah River Site. 1994. Westinghouse Savannah River Site, WSRC-RP-94-1221.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York.

Gladden, J., 1988. Evaluation of Stream Biological Communities in Nonthermal Reaches of Four Mile Creek. E.I. du Pont de Nemours and Company, Savannah River Laboratory, DPST-88-324.

Greenwood, K.P., M.E. Hane, A.J. Lander, C. Loehle, and C.J. Richardson. 1990. Assessment of Tree Toxicity Near the F- and H-Area Seepage Basins of the Savannah River Site. Westinghouse Savannah River Company, WSRC-TR-90-253.

Haselow, J.S. 1990. Analysis of Stream Bed Sediments of Four Mile Creek. Westinghouse Savannah River Company, WSRC-RP-90-0812.

Haselow, J.S., M. Harris, B.B. Looney, N.V. Halverson, and J.B. Gladden. 1990. Analysis of Soil and Water at the Four Mile Creek Seepage Line Near the F and H Areas of SRS. Westinghouse Savannah River Company, WSRC-RP-90-0591.

Hem, John D. 1989. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water-Supply Paper 2254, 3rd Edition.

Killian, T.H., N.L. Colb, P. Corbo, and I.W. Marine. 1987a. F-Area Seepage Basins Environmental Information Document. E.I. du Pont de Nemours and Co., Savannah River Laboratory, DPST-85-704.

Killian, T.H., N.L. Colb, P. Corbo, and I.W. Marine. 1987b. H-Area Seepage Basins Environmental Information Document. E.I. du Pont de Nemours and Co., Savannah River Laboratory, DPST-85-706.

Koch, J.W. and K.L. Dixon. 1996a. Results of the Tritium Survey of Fourmile Branch and its Seepages in the F and H-Areas of SRS: September 1996. Westinghouse Savannah River Company, WSRC-TR-97-0109.

Koch, J.W. and K.L. Dixon. 1996b. Results of the Tritium Survey of Fourmile Branch and its Seepages in the F and H-Areas of SRS: March 1996. Westinghouse Savannah River Company, WSRC-TR-96-0215.

Koch, J.W. and K.L. Dixon. 1995. Results of the Tritium Survey of Fourmile Branch and its Seepages in the F and H-Areas of SRS: May 1995. Westinghouse Savannah River Company, WSRC-TR-96-0369.

Koch, J.W. and K.L. Dixon. 1994. Results of the Tritium Survey of Fourmile Branch and its Seepages in the F and H-Areas of SRS: December 1994. Westinghouse Savannah River Company, WSRC-TR-95-0300.

Korthals, E.T. 1991. Assessment of the Toxicity of Seepage from the F and H Seepage Basins Located on the Savannah River Site. Normandeau Associates, Inc., Aiken SC 29802.

Lauritsen, D., W. Starkel, and W.L. Specht. 1989. A Study of Post-Thermal Recovery of the Macroinvertebrate Community of Four Mile Creek June 1985 - September 1987. Westinghouse Savannah River Company, WSRC-TR-90-472.

LeBlanc, D.C. and C. Loehle. 1990. The Effect of Contaminated Groundwater on Tree Growth: A Tree-Ring Analysis. WSRC-RP-90-552.

Loehle, C. 1990a. Recovery of Contaminated Wetland Soils at SRS by Natural Rainfall: An Experimental, Toxicological Study. Westinghouse Savannah River Company, WSRC-RP-90-14.

Loehle, C. 1990b. Summary of Vegetation Stress Factors at F- and H-Area Seepage Basin Outcrop Zones. Westinghouse Savannah River Company, WSRC-RP-90-551.

Loehle, C. 1990c. Vegetation Survey of FourMile Creek Wetlands. Westinghouse Savannah River Company, WSRC-RP-90-1207.

Loehle, C., and M. Paller. 1990. Heavy Metals in Fish from Streams Near F-Area and H-Area Seepage Basins. Westinghouse Savannah River Company, WSRC-RP-90-482.

Looney, B.B., J.E. Cantrell, and J.R. Cook. 1988. Sampling and Analysis of Surface Water in the Vicinity of the F and H-Area Seepage Basins. E.I. du Pont de Nemours and Company, Savannah River Laboratory, DPST-88-229.

Mackey, H.E. 1988. Initial Evaluation of Photographic Data of F- and H-Area Seepage Basin Outcrops. E.I. du Pont de Nemours and Company, Savannah River Laboratory, DPST-88-314.

- Metcalf and Eddy. 1994. Four Mile Creek Semi-Annual Sampling Report: April 1994 Sampling Event. Prepared for Westinghouse Savannah River Company, WSRC-TR-96-376.
- Metcalf and Eddy. 1993a. Four Mile Creek Semi-Annual Sampling Report: January 1993 Sampling Event. Westinghouse Savannah River Company, WSRC-TR-93-320.
- Metcalf and Eddy. 1993b. Four Mile Creek Semi-Annual Sampling Report: July 1993 Sampling Event. Westinghouse Savannah River Company, WSRC-TR-96-375.
- Nelson, E.A. and V.A. Rogers. 1995. Survival of Planted Tupelo Seedlings in F- and H-Area Tree-Kill Zones. Westinghouse Savannah River Company, WSRC-TR-95-0025.
- Nelson, E.A. and H.M. Westbury, Jr. 1994. Lettuce Seed Germination and Root Elongation Toxicity Evaluation of the F-Area Seepage Soils. Westinghouse Savannah River Company, WSRC-TR-94-0510.
- Nelson, E.A., and J.E. Irwin. 1994. Current Vegetation Characteristics Within Tree-Kill Zones of F-and H-Areas. Westinghouse Savannah River Company, WSRC-TR-94-0233.
- Paller, M.H., M.J.M. Reichert, and J.M. Dean. 1995. Rapid bioassessment methods for streams on the Savannah River Site. Westinghouse Savannah River Company, WSRC-TR-95-0287.
- Paller, M.H. and C. Storey. 1990. Effects of Outcropping Groundwater from the F- and H-Area Seepage Basins on the Distribution of Fish in Four Mile Creek. Westinghouse Savannah River Company, WSRC-TR-90-502.
- Parker, K., M.E. Hane, A.J. Lander, C.J. Richardson, and C. Loehle. December 1990. Assessment of tree toxicity near the F-and H-Area seepage basins of the Savannah River Site. Westinghouse Savannah River Company, WSRC-TR-90-253.
- Railsback, L.B., P.A. Bouker, T.P. Feeney, E.A. Goddard, K.E. Goggin, A.S. Hall, B.P. Jackson, A.A. McLain, M.C. Orsega, M.A. Rafter, and J.W. Webster. 1996. "A Survey of the Major-element Geochemistry of Georgia Groundwater". *Southeastern Geology* Vol. 36:99-122.
- Rogers & Associates Engineering Corporation (RAEC). 1995. Five-Year Ecological Monitoring Plan for the F- and H-Area Seepage Basins Remediation Program. Draft Report RAE-9424/1-1, Salt Lake City, Utah.
- Rogers, V.A. 1990. Soil Survey of Savannah River Plant Area, Parts of Aiken, Barnwell, and Allendale Counties, South Carolina. U.S. Department of Agriculture, Soil Conservation Service.
- Rogers, V.A., K.L. Dixon, and B.B. Looney. 1994a. Results of the Quarterly Tritium Survey of Fourmile Branch and its Seepages in the F and H Areas of SRS: December 1993. Westinghouse Savannah River Company, WSRC-TR-94-0342.
- Rogers, V.A., K.L. Dixon, and B.B. Looney. 1994b. Results of the Quarterly Tritium Survey of Fourmile Branch and its Seepages in the F and H Areas of SRS: March 1994. Westinghouse Savannah River Company, WSRC-TR-94-0408.
- Specht, W.L. 1996. Toxicity of Water Samples Collected in the Vicinity of the F/H Seepage Basins, 1990-1995. Westinghouse Savannah River Company, WSRC-TR-96-0261.
- Specht, W.L. and M.H. Paller. 1995. Rapid Bioassessment Methods for Assessing Stream Macroinvertebrate communities on the Savannah River Site. Westinghouse Savannah River Company, WSRC-TR-95-0351.
- Specht, W.L. 1994a. Results of Macroinvertebrate Sampling Conducted at 33 SRS Stream Locations, July-August 1993. Westinghouse Savannah River Company, WSRC-TR-95-0006.

Specht, W.L. 1987. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. E.I. du Pont de Nemours and Company, DP-1739-5.

Strom, R.N. and D.S. Kaback. 1992. SRP Baseline Hydrogeologic Investigations: Aquifer Characterization-Groundwater Geochemistry of the Savannah River Site and Vicinity. Westinghouse Savannah River Company, WSRC-RP-450.

U.S. Army Corps of Engineers. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1, Environmental laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

U.S. Environmental Protection Agency (EPA). March 1997. Risk Based Concentration Table. Compiled by Roy L. Smith, Region III. <http://www.epa.gov/reg3hwmd/risk/rbc971.htm>.

U.S. Environmental Protection Agency (EPA). November 1995. Ecological Screening Values. Ecological Risk Assessment Bulletin No. 2, Supplemental Guidance to RAGS: Region 4 Bulletins, Atlanta, Ga.

Weber, C.I., W.H. Pelteir, T.J. Norberg-King, W.B. Horning, F.A. Kessler, J.R. Menkedick, T.W. Neilheisel, P.A. Lewis, D.J. Klemm, Q.H. Pickering, E.L. Robinson, J.M. Lazorchak, L.J. Wymer, and R.W. Freyberg. 1989. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. U.S. Environmental Protection Agency, EPA/600/4-89/001.

Westbury, H.M. Jr., and E.A. Nelson. 1994. Plant Community Development within the F- and H-Area Tree-Kill Zones. Westinghouse Savannah River Company, WSRC-TR-94-0544.

Wike, L.D., R.W. Shipley, J.A. Bowers, A.L. Bryan, C.L. Cummins, B. R. del Carmen, G.P. Friday, J.E. Irwin, H.E. Mackey, Jr., J.J. Meyer, E.A. Nelson, M.H. Paller, V.A. Rogers, W.L. Specht, and E.W. Wilde. April 1994. SRS Ecology-Environmental Information Document. Westinghouse Savannah River Company, WSRC-TR-93-496.

WSRC. 1996. Savannah River Site Environmental Report for 1995. Westinghouse Savannah River Company, WSRC-TR-96-0075.

WSRC. 1995a. Savannah River Site Environmental Report for 1994. Westinghouse Savannah River Company, WSRC-TR-95-075.

WSRC. 1995b. Quality Control Summary Report for the F/H Seepage Basins Ecological Management Plan Project. Westinghouse Savannah River Company, ESH-EMS-950564.

WSRC. 1995c. Quality Control Summary Report for the Burial Ground Ecological Risk Assessment- September 26, 1995. Westinghouse Savannah River Company, Environmental Protection Department/Environmental Monitoring Section, ESH-EMS-950562.

WSRC. 1995d. Screening Risk Assessment to Support an Alternate Concentration Limit/Mixing Zone Demonstration for the F- & H-Area Seepage Basins Groundwater Unit. Westinghouse Savannah River Company, Draft Report.

WSRC. 1991. Savannah River Site Report. Westinghouse Savannah River Company, WSRC-IM-91-28.

APPENDIX A

Coordinates for Sampling and Well Locations

TABLE A1. Sediment sampling locations and SRS site coordinates, 1995 (WSRC 1996b).

Location	North	East
BG001	67208	59153
BG002	67229	59363
BG003	67633	59281
BG004	64723	68527
FMC001F	72200	43900
FMC001H	70350	57050
FMC002H	72600	53000
T4/1108	70957	55717
FSP012	73602	49644
FSP019	73177	49778
FSP026	72932	49801
FSP032	73367	50258
FSP035	73065	50297
FSP047	73609	50607
FSP204	73281	48801
FSP290	73160	46865
HSP008	71005	56990
HSP025	70960	56297
HSP029	71278	56257
HSP043	71644	55722
HSP052	71413	55743
HSP060	71629	55190
HSP092	72672	54129

TABLE A2. Surface water sampling locations and SRS site coordinates, 1989-1996 (WSRC 1996b).

Location	North	East
BG001	67208	59153
BG002	67229	59363
BG003	67633	59281
BG004	64723	68527
FMC001F	72200	43900
FMC001H	70350	57050
FMC002H	72600	53000
T4/1108	70957	55717
FSP012	73602	49644
FSP019	73177	49778
FSP026	72932	49801
FSP032	73367	50258
FSP035	73065	50297
FSP047	73609	50607
FSP204	73609	50607
FSP290	73609	50607
HSP008	71005	56990
HSP025	70960	56297
HSP029	71278	56257
HSP043	71644	55722
HSP052	71413	55743
HSP060	71629	55190
HSP092	72672	54129

TABLE A3. SRS site coordinates for piezometers in the F-and H-Areas.

Piezometer No.	North	East
FPZ001A	73655	48785
FPZ002A	73720	48870
FPZ003A	73207	49097
FPZ004A	73696	49811
FPZ005A	73337	49723
FPZ005B	73337	49723
FPZ006A	73211	49825
FPZ006B	73211	49825
FPZ007A	73258	50245
FPZ007B	73258	50245
FPZ008A	73291	50616
FPZ008B	73291	50616
HPZ001A	71301	55676
HPZ002A	71692	56151
HPZ003A	70938	56294
HPZ003B	70938	56294
HPZ004A	71155	56573
HPZ005A	70995	56890
HPZ005B	70995	56890
HPZ006A	70583	56839

TABLE A4. Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
1	72841.34222	49044.22060
2	72790.69763	49065.92426
3	72820.69830	49150.89457
4	72852.49897	49249.13695
5	72870.19993	49298.17702
6	72932.50384	49383.18673
7	73016.91358	49472.65275
8	73028.19446	49531.85553
9	73079.25712	49548.89080
10	73166.54831	49601.72865
11	73252.13345	49611.31879
12	73309.09988	49575.08810
13	73351.73047	49552.61749
14	73394.29403	49575.02283
15	73451.70347	49661.53481
16	73504.53974	49684.97778
17	73571.86421	49646.00969
18	73639.62073	49622.41845
19	73688.63460	49655.39420
20	73725.05344	49718.10357
21	73712.10522	49803.10572
22	73656.63266	49854.39339
23	73601.93007	49883.60591
24	73535.85331	49915.15607
25	73451.57422	49940.18731
26	73395.97971	49916.31643
27	73355.78744	49858.60356
28	73321.79952	49837.43654
29	73280.00224	49814.90518
30	73219.93051	49816.72396
31	73181.53612	49820.00255
32	73167.40205	49811.35788
33	73136.16284	49810.58316
34	73138.59094	49863.83782
35	73127.07329	49918.88131
36	73150.11728	49987.84023
37	73172.93372	50033.42744

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
38	73217.46611	50130.11073
39	73246.36890	50114.13346
40	73304.08628	50108.60829
41	73359.39361	50174.90731
42	73344.22653	50308.53865
43	73364.73206	50319.93478
44	73275.81400	50315.12179
45	73206.60650	50306.91554
46	73112.77350	50313.14559
47	73095.16048	50341.73179
48	73083.65932	50417.23624
49	73081.20913	50435.06242
50	73046.07687	50525.46763
51	73027.19723	50603.02206
52	73090.44605	50625.72707
53	73137.91544	50580.44984
54	73219.37577	50555.11210
55	73283.92846	50555.52213
56	73352.34278	50508.38124
57	73415.98908	50482.63149
58	73470.93976	50409.01193
59	73557.52705	50384.38394
60	73643.16095	50364.58409
61	73723.09253	50454.48475
62	73726.33538	50566.12743
63	73649.31416	50612.11390
64	73560.92764	50632.34350
65	73513.03175	50671.39331
66	73528.90061	50721.70225
67	73584.43344	50775.57927
68	73648.20015	50809.65769
69	73657.81229	50882.04148
70	73630.41786	50921.86327
71	73627.58096	51001.52438
72	73564.01802	51071.22060
73	73493.16944	51067.31597
74	73428.70362	51010.82847
75	73355.25485	50974.81003

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
76	73331.08630	50875.07597
77	73270.46843	50789.01971
78	73213.59234	50773.11879
79	73137.41783	50736.60572
80	73066.91505	50746.45588
81	73050.95495	50786.20601
82	73097.03213	50864.66713
83	73165.67242	50952.67123
84	73215.49078	51031.61951
85	73266.99617	51136.89914
86	73239.46818	51217.06716
87	73238.80840	51298.37155
88	73234.70802	51380.34174
89	73256.22226	51463.76595
90	73312.10534	51400.79246
91	73412.96805	51370.36954
92	73477.17622	51381.03289
93	73522.01765	51290.22335
94	73524.36950	51184.45213
95	73571.84016	51128.80490
96	73633.77764	51178.48821
97	73687.22071	51247.31329
98	73750.00192	51330.70687
99	73803.12080	51427.10975
100	73881.38083	51455.38017
101	73952.30833	51467.13609
102	74003.40255	51461.80603
103	74089.17878	51463.87640
104	74152.43510	51521.95416
105	74199.01106	51504.32784
106	74217.52014	51574.50012
107	74216.63899	51625.70262
108	74150.93055	51669.40175
109	74108.99332	51703.40688
110	74022.72759	51692.12448
111	73933.31056	51677.78650
112	73877.60668	51631.51824
113	73784.30223	51573.47442

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
114	73693.52390	51535.23235
115	73635.54775	51537.07156
116	73362.59123	51593.37966
117	73631.37830	51681.09454
118	73662.47438	51732.14912
119	73730.21744	51819.24907
120	73783.83402	51848.26834
121	73765.80670	51887.03387
122	73717.99106	51926.60058
123	73701.87016	51990.31940
124	73727.69271	52090.87746
125	73759.30327	52158.78222
126	73730.03775	52256.12566
127	73759.10824	52292.44105
128	73751.37989	52364.77539
129	73703.37593	52399.93696
130	73595.80257	52368.39163
131	73533.64241	52329.38406
132	73411.19493	52415.23080
133	73391.99875	52477.52435
134	73284.67359	52569.54316
135	73225.52625	52625.31188
136	73228.30346	52689.53280
137	73239.71838	52789.34492
138	73141.51780	52860.66367
139	73090.80702	52943.49984
140	73085.73611	53035.30008
141	72850.66338	52982.54979
142	72652.16210	52938.60618
143	72634.98802	53021.50885
144	72799.19988	53056.86418
145	72732.49714	53118.33302
146	72734.84058	53202.59213
147	72778.21238	53240.02000
148	72837.43429	53161.58780
149	72997.40869	53169.46324
150	73140.11300	53223.85672
151	73186.87806	53316.70549

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
152	73203.93476	53397.44405
153	73221.03247	53450.06213
154	73228.48826	53511.20766
155	73337.97950	53565.79430
156	73415.17444	53592.81030
157	73531.88419	53646.00168
158	73571.73289	53719.00323
159	73514.84805	53848.53159
160	73522.49697	53929.59603
161	73675.60097	53994.35500
162	73773.15154	53989.32868
163	73866.42472	53992.73936
164	73964.83520	54006.18031
165	73956.12542	54071.17764
166	73867.72711	54049.36245
167	73834.48770	54078.55420
168	73773.19870	54093.16210
169	73695.04602	54135.93360
170	73645.03032	54114.96578
171	73631.50554	54173.51485
172	73560.79997	54132.18490
173	73464.86830	54063.13393
174	73405.82836	53982.18571
175	73378.25804	53901.72981
176	73360.56130	53818.38937
177	73258.26638	53748.60941
178	73153.05014	53728.53688
179	73036.68076	53780.09576
180	72952.46258	53792.81834
181	72902.59084	53831.70059
182	72886.50845	53898.13281
183	72876.77421	53976.92446
184	72739.38738	54032.93192
185	72767.20994	54107.60802
186	72818.52637	54170.05482
187	72870.73468	54239.63650
188	72857.86926	54304.78935
189	72834.43736	54337.86305

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
190	72792.93140	54376.70694
191	72732.05625	54384.42884
192	72684.41842	54386.03745
193	72623.38223	54362.08122
194	72569.98511	54373.89857
195	72553.84806	54304.88921
196	72518.06480	54244.97454
197	72437.89892	54216.13832
198	72376.25415	54150.93179
199	72283.72313	54066.43602
200	72234.96885	54101.49317
201	72168.13542	54056.57484
202	72113.43993	53908.74411
203	72016.43166	53949.87132
204	71899.33753	53999.52665
205	71800.31498	54070.18527
206	71744.67131	54197.07543
207	71672.65920	54322.20187
208	71614.74051	54443.24514
209	71541.56122	54527.54984
210	71508.81053	54654.47033
211	71450.61593	54781.82934
212	71478.85610	54826.38790
213	71573.37358	54842.98001
214	71588.44384	54894.49446
215	71697.03754	54885.68916
216	71722.85373	54833.95435
217	71766.07823	54747.81617
218	71781.40078	54649.01541
219	71868.25095	54685.22158
220	71951.32820	54724.57170
221	71992.76456	54778.42805
222	72039.09399	54837.47900
223	71978.27310	54854.94788
224	71909.74716	54911.00124
225	71833.22346	54957.02258
226	71745.90011	55013.82211
227	71734.61729	55070.33297

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
228	71700.35822	55106.29548
229	71657.92340	55201.66518
230	71640.95019	55267.45750
231	71643.36863	55313.72690
232	71630.34153	55365.98390
233	71675.03405	55400.38443
234	71675.02610	55414.62935
235	71642.11019	55401.29793
236	71592.90170	55483.11936
237	71579.84751	55570.80414
238	71602.43866	55605.25092
239	71620.58805	55653.02012
240	71632.79391	55695.49697
241	71675.07580	55733.96146
242	71747.14853	55741.77021
243	71808.17823	55740.71565
244	71867.04409	55748.46780
245	71864.67321	55791.50106
246	71857.24038	55837.82609
247	71854.40746	55881.26404
248	71848.49402	55910.61257
249	71822.33500	55955.51709
250	71785.18714	55985.85666
251	71782.38144	56019.07160
252	71794.75325	56074.64276
253	71799.02427	56103.09970
254	71776.71750	56181.43786
255	71686.10152	56202.88132
256	71651.22997	56266.37167
257	71602.68613	56272.31277
258	71537.85048	56308.78833
259	71494.60756	56343.46960
260	71432.33943	56329.96654
261	71374.84025	56292.91175
262	71304.09351	56277.27839
263	71252.56267	56235.09915
264	71178.38139	56199.43077
265	71096.10367	56235.70671

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
266	71028.68249	56246.19085
267	70980.41146	56251.98551
268	70969.06325	56374.37386
269	70933.01817	56447.87644
270	70951.85485	56492.29573
271	71018.81769	56512.33204
272	71078.37911	56495.55954
273	71139.68442	56492.32079
274	71195.14045	56502.58021
275	71236.61342	56502.31339
276	71249.44245	56526.98892
277	71265.12554	56587.53216
278	71272.64862	56666.42828
279	71227.42906	56744.24865
280	71187.61916	56767.08919
281	71151.23985	56791.43820
282	71099.76921	56796.09380
283	71092.00919	56846.63532
284	71110.86538	56920.13907
285	71131.40305	56968.57636
286	71104.69208	57043.85595
287	71077.82008	57099.40872
288	71061.18221	57158.65502
289	70969.19611	57189.67073
290	70910.77081	57151.23690
291	70882.53895	57097.39075
292	70872.99419	57068.36013
293	70879.77612	56974.16440
294	70838.64579	56913.70256
295	70743.20412	56923.55735
296	70688.43393	56968.68178
297	70621.66833	57079.54558
298	70613.95053	57139.59273
299	70574.95565	57223.98937
300	70476.03327	57149.87421
301	70491.06574	57134.28080
302	70456.08952	57167.83047
303	70440.41990	57180.67703

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
304	70409.10336	57115.98404
305	70429.43191	57097.75177
306	70436.26302	57196.03493
307	70442.72945	57256.39302
308	70508.32918	57357.43842
309	70474.29322	57445.94152
310	70449.25149	57518.47331
311	70469.74336	57589.86568
312	70538.40910	57658.79820
313	70603.98373	57744.13125
314	70642.04818	57784.66913
315	70710.39669	57838.05654
316	70810.86010	57888.05416
317	70805.55332	57909.32912
318	72636.38015	53001.85762
319	72562.86559	52989.36205
320	72569.88034	52941.13636
321	72645.72723	52953.73193
1000	72855.45000	49062.78000
1002	72937.27415	49351.39023
1003	73155.99617	49520.15344
1004	73412.06315	49572.31033
1005	73762.56859	49606.35003
1006	73615.77064	49888.56337
1007	73323.02204	49936.70830
1008	73389.26692	50339.17372
1009	73791.73248	50382.43158
1010	73606.28735	50815.53074
1011	73583.36392	50834.00451
1012	73640.76227	51123.16435
1013	73323.26277	51011.35858
1014	73481.12457	51292.55000
1015	73980.56573	51379.05419
1016	73776.07471	51682.81191
1017	73820.47374	52204.38836
1018	73360.29476	52622.51990
1019	73059.82901	53039.30479
1021	73828.59000	53144.50000

TABLE A4. (Continued) Site grid coordinates used to delineate jurisdictional wetlands, 1993.

Location	North	East
1022	72995.29762	53088.79975
1023	73210.10154	53521.00373
1024	73503.24735	53724.54520
1025	73629.23924	53877.09755
1026	73333.50696	53851.46702
1027	72978.94881	53628.01696
1028	72824.09884	54165.81835
1029	72560.01356	54334.79634
1030	72071.06815	54178.50318
1031	71869.74478	54381.88280
1032	71766.42100	54648.23676
1033	71883.92047	55000.64301
1034	71674.96874	55466.74763
1035	71872.83618	55701.88699
1036	71978.40385	55966.00325
1037	71595.51511	56492.67141
1038	71354.52764	56372.47719
1039	71385.31974	56433.82999
1040	71064.68821	56430.41315
1041	71265.91859	56945.22308
1042	71226.77383	56867.11146
1043	71091.95134	57229.97257
1044	71033.27803	57325.21351
1045	70805.45212	57218.03241
1046	70485.85706	57209.97051
1047	70507.41010	57571.59442
1048	70759.32899	57702.14899

TABLE A5. Toxicity sampling locations and site grid coordinates, 1990-1994.

Location	North	East
FSP-012	73602	49644
FSP-032	73367	50258
FSP-047	73609	50607
FSP-204	73609	50607
FSP-256	73435	47770
HSP-008	71005	56990
HSP-020	71142	56489
HSP-043	71644	57722
HSP-060	71629	55190
HSP-103	72448	53665
H-6	71041	56394
FMC-001F	70350	57050
FMC-001H	72600	53000
FMC-002H	72200	43900
FMC Road C-4	72610	48812
FMC Road A-7	69279	40079
UTR-022	74990	61270
UTR-029	74855	60792
UTR-116	79665	59050
BGW-045	94651	82775
UTR RR Bridge	83358	51854

TABLE A6. Coordinates for Extraction and Injection Wells at F-Area.

Well ID	SRS North	SRS East
FEX-1	73880.37	50173.48
FEX-2	73704.62	50026.34
FEX-3	73892.03	49873.51
FEX-4	73973.40	49637.70
FEX-5	73955.14	49421.42
FEX-6	74060.50	49200.07
FEX-7	74215.53	48967.71
FEX-8	74771.03	49643.83
FEX-9	74575.58	49954.33
FEX-10	74702.87	50082.12
FEX-11	74802.41	49913.99
FIN-1	75814.61	50079.83
FIN-2	75820.25	50365.50
FIN-3	75720.85	50599.29
FIN-4	75639.56	50759.67
FIN-5	75708.32	51004.50
FIN-6	75746.73	51766.90
FIN-7	75599.62	51870.21
FIN-8	75770.28	50680.18
FIN-9	75723.19	51841.41
FIN-10	75580.00	49809.66

TABLE A7. Coordinates for Extraction and Injection Wells at H-Area.

Well ID	SRS North	SRS East
HEX-1	71957.13	56408.18
HEX-2	71892.34	56526.80
HEX-3	71225.27	56921.87
HEX-4	71203.62	56979.12
HEX-5	70691.95	57158.22
HEX-6	70637.70	57191.36
HEX-7	70549.05	57333.00
HEX-8	70556.36	57497.55
HEX-9	71371.66	58291.01
HEX-10	71492.96	58365.81
HEX-11	71670.44	58588.88
HEX-12	72155.84	55787.22
HEX-13	72061.35	55857.14
HEX-14	72039.16	55890.93
HEX-15	72012.53	55932.41
HEX-16	72377.35	56061.07
HEX-17	71887.19	56147.06
HEX-18	71337.24	57796.36
HEX-19	70934.79	57759.43
HIN-1	73072.22	56839.33
HIN-2	72291.93	58142.14
HIN-3	72403.99	58310.96
HIN-4	72290.87	58507.61
HIN-5	72291.60	58611.08
HIN-6	73361.46	56665.84
HIN-7	73292.10	56745.25
HIN-8	72950.83	57000.53
HIN-9	72863.13	57174.30
HIN-10	72384.94	57899.92

APPENDIX B

Sediment and Surface Water Statistics for
1995 and 1996

TABLE B1. Mean concentration and 95% upper confidence intervals (UCI) of non-radiological constituents in sediment, 1995 (WSRC 1995b).

Constituent (mg/kg)	Background			F-Area Seepine			H-Area Seepine			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI
Aluminum	4	3463	8043	8	5721	8232	8	5839	8869	3	5303	15625
NH3 as N	4	46	102	8	88	139	8	66	114	3	41	128
Antimony	4	3.7	4.4	8	5.1	7.1	8	4.2	5.1	3	4.2	8.6
Arsenic	4	11	13	8	15	21	8	12	15	3	8	15
Barium	4	19.5	55.9	8	50	109	8	48	85	3	27	84
Beryllium	4	0.16	0.36	8	0.28	0.44	8	0.29	0.52	3	0.34	1.14
Cadmium	4	0.18	0.21	8	1.8	5.2	8	0.403	0.821	3	1.6	7.9
Calcium	4	92	216	8	458	1243	8	457	849	3	317	851
Chloride	4	3.5	5.5	8	4.5	7.0	8	5.6	9.7	3	2.9	7.9
Chromium	4	4.0	9.2	8	3.7	4.6	8	5.8	8.4	3	11	36
Cobalt	4	0.73	1.7	8	15	36	8	2.0	4.2	3	7.4	35
Copper	4	1.4	2.8	8	2.9	4.6	8	2.2	3.2	3	6.5	29
Cyanide	4	0.741	0.897	8	1.5	2.6	8	1.2	2.0	3	0.82	1.65
Iron	4	2246	6754	8	2153	3176	8	2804	4639	3	4703	15079
Lead	4	5.6	11	8	9	13	8	11	17	3	6.9	22
Magnesium	4	63	109	8	167	323	8	211	322	3	154	260
Manganese	4	28	101	8	514	1281	8	161	382	3	100	348
Mercury	4	0.047	0.087	8	0.03	0.05	8	0.101	0.185	3	0.09	0.29
Nickel	4	1.0	2.0	8	3.5	6.6	8	3.6	6.9	3	6.1	23.4
Nitrate	4	0.378	0.466	8	63	151	8	2.0	3.8	3	0.41	0.77
Nitrate/Nitrite	4	0.622	0.922	8	66	156	8	1.8	3.7	3	0.6	1.5
Potassium	4	56	82	8	65	89	8	84	125	3	78	135
Selenium	4	11	13	8	15	21	8	13	15	3	13	26
Silver	4	0.9	1.1	8	2.6	3.6	8	1.0	1.3	3	1.1	2.2
Sodium	4	30	49	8	97	192	8	117	183	3	33	44
Thallium	4	11	13	8	15	21	8	12	15	3	13	26
Tin	4	3.2	4.6	8	5.2	7.0	8	4.1	5.1	3	4.2	8.6
Vanadium	4	9	23	8	6.7	9.4	8	10	16	3	11	31
Zinc	4	2.8	5.7	8	12.5	26.6	8	7.3	12.3	3	47	199

TABLE B2. Mean radioactivity (pCi/g) and 95% upper confidence intervals (UCI) of radioisotopes in sediment, 1995 (WSRC 1995b).

Constituent	Background			F-Area Seepage			H-Area Seepage			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI
Ac-228	4	0.7	1.6	8	0.9	1.4	8	0.7	1.1	3	1.6	3.0
Gross Alpha	4	9.3	15.4	8	25.2	50.7	8	20.7	33.6	3	38	128
Am-241	4	0.008	0.018	8	0.19	0.48	8	0.009	0.014	3	0.2	1.2
Ba-133	4	0.0002	0.0087	8	-0.0027	0.0086	8	-0.008	0.009	3	0.013	0.059
Gross Beta	4	6.7	10.7	8	40.8	89.0	8	72.8	168.6	3	70	257
Ce-144	4	0.006	0.0422	8	0.0064	0.059	8	0.035	0.117	3	-0.027	0.154
Co-57	4	0.0009	0.0042	8	0.0022	0.0043	8	0.0004	0.0044	3	-0.0019	0.0031
Co-58	4	-0.0028	0.0023	8	0.0017	0.0042	8	-0.016	0.027	3	-0.0022	0.016
Co-60	4	0.001	0.0024	8	0.1439	0.3058	8	11.2	36.9	3	0.234	1.134
Cs-134	4	0.0015	0.0068	8	-0.0015	0.0036	8	-0.022	0.013	3	-0.006	0.0578
Cs-137	4	0.17	0.332	8	0.495	0.811	8	0.679	1.17	3	54	205
Eu-152	4	-0.0048	0.0062	8	-0.0096	-0.001	8	-0.0009	0.033	3	-0.03	-0.008
Eu-154	4	-0.004	0.025	8	0.039	0.099	8	-0.095	0.317	3	0.039	0.22
Eu-155	4	0.01	0.029	8	0.024	0.049	8	0.018	0.052	3	0.016	0.087
I-129	4	0.08	0.178	8	8.6	23.5	8	1.25	2.56	3	-0.01	0.423
K-40	4	1.2	3.2	8	0.805	1.02	8	1.21	2.15	3	1.16	1.97
Mn-54	4	0.01	0.031	8	0.016	0.025	8	0.015	0.026	3	0.024	0.043
Na-22	4	-0.0005	0.0021	8	0.0015	0.0046	8	-0.0015	0.0011	3	0.001	0.002
Ni-63	4	0.65	1.58	8	0.425	0.925	8	22.34	71.29	3	0.754	2.812
Np-237	4	0.031	0.076	8	0.035	0.073	8	0.803	2.33	3	0.08	0.378
Np-239	4	0.014	0.068	8	0.012	0.023	8	0.029	0.104	3	0.067	0.406
Pb-212	4	0.7	1.60	8	0.99	1.54	8	1.22	2.17	3	1.69	3.59

TABLE B2. (Continued) Mean radioactivity (pCi/g) and 95% upper confidence intervals (UCI) of radioisotopes in sediment, 1995 (WSRC 1995b).

Constituent	Background			F-Area Seepage			H-Area Seepage			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI
Pm-144	4	0.0001	0.003	8	-0.001	0.0014	8	0.0014	0.0052	3	-0.0028	0.0075
Pm-146	4	0.0022	0.0054	8	0.0068	0.011	8	0.0098	0.0286	3	0.023	0.069
Ra-226	4	1.09	2.23	8	1.88	3.27	8	2.17	4.11	3	3.35	9.57
Ra-228	4	1.18	2.74	8	1.13	1.57	8	1.48	2.25	3	3.46	9.34
Ru-106	4	-0.0024	0.028	8	0.0001	0.0218	8	-0.027	0.021	3	0.01	0.168
Sb-124	4	0.0003	0.0033	8	-0.0012	0.0012	8	0.001	0.0094	3	-0.0037	0.029
Sb-125	4	-0.0003	0.0045	8	0.0016	0.006	8	0.029	0.097	3	0.03	0.079
Sn-113	4	-0.0051	0.0015	8	0.003	0.0135	8	-0.0066	0.0152	3	0.005	0.057
Sr-90	4	0.61	1.58	8	11.27	30.01	8	21.22	53.15	3	1.41	6.94
Tc-99	4	-0.38	0.26	8	56.46	156.7	8	14.2	31.8	3	2.27	12.08
Th-228	4	0.92	2.25	8	0.955	1.35	8	1.11	1.49	3	4.19	10.57
Th-230	4	0.55	1.10	8	0.377	0.478	8	1.9	4.65	3	1.27	3.48
Th-232	4	0.85	1.86	8	0.571	0.719	8	0.789	1.007	3	3.44	11.23
Th-234	4	0.86	1.51	8	7.313	21.92	8	0.89	1.36	3	4.05	17.51
Tritium	4	-0.45	3.13	8	175	344	8	81.6	158	3	289	1399
U-235	4	0.019	0.0361	8	0.3172	0.8558	8	0.04	0.063	3	0.281	1.258
U-238	4	0.36	0.57	8	5.066	13.5	8	0.61	0.805	3	3.8	16.2
U-233/234	4	0.35	0.52	8	4.59	12.08	8	0.65	0.876	3	3.6	14.3
Y-88	4	0.0016	0.0035	8	0.0014	0.0047	8	-0.0086	0.021	3	0.004	0.024
Zn-65	4	0.0035	0.0114	8	0.003	0.009	8	-0.097	0.115	3	0.014	0.076
Zr-95	4	0.0022	0.0065	8	0.0108	0.0203	8	0.038	0.098	3	0.015	0.052

TABLE B3. Mean concentrations (µg/L) and 95% upper confidence intervals of non-radiological constituents in surface water, 1995 (WSRC 1995b). [Note: Values denoted by an asterisk represent one-half the detection limit.]

Constituent (µg/L)	Background			Fourmile Branch			H-Area Seepine			F-Area Seepine		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI
Aluminum	4	2149	8070	3	214	515	8	8862	17994	8	12519	31486
Ammonia as N	4	90	228	3	50*	-	7	106	128	8	451	1054
Antimony	4	1.9	3.0	3	3.9	8.7	8	4.6	5.6	8	2.6	2.9
Arsenic	4	2.4	2.8	3	2.5*	-	8	4.2	5.9	8	2.1	2.6
Barium	4	34	56	3	37	87	8	69	136	7	220	459
Beryllium	4	1.5	5.3	3	0.05	0.11	8	4.1	8.2	8	3.6	5.3
Cadmium	4	1.8	3.1	3	1.4	3.9	8	4.5	5.7	8	5.1	9.3
Calcium	4	921	1495	3	4863	10880	8	2491	4553	8	12006	25787
Chloride	4	2358	3369	3	2573	2856	8	3344	4308	8	4186	5745
Chromium	4	5.5	13.4	3	2.3	6.5	8	22	32	8	13*	-
Cobalt	4	3.0	6.7	3	2.3	8.4	8	8.8	11.8	8	69	169
Copper	4	7.3	17	3	2.0*	-	8	21	27	8	13*	-
Cyanide	4	10*	-	3	13.7	40.7	8	8.8	16.6	8	10*	-
Iron	4	3265	5678	3	4875	17695	7	3481	6659	8	2012	4023
Lead	4	2.2	3.1	3	2.5*	-	8	9.0	14.0	8	2.2	3.2
Magnesium	4	467	570	3	591	957	8	1644	2981	8	6991	15958
Manganese	4	92	208	3	983	4316	8	535	1276	7	1848	4058
Mercury	4	0.08	0.14	3	0.08	0.33	8	0.11	0.16	8	0.039	0.52
Nickel	4	6.9	17	3	2.0	4.1	8	21	27	7	25	46
Nitrate	4	440	963	3	765	2669	6	114	181	8	46385	96552
Nitrate/Nitrite	4	2825	10053	3	663	2959	6	122	186	8	54370	112514
Potassium	4	588	1346	3	239	485	8	832	1404	8	1247	2035
Selenium	4	2.5*	-	3	3.8	8.9	8	4.1	5.5	8	2.3	2.8
Silver	4	6.8	17	3	1.0*	-	8	22	29	7	13*	-
Sodium	4	1475	1906	3	5363	1754	4	15675	37683	8	58673	120821
Thallium	4	2.5*	-	3	4.3	7.4	8	2.5*	-	8	2.5*	-
Tin	4	63	131	3	25*	-	8	94	109	8	50*	-
Vanadium	4	3.7	8.7	3	0.9	2.5	8	27	55	8	5.4	6.3
Zinc	4	7.1	9.9	3	9.6	28	8	42	107	8	131	265

TABLE B4. Mean radioactivity and 95% upper confidence intervals (UCL) for radiological constituents in surface water, 1995 (WSRC 1995b)

Constituent	Background			Fourmile Branch			F-Area Seepage			H-Area Seepage		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCL
Ac-228	4	3.65	5.3	3	2.9	10.1	8	7.6	13.6	8	4.4	6.2
Gross Alpha	4	1.1	1.9	3	3.2	7.2	8	29	68	8	5.1	8.4
Am-241	4	-0.009	0.064	3	0.073	0.192	8	0.52	1.33	8	0.095	0.169
Ba-133	4	0.196	2.2	3	-0.221	1.341	8	0.37	1.22	8	0.111	15
Gross Beta	4	1.3	2.1	3	27	69	8	602	1223	8	71	165
Ce-144	4	-0.87	9.9	3	3.2	21	8	1.37	8.52	8	-2.0	3.2
Cm-242	2	0.005	0.069	3	0.148	0.0589	8	0.018	0.057	7	0.021	0.105
Cm-243/244	4	0.001	0.031	3	0.141	0.675	8	0.744	1.94	8	0.044	0.01
Cm-245/246	-	-	-	3	0.0111	0.0334	8	0.076	0.186	7	0.083	0.285
Co-57	4	-0.21	1.5	3	-0.615	1.126	8	-0.137	0.621	8	0.049	1.2
Co-58	4	-0.31	1.8	3	0.12	1.74	8	-0.114	0.922	8	1.31	2.87
Co-60	4	0.73	1.35	3	0.282	2.76	8	10.889	2.33	8	2.6	6.5
Cs-134	4	0.71	2.3	3	0.134	2.9	8	-0.1501	0.967	8	-0.03	1.1
Cs-137	4	2.62	6.72	3	6.6	14.2	8	-0.241	0.769	8	3.15	4.9
Eu-152	4	0.066	3.2	3	0.285	7.7	8	2.01	5.32	8	2.6	5.1
Eu-154	4	-6.66	12.4	3	-9.1	13.9	8	-0.487	6.74	8	-7.08	476
Eu-155	4	-1.35	3.76	3	-0.737	4.74	8	1.74	3.89	8	0.991	3.97
I-129	4	0.779	1.38	3	2.9	8.1	8	21	57	8	23	44
K-40	4	16.8	25.9	3	25	45	8	25	34	8	19	32
Mn-54	4	0.91	3.44	3	0.584	2.9	8	-0.222	0.155	8	-0.54	-0.03
Na-22	4	0.68	2.1	3	-1.25	0.98	8	0.441	1.54	8	-0.21	0.24
Ni-63	4	20	75	3	19	30	8	-0.464	7.15	8	16	37
Np-237	4	0.0081	0.0523	3	0.098	0.422	8	0.317	0.653	8	1.9	4.0
Np-239	4	5.23	19.3	3	-3.2	9.7	8	1.289	7.4	8	-1.17	7.7

TABLE B4. (Continued) Mean radioactivity and 95% upper confidence intervals (UCL) for radiological constituents in surface water, 1995 (WSRC)

Constituent	Background			Fourmile Branch			F-Area Seepline			H-Area Seepline		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCL
Pb-212	4	1.54	4.86	3	2.3	7.9	8	4.2	5.8	8	1.4	2.6
Pm-144	4	0.289	1.51	3	0.16	1.77	8	-0.186	0.69	8	-0.246	0.25
Pm-146	4	0.472	3.1	3	-0.566	0.531	8	-0.162	1.38	8	0.322	1.724
Ra-226	4	0.626	1.267	3	0.496	1.5	8	5.4	13.3	8	0.5	0.8
Ra-228	4	-1.05	-0.16	3	-0.45	0.03	8	4.8	13.3	8	-0.066	0.60
Ru-106	4	2.42	11.7	3	3.27	33	8	1.7	9.9	8	3.61	4.0
Sb-124	4	-2.06	0.747	3	0.126	3.07	8	0.0623	1.4	8	-0.31	0.29
Sb-125	4	1.792	3.565	3	0.8	6.2	8	0.379	178	8	-0.378	362
Sn-113	4	0.034	2.63	3	-0.64	2.3	8	0.323	1.42	8	0.18	2.06
Sr-90	4	1.89	5	3	13	36	8	490	1148	8	21	45
Tc-99	4	-7.0	1.9	3	-6.7	1.9	8	22	45	8	51	91
Th-228	4	0.346	1.02	3	0.004	0.271	8	0.224	0.381	8	0.49	0.76
Th-230	4	0.038	0.12	3	0.58	0.37	8	0.82	1.6	8	0.09	0.14
Th-232	4	0.036	0.135	3	-0.011	0.003	8	0.076	0.151	8	0.013	0.034
Th-234	4	30.3	64.2	3	73	238	8	53	88	8	59	114
Tritium	4	3695	7555	3	283833	1206165	8	2.99E+06	6.2E+06	8	2.940E+06	6.06E+06
U-235	4	0.0004	0.05	3	0.0147	0.11	8	0.422	1.076	8	0.032	0.06
U-238	4	0.042	0.112	3	0.185	0.398	8	5.8	15.0	8	0.38	1.03
U-233/234	4	0.056	0.135	3	0.188	0.438	8	5.1	13.3	8	0.51	1.22
Y-88	4	-1.05	2.32	3	-0.136	3.35	8	0.611	1.075	8	0.53	1.1
Zn-65	4	1.09	4.27	3	0.019	3.8	8	-1.08	0.91	8	-2.12	1.24
Zr-95	4	2.02	5.17	3	-1.59	5.9	8	1.06	2.6	8	0.22	1.61

TABLE B5. Mean concentration ($\mu\text{g/L}$) and 95% upper confidence intervals of non-radiological constituents in surface water, 1996.

Constituent	Background			F-Area Seepine			H-Area Seepine			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCL
Antimony	4	4.04	7.09	3	-	-	5	-	-	5	-	-
Arsenic	4	-	-	3	-	-	5	4.63	5.65	5	5.49	6.84
Barium	4	22.69	39.82	3	22.37	24.95	5	111.6	275.67	5	45.84	87.82
Beryllium	-	-	-	3	2.03	6.21	5	0.84	2.42	5	0.08	0.14
Cadmium	4	1.54	3.0	3	1.43	3.88	5	2.04	4.66	5	1.7	2.54
Chromium	4	1.64	4.2	3	-	-	5	3.61	4.69	5	3.52	4.46
Cobalt	4	0.89	1.57	3	1.8	6.62	5	10.53	35.6	5	2.2	4.12
Copper	4	2.75	5.63	3	4.14	5.5	5	3.58	4.19	5	3.93	5.43
Cyanide	4	2.26	2.76	3	-	-	5	7.12	12.02	5	6.59	10.47
Lead	4	-	-	3	-	-	5	4.31	6.23	5	4.25	6.17
Mercury	4	0.03	0.05	3	0.078	0.196	5	0.13	0.22	5	0.11	0.19
Nickel	4	-	-	3	1.32	1.77	5	3.33	9.01	5	5.1	10.67
Selenium	4	-	-	3	4.01	8.28	5	-	-	5	-	-
Silver	4	-	-	3	-	-	5	-	-	-	5	-
Thallium	4	-	-	3	2.7	4.25	5	3.57	5.31	5	4.46	5.97
Tin	4	-	-	3	-	-	5	-	-	5	-	-
Vanadium	4	3.73	10.52	3	3.63	17.34	5	7.7	12.69	5	8.01	16.89
Zinc	4	3.58	5.49	3	6.29	18.68	5	36.7	112.25	5	5.26	7.08

Note: Analytical results and statistics are preliminary. Additional results are expected in summer, 1997.

TABLE B6. Mean radioactivity (pCi/L) and 95 % upper confidence intervals (UCL) for radionuclides constituents in surface water 1996.

Constituent	Background			F-Area Seepage			H-Area Seepage			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCL
Ac-228	4	5.12	8.90	5	4.13	7.49	5	4.97	8.74	3	3.08	5.24
Am-241	-	-	-	-	-	-	2	0.015	0.049	-	-	-
Ba-133	4	0.059	2.28	5	-0.17	0.77	5	-0.92	0.009	3	0.98	4.01
Ce-144	-	-	-	5	-1.43	7.99	5	2.18	11.66	3	5.08	9.81
Cm-242	-	-	-	-	-	-	2	-0.015	0.36	-	-	-
Cm-243/244	-	-	-	-	-	-	2	0.11	0.42	-	-	-
Cm-245/246	-	-	-	-	-	-	2	-0.004	0.04	-	-	-
Co-57	4	0.48	1.54	5	0.33	1.26	5	-0.102	0.77	3	0.25	0.82
Co-58	-	-	-	5	0.59	1.44	5	-0.60	0.70	3	0.17	0.88
Co-60	4	0.25	1.59	5	0.79	1.92	5	2.00	7.13	3	0.12	2.83
Cs-134	4	-2.10	1.87	5	0.36	1.40	5	-0.05	1.14	3	-0.56	2.93
Cs-137	4	-0.17	1.35	5	0.94	3.07	5	0.12	0.83	3	5.46	15.61
Eu-152	4	0.62	9.89	5	1.13	3.42	5	0.29	3.05	3	-0.26	5.08
Eu-154	4	0.90	8.71	5	2.00	5.68	5	0.62	3.43	3	1.62	2.37
Eu-155	4	3.32	10.83	5	0.07	3.39	5	1.95	5.78	3	-1.78	4.26
Gross Alpha	4	1.04	1.35	5	4.85	12.29	5	10.84	27.52	3	3.15	8.41
I-129	-	-	-	3	0.53	1.68	4	29.75	81.22	-	-	-
K-40	4	22.9	34.05	5	19.08	32.97	5	23.98	34.83	3	9.47	8.33
Pb-212	4	3.54	6.68	5	1.19	2.83	5	4.29	7.94	3	1.22	5.14
Mn-54	4	0.40	1.88	5	-0.81	-0.48	5	0.15	1.02	3	-0.19	0.59
Na-22	4	0.32	3.10	5	0.72	2.04	5	0.22	1.22	3	0.58	0.86
Ni-63	--	-	-	3	88.3	264	4	45.32	124.94	-	-	-

TABLE B6. (Continued) Mean radioactivity (pCi/L) and 95% upper confidence intervals (UCL) for radionuclides constituents in surface water

Constituent	Background			F-Area Seepine			H-Area Seepine			Fourmile Branch		
	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCI	n	Mean	95% UCL
Nonvolatile Beta	4	1.22	1.48	5	158	501	5	320	956	3	19.77	42.18
Np-237	-	-	-	-	-	-	2	0.07	0.77	-	-	-
Np-239	4	-4.48	10.57	5	-4.39	7.10	5	-3.34	5.14	3	3.72	14.10
Pm-144	4	-0.48	1.15	5	0.34	1.37	5	-0.44	0.54	3	0.65	1.52
Pm-146	4	-0.95	0.14	5	0.38	1.52	5	-0.02	0.86	3	0.17	1.72
Ra-226	-	-	-	-	-	-	2	2.92	15.88	-	-	-
Ra-228	-	-	-	3	1.31	4.52	4	0.59	2.42	-	-	-
Ru-106	4	-2.22	11.45	5	2.58	13.79	5	1.59	12.49	3	-3.59	19.75
Sb-124	4	-0.59	1.15	5	0.41	1.68	5	0.47	1.8	3	-0.096	1.44
Sb-125	4	-1.73	1.39	5	0.11	4.11	5	-0.66	1.82	3	-0.16	1.82
Sn-113	4	0.036	2.03	5	0.49	1.97	5	-0.06	0.76	3	0.15	0.82
Sr-90	-	-	-	3	120	535	4	190	694	-	-	-
Tc-99	-	-	-	3	10.96	56.63	4	23.98	37.2	-	-	-
U-233/234	-	-	-	-	-	-	2	1.15	9.62	-	-	-
U-235	-	-	-	-	-	-	2	0.03	0.52	-	-	-
U-238	-	-	-	-	-	-	2	0.31	2.28	-	-	-
Y-88	4	-0.020	1.66	5	0.35	1.77	5	0.67	1.69	3	0.15	2.62
Zn-65	4	0.39	3.40	5	0.17	2.18	5	-0.74	2.82	3	1.55	5.26
Zr-95	4	-0.12	2.44	5	1.12	1.85	5	-0.33	1.54	3	-0.047	1.95

Note: Analytical results and statistics are preliminary. Additional results are expected in summer, 1997.

APPENDIX C

Piezometer Data, January-August 1996

TABLE C1. Construction information for the F- and H-Area wetlands piezometer network (Dixon 1996a).

Piezometer No.	Latitude	Longitude	Elevation (ft) msl	Total Drilled Depth (ft)	Top of Casing (ft) msl	Casing Height (ft)	Piezometer Length (ft)	Depth to Screen (ft)	Top of Screen (ft) msl	Total Length of Screen ^a (ft)	Length of Sump Cap (ft)	Length of Sump (ft)	Bottom of Piezometer Elevation (ft)
FPZ001A	33.26827	81.68141	197.9	16.31	200.06	2.16	18.47	13.39	184.51	2.5	0.4	0	181.59
FPZ002A	33.26856	81.68131	201.2	12.27	203.41	2.21	14.48	9.35	191.85	2.5	0.4	0	188.93
FPZ003A	33.26779	81.67972	194	21.53	196.97	2.97	24.5	6.11	187.47	15	0.4	0	172.47
FPZ004A	33.27004	81.67879	203.1	11.56	205.94	2.84	14.4	8.64	194.46	2.5	0.4	0	191.54
FPZ005A	33.2691	81.67832	190.9	14.72	192.78	1.88	16.6	11.8	179.1	2.5	0.4	0	176.18
FPZ005B	33.2691	81.67832	190.9	6.95	192.88	1.98	8.93	1.95	188.95	5	0.4	0	183.95
FPZ006A	33.26899	81.67781	189.4	14.3	191.54	2.14	16.44	11.38	178.02	2.5	0.4	0	175.1
FPZ006B	33.26899	81.67781	189.4	7.7	191.6	2.2	9.9	2.7	186.7	5	0.4	0	181.7
FPZ007A	33.26978	81.67679	194.5	10.67	196.16	1.66	12.33	7.75	186.75	2.5	0.4	0	183.83
FPZ007B	33.26978	81.67679	194.5	5.4	196.4	1.9	7.3	0.4	194.1	5	0.4	0	189.1
FPZ008A	33.27046	81.67588	187.4	16.96	189.54	2.14	19.1	14.04	173.36	2.5	0.4	0	170.44
FPZ008B	33.27046	81.67588	187.4	10.5	189.6	2.2	12.7	3	184.4	7.5	0.4	0	176.9
HPZ001A	33.27431	81.65869	202.4	15.37	204.78	2.38	17.75	7.45	194.95	5	0.4	2.5	187.03
HPZ002A	33.27595	81.6582	218.8	12.07	220.88	2.08	14.15	6.65	212.15	5	0.4	0	206.73
HPZ003A	33.27452	81.65636	200.4	17.62	202.53	2.13	19.75	14.7	185.7	2.5	0.4	0	182.78
HPZ003B	33.27452	81.65636	200.4	7.43	202.8	2.4	9.83	2.43	197.97	5	0.4	0	192.97
HPZ004A	33.27545	81.65605	210.7	14.09	213.56	2.86	16.95	11.17	199.53	2.5	0.4	0	196.61
HPZ005A	33.27562	81.6549	213.8	9.89	215.66	1.86	11.75	6.97	206.83	2.5	0.4	0	203.91
HPZ005B	33.27562	81.6549	213.8	6.21	215.4	1.6	7.81	1.21	212.59	5	0.4	0	207.59
HPZ006A	33.27462	81.65424	201.7	9.41	205.29	3.59	13	3.99	197.71	5	0.4	0	192.29
FMB/C4			NA	NA	186.55 ^b	NA	NA	NA	NA	NA	NA	NA	NA
FMB/E1			NA	NA	215.18	NA	NA	NA	NA	NA	NA	NA	NA

^a Slot size for all screens is 0.010 inches.^b Stream locations are marked with a steel rod. This is the elevation of the steel rod.

TABLE C2. Monthly Water Level Measurements, January-August, 1996 (Dixon 1996a).

Piezometer No.	Water Level Elevations (ft) msl								Ground Elevation
	January	February	March	April	May	June	July	August	(ft) msl
FPZ001A	198.01	198	197.99	197.98	197.94	197.96	197.96	198.02	197.9
FPZ002A	201.65	201.47	201.83	201.6	201.36	201.35	201.23	201.8	201.2
FPZ003A	189.52	189.11	190.41	188.87	187.35	187.96	187.07	190.15	194
FPZ004A	201.59	201.42	201.72	201.59	201.36	201.35	201.26	201.57	203.1
FPZ005A	191.23	191.24	191.26	191.19	191.08	191.12	191.13	191.18	190.9
FPZ005B	ND	ND	ND	ND	ND	191.22	191.23	191.18	190.9
FPZ006A	189.49	189.35	189.56	189.19	188.6	188.84	188.99	189.34	189.4
FPZ006B	ND	ND	ND	ND	ND	188.5	188.87	189.04	189.4
FPZ007A	193.19	193.04	193.2	192.96	192.66	192.83	192.94	193.12	194.5
FPZ007B	ND	ND	ND	ND	ND	194.28	193.83	194.33	194.5
FPZ008A	187.7	187.67	187.72	187.65	187.56	187.58	187.59	187.63	187.4
FPZ008B	ND	ND	ND	ND	ND	187.55	187.58	187.59	187.4
HPZ001A	202.37	202.35	202.36	202.35	202.05	202.23	202.25	202.3	202.4
HPZ002A	218.58	218.4	218.89	218.69	218.17	218	217.93	218.5	218.8
HPZ003A	199.07	201.11	201.23	201.01	200.42	200.81	201.23	201.26	200.4
HPZ003B	ND	ND	ND	ND	ND	200.39	200.74	201.02	200.4
HPZ004A	210.36	210.3	210.38	210.3	210.11	210.11	208.88	210.3	210.7
HPZ005A	213.21	212.79	213.25	212.51	211.61	211.99	212.46	213.06	213.8
HPZ005B	ND	ND	ND	ND	ND	211.91	213.75	213.05	213.8
HPZ006A	201.77	201.74	201.78	201.7	201.53	201.76	201.83	202.09	201.7
FMB/C4	ND	178.42	178.4	178.33	178.18	178.2	178.23	178.26	NA
FMB/E1	ND	214.56	214.7	214.6	214.37	214.41	214.3	214.47	NA

TABLE C3. Water Level Measurements for the Period of January 1996 to August 1996 (Dixon 1996a).

Piezometer Number	Minimum Water Level (ft)	Maximum Water Level (ft)	Mean Water Level (ft)	Standard Deviation	Water Level Relative to Ground Elevation^a
FPZ001A	197.94	198.02	197.98	0.03	0.08
FPZ002A	201.23	201.83	201.54	0.22	0.34
FPZ003A	187.07	190.41	188.81	1.24	-5.19
FPZ004A	201.26	201.72	201.48	0.16	-1.62
FPZ005A	191.08	191.26	191.18	0.06	0.28
FPZ005B	191.18	191.23	191.21	0.03	0.31
FPZ006A	188.6	189.56	189.17	0.33	-0.23
FPZ006B	188.5	189.04	188.8	0.28	-0.6
FPZ007A	192.66	193.2	192.99	0.19	-1.51
FPZ007B	193.83	194.33	194.15	0.28	-0.35
FPZ008A	187.56	187.72	187.64	0.06	0.24
FPZ008B	187.55	187.59	187.57	0.02	0.17
HPZ001A	202.05	202.37	202.28	0.11	-0.12
HPZ002A	217.93	218.89	218.4	0.34	-0.41
HPZ003A	199.07	201.26	200.77	0.74	0.37
HPZ003B	200.39	201.02	200.72	0.32	0.32
HPZ004A	208.88	210.38	210.09	0.5	-0.61
HPZ005A	211.61	213.25	212.61	0.59	-1.19
HPZ005B	211.91	213.75	212.9	0.93	-0.9
HPZ006A	201.53	202.09	201.78	0.16	0.07
FMB/C4	178.18	178.42	178.29	0.1	NA
FMB/E1	214.3	214.7	214.49	0.14	NA

^a Positive values indicate the water level is above ground elevation. Negative values indicate the water level is below ground elevation.