WSRC-RP-2000-00425

KEY WORDS: Stewardship
Waste Management
Environmental Protection

Closure Plan for the E-Area Low-Level Waste Facility

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Rev. 2

September 2, 2002

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

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LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYMS

ASL	above mean sea level
ASTM	American Society of Testing and Materials
CB/TS	core barrels/thermal shields
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CIF	Consolidated Incinerator Facility
DAS	Disposal Authorization Statement
DCG	derived concentration guide
F&HSB	F and H-Area Seepage Basins
FML	flexible membrane liner
GCL	geosynthetic clay liner
GSA	General Separations Area
HD	hold down
HLW	High-Level Waste
IL	Intermediate-Level
ILNT	Intermediate-Level Non-Tritium
ILT	Intermediate-Level Tritium
KAPL	Knolls Atomic Power Laboratory
LAW	Low-Activity Waste
LLRWDF	Low-Level Radioactive Waste Disposal Facility
LLW	Low-Level Waste
LLWF	Low-Level Waste Facility
MCL	maximum contaminant level
MMI	Modified Mercalli Intensity
MSB	M-Area Settling Basin
msl	mean sea level
MWMF	Mixed Waste Management Facility
NPDES	National Pollutant Discharge Elimination System
NR	Naval Reactor
NRC	Nuclear Regulatory Commission
NWS	National Weather Service
PA	Performance Assessment
PSF	Pounds per square foot
QA/QC	Quality Assurance / Quality Control
RCRA	Resource Conservation and Recovery Act
ROI	Region of Influence

ACRONYMS (continued)

SCDHEC	South Carolina Department of Health and Environmental Control
SI	International system of units
SMCL	Secondary Maximum Contaminant Level
SRS	Savannah River Site
SWDF	Solid Waste Disposal Facility
TSR	Technical Safety Requirement
U.S.	United States
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USDOE-NR	United States Department of Energy – Naval Reactors
USEPA	United States Environmental Protection Agency
WAC	Waste Acceptance Criteria
WQS	water quality standard
WSRC	Westinghouse Savannah River Company

UNIT ABBREVIATIONS

c	cubic
c	centi
Ci	Curie
cm	centimeter
ft	foot, feet
^{0}F	degrees Fahrenheit
g	gram
gal	gallon
in	inch
k	kilo
km	kilometer
L	liter
lb	pound
m	meter
mg	milligram
mrem	millirem
n	nano
NTU	nephelometric turbidity unit
p	pico
R	rem
s	second
S	Siemen
yr	year
µ	micro

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1.0 EXECUTIVE SUMMARY

To comply with the applicable requirements of the U.S. Department of Energy (USDOE) Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b), this closure plan has been developed for the E-Area Low-Level Waste Facility (LLWF). The plan is organized according to the specifications of the *Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Closure Plans* (USDOE 1999d).

Section 2 provides a brief overview of the general facility description, closure approach, closure schedule, related activities, and key assumptions. Sections 3 and 4 provide specific details of facility characteristics and the technical approach to closure, respectively, as well as supporting information. Additional schedule details are provided in Section 5. Section 6 provides a list of recommended items for consideration in association with future revisions to the E-Area LLWF Closure Plan and Performance Assessment (PA).

The E-Area LLWF has been in operation for approximately seven years and has tens of years of operation remaining. The level of detail in this closure plan is consistent with the fact that the facility is in the first half its operational history. As the facility evolves and operational features are modified, the closure plan will be updated to reflect the current status of the facility. This will ensure that the closure concept is consistent with the ultimate facility configuration and design parameters. Additionally consistency will be maintained between the closure plan and the associated PA. As updates and revisions are made to either the closure plan or PA, the other document will be updated and revised as appropriate to maintain consistency between the documents. Finally the closure plan will be updated and revised as necessary to ensure compliance with applicable orders and regulations.

2.0 INTRODUCTION

2.1 General Facility Description

The E-Area LLWF is the site for low-level radioactive waste disposal and storage at the Savannah River Site (SRS) and has been designed to manage all Low-Level Waste (LLW) resulting from SRS operations for the next 20 years. The E-Area LLWF site is located on a 200-acre site immediately north of the former LLW burial site in an area of the SRS that is limited to industrial uses. Only 100 acres have been developed at this time; the additional 100 acres will allow for expansion of the LLW disposal capacity, as needed. The nearest SRS boundary to the E-Area LLWF is about 11 km to the west. The surrounding portions of the SRS are a mixture of industrial and administrative facilities as well as managed forestland. The general area adjacent to the SRS comprises forests, wetlands, water bodies, and unclassified predominantly rural lands. The current SRS Future Use Plan states that the entire SRS will never be released for unrestricted use. In particular, the plan states that the central portion of the SRS, which includes the E-Area LLWF, will only be used for industrial purposes (USDOE 1998).

The E-Area LLWF is a controlled release facility intended to maintain radionuclide migration from disposed LLW forms to below the Performance Objectives outlined within USDOE Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b). Both containerized and uncontainerized LLW are disposed within the following types of disposal units at the E-Area LLWF: Low-Activity Waste (LAW) Vaults, Intermediate-Level (IL) Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout

Trenches), and Naval Reactor Component Disposal Pads. Waste Acceptance Criteria (WAC) have been developed for each disposal unit type that outlines the waste acceptable for disposal in each. Over the life of the E-Area LLWF, additional types of disposal units and additional disposal units will be constructed as needed.

The E-Area LLWF closure will consist of interim/operational closure of individual disposal units as they are filled and final closure of the entire E-Area LLWF at the end of its operational life. Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste. The integrated closure system will consist of one or more closure caps installed over the disposal units and a drainage system.

2.2 General Closure Approach

The interim/operational closure of individual disposal units as they are filled will be specific to each type of disposal unit. Final closure of the entire E-Area LLWF will consist of construction of an integrated closure system at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system. It will take into account the waste types and forms, unit location, site hydrogeologic properties, potential exposure scenarios, and lessons learned implementing closure systems at other SRS facilities.

In general, the waste types and forms play a key role in disposal unit design. Each of the various types of disposal units at the E-Area LLWF has been designed to handle a range of specific waste types. The PA evaluates various exposure scenarios for the disposition of these various waste types and forms within the respectively disposal units with the closure system described in this plan in place. Using the PA as described, the design parameters of the E-Area LLWF interim/operational closure and integrated closure system are evaluated against the USDOE Order 435.1 Performance Objectives.

The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (WSRC, 2000). Previously the use of compacted kaolin as the barrier layer in the closure cap was assumed, whereas this closure plan (revision 2) replaces the kaolin with a geosynthetic clay liner (GCL) as the barrier layer. A closure cap utilizing a GCL has been shown to be equivalent to or better than one, utilizing compacted kaolin, in term of minimizing infiltration. The replacement of compacted kaolin with a GCL is the only significant change in the closure cap configuration from that presented in previous closure plan revisions and revision 1 of the PA. Other design features have been developed, based on the general design features included in the PA evaluation. Additional details have been added based on the current operational status of the facility. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure.

This closure system will work in concert with the waste types and forms and the disposal units features themselves, to the extent necessary, to minimize moisture contact with the waste, divert surface water, prevent unauthorized access, and minimize long-term maintenance in order that the USDOE Order 435.1 Performance Objectives are met. Specific details of the closure system features are provided in Section 4.0.

2.3 Closure Schedule

The E-Area LLWF is in the very early stages of its planned operational life. This closure plan reflects the currently available information based on the facility's operational status. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure. The schedule for final closure of the facility will be developed five years prior to completion of waste emplacement activities.

2.4 Related Activities

Operations at the E-Area LLWF will be managed to ensure that only waste meeting the criteria for classification as LLW will be disposed at the facility. There are currently no plans to handle any wastes that would invoke the requirements of the Resource Conservation and Recovery Act (RCRA). However, nearby/adjacent facilities are in various stages of compliance with RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements, based on former or current operations at these facilities.

Eventual closure and installation of the integrated closure system for the E-Area LLWF will require coordination with these other facilities to ensure that the closure system does not interfere with activities underway nearby. A multidisciplinary team of individuals cognizant of the current and, to the extent possible, the planned future activities at these facilities participated in the development and review of this closure plan. Continued interaction with personnel from these adjacent and nearby facilities will be key to the success of the E-Area LLWF closure.

The closure system described in this closure plan is based on the concept discussed in the PA with the replacement of compacted kaolin with a GCL as outlined in section 2.2. This system is designed to meet the Performance Objectives set forth in the PA and the Disposal Authorization Statement (DAS) [USDOE 1999c]. The PA Maintenance Program (WSRC 2000b) reviews the PA and associated documents, such as monitoring and closure plans, and ensures that the activities associated with each are coordinated and that ancillary tasks needed to support the work described in these documents is planned for and implemented. In addition, the PA Maintenance Program will review developments in closure system design, construction, performance in the field, and other developments relevant to closure at the E-Area LLWF and apply them to the closure as necessary.

2.5 Summary of Key Assumptions

The following are the key assumptions in the closure approach for the E-Area LLWF:

- Specific values for the hydraulic properties of the closure cap materials and the total thickness of the cap were utilized to demonstrate compliance with the Performance Objectives within revision 1 of the PA. It is assumed that the actual closure cap material properties will be equivalent to or better than those utilized within the PA.
- It has been shown within this closure plan that a closure cap utilizing a GCL is equivalent to or better than one, utilizing compacted kaolin, in term of minimizing infiltration. Therefore it is assumed that compliance with the Performance Objectives will be demonstrated when the PA is revised to account for this change in the closure cap.
- Though technological improvements are likely to make alternatives to the closure cap described herein more feasible, and perhaps, more cost effective, while still achieving the necessary hydraulic properties to meet the performance objectives, it is important to maintain

the total cap thickness assumed in the PA. This thickness is necessary for shielding in the inadvertent intruder scenario.

- It is assumed that active maintenance of the closure cap occurs during the 100-year institutional control period, following final closure of the entire E-Area LLWF.
- Specific times of failure for each type of disposal unit are estimated or assumed as outlined in section 3.2. It is further assumed that the integrity of the closure cap over each type of disposal unit is maintained until failure of the disposal unit itself. At which time it is assumed that the closure cap over that type of disposal unit also fails.
- It is assumed that a full IL Vault and a Components-In-Grout Trench has very little void volume and therefore the loss of structural stability does not necessarily imply structural collapse and subsequent subsidence.
- An infiltration rate of 40 cm/year past the evapotranspiration zone of the soil column is assumed under pre-capping conditions. Based upon this infiltration rate a flow rate through the closure cap and subsequently the disposal unit is calculated for the time period that the disposal unit and closure cap are assumed to be intact. At the assumed time of disposal unit and closure cap failure, the infiltration rate is assumed to revert back to 40 cm/year.
- It is assumed that the requirements within USDOE Order 435.1 and its associated Manual (USDOE 1999, USDOE 1999a), regarding long-term stability of the disposal units, minimization of subsidence, and minimization of the contact of the waste with water, are applicable only as required to ensure compliance with the USDOE Order 435.1 Performance Objectives.

Further details of the specific relationships between these key assumptions and closure system design are provided in Section 4.0 of this plan. Specific details of these assumptions and their role in the PA are provided in the PA.

3.0 DISPOSAL FACILITY CHARACTERISTICS

Per the guidance for preparation of LLW facility closure plans, this section summarizes information in the facility PA, which is referenced periodically throughout this section and listed in the reference section. For source references of specific data cited from the PA, refer to the PA (WSRC 2000).

3.1 Site Characteristics

Evaluation of radionuclide transport from the E-Area LLWF, and of human exposure resulting from release of radionuclides to the environment, requires careful consideration of factors affecting transport processes and exposure potential. Topographic features and hydrogeologic characteristics strongly affect the direction and flow of radionuclides potentially released from the disposal site. Projected land use and population distributions affect the estimation of human exposure. In this section, the relevant natural and demographic characteristics of the E-Area site and surrounding area are discussed.

3.1.1 Geography and Demography

3.1.1.1 Disposal Site Location

The SRS occupies about 780 km^2 in Aiken, Barnwell, and Allendale Counties on the Upper Atlantic Coastal Plain of southwestern South Carolina. The center of the SRS is approximately 36 km southeast of Augusta, GA; 32 km south of Aiken, SC; 160 km from the Atlantic Coast; and is bounded on the southwest by the Savannah River for about 28 km. The Fall Line, which separates the Atlantic Coastal Plain physiographic province from the Piedmont physiographic province, is approximately 50-km northwest of the central SRS (Figure 3-1).

Prominent geographic features within 80 km of the SRS are the Savannah River, Thurmond Lake, Par Pond, and L Lake. The Savannah River forms the southwest boundary of the SRS. Thurmond Lake is the largest nearby public recreational area. This reservoir is on the Savannah River and is about 64 km upstream of the center of the SRS. Par Pond is an 11 km^2 former reactor cooling water impoundment that lies in the eastern sector of the SRS. L Lake is a 4 km^2 former reactor cooling water impoundment that lies in the southern sector of the SRS.

The E-Area LLWF is located in the central region of the SRS known as the General Separations Area (GSA). The disposal site consists of approximately 0.8 km^2 (200 acres) and is situated immediately north of the former LLW burial grounds. Construction of the E-Area LLWF began in October 1989. Planned construction covers an elbow-shaped, cleared area of 0.4 km^2 (100 acres), curving to the northwest on an interfluvial plateau.

3.1.1.2 Disposal Site Description

The elevation of the SRS ranges from 24 m above msl (ASL) at the Savannah River to about 122 m ASL in the upper northwest portion of the site. The Pleistocene Coastal terraces and the Aiken Plateau form two distinct physiographic subregions at the SRS (WSRC 2000). The Pleistocene Coastal terraces are below 82 m in elevation, with the lowest terrace constituting the present flood plain of the Savannah River and the higher terraces characterized by gently rolling topography. The relatively flat Aiken Plateau occurs above 82 m.

Numerous streams dissect the Aiken Plateau. Because of the large number of tributaries to small streams on the SRS, no location on the site is far from a flowing stream, most of which drain to the Savannah River.

The E-Area site has low to moderate topographic relief and is drained by several perennial streams (Figure 3-1). It slopes from an elevation of about 88-m in the southernmost corner to an elevation of 76 m in the northernmost corner. The site is bordered by three streams with several intermittent streams present within the area boundary. Runoff is to the north toward Upper Three Runs, to the east toward Crouch Branch, and to the west toward an unnamed branch. Upper Three Runs is approximately 760 m north of the facility boundary. The nearest perennial stream is approximately 370-m northeast of the boundary.

The dominant vegetation on the SRS is forest, with types ranging from scrub oak communities on the driest areas to bald cypress and black gum in the swamps. Pine forests cover more area than any other forest type. Land utilization presently is about 56 percent in pine forests, 35 percent in hardwoods, 7 percent in SRS facilities and open fields, and 2 percent in water (WSRC 2000).

Except for three roadways and a railway that are near the edge of the SRS, public access to the SRS is restricted to guided tours, controlled deer hunts, and authorized environmental studies. The major production areas located at the site include: Raw Materials (M Area), Separations (F and H Areas), Waste Management Operations (E, F, and H Areas), and Defense Waste Processing (S and Z Areas). Administrative and support services, the Savannah River Technology Center, and the Savannah River Ecology Laboratory are located in A Area.

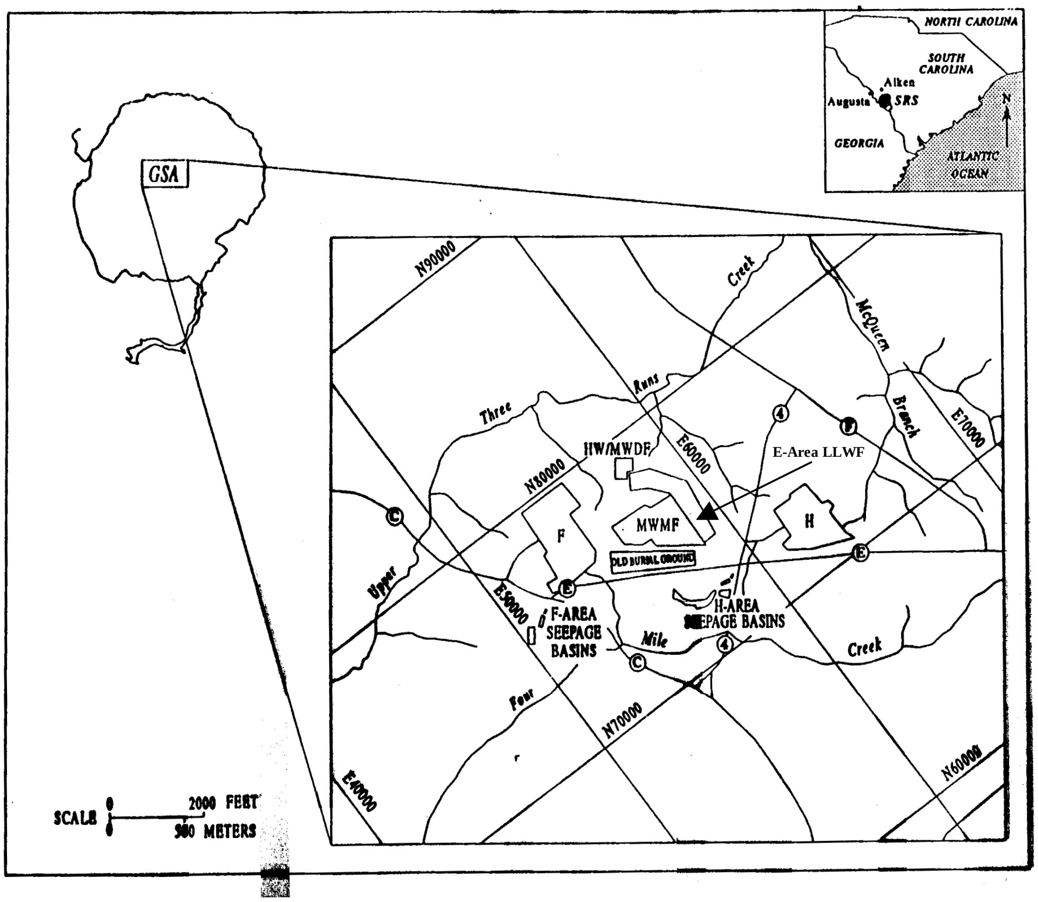

Figure 3-1 Location of the E-Area Low-Level Waste Facility

3.1.1.3 Population Distribution

Based on state and federal agency surveys and trends, the estimated 1994 population in the region of influence was 457,824. More than 89 percent lived in Aiken (28.8 percent), Columbia (17.5 percent), and Richmond (42.8 percent) counties (Table 3-1). The population in the region grew at an average annual growth rate of 1.2 percent during the 1980s and slowed to a less than 1-percent rate between 1990 and 1994. The positive net immigration that occurred in the region was consistent with population growth in Georgia and South Carolina. Columbia County experienced the greatest increase, 146 percent total net increase. Aiken County was second with a 53 percent total net increase. Over the same period, however, Bamberg, Barnwell, and Richmond counties experienced a net loss of population.

Population projections indicate that the overall population in the region should continue to grow until about 2040. Three counties—Allendale, Bamberg, and Barnwell—should experience little growth after 2000, while the others should increase consistently (Table 3-2). Columbia County will continue to show a significant upward growth pattern (WSRC 2000).

Table 3-1 Population Distribution and Percent of Region of Influence for Counties and Selected Communities

Jurisdiction	1994 Population	1994 %ROI
South Carolina	3,663,990	
Aiken County	132,060	28.8
Aiken	24,930	5.4
Jackson	1,880	0.4
New Ellenton	2,490	0.5
North Augusta	17,610	3.8
Allendale County	11,690	2.6
Bamberg County	16,700	3.6
Barnwell County	21,420	4.7
Barnwell	5,600	1.2
Georgia	7,055,340	
Columbia County	79,920	17.5
Augusta/Richmond County	196,030	42.8
Six-county total	457,820	
United States	260,341,000	

NOTES:
ROI - Region of Influence
SOURCE:
WSRC 2000

Table 3-2 Population Projections and Percent of Region of Influence

	2000		2010		2020		2030		2040	
Jurisdiction	Population	% ROI	Population	% ROI	Population	% ROI	Population	% ROI	Population	% ROI
South Carolina										
Aiken County	133,760	26.81	145,800	26.35	156,590	26.22	168,180	26.19	180,620	26.07
Allendale County	12,960	2.60	14,130	2.55	15,180	2.54	16,300	2.54	17,510	2.53
Bamberg County	18,690	3.75	20,380	3.68	21,880	3.66	23,500	3.66	25,240	3.64
Barnwell County	22,440	4.50	24,460	4.42	26,270	4.40	28,220	4.39	30,310	4.37
Georgia										
Columbia County	80,290	16.10	90,010	16.27	97,390	16.31	105,376	16.41	114,020	16.46
Richmond County	230,700	46.25	258,610	46.73	279,820	46.86	300,526	46.80	325,170	46.93
Six-county total	498,850	100	533,390	100	597,130	100	642,098	100	692,860	100

NOTES:
ROI - Region of Influence
SOURCE:
WSRC 2000

3.1.1.4 Uses of Adjacent Lands

In the area adjacent to the SRS, less than 8 percent of the existing land is devoted to urban and built-up uses. Most such uses are in and around the cities of Augusta and Aiken. Agriculture accounts for about 21 percent of total land use; forests, wetlands, water bodies, and unclassified, predominantly rural, lands account for about 70 percent.

The projected future land uses of the area adjacent to the SRS are similar to existing patterns. Developed urban land is projected to increase by 2 percent in the next 20 years. The largest percentage of this growth is expected to occur in Aiken and Columbia Counties as a result of the expansion of the Augusta metropolitan area (WSRC 2000).

3.1.2 Meteorology and Climatology

The southeastern United States has a humid, subtropical climate characterized by relatively short, mild winters and long, warm, and humid summers. Summer-like weather typically lasts from May through September, when the area is subject to the persistent presence of the Atlantic subtropical anticyclone (i.e., the “Bermuda” high). The humid conditions often result in scattered afternoon thunderstorms. Average seasonal rainfall is usually lowest during the fall.

The weather is changeable during the winter as mid-latitude low-pressure systems and fronts migrate through the region. Measurable snowfall is rare. Spring is characterized by a higher frequency of tornadoes and severe thunderstorms than the other seasons. During spring, temperatures are mild and the humidity is relatively low.

Sources of data used to characterize the climatology of the SRS consist of a standard instrument shelter in A Area (temperature, humidity, and rainfall for 1961 to 1994), the Central Climatology Meteorological Facility near N Area (temperature, humidity, and precipitation for 1995-1996), and the H-Area meteorological tower (winds and atmospheric stability).

The average annual temperature at the SRS is 64.7°F. July is the warmest month of the year with an average daily maximum of 92°F and an average daily minimum near 72°F. January is the coldest month with an average daily high around 56°F and an average daily low of 36°F. Temperature extremes recorded at the SRS since 1961 are 107°F in July 1986 and -3°F in January 1985.

Annual precipitation averages 49.5 inches. Summer is the wettest season of the year with an average monthly rainfall of 5.2 inches. Fall is the driest season with an average monthly rainfall of 3.3 inches. Relative humidity averages 70 percent annually with an average daily maximum of 91 percent and an average daily minimum of 45 percent.

Winds are most frequently from the northeast and southwest sectors. Measurements of turbulence are used to determine whether the atmosphere has relatively high, moderate, or low potential to disperse airborne pollutants (commonly identified as unstable, neutral, or stable atmospheric conditions, respectively). Generally, SRS atmospheric conditions were categorized as unstable 56 percent of the time (WSRC 2000).

Meteorological data are critical input to atmospheric transport and dose models that are used to estimate the effects of releases from SRS facilities. The atmospheric transport and dose modeling performed for this PA is based upon a 5-year average meteorological data set from the period 1987 to 1991. This quality-assured meteorological database is the most recent for the SRS.

An average of 54 thunderstorm days per year were observed at the National Weather Service (NWS) Augusta, GA, office during the period 1951-1995. About half of the thunderstorms occurred during the summer. Since operations began at the SRS, ten confirmed tornadoes have occurred on or in close proximity to the site. Several of these tornadoes were estimated to have winds up to 150 miles per hour and did considerable damage to forested areas of the SRS. None caused damage to structures. Tornado statistics indicate that the average frequency of a tornado striking any single point on the site is 7.11×10^{-5} per year or about once every 14,000 years (WSRC 2000).

The highest sustained wind recorded at the Augusta NWS Office is 82 miles per hour. The maximum 100-year straight-line wind speed for the SRS area has been estimated to be 107 miles per hour. Straight-line winds are produced by hurricanes, thunderstorms, and strong winter storms. Hurricanes struck South Carolina 36 times during the period 1700 to 1992, an average recurrence frequency of once every 8 years. A hurricane force wind of 75 miles per hour has been observed at SRS only once, during Hurricane Gracie in 1959.

3.1.3 Ecology

3.1.3.1 Aquatic Ecology

Flora in the Savannah River basin and in creeks on the SRS is diverse and seasonally variable. Several species of diatoms, green algae, yellow-green algae, and blue-green algae are present. In seasonally flooded areas, bald cypress and tupelo gum thrive. In less severely flooded areas, oak, maple, ash, sweet gum, ironwood, and other species less tolerant of flooding are found. In the river swamp formed by the Savannah River in the vicinity of the SRS, herbaceous growth is sparse. A number of macrophytes, such as cattail and milfoil, are found in areas receiving sufficient sunlight.

The fish communities in the Savannah River and in creeks on the SRS are very diverse. Redbreast sunfish, spotted sucker, channel catfish, and flat bullhead are the dominant species. Sunfish, crappies, darters, minnows, American shad, and striped bass are also abundant.

Macroinvertebrate communities are largely comprised of true flies, mayflies, caddisflies, stoneflies, and beetles. Leaf litter input is high but is rapidly broken down by macroinvertebrate shredders. The Asiatic clam is found in the Savannah River and its larger tributary streams.

3.1.3.2 Terrestrial Ecology

Prior to its acquisition by the United States (U.S.) Government in 1951, approximately one-third of the SRS was cropland, about half was forested, and the remainder was floodplain and swamp. Since that time, the U.S. Forest Service has reclaimed many previously disturbed areas through natural plant succession or by planting pine trees. As was noted in Section 3.1.1.2, 91 percent is now pine or hardwood forests, with the remaining 9 percent divided between SRS facilities and water bodies.

A variety of vascular plants exist on the site. Scrub oak communities cover the drier sandy areas, which include predominantly longleaf pine, turkey oak, bluejack oak, blackjack oak, dwarf post oak, three awn-grass, and huckleberry. On the more fertile, dry uplands, white oak, post oak, southern red oak, mockernut hickory, pignut hickory, and loblolly pine predominate, with an understory of sparkleberry, holly, greenbriar, and poison ivy. Pine trees cover more area than any other tree genus (WSRC 2000).

The heterogeneity of the vegetation on the SRS supports a diverse wildlife population. Several species of reptiles and amphibians are present due to the variety of aquatic and terrestrial habitats. These include snakes, frogs, toads, salamanders, turtles, lizards, and alligators. More than 213 species of birds have been identified on the SRS. Burrowing animals at the SRS include: Peromyscus polionotus, known commonly as the Old Field Mouse; Blarine brevicauda, known as the short tail shrew; Scalopus aquiticus, known as the eastern mole; Pogonomyrmex badius, known as the harvester ant; Dorymyrmex pyramicus, known as the pyramid ant; and earthworms (WSRC 2000).

3.1.4 Geology

3.1.4.1 Regional and Site-Specific Geology/Topography

The surface of the Upper Atlantic Coastal Plain on which the SRS is located slopes gently seaward. The province is underlain by a seaward dipping wedge of unconsolidated and semi-consolidated sediments that extends from the Fall Line to the seaward edge of the continental shelf. Sediment thickness increases from zero at the Fall Line, where the crystalline Piedmont province gives way to the Coastal Plain, to more than 1.2 km near the coast of South Carolina. The SRS is underlain by about 180 to 370 m of Coastal Plain sediments. These sediments vary in age from Late Cretaceous to Miocene and are divided into several groups based principally on age and lithology. A brief discussion of these groups follows. The presence and approximate thicknesses of the sediments in the vicinity of E Area are also provided. An in-depth treatment of the stratigraphy of the SRS is given in a recent report by the State of South Carolina’s Department of Natural Resources (Aadland et al. 1995).

Late Cretaceous Sediments

The Late Cretaceous sediments include, from oldest to youngest, the Cape Fear Formation and the three formations of the Lumbee Group: the Middendorf, Black Creek, and Steel Creek Formations. These sediments are approximately 210 m thick at the center of the SRS, near E Area. The lowermost Cape Fear Formation rests on a thin veneer of saprolitic bedrock, which defines the surface of the crystalline and sedimentary basement rock. This formation is composed of poorly sorted silty-to-clayey quartz sands and interbedded clays. Bedding thicknesses range from 1.5 to 6 m, with sand beds being thicker than clay beds. The formation is about 9 m thick at the northwestern boundary of the SRS, and it increases to more than 55 m near the southeastern boundary. This formation has not been observed to outcrop in the vicinity of the SRS (WSRC 2000).

The thickness of the Lumbee Group, which overlies the Cape Fear Formation, varies across the SRS from 120 m in the northwest to more than 230 m near the southeastern boundary. The Middendorf Formation, which directly overlies the Cape Fear Formation, is composed mostly of medium and coarse quartz sand that is cleaner and less indurated than the underlying sediments. Clay casts and pebbly zones occur in several places in the Middendorf Formation. A clay zone up to 24 m thick forms the top of this formation over much of the SRS. In total, the Middendorf Formation ranges from approximately 40 to 55 m thick from the northwestern to southeastern boundary of the SRS. Outcrops of this formation have been identified northwest of the SRS (WSRC 2000).

The Black Creek Formation consists of quartz sands, silts, and clays. The lower section consists of fine- to coarse-grained sands with layers of pebbles and clay casts. The upper section changes in composition as it crosses the SRS from northwest to southeast, from massive clay to silty sand with interbeds of clay. Thickness of the Black Creek Formation under the SRS ranges from 34 m in the northwest to 76 m in the southeast. Outcropping in the vicinity of the SRS has not been confirmed (WSRC 2000).

The uppermost formation in the Lumbee Group is the Steel Creek Formation (previously referred to as the Peedee Formation), which consists of fine-grained sandstone and siltstone with marine fossils. This formation is comparable in age, but lithologically distinct, from the Peedee Formation in southwestern South Carolina. The lower portion of this formation consists of fine- to coarse-grained quartz sand and silty sand, with a pebble-rich zone at its base. Pebbly zones and clay casts are common throughout the lower portion of the Steel Creek Formation. The upper portion of this formation is a clay that varies from more than 15 m to less than 1 m in thickness at the SRS. The Steel Creek Formation is about 34 m thick at the northwestern SRS boundary and about 40 m thick at the southeastern boundary. No nearby outcropping has been identified (WSRC 2000).

Paleocene-Eocene Black Mingo Group

Paleocene-Early Eocene sediments make up the Black Mingo Group. In E Area, this group consists of the Early Paleocene Lang Syne/Sawdust Landing Formations, the Late Paleocene Snapp Formation, and the Early Eocene Fourmile Formation. This group is about 21 m thick at the northwestern SRS boundary, thickens to about 46 m near the southeastern boundary, and is about 210 m thick at the coast (WSRC 2000).

The Lang Syne/Sawdust Landing Formations together are equivalent to the lithologic unit previously referred to as the Ellenton Formation (WSRC 2000). These formations, treated as a single unit due to difficulty in mapping them separately (Aadland et al. 1995), consist mostly of gray, poorly sorted, micaceous, lignitic, silty and clayey quartz sand interbedded with gray clays. They are approximately 12 m thick at the northwestern boundary of the SRS and thicken to about 30 m near the southeastern boundary. These formations outcrop about four miles northwest of the SRS.

The deposits near the SRS that are time-equivalent to the Williamsburg Formation differ from the type Williamsburg and are designated as the Snapp Formation. The sediments are typically silty, medium- to coarse-grained quartz sand interbedded with clay. The Snapp Formation pinches out at the northwestern SRS boundary and thickens to about 15 m near the southeastern boundary. In E Area, the distribution of the Snapp Formation is sporadic, not continuous.

Sand immediately overlying the Snapp Formation is identified as the Fourmile Formation. The well-sorted sand of this formation is an average of 9 m in thickness. Clay beds near the middle and top of the formation are a few feet thick. In E Area, this formation may not be continuous.

Middle Eocene Orangeburg Group

The middle Eocene sediments make up the Orangeburg Group, which in E Area consists of the lower middle Eocene Congaree Formation, the upper middle Eocene Warley Hill Formation, and the late middle Eocene Tinker/Santee Limestone Formation. The sediments thicken from about 30 m at the northwestern SRS boundary to about 49 m near the southeastern boundary (Aadland et al. 1995). The dip of the upper surface of this formation is about .002 m/m to the southeast across the site. The Orangeburg Group is about 100 m thick at the coast. The group outcrops at lower elevations in many places near and on the SRS.

The Congaree Formation consists of fine to coarse, well-sorted and rounded quartz sands. Thin clay laminae occur throughout, as do small pebble zones. The sand is glauconitic in places. The formation is about 26 m thick at the center of the SRS (WSRC 2000).

The Warley Hill Formation, made up of glauconitic sand and green clay beds and thus previously referred to as the "green clay," overlies the Congaree Formation. This formation is generally 3 to 6 m in thickness. However, northwest of E Area, the Warley Hill Formation is missing or very thin, such that the overlying Tinker/Santee Formation rests unconformably on the Congaree Formation.

The Tinker/Santee Formation consists of calcilutite, calcarenite, shelly limestone, calcareous sands and clays, and micritic limestone. The sands are glauconitic in places and fine- to medium-grained. The sediments comprising this formation have been referred to in the past as the Santee Limestone, McBean, and Lisbon Formations and indicate deposition in shallow marine environments. The Tinker/Santee Formation is about 12 to 15 m thick in the center of E Area (WSRC 2000). In places where the Warley Hill Formation is absent, the Tinker/Santee Formation rests directly on the Congaree Formation.

Late Eocene Barnwell Group

The Late Eocene sediments make up the Barnwell Group, which consists of the Clinchfield, Dry Branch, and Tobacco Road Sand. The Clinchfield Formation, the oldest of the three, is made up of quartz sand, limestone, calcareous sand, and clay. It is generally identified only when the contrasting carbonates of the overlying Dry Branch and underlying Tinker/Santee Formations are present, with the sand of the Clinchfield Formation sandwiched between them. It has been identified at several areas within the SRS, where it is up to 8 m thick, but is indistinguishable in the central regions of the SRS, near E Area.

The Dry Branch Formation consists of three distinguishable members: the Twiggs Clay Member, the Griffins Landing Member, and the Irwinton Sand Member. The Twiggs Clay Member is not mapable as a continuous unit within the SRS, but lithologically similar clay is present at various levels within this formation. The tan, light gray, and brown clay of the Twiggs Clay Member has previously been referred to as the "tan clay" at the SRS. The Griffins Landing Member is up to 15 m thick in the southeastern part of the SRS. This member consists mostly of calcilutite and calcarenite, calcareous quartz sand, and slightly calcareous clay. It occurs sporadically and pinches out in the center of the SRS. The remainder of the Dry Branch Formation within the SRS is made up of the Irwinton Sand Member, which is composed of moderately sorted quartz sand, with interlaminated clays abundant in places. Clay beds of this member have also been referred to as the "tan clay" at the SRS. The Irwinton Sand is about 12 m thick at the northwestern SRS boundary and thickens to 21 m near the southeastern boundary. It outcrops in many places around and within the SRS.

The Tobacco Road Sand overlies the Dry Branch Formation. This formation consists of moderately to poorly sorted quartz sands, interspersed with pebble layers and clay laminae. The sediments have the characteristics of a shallow marine deposit. The upper surface of this formation is irregular due to an incision that accompanied deposition of the overlying "Upland Unit" and later erosion. The thickness is variable as a result of erosive processes, but it is at least 15 m in places (WSRC 2000).

“Upland Unit”

The “Upland Unit” is an informal stratigraphic term applied to terrestrial deposits that occur at higher elevations in some places in the southwestern South Carolina Coastal Plain. This unit overlies the Barnwell Group in the Upper Coastal Plain of western South Carolina, on which the SRS is located. This unit occurs at the surface at higher elevations in many places around and within the SRS, but it is not present at all higher elevations. The sediments are poorly sorted, clayey-to-silty sands, with lenses and layers of conglomerates, pebbly sands, and clays. Clay casts are abundant. The “Upland Unit” is up to 21 m thick in parts of the SRS. Much of this unit corresponds to the Hawthorne Formation and the Tertiary alluvial gravels identified in previous documents (WSRC 2000).

Soils

Most of the soils at the SRS are sandy over a loamy or clayey subsoil. The distribution of soil types is very much influenced by the creeks on the site, with colluvial deposits on hilltops and hillsides giving way to alluvium in valley bottoms (WSRC 2000). Road cuts and excavations on interstream areas near the SRS commonly expose a deeply developed soil profile. Two horizons are apparent. The A horizon may be up to 3 m thick and typically consists of structureless fine- to medium-grained quartz sand, and the lower B horizon, which may be from 0.6 to 3 m in thickness, contains iron and aluminum compounds leached from the overlying material.

Weathering effects are evident. In some areas, intense weathering has produced tensional soil fractures as a result of volume reduction. These fractures are dominant features in shallow exposures such as drainage ditches or roadside embankments. Average soil erosion rates for the area surrounding the SRS, much of which is cropland, range from 1.5 to 2.0 kg/m^2/yr. The PA provides an estimate predicting that the presence of natural successional forests would reduce erosion by a factor of 400 to 500 over cropland erosion.

Seismology

The susceptibility of the SRS, and particularly E Area, to seismic motion is of interest to establish if E Area is suitable for waste disposal. Seismic events could result in cracking of the encapsulating material. Cracking could be fairly severe if liquefaction of supporting soils were to take place. However, liquefaction of supporting soils is not considered to be a potential problem at the SRS based on a review of previous studies at the SRS. Following is a discussion of seismic zones that are known to exist in the vicinity of the SRS and the expected intensity associated with seismic activity in these zones at the SRS.

Location of Nearby Seismic Zones

The SRS is located in the interior of the North American plate. In the past 200 years, the nearest zones of concentrated seismic activity in the region have been centered in the Charleston-Summerville area of South Carolina and near Bowman, SC, which is 60 km northwest of Summerville, SC. Recent seismic activity in the Charleston area, probably including the earthquake of 1886, has originated largely or entirely in the basement beneath the Coastal Plain sediments. The seismicity in the Charleston area is believed to occur at the intersection of the Ashley River fault and the Woodstock fault, at minimum depths of 4 km and 8 km, respectively. Seismicity associated with the Bowman seismic zone occurs along a border fault of a buried Triassic basin, extending to a depth of about 6-km (WSRC 2000).

Underlying the Coastal Plain sediments of the central and southern portions of the SRS is a Triassic-Jurassic rift basin within the crystalline basement. This basin, called the Dunbarton Triassic basin, is located in the Aiken Plateau, about 50-km southeast of the Fall Line. Associated with this basin on the SRS are at least two faults; the northern border fault and a parallel fault, the Pen Branch fault, which may coincide with the border fault. These faults do not extend upward into post-Oligocene sediments at the SRS.

Faulting has also been recognized in sediments as young as Oligocene in the Atlantic Coastal Plain sediments of South Carolina. Faulting has been postulated to occur in these sediments based on structure-contour mapping of the Eocene-Oligocene unconformity, which lies between 30 and 61 m below the surface, in the vicinity of Charleston, and about 100 km from the SRS. A shallow fault, associated with a 16-km wide graben of Oligocene and Miocene rocks which crosses beneath the Savannah River from Georgia into South Carolina, is postulated about 56 km southeast of the SRS. It is not currently possible to relate these shallow faults to modern earthquakes that occur at depths greater than about 2 km.

Intensities of Historical Earthquakes

The largest known earthquake to affect the site region was the Charleston earthquake of 1886. This Modified Mercalli Intensity (MMI) X earthquake struck Charleston SC, on August 31, 1886. The greatest intensity felt at the SRS has been estimated at MMI VI-VII (felt by all; everyone runs outdoors; damage negligible in buildings of good structure, but considerable in poorly built structures) as a result of the Charleston earthquake. Minor tremors from aftershocks of the 1886 Charleston event were also felt in the area where the SRS is now located. Intensities of these tremors were estimated to be equal to or less than MMI IV.

Seismic activity producing earthquakes of estimated MMI up to V to VII has been present in the Bowman area (about 95-km northeast of the SRS) over the last 200 years. These earthquakes produced acceleration at the SRS of less than 0.1 times the earth's gravitational acceleration. An earthquake (MMI VIII) that struck Union County, SC, about 160-km north-northeast of the SRS in 1913 was felt at Aiken (6-km north-northwest of the SRS) with an MMI of II-III (vibration indoors like a passing truck).

Two earthquakes of MMI III or less have occurred with epicentral locations within the boundaries of the SRS. An MMI III earthquake occurred in June 1985 at the SRS, as did an MMI I-II earthquake in August 1988. Neither of the earthquakes triggered the seismic alarms at the SRS facilities, which are triggered when ground accelerations equal or exceed 0.002 times the earth's gravitational acceleration. The epicenters of these earthquakes appear to be located within about six miles of the intersection of a northwest-trending fault and the northeast-trending border fault at the northern edge of the Dunbarton Triassic basin and are relatively shallow (1 to 3 km below the earth's surface).

Projected Recurrence of Earthquakes

The recurrence interval for a Charleston-size shock (MMI X) for the Charleston area and for the Coastal Plain is on the order of 1,000 years, at the 95 percent confidence level. A recurrence of the 1886 Charleston earthquake would result in an intensity of MMI VII at the SRS. Recurrence of earthquakes associated with other known seismic zones in the region are not expected to be of greater intensity nor cause greater shaking at the SRS (WSRC 2000).

3.1.5 Hydrology

3.1.5.1 Surface Water

The Savannah River cuts a broad valley approximately 76 m deep through the Aiken Plateau, on which most of the SRS sits. The Savannah River Swamp lies in the floodplain along the Savannah River and averages about 2.4 km wide. Upper Three Runs, Fourmile Branch, Tinker Creek, Pen Branch, Steel Creek, and Lower Three Runs are the major tributaries of the Savannah River that occur on the SRS. Three breaches of the natural levee occur at the confluences of the Savannah River with Beaver Dam Creek, Fourmile Branch, and Steel Creek, allowing discharge of these streams to the river. During swamp flooding, water from Beaver Dam Creek and Fourmile Branch flows through the swamp that parallels the river and combines with the Pen Branch flow. Pen Branch joins Steel Creek about 0.8 km above its mouth.

Surface water is held in artificial impoundments and natural wetlands on the Aiken Plateau. Par Pond, the largest impoundment on the SRS, is located in the eastern part of the SRS, covering about 11 km^2. A second impoundment, L Lake, lies in the southern portion of SRS and covers approximately 4 km^2. The waters drain from Par Pond and L Lake to the south via Lower Three Runs and Steel Creek, respectively, into the Savannah River. Lowland and upland marshes and natural and man-made basins on the SRS retain water intermittently.

Near the SRS, the flow of the Savannah River has been stabilized by the construction of upstream reservoirs. The yearly average flow is approximately 300 m^3/s (10,400 cubic feet per second [cfs]) at the point where Highway 301 crosses the river (approximately 20 km downstream of the site). Based on data collected from 1954 to 1988, the minimum average annual flow rate at this location was 150 m^3/s (5,200 cfs) in 1988. From the SRS, river water usually reaches the coast in five to six days but may take as few as three days. At the Beaufort-Jasper water treatment plant, approximately 160-km downstream of the site, the average annual flow rate is estimated to be approximately 450 m^3/s (15,800 cfs).

The watershed of Upper Three Runs drains about 500 km^2 of the Upper Coastal Plain northeast of the Savannah River. Significant tributaries to this creek are Tinker Creek, which is a headwaters branch that comes in northeast of E Area, and Tims Branch, which connects up west of E Area. There are no lakes or flow control structures on Upper Three Runs or its tributaries. The stream channel has a low gradient and is meandering. Its floodplain ranges in width from 0.4 to 1.6 km and is heavily forested with hardwoods.

Upper Three Runs is gauged by the U. S. Geological Survey about 14 km above the confluence with the Savannah River, just above Road C. This location is of interest in this analysis because it is just west of E Area and thus is a point through which radionuclides potentially discharged to Upper Three Runs and tributaries in E Area would pass. The average annual flow at this location, as measured by the U.S. Geological Survey between 1989 and 1992, was approximately 6.2 m^3/s (220 cfs). During the driest of the four years of measurement, the average flow was 4.8 m^3/s (170 cfs). These flow rates reflect contributions of upstream tributaries, including McQueen Branch and others that receive groundwater discharges from E Area. All of the major streams at SRS, including Upper Three Runs and Fourmile Branch, receive groundwater discharge and are gaining streams.

Fourmile Branch has been gauged in the vicinity of E Area, approximately 10 km from its confluence with the Savannah River. Data were collected at this gauging station for approximately four years (1985 through 1988). These data indicate an average annual flow of

0.40 m^3/s (14 cfs) at this location. A minimum annual flow rate during the gauging period of approximately 0.34 m^3/s (12 cfs) was measured in 1988 (WSRC 2000).

3.1.5.2 Groundwater

A discussion of groundwater hydrology must consider all the aquifers and confining units that affect the subsurface distribution of contaminants potentially released from the E-Area LLWF. In this report, the discussion of groundwater hydrology is restricted to hydrostratigraphic units above the Meyers Branch confining system because units below that system are considered protected from contamination. Justification for this assumption is given in the subsection entitled "Meyers Branch Confining System" below.

The nomenclature used in this report to identify hydrostratigraphic units is consistent with Aadland et al. (1995). Two different alphanumeric systems of hydrostratigraphic nomenclature were utilized in the Z- and original E-Area Performance Assessments. These systems are listed in Table 3-3, along with the present nomenclature. The "common" names listed in this table are names that have historically been used for the hydrostratigraphic units and that are utilized in many older documents on this subject. These units, and their hydrologic properties, are defined and described below.

Potentiometric surfaces and particle tracking data provided in the discussion of flow modeling in Section 4.3.3 of the PA support this interpretation of E-Area hydrology (WSRC 2000).

Table 3-3 Hydrostratigraphic Nomenclature

Nomenclature of Aadland et al. 1995	E-Area Nomenclature	Z-Area Nomenclature	Common Nomenclature
Floridan Aquifer System	Aquifer System II		
Upper Three Runs aquifer			
"upper" zone	Aquifer unit IIB, zone 2	Zone 7c/8	Water table unit
"tan clay" zone	Confining unit IIB_1-IIB_2	Zone 7b	Tan clay
"lower" zone	Aquifer unit IIB, zone 1	Zone 6/7a	Barnwell/McBean
Gordon confining unit	Confining unit IIA-IIB	Zone 5b	Green clay
Gordon aquifer	Aquifer unit IIA	Zone 5a	Congaree
Meyers Branch Confining System	Confining System I-II	Zone 4	Ellenton clays

SOURCE:
WSRC 2000

Meyers Branch Confining System

The Meyers Branch confining system overlies the Dublin and Dublin-Midville aquifer systems. Sediments of this Late Cretaceous-Paleocene system correspond to the lignitic clays and interbedded sands of the upper Steel Creek Formation and the laminated clays and shale of the

Lang Syne/Sawdust Landing and Snapp Formations. At the SRS, the Meyers Branch system consists of a single hydrostratigraphic unit, the Crouch Branch confining unit, which includes several thick and relatively continuous (over several miles) clay beds. East of E Area, the Meyers Branch confining system is 41-m thick, 21 m of which are clay beds. The Crouch Branch confining unit constitutes the Meyers Branch confining system over much of the SRS, ranging in thickness from 17 m to 56 m. The updip limit of the Meyers Branch confining system, where the system is no longer a regional confining system, occurs north of the intersection of McQueen Branch and Upper Three Runs streams and runs approximately east to west. North of the updip limit, the Crouch Branch confining unit continues and is considered part of the Floridan-Midville aquifer system (in which all aquifer units above and including the McQueen Branch aquifer are considered layered parts of one aquifer system).

Areas of the SRS which are adjacent to the Savannah River flood plain and the Upper Three Runs drainage systems, including E-Area, exhibit an "upward" gradient across the Crouch Branch confining unit. Hydraulic heads in the underlying Crouch Branch aquifer are higher than those in the overlying Gordon aquifer in these areas, due to the incisement of the overlying aquifer by these two river systems. This area of upward gradient encompasses all of E Area. The magnitude of the upward gradient is about 5 meters in the vicinity of E Area, but the low transmissivity of the Meyers Branch Confining System results in a low water flux into the Gordon Aquifer. Thus, in E Area, the confining nature of the Crouch Branch confining unit along with the head-reversal phenomenon, provides a natural protection of aquifers beneath the Floridan aquifer system from contamination.

Floridan Aquifer System

Because of relative hydrologic isolation due to the Meyers Branch confining system, only the Floridan aquifer system is of interest in the performance assessment and special analysis of potential groundwater contamination from operations at E Area. The Floridan aquifer system is comprised of the lowermost Gordon aquifer unit, the Gordon confining unit, and the uppermost Upper Three Runs aquifer unit, which contains the water table.

Gordon Aquifer Unit The Gordon aquifer unit overlies the Crouch Branch confining system and is approximately 23 m thick at E Area. The aquifer consists of sandy parts of the Late Paleocene-Early Eocene Snapp, Fourmile, and Congaree Formations. Sands and clayey sands of the Gordon aquifer unit are largely yellow to orange in color and consist of fine- to coarse-grained, subangular to subrounded quartz. The sands range from well to poorly sorted. Locally confining clay beds are present, as are pebbly zones. The unit dips at 1.5 to 1.7 m/km to the south and southeast and thickens in the western portion of E Area and to a minor extent to the southeast (WSRC 2000).

The hydraulic gradient in the Gordon aquifer across the SRS is generally from northeast to southwest, averaging 0.9 m/km, towards the Savannah River. However, the potentiometric surface (Aadland et al. 1995) indicates considerable deflection of the contours due to incisement of aquifer sediments by Upper Three Runs, such that flow from E Area is westerly. Potentiometric surfaces demonstrating this trend are provided in Section 4.3.3 of the PA (WSRC 2000). Based on measurements and modeling (Aadland et al. 1995), an average horizontal hydraulic conductivity of 1×10^{-2} m/s is reported for this unit.

Gordon Confining Unit The Gordon confining unit separates the underlying Gordon aquifer unit from the Upper Three Runs aquifer unit. This confining unit is informally known as the "green clay." It is comprised of the fine-grained glauconitic sand and clay beds of the Middle Eocene

Warley Hill Formation and the micritic limestone of the Tinker/Santee Formation. Thickness of the Gordon confining unit in the vicinity of the SRS varies from 1.5 to 25 m. In the vicinity of E Area, it is from 0.6 to 9 m thick. Recent studies indicate the unit is composed of several lenses of green and gray clay that thicken, thin, and pinch out abruptly. Extensive carbonate sediments associated with areas of thin or truncated clay beds are present in E Area.

Leakance coefficients, estimated from modeling and pump tests, indicate an updip limit of the Gordon confining unit at the SRS that runs southwest to northeast along Upper Three Runs and Tinker Creek. Southeast of this limit, leakances are relatively low except in areas associated with extensive faulting. Laboratory- and model-derived vertical hydraulic conductivities in E Area are on the order of 5×10^{-10} m/s (Aadland et al. 1995), suggesting that the Gordon confining unit is an effective aquitard in this region. Horizontal hydraulic conductivities ranging from 1.4×10^{-10} to 1.6×10^{-9} m/s have been determined from laboratory tests. A map of hydraulic head differences across the Gordon confining unit (Aadland et al. 1995) shows a downward gradient in the vicinity of Upper Three Runs and the Savannah River.

Upper Three Runs Aquifer Unit The Upper Three Runs aquifer unit overlies the Gordon confining unit and is the water table unit. This unit includes the sandy sediments of the Tinker/Santee Formation and all the heterogeneous sediments in the Late Eocene Barnwell Group. In the center of the SRS, the aquifer unit is 40 m thick. In E Area, the aquifer unit is divided into three hydrostratigraphic zones with respect to hydraulic properties (Aadland et al. 1995): a "lower" zone, a "tan clay" locally-confining zone, and an "upper" aquifer zone (the water table zone).

In E Area, the "lower" aquifer zone occurs between the overlying "tan clay" confining zone and the Gordon confining unit. It consists of sand, clayey sand, and calcareous sand of the Tinker/Santee Formation and of the lower part of the Dry Branch Formation. Groundwater that leaks across the "tan clay" confining zone recharges this zone. Most of the recharge water moves laterally toward the bounding streams that incise this zone; the remainder flows vertically downward across the Gordon confining unit. Hydraulic conductivity of the "lower" zone has been estimated for the E-Area vicinity by several methods: slug tests, pumping tests, minipermeameter test, and sieve analyses. Average values for the various methods range from 3×10^{-6} m/s to 6×10^{-4} m/s. The lower values are based on pumping tests, and the higher values are based on sieve analyses. The large discrepancy between the two methods suggests that large-scale heterogeneities, not sample-in-sieve-analysis techniques, are important in determining conductivity.

The "tan clay" confining zone is a leaky confining zone, ranging in thickness from 0 to 10 m throughout the E-Area vicinity. The average thickness is about 3 m. The clay beds of this confining zone, when present, generally support a head difference (up to 5 m) in E Area between the "upper" and "lower" aquifer zones of the Upper Three Runs aquifer unit and thus retard the movement of water downward across this zone. Laboratory analyses of undisturbed samples of the "tan clay" confining zone yielded a range of hydraulic conductivities from 6×10^{-11} to 5×10^{-7} m/s in the horizontal direction and 1×10^{-11} to 4×10^{-7} m/s in the vertical direction (Aadland et al. 1995).

In E Area, the "upper" aquifer zone consists of the silty sands of the Irwinton Sand Member of the Dry Branch Formation overlain by the clayey sands of the Tobacco Road Formation. The water table occurs in the "upper" zone. This zone overlies the "tan clay" confining zone, when present, or the "lower" aquifer zone when the confining zone is absent. Units below the "upper" aquifer zone are always saturated, so the "upper" aquifer is not a perched system. Slug tests, minipermeameter tests, pumping tests, and sieve analyses have been used to estimate hydraulic conductivity of the "upper" zone in the vicinity of E Area (Aadland et al. 1995). The average hydraulic conductivity estimates for the "upper" aquifer zone ranged from 2×10^{-6} to 5×10^{-4} m/s for the various methods.

Three streams on site, Upper Three Runs to the north of E Area, McQueen Branch (a tributary of Upper Three Runs) to the northeast, and Fourmile Branch to the south, are natural boundaries to groundwater flow in the Upper Three Runs aquifer unit. All creeks cut into this, and thus groundwater is either intercepted by the creeks or recharges the underlying Gordon aquifer unit. A groundwater divide occurs in this water table unit due to the influence of these streams.

Hydrologic Characteristics of the Vadose Zone

The vadose zone extends from the ground surface downward to the water table. Hydraulic characteristics of unsaturated soil in E Area were most recently investigated by Core Laboratories, Inc., in Carollton, Texas (WSRC 2000). Capillary pressure vs. water saturation relationships and relative permeability vs. water saturation relationships were developed for field samples of topsoil, gravel, two clays, sand, and backfill to provide a range of analyses for various vadose zone materials found, or planned for use, in the E-Area LLWF. Saturated hydraulic conductivity of topsoils was measured to be on the order of 10^{-5} m/s, with porosity on the order of 0.40. Saturated hydraulic conductivity of gravels and clays were measured to be on the order of 10^{-1} and 10^{-8} m/s, respectively, with respective porosities of 0.38 and 0.56.

3.1.6 Geochemistry

Geochemical aspects of the disposal site are not evaluated nor used directly in assessing radionuclide migration. Rather, site-specific sorption coefficients, which are affected by pH and other geochemical conditions, are used when available. Geochemical modeling conducted for the E-Area PA (WSRC 2000) was restricted to the vault environment and thus is not pertinent to the present discussion of disposal site characteristics.

3.1.7 Natural Resources

3.1.7.1 Geologic Resources

The only material of significance as a geologic resource in the vicinity of the SRS is kaolin clay. About 90 percent of the U. S. production of kaolin at one time came from a district in Georgia and South Carolina that includes Aiken County. Commercial deposits occur as lenses in the Lang Syne Formation along the Fall Line bordering the northwestern edge of the Coastal Plain (WSRC 2000).

At E Area, the Lang Syne Formation is at a depth greater than 100 m from the ground surface, making commercial exploration unlikely due to the large amount of overburden that would have to be removed to exploit a deposit.

3.1.7.2 Water Resources

The South Carolina Department of Health and Environmental Control (SCDHEC) has been delegated authority by the United States Environmental Protection Agency (USEPA) to implement and enforce the requirements of the Clean Water Act for the State of South Carolina. SCDHEC therefore is responsible for maintaining the chemical and biological integrity of all state waters, including those on federal reservations such as SRS. It does this by enforcing a system of water quality standards and by regulating all point-source discharges through the National Pollutant Discharge Elimination System (NPDES) program. SCDHEC is the principal regulatory authority for water quality issues on the SRS.

Surface Water

The Savannah River is the principal surface water system associated with the SRS. Five of its major tributaries (Upper Three Runs, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs) flow through and drain the SRS. Mean annual flow at river mile 187.4, approximately 12 miles south of Augusta, GA, during the period 1984 to 1996 was 16,580 cfs. The Savannah River serves as a domestic and industrial water source for the SRS and several downstream communities (the cities of Port Wentworth and Savannah in Georgia and Beaufort and Jasper counties in South Carolina). The intakes for these downstream water systems are located at river miles 29 and 39.2, respectively. In addition, the Vogtle Electric Generating Plant, located across the river from the SRS, uses the Savannah River for cooling water, withdrawing an average of 46 cfs. Table 3-4 characterizes Savannah River water quality both up- and downstream of the SRS. Table 3-5 characterizes water quality in SRS streams (WSRC 2000).

Groundwater

Within 20 miles of the SRS, there are more than 56 major municipal, industrial, or agricultural groundwater users that consume approximately 36 million gallons of water per day. Total SRS groundwater (domestic and process water) use ranges from 9 to 12 million gallons per day. At the SRS, only the deeper aquifers (Crouch Branch and McQueen Branch) are used as groundwater sources.

Under most of the SRS, the quality of groundwater is considered to be good. The pH for SRS groundwater ranges from 4.9 to 7.7 and the water is generally soft. Concentrations of dissolved and suspended solids are low, but iron concentrations are elevated in some of the aquifers. At the SRS, approximately 5 to 10 percent of the shallow aquifer system has been contaminated with tritium, industrial solvents, metals, and other chemicals (WSRC 2000).

Table 3-4 Water Quality in the Savannah River Upstream and Downstream from SRS (Calendar Year 1996)[a,b]

Parameter	Unit of measure[c]	MCL[d,e] or DCG[f]	Upstream		Downstream	
			Minimum	Maximum[g]	Minimum	Maximum
Aluminum	mg/L	0.05-0.2[h]	0.15	0.71	0.16	79
Ammonia	mg/L	NA[i,j]	ND	0.27	ND	0.33
Cadmium	mg/L	0.005[d]	ND[k]	ND	ND	ND
Chemical oxygen demand	mg/L	NA	ND	22	ND	20
Chloride	mg/L	250[h]	4	9	4	9
Chromium	mg/L	0.1[d]	ND	ND	ND	0.011
Copper	mg/L	1.3[l]	ND	ND	ND	ND
Dissolved oxygen	mg/L	>5.0[m]	6.4	11.5	6.2	13
Fecal coliform	colonies/.1L	1,000[m]	Nr[n]	300	Nr[n]	1,100
Gross alpha radioactivity	pCi/L	15[d]	<0.62[o]	0.7	<0.62[o]	0.97
Lead	mg/L	0.015[l]	ND	ND	ND	ND
Mercury	mg/L	0.002[d,e]	ND	0.0005	ND	0.0003
Nickel	mg/L	0.1[d]	ND	ND	ND	ND
Nitrite/nitrate (as N)	mg/L	10[d]	0.24	0.47	0.24	0.51
Nonvolatile (dissolved) beta radioactivity	pCi/L	50[d]	<1.6	3.	<1.6	2.8
pH	pH units	6.5-8.5[h]	5.8	6.8	5.5	7
Phosphate	mg/L	NA	ND	ND	ND	ND
Sulfate	mg/L	250[h]	4	9	5	10
Suspended solids	mg/L	NA	6	36	8	23
Temperature	°F	90[p]	44	76	42	78
Total dissolved solids	mg/L	500[h]	51	72	58	76
Tritium	pCi/L	20,000[d,e]	<410	450	520	2,200
Zinc	mg/L	5[h]	ND	0.029	ND	0.046

NOTES:

a. Source: WSRC 2000.
b. Parameters are those USDOE routinely measures as a regulatory requirement or as part of ongoing monitoring programs.
c. mg/L = milligrams per liter; a measure of concentration equivalent to the weight/volume ratio.
d. Maximum Contaminant Level (MCL), USEPA National Primary Drinking Water Standards (40 CFR Part 141).
e. Maximum Contaminant Level (MCL), SCDHEC (1976).
f. USDOE Derived Concentration Guides (DCGs) for water (USDOE Order 5400.5, “Radiation Protection for the Public and the Environment”). DCG values are based on committed effective dose of 100 millirem per year for consistency with drinking water MCL of 4 millirem per year.
g. Minimum concentrations of samples. The maximum listed concentration is the highest single result found during one sampling event.
h. Secondary Maximum Contaminant Level (SMCL), USEPA National Secondary Drinking Water Regulations (40 CFR Part 143).
i. i. NA = none applicable.
j. Dependent upon pH and temperature.
k. ND = none detected.
l. Action level for lead and copper.
m. WQS = water quality standard.
n. Only fecal coliform bacteria exceedances are reported.
o. Less than (<) indicates concentration below lower limit of detection (LLD).
p. Shall not exceed weekly average of 32.2°C (90°F) after mixing nor rise more than 2.8°C (5°F) in 1 week unless appropriate temperature criterion mixing zone has been established.

pCi/L = picocuries per liter; a picocurie is a unit of radioactivity; one trillionth of a curie.

Table 3-5 Water Quality in Selected SRS Streams

Sampling location		Temperature (°F)	pH	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (NTU)	Total suspended solids (mg/L)
Upper Three Runs at Road A (1996)	Mean	63	6.35	8.21	24.3	13.55	13.33
	Range	45.3-74.3	6-7	6.5-12.7	21-29	3.2-65	3-51
Upper Three Runs at Road A (1987-1991)	Mean	66.7	6.08	8.36	24.5	5.24	10
	Range	NA	NA	4.9 - 12	3.0 - 41	1.0 - 22	2- 97
Upper Three Runs at Road 8-1 (1996)	Mean	61.5	6.03	8.29	48.2	5.60	9
	Range	49.6-71.2	5.3-6.8	5.2-10.2	3-140	1.6-11	2-15
Crouch Branch at Road 4 (1996)	Mean	64.9	6.06	7.13	37.9	26.23	16
	Range	46.4-76.6	5.4-6.4	5.2-8.5	22-50	3.4-130	4-76
Lower Three Runs at Patterson Mill (1996)	Mean	64	6.29	7.49	84.5	4.28	9
	Range	49.3-80.6	6-7	5.8-10.6	60-120	1.2-9.8	2-24
Lower Three Runs at Patterson Mill (1987-1991)	Mean	64.4	NA	8.0	75	2.8	5
	Range	45.9-84.2	5.9 - 7.4	5.8 - 11	13 - 140	0.94 - 38	1 - 34

NOTES:
NA = Not available
SOURCE:
WSRC 2000

3.2 Facility Characteristics

3.2.1 Water Infiltration and Disposal Unit Cover Integrity

As outlined in section 2.5, a water infiltration rate of 40 cm/year past the evapotranspiration zone of the soil column is assumed under pre-capping conditions in the PA. Based upon this infiltration rate a flow rate through the closure cap and subsequently the disposal unit is calculated for the time period that the disposal unit and closure cap are assumed to be intact. At the assumed time of disposal unit and closure cap failure, the infiltration rate is assumed to revert back to 40 cm/year. Infiltration into the waste is impacted not only by the closure cap, but also by the design characteristics of the individual disposal units. Therefore the interim/operational closure of each type of disposal unit and the final closure of the entire E-Area LLWF are discussed in the sections below in relation to water infiltration and disposal unit cover integrity.

3.2.1.1 Low-Activity Waste Vaults

Interim/operational closure of the Low-Activity Waste Vaults (LAW Vaults) will be conducted in stages. Individual cells within a reinforced concrete vault will be closed as they are filled with metal and/or concrete containers of waste and the entire vault will be closed as it is filled. Such interim/operational closure includes the sealing of cell and/or vault opening with reinforced concrete. The reinforcing steel will be tied into the reinforcing steel of the cell and/or vault itself, forming a unified structure. Additionally as part of the interim/operational closure the roof slab will be covered with a bonded-in-place layer of fiberboard insulation and a layer of waterproof membrane roofing.

Final closure of the LAW vaults will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the LAW Vaults is assumed to remain intact until the calculated time of LAW Vault failure. At which time both the LAW Vault and overlying closure cap are assumed to fail and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1. For the LAW Vaults failure has been calculated to occur 3,100 years after final closure.

The potential for increased infiltration due to subsidence at the time of roof collapse is addressed in the PA in Section 5.4 (WSRC 2000). This PA evaluation shows that increasing infiltration by a factor of three causes an increase in amount of a radionuclide released ranging from 0 to 2.6 times.

3.2.1.2 Intermediate-Level Vaults

Interim/operational closure of the Intermediate-Level Vaults (IL Vaults) will be conducted in stages. Metal and/or concrete containers of waste are stacked in layers in each cell within the reinforced concrete vault. After a layer of waste containers is placed in a cell, grout will be poured to encapsulate the containers and form a surface for emplacement of the next layer of containers. One cell is used to dispose of tritium crucibles in silos. The tritium crucibles are place in vertical silos and concrete plugs are placed above the filled silos. After being filled with waste and layers of grout, each cell will be covered with a top layer of grout. After all cells have been filled with waste and grout, a thick reinforced concrete roof slab will completely cover all cells of the IL Vault. The roof slab will be covered with a bonded-in-place layer of fiberboard insulation and layer of waterproof membrane roofing.

Final closure of the IL Vaults will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the IL Vaults is assumed to remain intact until the calculated time of IL Vault failure. At which time both the IL Vault and overlying closure cap are assumed to fail hydraulically and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1. For the IL Vaults failure has been calculated to occur 1,050 years after final closure.

3.2.1.3 Engineered Trenches

Interim/operational closure of the Engineered Trenches will be conducted in stages. Metal containers of waste (typically B-25 boxes) are stacked in rows four high (approximately 17 feet high) within the gravel lined Engineered Trench. As a sufficient number of B-25 rows are placed, clean soil is bulldozed over some of the completed rows so that the rows are covered with a minimum 4-foot interim soil cover. This interim soil cover is only applied to that portion of the completed rows that still allows maintenance of a safe distance from the working face (i.e. where new boxes are placed in the stack) within the trench. The interim soil cover is graded to provide positive drainage off the trench and away from the working face. Placement of the B-25 boxes continues until the trench is filled with boxes. At that point the minimum 4-foot interim soil cover is placed over the remaining portion of the trench, and the entire area is graded to provide positive drainage off the trench. (WSRC, 2001)

Final closure of the Engineered Trenches will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the Engineered Trench will be assumed to remain intact until the estimated time of Engineered Trench failure, which is assumed to occur due to the corrosion and subsequent structural collapse of the metal containers. At which time both the Engineered Trench and overlying closure cap are assumed to fail and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1. For the Engineered Trench failure has been assumed to occur “200 to 300 years after burial for B-25s that are not dynamically compacted.” (WSRC, 2001) Additional work is currently in progress to better estimate the anticipated time period of B-25 structural collapse following burial.

3.2.1.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

Interim/operational closure of the Slit Trenches will be conducted in stages. Placement of bulk and containerized waste in a Slit Trench typically begins at one end of the trench and proceeds toward the other end. Bulk waste is pushed into the trench from one end. Containerized waste is typically placed in one end of the trench with a crane. Eventually containerized waste areas of the trench are filled in with either bulk waste or clean soil to fill the voids between adjacent containers and the trench wall. Slit trenches are typically filled to within four feet below the top of the trench with waste. Once a section of the slit trench is filled, clean soil is used to provide a minimum 4-foot an interim soil cover. The interim soil cover is graded to provide positive drainage off and away from the disposal operation. Subsequent trench sections are filled with waste, covered with an interim soil cover, and graded to promote positive drainage until the entire trench is filled. The only mechanical compaction that the soil and waste in the trench receive is from the bulldozer and other heavy equipment moving over the top of a completely backfilled trench. No equipment is allowed in the trench.

Final closure of the Slit Trenches will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the Slit Trenches is assumed to remain intact during the 100-year institutional control period, following final closure of the entire E-Area LLWF, during which active maintenance of the closure cap is assumed to occurs. At the end of the institutional control period both the Slit Trench and overlying closure cap are assumed to fail and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1.

3.2.1.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

Interim/operational closure of Components-In-Grout Trenches consists of the placement of large equipment in the trench, its encapsulated with grout or other cementitious backfill, and the placement of a minimum 4-foot interim soil cover over the encapsulated waste. The interim soil cover is graded to provide positive drainage off and away from the trench.

Final closure of the Components-In-Grout Trenches will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the Components-In-Grout Trenches is assumed to remain intact until the calculated time of Components-In-Grout Trench failure. At which time both the Components-In-Grout Trench and overlying closure cap are assumed to fail hydraulically and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1. For the Components-In-Grout Trenches failure has been assumed to occur 300 years after interim/operational closure.

3.2.1.6 Naval Reactor Component Disposal Pads

Interim/operational closure of the above grade Naval Reactor Component Disposal Pads simply consists of the placement of the steel Naval Reactor Waste Disposal Casks containing the naval reactor components on the pad. A gasket or welds are used to closure the casks.

Final closure of the Naval Reactor Component Disposal Pads will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the Naval Reactor Component Disposal Pads is assumed to remain intact until the assumed time of the Naval Reactor Waste Disposal Cask hydraulic failure. At which time both the casks and overlying closure cap are assumed to hydraulically fail and infiltration is assumed to revert back to that of pre-capping conditions as discussed in section 3.2.1. For the Naval Reactor Component Disposal Pads hydraulic failure has been assumed to occur 750 years after final closure.

3.2.2 Structural Stability and Inadvertent Intruder Barrier

3.2.2.1 Low-Activity Waste Vaults

The LAW Vault features that promote structural stability until roof collapse (Appendix D of the PA [WSRC 2000]) are:

- The vaults are on-grade, reinforced concrete structures within an excavated area. The walls are structurally mated to a 30-inch footer that is continuous under all cells in each module. The vaults have no liners attached to them. The vaults are designed to withstand Design Basis Accident loads (as specified in Project S2889) and therefore assure continued structural stability.

- Upon filling the cells with waste, the exterior access opening is sealed with cast-in-place concrete to form a continuous wall.

- The entire vault is covered with a reinforced concrete roof slab, supported on pre-cast concrete beams. The roof slab will be covered with a bonded-in-place layer of fiberboard insulation and a layer of waterproof membrane roofing.

The roof slab and pre-cast beams ensure structural stability for about 3,100 years after final closure. They also provide a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating the roof structure.

Final closure of the LAW Vaults will be included in the final closure of the entire E-Area LLWF, which will consist of construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. It has been estimated that a full LAW Vault has a void volume of approximately 50 percent. However, this void volume does not impact the structural stability of the LAW Vaults until the walls and roof weaken to the point of collapse. At that time both the LAW Vaults and overlying closure cap are assumed to structurally fail (i.e. subsidence occurs).

3.2.2.2 Intermediate-Level Vaults

The IL Vault features that promote structural stability are:

- The vaults are below-grade reinforced concrete structures. All walls are structurally mated to 2 1/2-foot thick concrete slabs that extend approximately 2 feet beyond the outside of the exterior walls. The vaults are designed to withstand loads imposed by Design Basis Accidents (as specified in Project S2889) and therefore assure continued structural stability.

- Waste is containerized in engineered metal containers before being brought to the vault. The containers are stacked in layers. After a layer of waste containers is placed in a cell, grout will be poured to encapsulate the containers and form a surface for emplacement of the next layer of containers.

- One vault cell is used to dispose of tritium crucibles in silos. The tritium crucibles are place in vertical silos and concrete plugs are placed above the filled silos.

- After being filled with waste and layers of grout, the vault will be covered with a top layer of grout. A thick (thickness varies from 2-feet–3 inches to 3-feet–2 inches) reinforced concrete roof slab will completely cover all nine cells of the IL Vault. The roof slab will extend over and around the cell-wall stubs and will be covered with a bonded-in-place layer of fiberboard insulation and layer of waterproof membrane roofing.

Structural stability of the IL Vault roof is expected for about 1,050 year after final closure. They also provide a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating the roof structure.

Final closure of the IL Vaults will be included in the final closure of the entire E-Area LLWF, which will consist of construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. It is assumed that a full IL Vault has very little void volume and therefore the loss of structural stability of the IL Vault roof does not necessarily imply structural collapse of the vault and subsequent subsidence. Even though structural collapse and subsequent subsidence are not anticipated at the time of IL Vault roof structural stability loss, the PA assumes that that portion of the closure cap overlying the IL Vaults fails hydraulically at that time as outlined in section 3.2.1.2.

3.2.2.3 Engineered Trenches

Engineered Trenches are gravel lined and designed to accommodate vehicular traffic. Engineered Trenches are filled with metal containers of waste (typically B-25 boxes) stacked in rows four high (approximately 17 feet high). The containers are stacked one on top of another and the stacks of containers are generally placed immediately adjacent to one another with very little void space between the stacks. During placement of the interim soil cover the lid of the top B-25 box in a stack is assumed to collapse into the box and the lower three boxes in the stack are assumed to remain undamaged. At that point the matrix of B-25 boxes provides significant structural stability to the Engineered Trench.

It has been estimated that an Engineered Trench, containing B-25 boxes of waste stacked four high which have not been processed through the Supercompactor Facility (SCF), has a subsidence potential of approximately 13.6 feet. It has also been assumed that B-25 boxes that have not been dynamically compacted will structurally collapse 200 to 300 years after burial due to corrosion. (WSRC 2001) At that point the Engineered Trench and that portion of the closure cap overlying the trench is assumed to fail due to the estimated 13.6 feet of subsidence potential. The B-25 boxes are assumed to provide a barrier to inadvertent human intrusion prior to the time of their structural collapse.

Static surcharging and dynamic compaction have been methods utilized at other SRS waste disposal sites to reduce the subsidence potential associated with trenches containing stacked B-25 boxes prior to installation of closure caps. This prior static surcharging and dynamic compaction was conducted soon after disposal. However it has been estimated that such prior static surcharging and dynamic compaction has only reduced the subsidence potential of those trenches by approximately 19.4 and 32 percent, respectively. The low efficiency of these methods to previously reduce subsidence potential was due to the initial inherent structural stability of the matrix of B-25 boxes prior to significant corrosion. However over time the structural stability of the matrix of B-25 boxes will be degraded due to corrosion of the boxes, and therefore use of static surcharging and dynamic compaction will become more efficient over time. (WSRC 2001)

Additional work is currently in progress to better estimate the anticipated time period of B-25 box structural collapse following burial. Additionally the timing of the use of static surcharging and/or dynamic compaction on the Engineered Trenches to achieve more efficient results is also currently in progress. The use of static surcharging may be required prior to installation of the closure cap to fill in void spaces between stacks of boxes in order to minimize closure cap maintenance during the 100-year institutional control period. Static surcharging may help to eliminate voids between containers, which could potentially cause subsidence during the institutional control period.

3.2.2.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

The Slit Trenches do not have features that provide structural stability nor a barrier to inadvertent human intrusion. That portion of the closure cap overlying the Slit Trenches is assumed to fail at the end of the institutional control period, 100 years after final closure of the entire E-Area LLWF.

Subsidence may occur within Slit Trenches either due to the degradation and volume reduction of readily degradable materials or to the collapse of containers containing significant void space. It is anticipated that the bulk of the Slit Trench subsidence will occur during the 100-year institutional control period. However subsidence due to the collapse of container containing significant void space could occur beyond the institutional control period, as anticipated for the Engineered Trenches containing B-25 boxes. The subsidence potential of the slit trenches has not been estimated, and it is assumed to be highly variable. It is assumed in the PA that damage to the closure cap due to subsidence will be repaired during this period. A sensitivity analysis was also conducted to evaluate the effect of increased infiltration due to subsidence on disposal trench performance. This analysis indicated that the effects on flux of tripling the infiltration ranged from almost no effect for certain radionuclides to an increase of approximately two times for other radionuclides.

Dynamic compaction has been a method utilized at other SRS waste disposal sites to reduce the subsidence potential associated with Slit Trenches prior to installation of closure caps. The use of dynamic compaction on the slit trenches, to minimize the closure cap maintenance required during the 100-year institutional control period, will be evaluated.

3.2.2.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

Components-In-Grout Trenches contain large equipment encapsulated with grout or other cementitious backfill that have been covered with a minimum 4-foot interim soil cover. Final closure of the Components-In-Grout Trenches will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. The cement-stabilized encapsulated wasteform is likely to maintain its structural stability for 300 years after interim/operational closure, thus maintaining the stability of the closure cap and deterring inadvertent human intrusion into the waste during this time period. It is assumed that a Components-In-Grout Trench has very little void volume and therefore the loss of structural stability does not necessarily imply structural collapse of the trench and subsequent subsidence. Even though structural collapse and subsequent subsidence are not anticipated at the time of Components-In-Grout Trench structural stability loss, the PA assumes that that portion of the closure cap overlying the Components-In-Grout Trenches fails hydraulically at that time as outlined in section 3.2.1.5.

3.2.2.6 Naval Reactor Component Disposal Pads

The steel Naval Reactor Waste Disposal Casks are closed with a gasket or welds, contain naval reactor components, and are placed on the Naval Reactor Component Disposal Pads. Final closure of the above grade Naval Reactor Component Disposal Pads will take place at final closure of the entire E-Area LLWF, which will occur at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). Final closure will consist of construction of an integrated closure system. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0.

In the PA, that portion of the closure cap overlying the Naval Reactor Component Disposal Pads is assumed to remain intact until the assumed time of the Naval Reactor Waste Disposal Cask hydraulic failure which has been assumed to occur 750 years after final closure. At which time both the casks and overlying closure cap are assumed to hydraulically fail. However due to the strength requirements of the Naval Reactor Waste Disposal Casks for transportation of the Naval Reactor components, it is expected that these containers will maintain structural stability and deter inadvertent human intrusion for 10,000 years after final closure. The subsidence potential of the Naval Reactor Component Disposal Pads has not been estimated, and it is assumed to be highly variable.

3.3 Waste Characteristics

Low-level radioactive solid waste may be characterized and segregated into three categories. The disposition of waste in the E-Area LLWF will be based on these categories. The waste categories are as follows:

1) Low-activity waste

2) Intermediate-level waste

3) Naval Reactor components.

Low-activity waste will be disposed in the LAW Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Cement-Stabilized Encapsulated Waste Dsiposal Trenches (Components-In-Grout Trenches). Intermediate-level waste will be disposed in the Intermediate-Level Vaults. Naval Reactor components will be disposed in the Naval Reactor Components Disposal Pads.

Estimated radionuclide inventories for each of the disposal units are provided in the PA. For those disposal units that have an operational history (i.e., LAW Vault, IL Vault, and Slit Trenches), the actual inventory as of 6/1/98 was used to develop a concentration value for each radionuclide; the concentrations were then applied to the forecasted waste volume to estimate the forecasted inventory. The inventory for the Engineered Trenches was not forecast in revision 1 of the PA. The inventory for the Components-In-Grout Trenches was derived from information available on currently stored equipment that will be considered for such disposal. The projected inventory for the Naval Reactor Components Disposal Pads was derived from forecasted waste volumes provided by USDOE-NR.

3.3.1 Low-Activity Waste Vaults

3.3.1.1 Waste Type/ Chemical and Physical Form

The LAW will include job control waste, scrap metal, and contaminated soil and rubble. Job control waste will consist of potentially contaminated protective clothing including plastic suits, shoe covers, lab coats, and plastic sheeting. Scrap metal will be contaminated tools, process equipment, and laboratory equipment. Soil and rubble will be generated from demolition and cleanup activities. Historically, the majority of this waste has been generated by the High-Level Waste (HLW) tank farms.

The radioactive content of LAW is primarily fission products from the tank farms and Separations. Waste will also be received from offsite facilities, which will have a variety of radionuclides.

3.3.1.2 Radionuclide Inventory

The radiation dose rate measured at 5 cm from the surface of an unshielded container is less than 200 mR/hr for containers destined for the E-Area LLWF (LAW Vault). The transuranic activity concentration for the LAW Vault is less than 100 nCi/g of alpha activity.

The 20-year projected inventory for the LAW Vault is provided in the PA.

3.3.1.3 Waste Volume

The LAW Vault provides approximately 4.8×10^4 m^3 of LAW capacity. Provided that curie inventory limits are not exceeded, waste volumes may approach that capacity for the LAW Vault during the period of operation.

3.3.1.4 Packaging Criteria

All LLW is subject to the packaging requirements of the 1S Manual. Most of the LAW will be received in standard 1.2 m × 1.2 m × 1.8 m metal containers (B25 boxes), but some waste will also be received in standard 0.6 m × 1.2 m × 1.8 m containers (B12 boxes). The LAW may also receive waste in non-standard engineered concrete or metal containers. These containers shall be pre-approved by Solid Waste Management prior to their receipt at the E-Area LLWF.

Many different containers will be received at the E-Area LLWF. However, all containers are required by the Technical Safety Requirements (TSRs) to be engineered concrete or metal containers that have been approved by Solid Waste. A procedure has been written that defines this approval process and requires Solid Waste Management Engineering, Solid Waste Management Operations, and Solid Waste Management Maintenance to concur that the container can be safely handled, will not impair vault space utilization, and will satisfactorily contain the waste contents.

The B25 and B12 containers are carbon steel boxes that have been used in the past for waste disposal in the Solid Waste Disposal Facility (SWDF). The boxes are similar in construction with the exception of size. The B25 is a 2.5 m^3 container that is approximately 1.2 m high, 1.2 m wide, and 1.8 m long. It is typically constructed of 14-gauge carbon steel (1.9 mm) but some B25s are constructed of 12-gauge carbon steel (2.6 mm) to allow use in the compactor. The B12 is a 1.3 m^3

container that is approximately 0.6 m high, 1.2 m wide, and 1.8 m long and is constructed of either 12-gauge or 14-gauge carbon steel.

The B12 and B25 containers are constructed with a rubber-gasket seal between the lid and the container with a gasket compression of 20 to 30 percent. The interior and exterior of each container is coated with a zinc chromate primer. The exteriors are given an additional coating of alkyd enamel as a finish coat of paint.

A variety of drums, corresponding to international drum specifications, will also be received as standard containers. Use of these containers is restricted to situations where use of a B25 is not practical. Drums will be banded together and banded to a fire-resistant pallet prior to shipment to the E-Area LLWF.

For waste that cannot be placed in a standard container, specific size and weight limits have been specified. Maximum dimensions for containers in the LAW Vaults are 4.3 m high $\times$ 7.3 m wide $\times$ 15.2 m long. The maximum dimensions for containers in the IL Vaults are 7.3 m high $\times$ 10.7 m long $\times$ 6.1 m wide. The maximum uniform load on the vault floor cannot exceed 4.9×10^6 kg/m^2 for the IL Vaults and 2.8×10^6 kg/m^2 for the LAW Vaults.

3.3.1.5 Pre-Disposal Treatment Methods

Many LAW containers, upon receipt at the E-Area LLWF, were opened, and the contents were sorted at the Waste Sort Facility (WSF). The compactible fraction was compressed with a super-compactor in the Supercompactor Facility (SCF) prior to disposal. It is anticipated that the WSF/SCF will be permanently shut down after fiscal year 2002.

3.3.1.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the LAW Vaults must conform to criteria put forth in the SRS Waste Acceptance Criteria (WAC) [WSRC 1999].

3.3.2 Intermediate-Level Vaults

3.3.2.1 Waste Type/ Chemical and Physical Form

The IL Vault will be used for disposal of IL waste. Intermediate-level waste consists of job control waste, scrap hardware, and contaminated soil and rubble. Job control waste is primarily highly contaminated lab coats, plastic suits, shoe covers, plastic sheeting, etc. This material is assumed to be combustible and is contaminated primarily with fission products. Scrap hardware consists of reactor hardware, reactor fuel fittings and target fittings, jumpers, and used canyon and tank farm equipment contaminated with fission products and/or induced activity.

All of the IL waste will be packaged in engineered metal or concrete containers that have been approved by Solid Waste Management. The containers will be remotely placed into the vault in layers. IL waste containers will be grouted in place to provide better waste isolation, reduce dose to operators, and improve stacking of additional containers.

Tritiated waste will be disposed in the ILT portion of the IL Vault. This portion consists of two cells, one for each of the two subcategories of tritiated waste. Tritium crucibles will be disposed of in the first cell. This wasteform is generated by the tritium facilities in the process used to recover tritium from target assemblies. The crucibles will be over-packed into a stainless-steel container that is 0.46-m in diameter and 6.1 m in length. The crucible cell is specially designed with vertical silos to receive waste. All other tritiated waste will be disposed of in the bulk tritiated waste cell. This waste will consist of job control waste and used process equipment that is contaminated with tritium. Bulk tritiated waste will be disposed of in engineered metal or concrete containers.

Depending on the origin of this waste, it can contain either fission products or induced activity contamination. The induced activity waste will be mostly metal reactor hardware and fittings that have been exposed to a high neutron field. This waste generates a high radiation field but the activity is fairly immobile due to the metal matrix. Job control waste and process piping from Separations and High Level Waste Management will be contaminated with fission products. These fission products will be both loose and fixed surface contamination.

3.3.2.2 Radionuclide Inventory

Waste is categorized as IL if the radiation dose rate measured at 5 cm from the surface of the unshielded container is greater than 200 mR/hr. Also, the transuranium element alpha activity concentration is less than 100 nCi/g.

The 20-year projected inventory for the two IL Vaults planned for the E-Area LLWF is provided in the PA.

3.3.2.3 Waste Volume

The IL Vault provides approximately 5.7×10^3 m^3 of waste capacity for Intermediate-Level Non-Tritium (ILNT) waste and 1.6×10^3 m^3 for ILT waste. Provided that curie inventory limits are not exceeded, waste volumes may approach that capacity for both IL Vaults during the period of operation of these units.

3.3.2.4 Packaging Criteria

The bulk of the waste received by the E-Area LLWF is containerized by the waste generator in B-25 or B-12 engineered metal boxes, or in 55-gallon drums. Tritium crucibles will be packaged in a stainless steel overpack container. The overpack will be a 0.46-m diameter pipe which is approximately 6.1 m long. The lid will be sealed to the overpack with a compression O-ring. The O-ring will not prevent off-gassing of tritium in the IL Tritium Vault crucible silos. The IL Tritium Vault is designed to receive 142 of these tritium crucible overpacks.

3.3.2.5 Pre-Disposal Treatment Methods

No pre-disposal treatment methods are currently planned for IL waste.

3.3.2.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the IL Vaults must conform to criteria put forth in the SRS WAC (WSRC 1999).

3.3.3 Engineered Trenches

3.3.3.1 Waste Type/ Chemical and Physical Form

The waste disposed in the Engineered Trenches is similar to that disposed in the LAW Vault (see section 3.3.1.1). In addition M Area glass waste contaminated with uranium will be received.

3.3.3.2 Radionuclide Inventory

The 20-year projected inventory for the Engineered Trenches has not yet been developed.

3.3.3.3 Waste Volume

The projected disposal volume for the Engineered Trench is approximately 46,000 cubic meters.

3.3.3.4 Packaging Criteria

The Engineered Trench packaging criteria is similar to that for the LAW Vault (see section 3.3.1.4).

3.3.3.5 Pre-Disposal Treatment Methods

No pre-disposal treatment methods are currently planned for Engineered Trench waste.

3.3.3.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the Engineered Trenches must conform to criteria put forth in the SRS Waste Acceptance Criteria (WAC).

3.3.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

3.3.4.1 Waste Type/Chemical and Physical Form

Waste destined for trench disposal can generally be described as contaminated soil, rubble, concrete, wood debris, job control waste, and various containerized wastes and large equipment components. In addition M Area glass waste contaminated with uranium will be received. Levels of radioactivity are lower than for waste destined for vault disposal.

3.3.4.2 Radionuclide Inventory

The 20-year projected inventory for ten trenches planned for the E-Area LLWF is provided in the PA.

3.3.4.3 Waste Volume

The volume capacity of each trench is 5760 m^3. Therefore the capacity of ten trenches is 5.7×10^4 m^3.

3.3.4.4 Packaging Criteria

No packaging criteria apply to the waste destined for very-low activity trench disposal.

3.3.4.5 Pre-Disposal Treatment Methods

Containerized waste will be considered for pretreatment in the sorting and segregation facility (see Section 3.3.1.5). This may include supercompaction of a portion of the waste.

3.3.4.6 Waste Acceptance Restrictions

Waste acceptance for disposal in trenches must conform to criteria put forth in the SRS WAC (WSRC 1999).

3.3.5 Disposal Trenches for Cement-Stabilized Encapsulated Waste (Components-In-Grout Trenches)

3.3.5.1 Waste Type/Chemical and Physical Form

In general, large equipment contaminated with radioactive materials will constitute the type of waste destined for disposal in these trenches. Any solid wasteform, however, that meets the WAC, which is based on the results of the PA, will be suitable for disposal as an encapsulated wasteform.

3.3.5.2 Radionuclide Inventory

The 20-year projected inventory for the cement-stabilized encapsulated waste planned for disposal in ten E-Area LLWF trenches is provided in the PA.

3.3.5.3 Waste Volume

The volume capacity of each trench is 5760 m^3. Therefore the capacity of ten trenches is 5.7×10^4 m^3.

3.3.5.4 Packaging Criteria

Wasteforms encapsulated in grout will be placed directly in the designated trenches. No packaging criteria apply to waste destined for these trenches.

3.3.5.5 Pre-Disposal Treatment Methods

Waste destined for these trenches will be encapsulated by grout or other cementitious backfill as an alternative to vault disposal.

3.3.5.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the trenches designated to receive cement-stabilized encapsulated waste must conform to criteria put forth in the SRS WAC.

3.3.6 Naval Reactor Components Disposal Pads

Heavily shielded shipping/disposal casks containing NR waste components are planned to be disposed of at the Naval Reactor Pad, within the fenced 100-acre boundary of the E-Area LLWF, at the SRS. Large quantities of activation products are associated with the metal matrix of the waste forms within the disposal containers. Lesser amounts of radioactive contaminants are present in “crud” corrosion products.

3.3.6.1 Waste Type/ Chemical and Physical Form

Within the E-Area LLWF, disposal of up to 100 steel casks with carbon steel or low-alloy steel shipping containers containing NR components is proposed. The NR component waste is composed of activated metals and can include control rods, control rod drive mechanisms, resin vessels, adapter flanges, and similar equipment. The high shielding shipping/disposal containers reduce the safety risks involved in the disposal of NR component wastes.

Naval Reactor waste consists of a variety of solid activated metal naval nuclear reactor components, including core barrels/thermal shields (CB/TS), adapter flanges, closure heads, holddown (HD) barrels, pumps and other similar equipment. Certain components are also covered with a thin layer of adherent corrosion products, referred to as “crud,” which contains lesser amounts of radioactive contamination. These waste components include Bettis CB/TS, HD barrels, Bettis heads, Bettis adapter flanges, Bettis shrouds, Bettis pumps, Knolls Atomic Power Laboratory (KAPL) CB/TS, and KAPL Heads. Volumes of the metal waste components range between 1.05 and 7.05 m^3 for each component. Most waste components also contain some water, with the maximum amount being about 9.5×10^{-3} m^3 (2.5 gal). More detailed configurational descriptions of the NR waste components are not available because of the classified nature of this information.

3.3.6.2 Radionuclide Inventory

The 20-year projected inventory of radionuclides for 100 naval reactor component waste containers is provided in the PA.

3.3.6.3 Waste Volume

Naval reactor core barrels and reactor components are to be disposed of on gravel pads in the E-Area LLWF. The gravel pads have a total storage capacity of 697 square meters (7,500 square feet). Up to 100 containers may be disposed at the E-Area LLWF per the PA evaluation. The metal volume of the waste is approximately 3.5 m^3 per container.

3.3.6.4 Packaging Criteria

There is no standard Naval Reactor Component waste disposal container due to the variety of waste components. The actual container configuration, thickness, material of construction and closure method may be tailored to the characteristics of the Naval Reactor waste component at the time of disposal. Table 3-6 shows that the planned or proposed containers for Naval Reactor waste disposal are mostly composed of carbon steel or low-alloy steel and closed by a gasket or a weld. The assumed thickness of the container is based on estimated shielding requirements (by Bettis) for a bounding KAPL CB/TS radionuclide inventory. From The overall containerized waste volume is about 43 m^3.

The life expectancy and shielding capacity of the shipping/disposal casks are determined by the specifications of the containers.

3.3.6.5 Pre-Disposal Treatment Methods

The offsite generator is responsible for any pre-disposal treatment methods prior to shipment to SRS.

3.3.6.6 Waste Acceptance Restrictions

Waste acceptance for disposal on the Naval Reactor Waste pad must conform to criteria put forth in the SRS WAC.

Table 3-6 Forecast of Naval Reactor Waste Components for E-Area Low-Level Waste Facility Disposal

Description	Bettis CB/TS	Bettis H Barrels	Bettis Head/CP	Bettis Head/CP	Bettis Adapter Flange	Bettis Shrouds	Bettis Pump	KAPL CB/TS	KAPL Head
Number of units[1]	8	8	2	10	2	2	1	16	16
Gross Weight (lb)	241000	159070	152600	87710	26090	111350	290065	360000	78000
Component									
Component weight (lb.)	61000	59710	121920	42910	18090	90130	60065	72000	47000
Component volume (ft^3)	125	122	249	86	37	184	123	147	96
Component Alloy[3]	304 s.s.	Inconel	Carbon steel	Carbon steel	Inconel	Carbon steel	Inconel	Inconel/ Zircaloy	Inconel clad c. steel
Max water (gals)	1	5	13.5	0.4	1.5	8	8	3.5	0
Container									
Container weight (lb.)	180000	99360	30680	44800	8000	21220	230000	288000	31000
Thinnest thickness of container (in)[4]	5.2	4	0	0	0	0	1.25	1.64	0
Container alloy	Carbon steel	HY-80	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel
Type of container closure	Full pen weld	Full pen weld	Gasket	Gasket[2]	Gasket	Gasket	Full pen weld	Full pen weld	Gasket

NOTES:
1 Includes components recently shipped and identified as above ground (8 CB/TS + 8 HD Barrels + 8 Adap. Flanges)
2 Eight of the Adap. Flange containers were welded shut. The remaining two will be rubber gasketed and bolted.
3 Alloy shown is major alloy of construction.
4 Zero indicates gasketed and bolted closure.
SOURCE:
WSRC 2000

4.0 TECHNICAL APPROACH TO CLOSURE

The E-Area LLWF is a controlled release facility intended to maintain radionuclide migration from disposed LLW forms to below the Performance Objectives outlined within USDOE Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b). The following design objectives are applicable to the E-Area LLWF closure to the extent required to ensure compliance with the USDOE Order 435.1 Performance Objectives:

- Maintain waste confinement to the extent necessary to meet the Performance Objectives
- Provide long-term stability to the extent necessary to meet the Performance Objectives:
  - Minimize settling and subsidence
  - Minimize erosion
  - Minimize slope failure
- Minimize the contact of the waste with water to the extent necessary to meet the Performance Objectives:
  - Promote drainage
  - Minimize infiltration
  - Minimize run on
- Minimize the need for active maintenance during the institutional control period

One of the primary design objectives to ensure compliance with the Performance Objectives is to minimize infiltration (i.e. limit moisture flux through the waste). Therefore this design objective will be an integral part of the long-term strategy for E-Area LLWF closure as previously outlined in section 3.2.1.

E-Area LLWF closure will consist of interim/operational closure of individual disposal units as they are filled followed by final closure of the entire E-Area LLWF at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). The interim/operational closure of individual disposal units as they are filled will be specific to each type of disposal unit (see section 4.2). Because final closure of the E-Area LLWF will be delayed for several years, a detailed closure design has not been fully developed for the E-Area LLWF. Thus an integral part of the E-Area LLWF PA required that a closure concept be described and subsequently tested in models that simulate the performance characteristics of the proposed closure concept. Final closure of the entire E-Area LLWF will consist of construction of an integrated closure system at the end of its entire operational life. The integrated closure system will consist of site preparation, the installation of one or more closure caps over all the disposal units, and the installation of an integrated drainage system (see section 4.3). The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (WSRC, 2000). Previously the use of compacted kaolin as the barrier layer in the closure cap was assumed, whereas this closure plan (revision 2) replaces the kaolin with a geosynthetic clay liner (GCL) as the barrier layer. The equivalence, in term of minimizing infiltration, of a GCL to compacted kaolin as the barrier layer has been evaluated utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994; USEPA 1994a) as outlined in the sections below.

4.1 Compliance with Performance Objectives and Other Requirements

Each disposal unit at the E-Area LLWF has been designed, is operated and will be closed in accordance with the Performance Objectives set forth in USDOE Order 435.1 (USDOE 1999). Closure activities are thus an important part of the overall waste management system at SRS.

4.1.1 All Pathways Dose

As shown in the PA (WSRC 2000), the calculated dose from the All Pathways scenario is totally due to contaminant transport by the groundwater pathway. Therefore, the limitation of moisture flux through the waste is necessary to achieve compliance with the All Pathways Dose Performance Objective. The primary aspect of the closure system that is significant to limiting the moisture flux through the waste is the overall hydraulic properties of the integrated closure system. The hydraulic conductivity and thickness of the closure cap's barrier layer (i.e. GCL), the hydraulic effectiveness of the closure cap's lateral drainage layer, and hydraulic effectiveness of the overall E-Area LLWF drainage system are the most significant hydraulic consideration to limiting the moisture flux through the waste. Other factors that will be considered during closure design include:

- the amount of cap overhang
- the durability of the system
- the configuration of the system
- the size of the drains
- the thickness of each layer
- filter design
- anticipated subsidence and necessary methods to minimize
- erosion control

4.1.2 Air Pathway Dose

The only feature of the closure system that is a factor in the calculation of the air pathway dose is the total thickness of the closure cap.

4.1.3 Radon Flux

The major feature of the closure system that is a factor in the calculation of the radon flux is the total thickness of the closure cap

4.1.4 Other Requirements

4.1.4.1 Groundwater Resource Protection

The closure system features that are significant to the Groundwater Resource Protection requirement are those that help to limit moisture flux through the waste. the hydraulic properties of the cover system. The hydraulic conductivity and thickness of the closure cap's barrier layer (i.e. GCL), the hydraulic effectiveness of the closure cap's lateral drainage layer, and hydraulic effectiveness of the overall E-Area LLWF drainage system are the most significant hydraulic consideration to limiting the moisture flux through the waste.

4.1.4.2 Intruder Protection

The important parameter in the closure system for Intruder Protection is the total thickness of the cover system. This thickness provides shielding from gamma radiation and dilution of the waste in scenarios involving excavation.

4.2 Operational/Interim Closure

The interim/operational closure of individual disposal units as they are filled will be specific to each type of disposal unit.

4.2.1 Low-Activity Waste Vault Units

Interim/operational closure of the Low-Activity Waste Vaults (LAW Vaults) will be conducted in stages. Individual cells within a reinforced concrete vault will be closed as they are filled with metal and/or concrete containers of waste and the entire vault will be closed as it is filled. Such interim/operational closure includes the sealing of cell and/or vault openings (i.e., large exterior door, small interior door and exhaust fan openings) with reinforced concrete. The reinforcing steel will be tied into the reinforcing steel of the cell and/or vault itself, forming a unified structure to provide continuous, structurally sound walls to isolate the waste from the environment. Additionally as part of the interim/operational closure the roof slab will be covered with a bonded-in-place layer of fiberboard insulation and a layer of waterproof membrane roofing.

4.2.2 Intermediate-Level Vault Units

Interim/operational closure of the Intermediate-Level Vaults (IL Vaults) will be conducted in stages. Metal and/or concrete containers of waste are stacked in layers in each cell within the reinforced concrete vault. After a layer of waste containers is placed in a cell, grout will be poured to encapsulate the containers and form a surface for emplacement of the next layer of containers. One cell is used to dispose of tritium crucibles in silos. The tritium crucibles are place in vertical silos and concrete plugs are placed above the filled silos. After being filled with waste and layers of grout, each cell will be covered with a top layer of grout, which will be leveled at the wall ledges used to support the shielding slab. After all cells have been filled with waste and grout, a thick reinforced concrete roof slab will completely cover all cells of the IL Vault. The roof slab will be covered with a bonded-in-place layer of fiberboard insulation and layer of waterproof membrane roofing.

4.2.3 Engineered Trenches

Interim/operational closure of the Engineered Trenches will be conducted in stages. Metal containers of waste (typically B-25 boxes) are stacked in rows four high (approximately 17 feet high) within the gravel lined Engineered Trench. As a sufficient number of B-25 rows are placed, clean soil is bulldozed over some of the completed rows so that the rows are covered with a minimum 4-foot interim soil cover. This interim soil cover is only applied to that portion of the completed rows that still allows maintenance of a safe distance from the working face (i.e. where new boxes are placed in the stack) within the trench. The interim soil cover is graded to provide positive drainage off the trench and away from the working face. Placement of the B-25 boxes continues until the trench is filled with boxes. At that point the minimum 4-foot interim soil cover is placed over the remaining portion of the trench, and the entire area is graded to provide positive drainage off the trench. The interim soil cover also provides shielding for operations personnel. An interim vegetative cover of shallow rooted grass will be established to help control erosion. (WSRC, 2001)

4.2.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

Interim/operational closure of the Slit Trenches will be conducted in stages. Placement of bulk and containerized waste in a Slit Trench typically begins at one end of the trench and proceeds toward the other end. Bulk waste is pushed into the trench from one end. Containerized waste is typically placed in one end of the trench with a crane. Eventually containerized waste areas of the trench are filled in with either bulk waste or clean soil to fill the voids between adjacent containers and the trench wall. Slit trenches are typically filled to within four feet below the top of the trench with waste and daily cover. Once a section of the slit trench is filled, clean soil is used to provide a minimum 4-foot an interim soil cover. The interim soil cover is graded to provide positive drainage off and away from the disposal operation. The interim soil cover also provides shielding for operations personnel. Subsequent trench sections are filled with waste, covered with an interim soil cover, and graded to promote positive drainage until the entire trench is filled. The only mechanical compaction that the soil and waste in the trench receive is from the bulldozer and other heavy equipment moving over the top of a completely backfilled trench. No equipment is allowed in the trench. An interim vegetative cover of shallow rooted grass will be established to help control erosion.

4.2.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

Interim/operational closure of Components-In-Grout Trenches consists of the placement of large equipment in the trench, its encapsulated with grout or other cementitious backfill, and the placement of a minimum 4-foot interim soil cover over the encapsulated waste. The interim soil cover is graded to provide positive drainage off and away from the trench. The interim soil cover also provides shielding for operations personnel. An interim vegetative cover of shallow rooted grass will be established to help control erosion.

4.2.6 Naval Reactor Component Disposal Pads

Interim/operational closure of the above grade Naval Reactor Component Disposal Pads simply consists of the placement of the steel Naval Reactor Waste Disposal Casks containing the naval reactor components on the pad. A gasket or welds are used to closure the casks.

4.3 Final Closure

Final closure of the entire E-Area LLWF will consist of construction of an integrated closure system at the end of the operational life of the entire E-Area LLWF (i.e. after it has been filled). The integrated closure system will consist of site preparation, the installation of one or more closure caps over all the disposal units and an integrated drainage system. The final closure will thus be essentially the same for each disposal unit. An Independent Professional Engineer will be retained by SRS to certify that the E-Area LLWF final closure system has been constructed in accordance with the approved closure plan and the final plans and specifications at the time of final closure.

4.3.1 Closure System Conceptual Design

An E-Area LLWF integrated closure system will be construction over the entire facility at the end of its operational life. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system. The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (WSRC, 2000). Previously the use of compacted kaolin as the barrier layer in the closure cap was assumed, whereas this closure plan (revision 2) replaces the kaolin with a geosynthetic clay liner (GCL) as the barrier layer. The type of GCL outlined within this closure plan is one that consists of “bentonite sandwiched between two geotextiles” (USEPA 2001). The following is the definition of a Geotextile GCL as defined by the Environmental Protection Agency (USEPA 2001):

> A Geotextile GCL “is a relatively thin layer of processed” bentonite … “fixed between two sheets of geotextile. … A geotextile is a woven or nonwoven sheet material … resistant to penetration.” … “Adhesives, stitchbonding, needlepunching, or a combination of the three” are used to affix the bentonite to the geotextile. “Although stitchbonding and neddlepunching create small holes in the geotextile, these holes are sealed when the installed GCL’s clay layer hydrates.”

The following are some of the typical advantages of a Geotextile GCL over compacted clay layers, which led to the replacement of the compacted kaolin with a GCL:

- Faster and easier to install (USEPA 2001) The GCL is installed in a dry condition while unrolling it like a carpet whereas compacted kaolin must be installed wet of optimum in multiple lifts.
- Lower hydraulic conductivity (i.e. < 5.0×10^{-9} for a GCL versus < 1.0×10^{-7} for a compacted clay layer) (USEPA 2001)
- Ability to self-heal rips or holes (USEPA 2001)
- Cost-effective (USEPA 2001)
- Not as thick (USEPA 2001)
- Less negative impact “due to differential settlement, freezing-thawing cycles, and wetting-drying cycles” (Rumer and Mitchell, 1995)
- The bulk of the required Quality Assurance / Quality Control (QA/QC) associated with a GCL is factory based whereas that of compacted kaolin is entirely field based. Factory based QA/QC generally provides a higher degree of QA/QC, and it is included in the cost of the material. (Phifer 1991; GSE 2002)

The previous kaolin closure cap consisted from top to bottom of 0.15 m of topsoil, 0.76 m of backfill, a geotextile fabric, 0.3 m of gravel, 0.76 m of kaolin clay, and 0.9 m of backfill (See Figure 4-1). This resulted in a minimum 2.9 m of soil above each operationally/interimly closed disposal unit for shielding purposes. The replacement GCL closure cap consists from top to bottom of 0.15 m of topsoil, 0.76 m of backfill, a geotextile fabric, 0.3 m of gravel, a 0.005 m GCL, and 1.67 m of backfill (see Figure 4-2). This also results in the minimum 2.9 m of soil above each operationally/interimly closed disposal unit as required for shielding purposes. The layer thicknesses of the actual closure cap installed may vary from those presented herein. The thicknesses presented herein are conceptual in nature and are required for modeling purposes. However an overall minimum thickness of 2.9 m is required for shielding purposes. The equivalence, in term of minimizing infiltration, of the GCL closure cap to the kaolin closure cap has been evaluated utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994; USEPA 1994a). The HELP model estimate for the average annual percolation out the bottom of the kaolin closure cap was 0.0177 m/year (i.e. amount of water reaching the top of the operationally/interimly closed disposal unit). Whereas the HELP model estimate for the average annual percolation out the bottom of the GCL closure cap was 0.006 m/year. The percolation out the GCL closure cap was estimated to be approximately a third of that estimated for the kaolin closure cap, thus demonstrating that the GCL closure cap is equivalent or better than the kaolin closure cap. See Appendix A for detailed information concerning the HELP model percolation estimates for both the kaolin and GCL closure caps.

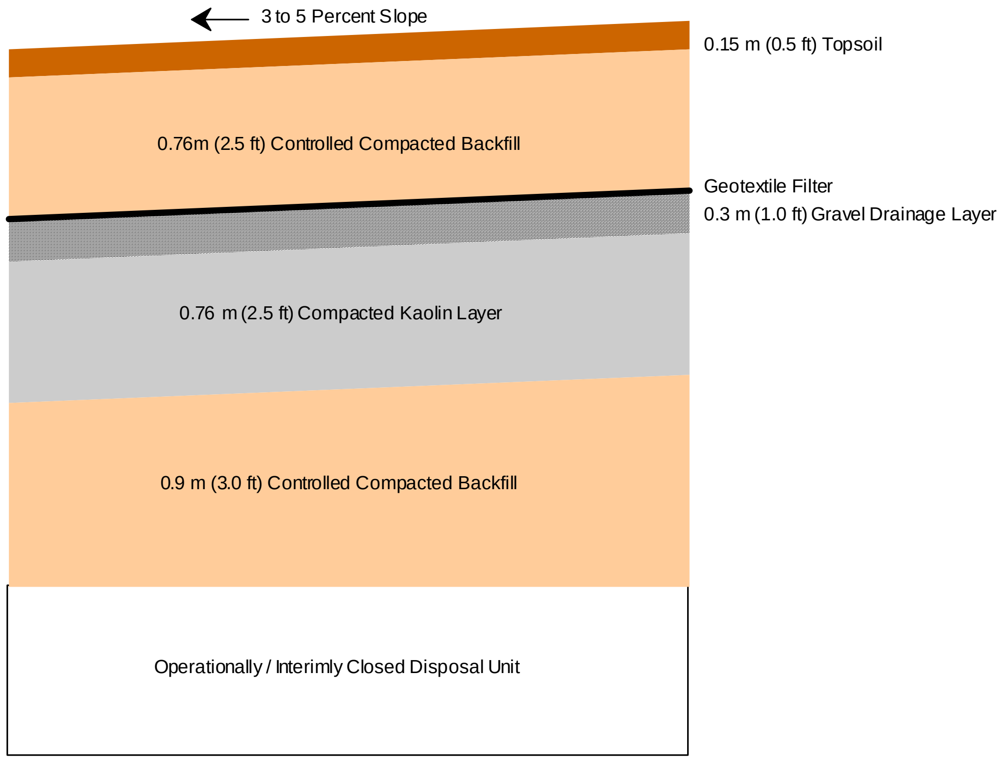

Figure 4-1 Kaolin Closure Cap Configuration

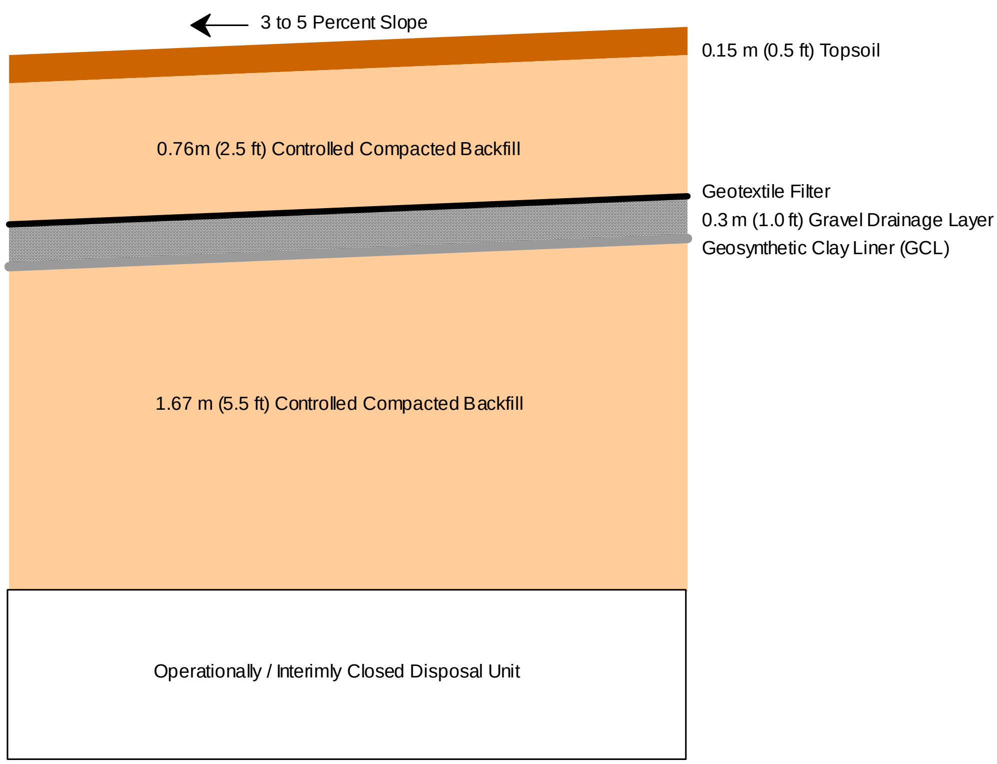

Figure 4-2 Geosynthetic Clay Liner Closure Cap Configuration

4.3.2 Closure System Installation

Final closure of the entire E-Area LLWF will consist of site preparation of the interimly/operationally closed disposal units, construction one or more closure caps installed over all the disposal units (see Figure 4-2), and construction of an integrated drainage system.

4.3.2.1 Site Preparation

Seismic conditions were reviewed and it was determined that no active faults are located within the proximity of the E-Area LLWF and earthen fill embankments. Underlying subsoil and embankment side slope deformation is negligible and liquefaction potential is also negligible for general site (SRS) facilities. Therefore no additional site preparation is deemed necessary to account for seismic activity.

As determined in Volume II of the Mixed Waste Management Facility (MWMF) Closure Plan (WSRC 1999a), settlement of the closure cap could result from compression of the disposal unit subgrade due to the overlying weight of the disposal unit, waste, interim soil cover, if present, and the closure cap. Based on the information in Volume II of the MWMF Closure Plan, settlement of trench subsoil at the E-Area LLWF will be minor. Therefore no additional site preparation is deemed necessary to account for any potential, disposal unit, subgrade settlement.

The estimated subsidence potential and estimated subsidence time frames for each type of disposal unit were discussed in section 3.2.2. A summary of this information is provided in Table 4-1 along with the potential subsidence treatments that will be considered beyond that provided by the interim/operational closure discussed in section 4.2.1. As indicated in Table 4-1, there are no subsidence treatments that are currently anticipated for the LAW Vaults, IL Vaults, and Components-In-Grout Trenches beyond that already provided by the interim/operational closure. In particular dynamic compaction will not be conducted over these three types of disposal units.

The subsidence time frame for the Engineered Trenches is dependent upon the corrosion rate and subsequent structural collapse of B-25 boxes. The estimated subsidence time frame presented in Table 4-1 is an assumed time frame for B-25 boxes that have not been dynamically compacted (WSRC 2001). Additional work is currently in progress to better estimate the anticipated time period of B-25 box structural collapse following burial. Additionally the timing of the use of static surcharging and/or dynamic compaction on the Engineered Trenches to achieve more efficient results is also currently in progress. Finally the use of static surcharging may be required prior to installation of the closure cap to fill void between stacks of boxes in order to minimize closure cap maintenance during the 100-year institutional control period. Static surcharging may help to eliminate voids between containers, which could potentially cause subsidence during the institutional control period.

Subsidence may occur within Slit Trenches either due to the degradation and volume reduction of readily degradable materials or to the collapse of containers containing significant void space. It is anticipated that the bulk of the Slit Trench subsidence will occur during the 100-year institutional control period. However subsidence due to the collapse of containers containing significant void space could occur beyond the institutional control period, as anticipated for the Engineered Trenches containing B-25 boxes. Dynamic compaction has been a method utilized at other SRS waste disposal sites to reduce the subsidence potential associated with Slit Trenches prior to installation of closure caps. The use of dynamic compaction on the slit trenches, to minimize the closure cap maintenance required during the 100-year institutional control period, will be evaluated.

While structural stability of the Naval Reactor Waste Disposal Casks is expected to last for 10,000 years after final closure, the void space between casks must be appropriately filled with soil in order to support the closure cap. Due to the proximity of casks to each other typical heavy equipment used for soil compaction will not be able to be utilized to fill the void space between casks. This void space between casks may be appropriately filled by one of the following methods:

- The use of hand operated compaction equipment to fill up the void space between casks with compacted soil layers,
- Filling the void space between casks with granite aggregate or quartz sand utilizing a crane, and/or
- Filling the void space between casks with on site soils utilizing a crane followed by a static surcharging

The method most appropriate to filling the void space between casks to achieve structural stability for closure cap installation will be evaluated.

Table 4-1 Potential Subsidence Treatments

Disposal Unit	Estimated Subsidence Potential	Estimated Subsidence Time Frame	Potential Subsidence Treatment Beyond that of Interim/Operational Closure
LAW Valuts	4.1 m (13.5 ft) [1]	3,100 years after final closure	None anticipated
IL Vaults	Assumed minimal	1,050 years after final closure	None anticipated
Engineered Trenches	4.1 m (13.6 ft) [2]	200 to 300 years after burial [2]	Static surcharging and/or dynamic compaction
Slit Trenches	Variable: Not estimated	Within 100-year institutional control period	Dynamic compaction
Components-In-Grout Trenches	Assumed minimal	300 years after interim/operational closure	None anticipated; dynamic compaction will not be performed
Naval Reactor Component Disposal Pads	Variable: Not estimated	10,000 years after final closure	Hand compaction equipment, aggregate filling and/or soil filling and static surcharging

NOTES:
[1] Based upon an 8.2 m (27 ft) high vault with 50% void space.
[2] WSRC 2001.
Dynamic compaction will not be performed over any portion of a disposal unit containing ETF Carbon Columns.

The existing soils over which the closure cap will be constructed must be prepared prior to closure cap construction. The top 0.08 to 0.15 m (3 to 6 inches) of existing soils in these areas will be removed in order to remove any topsoil and vegetation present. These areas will then be rough graded to establish a base elevation for the closure cap. Finally these areas will be compacted with a vibratory roller, particularly the areas with interim soil covers, which have not been previously compacted. No such preparation will be required over the LAW Vaults, IL Vaults, or Naval Reactor Component Disposal Pads, since soil and vegetation will not exist over these facilities after interim/operational closure. Areas adjacent to these disposal unit may require this preparation.

4.3.2.2 Closure Cap Construction

This section on closure cap construction provides sufficient information for planning purposes and to evaluate the constructibility of the conceptual closure system described herein, but it is not intended to constitute final design (i.e. final plans and specifications). Future revisions of the closure plan will describe the recommended tests to be performed during closure cap construction in order to provide appropriate Quality Assurance / Quality Control (QA/QC). Such tests will be included in the final project plans and specifications when prepared. The final plans and specification will include provisions for protecting the integrity of the E-Area LLWF closure cap during construction and protection of the existing closure caps adjacent to the E-Area LLWF.

The closure cap, installed above each operationally/interimly closed disposal unit, will consist of the layers outlined in Table 4-2 from bottom to top (also see Figure 4-2). Table 4-2 also includes the minimum thickness of each layer and its anticipated saturated hydraulic conductivity.

Table 4-2 Closure Cap Layers from Bottom to Top

Layer	Minimum Layer Thickness	Saturated Hydraulic Conductivity
Controlled Compacted Backfill	1.67 m (5.5 ft)	1.0E-04 cm/s [1, 4]
Geosynthetic Clay Liner (GCL)	0.005 m (0.2 in)	5.0E-09 cm/s through plane [2, 3, 5]
Gravel	0.3 m (1.0 ft)	1.0E-03 cm/s [1, 6]
Geotextile fabric	0.0025 m (0.1 in)	0.1 cm/s through plane [2, 6]
Controlled Compacted Backfill	0.76 m (2.5 ft)	1.0E-04 cm/s [1, 4]
Topsoil	0.15 m (0.5 ft)	1.0E-03 cm/s [1, 4]

NOTES:
1 WSRC 2002, draft
2 GSE 2002
3 USEPA 1994; USEPA 1994a
4 The saturated hydraulic conductivity for these layers has been estimated for modeling purposes. It is neither a minimum nor maximum.
5 The saturated hydraulic conductivity for this layer is a maximum allowable.
6 The saturated hydraulic conductivity for these layers is a minimum allowable.

The following are additional generic closure cap design details:

- The top surface of the closure cap will be sloped between three to five percent to promote run-off and minimize erosion.
- The side slope of the closure cap will be at a maximum 3 horizontal to 1 vertical (3:1 or 19.5 degrees) to promote slope stability.
- The closure cap will be constructed to have minimal impact on area operations and infrastructure.

The bottom most controlled compacted backfill will be utilized to create the required contours and provide structural support for the rest of the overlying closure cap. It will be used to produce the 3 to 5 percent top slopes and the maximum 3:1 side slopes of the closure cap. Therefore the thickness of this bottom most controlled compacted backfill layer will vary, but in all cases it will have a minimum thickness of 1.67 m (5.5 ft) over all disposal units. The maximum thickness will depend upon the closure cap aerial geometry and the drainage paths. This layer is not intended to act as an infiltration barrier, but it is intended to provide a suitable base for installation of the GCL. It will be placed in a manner that prevents or minimizes possible contamination. The controlled compacted backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The controlled compacted backfill shall be placed in lifts not to exceed 0.23 m (9 inches) in uncompacted thickness in areas where hand-operated mechanical compaction equipment is used and not to exceed 0.30 m (12 inches) in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 90% of the maximum dry density per the Modified Proctor Density Test (ASTM D1557 [ASTM 1992a]) or 95% per the Standard Proctor Density Test (ASTM D698 [ASTM 1992]). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The top lift, upon which the GCL will be placed, shall be proof-rolled with a smooth drum roller to produce a surface satisfactory for placement of the GCL. All work in association with the controlled compacted backfill shall be performed in accordance to the approved plans and specifications.

The GCL is the sole hydraulic barrier layer for the closure cap. The GCL shall have a maximum through plane saturated hydraulic conductivity of 5.0×10^{-9} cm/s. The GCL shall be obtained from the manufacturer in rolls, which are on the order of 4.6 m (15 ft) wide by 46 m (150 ft) long. The GCL rolls shall be stored flat and kept dry. The GCL shall be placed directly on top of the controlled compacted backfill, which would have been appropriately contoured and smooth drum rolled. Placement of the rolls of GCL shall consist of unrolling the GCL roll per the manufacturer’s directions directly onto the surface of the controlled compacted backfill, producing a GCL panel. The GCL shall not be placed during periods of precipitation or under other conditions that could cause the bentonite to hydrate prematurely (i.e. prior to placement of 0.30 m (1 foot) gravel on top of it). GCL panels shall be overlapped a minimum of 0.15 m (6 inches) on panel edges and a minimum of 0.30 m (1 ft) on panel ends. The minimum overlap shall consist of bentonite containing portions of the GCL overlapping from each panel. The geotextile only portions of the GCL shall not be included in the minimum overlap. Loose granular bentonite shall be placed between overlapping panels at a rate of 1.8 kg per linear meter (¼ pound per linear foot). The GCL shall be inspected for rips, tears, displacement, and premature hydration prior to placement of the gravel on top of it. Any rips, tears, displacement, and premature hydration shall be repaired per the manufacturer’s directions prior to placement of the gravel on top of it. The overlying 0.30 m (1 foot) gravel drainage layer shall be placed in a single lift on top of the GCL per the manufacturer’s directions in order to avoiding damaging the GCL. No equipment used to place the gravel shall come into direct contact with the GCL. At the end of each working day, the uncovered edge of the GCL (i.e. that portion that does not have the gravel on it) shall be protected with a waterproof sheet that is secured adequately with ballast to avoid premature hydration. (GSE 2002) All work in association with placement of the GCL shall be performed in accordance to the approved plans and specifications. (USEPA 2001; GSE 2002)

The gravel will be placed on top of the GCL to form a lateral drainage layer and to provide the necessary confining pressures to allow the GCL to hydrate appropriately. The gravel drainage layer will be hydraulically connected to the overall facility drainage system in order to divert and transport as much infiltrating water as possible through the gravel drainage layer to the facility drainage system and away from the underlying disposal units. Computer simulations of flow through the cover, conducted for the PA (WSRC 2000) show that the gravel drainage layer will carry away a major portion of the water that is assumed to normally infiltrate past the evapotranspiration zone of the closure cap at the E-Area LLWF (40 cm/yr). The gravel shall consist of material with a hydraulic conductivity of at least of 1×10^{-3} cm/sec and it shall be free of any materials deleterious to either the underlying GCL or overlying geotextile. The gravel drainage layer shall be placed in a single 0.30 m (1 foot) lift on top of the GCL per the GCL manufacturer's directions in order to avoiding damaging the GCL. The gravel layer will be fine graded to the required contours. No equipment used to place the gravel shall come into direct contact with the GCL; the equipment used to place and fine grade the gravel shall be low ground pressure equipment that is driven on top of the previously placed 0.30 m (1 foot) thick gravel layer. No compactive effort shall be applied to the gravel layer other than that provided by the equipment used to place and fine grade it. All work in association with placement of the gravel drainage layer shall be performed in accordance to the approved plans and specifications.

An appropriate geotextile shall be placed on top of the gravel to provide filtration between the gravel and the overlying backfill. Koerner (Koerner 1990) has defined filtration with a geotextile as:

> "The equilibrium fabric-to-soil system that allows for free liquid flow (but no soil loss) across the plane of the fabric over an indefinitely long period of time."

The geotextile shall have a minimum thickness of 0.0025 m (0.1 in), a minimum through plane saturated hydraulic conductivity of 0.1 cm/s, and an apparent opening size small enough to appropriately filter the overlaying backfill. The geotextile shall be obtained from the manufacturer in rolls, which are on the order of 4.6 m (15 ft) wide by 91 m (300 ft) long or greater. The geotextile rolls shall be stored flat, kept dry, protected from ultraviolet light exposure. The geotextile shall be placed directly on top of the gravel drainage layer, which would have been appropriately contoured and determined to be free of materials deleterious to the geotextile. Placement of the rolls of geotextile shall consist of unrolling the geotextile roll down slope per the manufacturer's directions directly onto the surface of the gravel, producing a geotextile panel. Adjacent geotextile panels shall be seamed using heat seaming of stitching methods per the manufacturer's directions. The in place geotextile panels shall be held down with sandbags or approved equivalent until replaced with the overlying backfill to prevent the geotextile from being blown out of place. The in place geotextile panels shall not be exposed to direct sun light for more than 7 days prior to placement of the overlying backfill. The in place geotextile shall be inspected for rips, tears, wrinkling, and displacement prior to placement of the backfill on top of it. Any rips, tears, wrinkling, and displacement shall be repaired per the manufacturer's directions prior to placement of the backfill on top of it. The initial loose lift of the overlying backfill shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoiding damaging the geotextile. No equipment used to place the backfill shall come into direct contact with the geotextile. The feet of any compaction equipment used on the backfill shall be sized so that compaction of the backfill does not damage the geotextile. All work in association with placement of the geotextile shall be performed in accordance to the approved plans and specifications. (Koerner 1990; GSE 2002)

The upper most controlled compacted backfill will be a 0.76 m (2.5 ft) thick layer used to bring the elevation of the closure cap up to that necessary for placement of the topsoil. This backfill will also store water for evapotranspiration. The controlled compacted backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The initial loose lift of the overlying backfill shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoiding damaging the geotextile. No equipment used to place the backfill shall come into direct contact with the geotextile. It shall be driven only on top of previously placed backfill. The feet of any compaction equipment used on the backfill shall be sized so that compaction of the backfill does not damage the geotextile. The controlled compacted backfill shall be placed in lifts not to exceed 0.23 m (9 inches) in uncompacted thickness in areas where hand-operated mechanical compaction equipment is used and not to exceed 0.30 m (12 inches) in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 85% of the maximum dry density per the Modified Proctor Density Test (ASTM D1557 [ASTM 1992a]) or 90% per the Standard Proctor Density Test (ASTM D698 [ASTM 1992]). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The backfill will be fine graded to the required contours. All work in association with the controlled compacted backfill shall be performed in accordance to the approved plans and specifications.

The upper most soil layer of the closure cap shall consist of soils capable of supporting a vegetative cover (i.e. topsoil). The topsoil in conjunction with the vegetative cover will store water and promote evapotranspiration. The topsoil shall be placed in a single 0.15 m (0.5 ft) lift on top of the upper most controlled compacted backfill. The equipment used to place and fine grade the topsoil shall be low ground pressure equipment. No compactive effort shall be applied to the topsoil other than that provided by the equipment used to place and fine grade it. Measures shall be taken to minimize erosion of the topsoil layer prior to the establishment of the vegetative cover. Any such erosion shall be repaired by the installation subcontractor until such time as the vegetative cover has been established and the closure cap has been accepted as constructed per the approved plans and specifications by the Professional Engineer providing certification of the closure cap construction. All work in association with the topsoil shall be performed in accordance to the approved plans and specifications.

A vegetative cover will be established to promote runoff, minimize erosion, and evapotranspirate water. The topsoil will be fertilized, seeded, and mulched to provide a vegetative cover. The initial vegetative cover shall be a persistent grass. This initial grass will provide erosion control while the final vegetative cover is being established. During seeding and establishment of the initial grass, appropriate mulch, erosion control fabric, or similar substances will protect the surface. The area will be repaired through transplanting or replanting to ensure that a permanent self-maintaining cover is developed. The final vegetative cover will be a persistent, shallow rooted species, such as bamboo, that will effectively minimize erosion and sustain growth with minimal maintenance. A study conducted by the U.S. Department of Agriculture (USDA) Soil Conservation Service has shown that these two species of bamboo (*Phyllostachys bissetii* and *Phyllostachys rubromarginata*) will quickly establish a dense ground cover which will prevent the growth of pine trees, the most deeply rooted naturally occurring plant type at SRS. Bamboo is a shallow-rooted climax species which evapotranspirates year-round in the SRS climate, thus removing a large amount of moisture from the soil and decreasing the infiltration into the underlying disposal system. All work in association with the vegetative cover shall be performed in accordance to the approved plans and specifications.

Similar closure caps to that described within this closure plan have been constructed at SRS. These closure caps include:

- The Mixed Waste Management Facility (MWMF) Closure, which utilized compacted kaolin as the hydraulic barrier layer,
- The F and H-Area Seepage Basin (F&HSB) Closure, which included a sand drainage layer and utilized compacted kaolin as the hydraulic barrier layer,

- The M-Area Settling Basin (MSB) Closure, which included a sand drainage layer and utilized a combination of a flexible membrane liner (FML) and compacted kaolin as the hydraulic barrier layers,
- The Low-level Radioactive Waste Disposal Facility (LLRWDF) Closure, which included a GeoNet drainage layer and utilized a combination of a FML, and a GCL as the hydraulic barrier layers, and
- The Sanitary Landfill Closure, which included a GeoNet drainage layer and utilized a combination of a FML, and a GCL as the hydraulic barrier layers.

SRS has much experience with the construction and subsequent maintenance of closure caps, including those utilizing GCLs and drainage layers. The conceptual closure cap described within this closure plan is similar to these previously successfully installed caps. It includes materials of construction that were successfully used in these previous caps. Therefore it is known with certainty that the conceptual closure cap described within this closure plan can be successfully constructed. Based upon this conceptual design, it appears that there is sufficient area to construct the disposal units and overlying closure caps. However a fairly substantial thickness of controlled compacted backfill will be required to create the required contours for those portions of the closure cap overlying the LAW Vaults and Naval Reactor Component Disposal Pads.

4.3.2.3 Integrated Drainage System

This section on the integrated drainage system provides sufficient information for planning purposes and to evaluate the functionality of the conceptual drainage system described herein, but it is not intended to constitute final design (i.e. final plans and specifications). The final plans and specification will include provisions for protecting the integrity of the E-Area LLWF closure cap during construction and protection of the existing closure caps adjacent to the E-Area LLWF.

The existing E-Area LLWF drainage system may be improved, as necessary, prior to site preparation and closure cap installation in order to accommodate anticipated increases in runoff and sediment transport, produced due to the construction activities. Temporary erosion control measures such as silt fences, hay bales, etc. will be utilized as necessary. Sedimentation basins will be constructed as necessary. The improvements will be made to meet the construction site's drainage requirements, to minimize infiltration over disposal units, to prohibit localized flooding, to minimize sediment transport off site, and to prohibit runoff from the construction site onto adjacent closure caps and/or facilities. Additionally the vegetative cover will be established as quickly as possible as construction is completed on any particular portion of the closure system. All work in association with storm water management and erosion control during the construction activities shall be performed in accordance to the approved plans and specifications.

The final configuration of the integrated drainage system will tie into the existing E-Area LLWF drainage system as improved to accommodate E-Area LLWF final closure to the extent practical. Runoff from the closure caps and lateral drainage out the closure cap gravel drainage layers will be directed to a system of rip-rap lined ditches, which will direct the water away from the disposal units and E-Area LLWF as a whole. The rip-rap lined ditches will be constructed in between individual closure caps and around the perimeter of the E-Area LLWF. The ditches will discharge into sedimentation basins as necessary for sediment control.

The top surface of the closure caps will be sloped to between 3 to 5 percent, the slope lengths will be minimized to the extent practical, and a vegetative cover will be established. This will be done in order to maximize sheet flow of runoff and minimize rill or gully flow of runoff so that erosion of the closure cap will be minimized. The side slopes of the closure caps, which will be sloped at a maximum 19.5 degrees (3 horizontal to 1 vertical), will be rip-rap lined, as necessary, to minimize erosion caused by flow off the top of the closure cap and out the closure cap's gravel drainage layer. All ditches, channels, and culverts will be designed to convey non-erosive flow in order to minimize erosion potential. In areas of potential erosion, erosion and sediment control measures will be used in an effort to protect surface soils from erosion and to retain migrating soils on site.

4.3.3 Institutional Control

USDOE has committed to a term of institutional control of not less than 100 years following final closure of the E-Area LLWF. During this time periodic inspections will be conducted and maintenance activities will be performed as needed.

4.3.4 Unrestricted Release of Site

The current SRS Future Use Plan states that the entire Savannah River Site will never be released for unrestricted use. In particular, the plan states that the central portion of the SRS, which includes the E-Area LLWF, will only be used for industrial purposes (USDOE 1998). This is consistent with the PA assumption of 100 years of restricted use for the intruder scenario.

4.4 Monitoring

4.4.1 Operational/Interim Closure Period

During the operational/interim closure periods, the E-Area LLWF will have a monitoring program in place. The program will include a vadose zone monitoring system around and underneath trench disposal units, scheduled sampling and analysis of any water found in vault disposal unit sumps, and visual inspection of all disposal units as discussed in the *E-Area Monitoring Program for the E-Area Low-Level Radioactive Waste Facility* (WSRC 2000a). Additional details of the monitoring system will be included as the monitoring plan develops.

4.4.2 Final Closure/Institutional Control Period

Following final closure and during the institutional control period, the E-Area LLWF will be part of the overall SRS Environmental Monitoring Program. Groundwater samples will be taken on a regularly scheduled basis. The samples will be analyzed for constituents that could indicate release of contaminants from the E-Area LLWF.

Periodic inspections of the closure system will be performed. Maintenance activities necessary for continued system performance will be conducted as required.

Some subsidence may occur during the 100-year institutional control period. Inspection and maintenance programs will be implemented to address any such occurrences.

5.0 CLOSURE SCHEDULE

As discussed previously, the E-Area LLWF is in the first half of its planned operational life. This closure plan reflects the currently available information based on the facility's operational status. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure. The schedule for final closure of the facility will be developed five years prior to completion of waste emplacement activities.

6.0 RECOMMENDED CLOSURE CONSIDERATIONS

It is recommended that consideration be given to the following items in association with future revisions to the E-Area LLWF Closure Plan and PA:

- The PA should be updated to reflect the changes in the closure cap configuration outlined within revision 2 of the closure plan.
- The PA should be updated to include the Engineered Trench specifically since the Engineered Trench is operated significantly differently than the Very-Low-Activity Waste Disposal Trenches (Slit Trenches).
- The assumption under pre-capping conditions that an infiltration rate of 40 cm/year past the evapotranspiration zone of the soil column occurs should be re-evaluated for disposal units with an interim soil cover.
- The HELP model should be considered for use in determining the quantity of infiltration, which passes through the hydraulic barrier layer of the closure cap within the PA. This output from the HELP model could then be utilized as input to the PA two-dimensional vadose zone model. This would eliminate the need to assume an infiltration rate of 40 cm/year (15.7 inches/year) past the evapotranspiration zone of the closure cap.
- Future revisions to the PA and closure plan should discuss the fate of non-disposal facilities located within the boundaries of the E-Area LLWF.
- The use of temporary GCL covers over Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches) should be evaluated as an additional operational/interim closure provision to reduce infiltration. It should be determined if disposal unit radiological inventories could be increased with the addition of a temporary cover.
- The closure cap described within this closure plan is essentially a minimal closure cap utilizing a GCL as the sole hydraulic barrier layer to infiltration. Additional barrier layers could be added to the closure cap in order to reduce infiltration to the waste zone further. It should be determined if disposal unit radiological inventories could be increased with the addition of more effective barrier layers.
- Directing closure cap runoff and flow from the closure cap gravel drainage layers to perimeter infiltration galleries should be investigated as a means to reduce the concentrations of the controlled subsurface release of radionuclides from the E-Area LLWF. Additionally it should be determined if disposal unit radiological inventories could be increased with the use of infiltration galleries.
- The closure cap over the Low-Activity Waste Vaults is assumed to fail due to subsidence when the vault itself is assumed to structurally fail at an estimated 3,100 years after final closure. An evaluation should be performed to determine if the closure cap might fail due to erosion or other factors prior to the 3,100 years.
- The closure cap over the Intermediate-Level Vaults is assumed to hydraulically fail when the vault itself is assumed to hydraulically fail at an estimated 1,050 years after final closure. An evaluation should be performed to determine if the closure cap might fail due to erosion or other factors prior to the 1,050 years.
- The subsidence potentials of the Low-Activity Waste Vaults, Intermediate-Level Vaults, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches), and Naval Reactor Component Disposal Pads should be determined similar to that of the Engineered Trenches as documented in WSRC-RP-2001-00613 (WSRC 2001)

- The PA does not currently take into account the waste compression and subsequent increase in radionuclide concentration that will occur due to failure, collapse, and subsidence of the disposal units and waste. The PA should be updated to take this into account for the facilities to which it is applicable. This may be significant for the Low-Activity Waste Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Naval Reactor Component Disposal Pads.
- The potential for differential subsidence and its impact upon the intruder scenarios should be considered in the PA.
- A conceptual understanding of the physical configuration of the entire system after failure should be developed and the implications of this configuration on the PA should be considered.
- The assumption that infiltration past the evapotranspiration zone of the soil column at the estimated time of disposal unit failure reverts back to that of pre-capping conditions (i.e. 40 cm/year (15.7 inches/year)) past the evapotranspiration zone of the soil column should be reevaluated in light of the estimated subsidence potential of each disposal unit. Significant subsidence could result in increased infiltration over this value due to depressions created by subsidence that limit or prohibit runoff and promote infiltration.
- Engineered Trench failure has been assumed to occur “200 to 300 years after burial for B-25s that are not dynamically compacted.” (WSRC, 2001) Work should continue to better estimate the anticipated time period of B-25 structural collapse following burial.
- Work should continue to determine the optimal timing for the use of static surcharging and/or dynamic compaction on the Engineered Trenches to achieve more efficient subsidence potential reduction results.
- The use of static surcharging on the Engineered Trenches prior to installation of the closure cap should be investigated as a means to fill the voids between stacks of boxes and thereby minimize closure cap maintenance during the 100-year institutional control period. Such static surcharging may help to eliminate voids between containers, which could potentially cause subsidence during closure cap construction and the institutional control period.
- A global evaluation of possible alternatives to managing the inherent subsidence potential of B-25 boxes and the resulting life-cycle costs should be performed.
- It is anticipated that the bulk of the Slit Trench subsidence will occur during the 100-year institutional control period, requiring that cap maintenance be performed. The use of dynamic compaction on the slit trenches, to minimize the required closure cap maintenance during the 100-year institutional control period, should be evaluated.
- It is anticipated that some of the Slit Trench subsidence may occur after the 100-year institutional control period due to the collapse of containers containing significant void space. The use of dynamic compaction on the slit trenches, to minimize subsidence due to the collapse of containers after the 100-year institutional control period, should be evaluated. This could help justify an assumption in the PA that the closure cap will remain intact significantly beyond the 100-year institutional control period.
- The most appropriate method to fill the void space between casks at the Naval Reactor component Disposal Pads to achieve structural stability for closure cap installation should be evaluated. Potential methods include:
  - The use of Controlled Low Strength Material (CLSM) to fill up the void space between casks (CLSM is a sand, cement, water mixture with a low cement content),
  - The use of hand operated compaction equipment to fill up the void space between casks with compacted soil layers,
  - Filling the void space between casks with granite aggregate or quartz sand utilizing a crane,

  - Filling the void space between casks with on site soils utilizing a crane followed by a static surcharging, and/or
  - A combination of the above
- Consideration should be given in future revisions of the Closure Plan to unit consistency throughout the document. International system of units (SI) and English units are mixed within the current version.
- The maximum uniform vault floor loads of 4.9×10^6 kg/m^2 for the IL Vaults and 2.8×10^6 kg/m^2 for the LAW Vaults should be verified.

7.0 REFERENCES

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APPENDIX A
HELP MODEL RESULTS

Table A-1, E-Area Kaolin Closure Cap HELP Model Input
Input file: Ekao1.d10; Output file: Ekao1out.out

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	100 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 in
CN Input Parameter (HELP Model Query)	**CN Input Parameter Value**
Slope =	3 % [1, 2]
Slope length =	350 ft [12]
Soil Texture =	5 (HELP model default soil texture) [3]
Vegetation =	4 (i.e., a good stand of grass) [3]
HELP Model Computed Curve Number = 55.2	

Layer [1, 2]	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Geotextile Fabric	Not modeled	Not modeled
Gravel	3	2 (lateral drainage layer)
Clay	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)

	Layer Type	Layer Thickness [1, 2] (in)	Soil Texture No.	Total Porosity [3] (Vol/Vol)	Field Capacity [3] (Vol/Vol)	Wilting Point [3] (Vol/Vol)	Initial Moisture [3] (Vol/Vol)
1	1	6		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	2	12		0.38	0.08	0.013	0.08
4	3	30		0.56	0.55	0.5	0.56
5	1	36		0.37	0.24	0.136	0.24

	Layer Type	Sat. Hyd. Conductivity [3] (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	2	1.00E-01	350 [2]	3 [1, 2]			
4	3	1.00E-07					
5	1	1.00E-04					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	3				
5	1				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data is missing from the table.

[1] WSRC 2000c
[2] WSRC 2000
[3] Draft WSRC 2002

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******************************************************************************
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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     D:\HELP3\Hweather\AUGPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\AUGTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\AUGSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\AUGEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hearea\EKAO1.D10
OUTPUT DATA FILE:            D:\HELP3\Hearea\ekao1out.OUT


TIME:  14:19     DATE:   8/ 8/2002


******************************************************************************

     TITLE:  E-Area Kaolin Closure Cap

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                   =      6.00   INCHES
           POROSITY                    =      0.4000 VOL/VOL
           FIELD CAPACITY              =      0.1100 VOL/VOL
           WILTING POINT               =      0.0580 VOL/VOL
           INITIAL SOIL WATER CONTENT  =      0.1100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.100000005000E-02 CM/SEC
```

```
                        LAYER  2
                        --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                   =     30.00   INCHES
POROSITY                    =      0.3700 VOL/VOL
FIELD CAPACITY              =      0.2400 VOL/VOL
WILTING POINT               =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.2400 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC


                        LAYER  3
                        --------

                TYPE 2 - LATERAL DRAINAGE LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                   =     12.00   INCHES
POROSITY                    =      0.3800 VOL/VOL
FIELD CAPACITY              =      0.0800 VOL/VOL
WILTING POINT               =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0800 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.100000001000     CM/SEC
SLOPE                       =      3.00   PERCENT
DRAINAGE LENGTH             =    350.0    FEET


                        LAYER  4
                        --------

                  TYPE 3 - BARRIER SOIL LINER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                   =     30.00   INCHES
POROSITY                    =      0.5600 VOL/VOL
FIELD CAPACITY              =      0.5500 VOL/VOL
WILTING POINT               =      0.5000 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.5600 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.100000001000E-06 CM/SEC


                        LAYER  5
                        --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                   =     36.00   INCHES
POROSITY                    =      0.3700 VOL/VOL
FIELD CAPACITY              =      0.2400 VOL/VOL
WILTING POINT               =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.2400 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 5 WITH A GOOD STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 350. FEET.

SCS RUNOFF CURVE NUMBER	=	55.20	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	100.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	4.500	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	8.320	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.524	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	34.260	INCHES
TOTAL INITIAL WATER	=	34.260	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM AUGUSTA GEORGIA

STATION LATITUDE	=	33.22	DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50	
START OF GROWING SEASON (JULIAN DATE)	=	68	
END OF GROWING SEASON (JULIAN DATE)	=	323	
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	6.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	70.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	77.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR AUGUSTA GEORGIA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.99	4.04	4.92	3.31	3.73	3.88
4.40	3.98	3.53	2.02	2.07	3.20

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
46.00	47.50	54.80	63.20	71.00	77.40
80.60	79.90	74.60	63.50	53.90	46.90

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.22 DEGREES

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        AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH  100
------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
  PRECIPITATION
  -------------
    TOTALS                 4.15     3.66     5.01     3.11     3.77     3.89
                           4.70     3.92     3.94     1.95     1.92     3.14

    STD. DEVIATIONS        2.23     1.64     2.60     1.49     2.22     2.03
                           2.29     2.17     2.27     1.48     1.20     1.76

  RUNOFF
  ------
    TOTALS                 0.001    0.000    0.008    0.001    0.000    0.000
                           0.001    0.022    0.005    0.000    0.000    0.000

    STD. DEVIATIONS        0.010    0.000    0.043    0.010    0.003    0.000
                           0.007    0.122    0.038    0.001    0.000    0.000

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                 1.473    1.917    2.966    3.604    3.892    3.699
                           4.286    3.828    2.996    1.458    0.868    1.001

    STD. DEVIATIONS        0.258    0.257    0.510    0.746    1.494    1.480
                           1.586    1.388    1.098    0.600    0.216    0.228

  LATERAL DRAINAGE COLLECTED FROM LAYER  3
  ----------------------------------------
    TOTALS                 2.2235   1.8941   2.1596   1.1372   0.3601   0.2208
                           0.1733   0.2649   0.3401   0.3492   0.3212   0.9609

    STD. DEVIATIONS        1.7698   1.5678   1.8137   1.1155   0.6622   0.4944
                           0.3866   0.5402   0.6813   0.6580   0.6307   1.0791

  PERCOLATION/LEAKAGE THROUGH LAYER  4
  ------------------------------------
    TOTALS                 0.0972   0.0947   0.1051   0.0895   0.0488   0.0285
                           0.0275   0.0326   0.0323   0.0381   0.0368   0.0630

    STD. DEVIATIONS        0.0300   0.0206   0.0185   0.0289   0.0379   0.0400
                           0.0378   0.0420   0.0376   0.0459   0.0443   0.0450

  PERCOLATION/LEAKAGE THROUGH LAYER  5
  ------------------------------------
    TOTALS                 0.0683   0.0614   0.0749   0.0767   0.0637   0.0499
                           0.0495   0.0509   0.0502   0.0480   0.0456   0.0588

    STD. DEVIATIONS        0.0261   0.0274   0.0314   0.0300   0.0421   0.0463
                           0.0447   0.0438   0.0405   0.0428   0.0379   0.0346
```

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 4

AVERAGES	1.4774	1.3848	1.4366	0.7822	0.2392	0.1516
	0.1152	0.1760	0.2335	0.2320	0.2205	0.6384
STD. DEVIATIONS	1.1759	1.1651	1.2086	0.7710	0.4400	0.3395
	0.2569	0.3589	0.4678	0.4372	0.4330	0.7170

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

	INCHES	CU. FEET	PERCENT
PRECIPITATION	43.17 (6.687)	15669877.0	100.00
RUNOFF	0.039 (0.1327)	14039.40	0.090
EVAPOTRANSPIRATION	31.987 (3.5741)	11611458.00	74.101
LATERAL DRAINAGE COLLECTED FROM LAYER 3	10.40492 (4.72693)	3776984.750	24.10347
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.69413 (0.17077)	251969.141	1.60798
AVERAGE HEAD ON TOP OF LAYER 4	0.591 (0.269)		
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.69802 (0.21741)	253379.594	1.61699
CHANGE IN WATER STORAGE	0.039 (1.6844)	14012.33	0.089

****

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             PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
  ------------------------------------------------------------------------
                                              (INCHES)      (CU. FT.)
                                             ----------   -------------
    PRECIPITATION                               5.05       1833150.120

    RUNOFF                                      0.937       340151.7500

    DRAINAGE COLLECTED FROM LAYER  3            0.58159     211117.06200

    PERCOLATION/LEAKAGE THROUGH LAYER  4        0.005733      2081.23364

    AVERAGE HEAD ON TOP OF LAYER  4           20.566

    MAXIMUM HEAD ON TOP OF LAYER  4           28.825

    LOCATION OF MAXIMUM HEAD IN LAYER  3
          (DISTANCE FROM DRAIN)              103.9 FEET

    PERCOLATION/LEAKAGE THROUGH LAYER  5        0.006716      2437.83325

    SNOW WATER                                  2.14        776934.3750


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.3504

    MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1147

     ***  Maximum heads are computed using McEnroe’s equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 100

LAYER	(INCHES)	(VOL/VOL)
1	1.6334	0.2722
2	8.9659	0.2989
3	2.4694	0.2058
4	16.8000	0.5600
5	8.2515	0.2292
SNOW WATER	0.000	

****
****

Table A-2, E-Area GCL Cap HELP Model Input
Input file: Egcl1.d10; Output file: Egcl1out.out

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	100 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 in
CN Input Parameter (HELP Model Query)	**CN Input Parameter Value**
Slope =	3 % [1, 2]
Slope length =	350 ft [12]
Soil Texture =	5 (HELP model default soil texture) [3]
Vegetation =	4 (i.e., a good stand of grass) [3]
HELP Model Computed Curve Number = 55.2	

Layer [1, 2]	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Geotextile Fabric	Not modeled	Not modeled
Gravel	3	2 (lateral drainage layer)
Geosynthetic Clay Liner (GCL)	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)

	Layer Type	Layer Thickness [1, 2] (in)	Soil Texture No.	Total Porosity [3] (Vol/Vol)	Field Capacity [3] (Vol/Vol)	Wilting Point [3] (Vol/Vol)	Initial Moisture [3] (Vol/Vol)
1	1	6		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	2	12		0.38	0.08	0.013	0.08
4	3	0.20 [4]		0.75 [5]	0.747 [5]	0.400 [5]	0.75
5	1	65.8		0.37	0.24	0.136	0.24

	Layer Type	Sat. Hyd. Conductivity [3] (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	2	1.00E-01	350 [2]	3 [1, 2]			
4	3	5.00E-09 [6]					
5	1	1.00E-04					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	3				
5	1				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data is missing from the table.

[1] WSRC 2000c
[2] WSRC 2000
[3] Draft WSRC 2002
[4] USEPA 2001
[5] USEPA 1994 and 1994a
[6] GSE 2002

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     D:\HELP3\Hweather\AUGPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\AUGTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\AUGSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\AUGEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hearea\EGCL1.D10
OUTPUT DATA FILE:            D:\HELP3\Hearea\Egcl1out.OUT


TIME:  14:24     DATE:   8/ 8/2002


******************************************************************************

     TITLE:  E-Area GCL Closure Cap

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                    =      6.00   INCHES
           POROSITY                     =      0.4000 VOL/VOL
           FIELD CAPACITY               =      0.1100 VOL/VOL
           WILTING POINT                =      0.0580 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.1100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC
```

```
                        LAYER  2
                        --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                  =     30.00   INCHES
POROSITY                   =      0.3700 VOL/VOL
FIELD CAPACITY             =      0.2400 VOL/VOL
WILTING POINT              =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.2400 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC

                        LAYER  3
                        --------

                TYPE 2 - LATERAL DRAINAGE LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                  =     12.00   INCHES
POROSITY                   =      0.3800 VOL/VOL
FIELD CAPACITY             =      0.0800 VOL/VOL
WILTING POINT              =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.0800 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.100000001000     CM/SEC
SLOPE                      =      3.00   PERCENT
DRAINAGE LENGTH            =    350.0    FEET

                        LAYER  4
                        --------

                  TYPE 3 - BARRIER SOIL LINER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                  =      0.20   INCHES
POROSITY                   =      0.7500 VOL/VOL
FIELD CAPACITY             =      0.7470 VOL/VOL
WILTING POINT              =      0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.499999997000E-08 CM/SEC

                        LAYER  5
                        --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER   0
THICKNESS                  =     65.80   INCHES
POROSITY                   =      0.3700 VOL/VOL
FIELD CAPACITY             =      0.2400 VOL/VOL
WILTING POINT              =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.2400 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 5 WITH A GOOD STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 350. FEET.

SCS RUNOFF CURVE NUMBER	=	55.20	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	100.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	4.500	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	8.320	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.524	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	24.762	INCHES
TOTAL INITIAL WATER	=	24.762	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM AUGUSTA GEORGIA

STATION LATITUDE	=	33.22	DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50	
START OF GROWING SEASON (JULIAN DATE)	=	68	
END OF GROWING SEASON (JULIAN DATE)	=	323	
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	6.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	70.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	77.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR AUGUSTA GEORGIA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.99	4.04	4.92	3.31	3.73	3.88
4.40	3.98	3.53	2.02	2.07	3.20

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
46.00	47.50	54.80	63.20	71.00	77.40
80.60	79.90	74.60	63.50	53.90	46.90

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.22 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 100

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.15	3.66	5.01	3.11	3.77	3.89
	4.70	3.92	3.94	1.95	1.92	3.14
STD. DEVIATIONS	2.23	1.64	2.60	1.49	2.22	2.03
	2.29	2.17	2.27	1.48	1.20	1.76
RUNOFF						
TOTALS	0.001	0.000	0.008	0.001	0.000	0.000
	0.001	0.022	0.005	0.000	0.000	0.000
STD. DEVIATIONS	0.010	0.000	0.043	0.010	0.003	0.000
	0.007	0.122	0.038	0.001	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	1.473	1.917	2.966	3.604	3.892	3.699
	4.286	3.828	2.996	1.458	0.868	1.001
STD. DEVIATIONS	0.258	0.257	0.510	0.746	1.494	1.480
	1.586	1.388	1.098	0.600	0.216	0.228
LATERAL DRAINAGE COLLECTED FROM LAYER 3						
TOTALS	2.2744	1.9480	2.2212	1.1995	0.4058	0.2430
	0.1953	0.2898	0.3632	0.3777	0.3494	0.9998
STD. DEVIATIONS	1.7597	1.5512	1.7951	1.1072	0.6710	0.5116
	0.4015	0.5577	0.6901	0.6763	0.6486	1.0907
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0446	0.0389	0.0442	0.0260	0.0113	0.0066
	0.0056	0.0075	0.0088	0.0090	0.0084	0.0209
STD. DEVIATIONS	0.0313	0.0279	0.0316	0.0197	0.0123	0.0103
	0.0083	0.0113	0.0132	0.0135	0.0129	0.0204
PERCOLATION/LEAKAGE THROUGH LAYER 5						
TOTALS	0.0409	0.0377	0.0393	0.0300	0.0137	0.0083
	0.0073	0.0090	0.0098	0.0112	0.0110	0.0209
STD. DEVIATIONS	0.0208	0.0181	0.0186	0.0182	0.0128	0.0122
	0.0102	0.0126	0.0127	0.0157	0.0158	0.0185

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-----------------------------------------------------------------------------
             AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-----------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES                1.5112   1.4240   1.4775   0.8250   0.2696   0.1668
                            0.1297   0.1925   0.2494   0.2509   0.2399   0.6643

    STD. DEVIATIONS         1.1692   1.1526   1.1962   0.7652   0.4458   0.3512
                            0.2667   0.3706   0.4738   0.4494   0.4454   0.7247

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     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-----------------------------------------------------------------------------
                                      INCHES            CU. FEET      PERCENT
                               -------------------   -------------   ---------
 PRECIPITATION                  43.17    (   6.687)   15669877.0     100.00

 RUNOFF                          0.039   (  0.1327)      14039.40      0.090

 EVAPOTRANSPIRATION             31.987   (  3.5741)   11611458.00     74.101

 LATERAL DRAINAGE COLLECTED     10.86704 (  4.74732)   3944736.500   25.17401
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH     0.23190 (  0.08776)     84181.508    0.53722
   LAYER  4

 AVERAGE HEAD ON TOP             0.617 (    0.270)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH     0.23893 (  0.07385)     86730.945    0.55349
   LAYER  5

 CHANGE IN WATER STORAGE         0.036   (  1.6897)      12909.36      0.082

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             PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
  ------------------------------------------------------------------------
                                                 (INCHES)      (CU. FT.)
                                                ----------   -------------
   PRECIPITATION                                  5.05       1833150.120

   RUNOFF                                         0.937       340151.7500

   DRAINAGE COLLECTED FROM LAYER  3               0.58117     210965.17200

   PERCOLATION/LEAKAGE THROUGH LAYER  4           0.017636      6401.95947

   AVERAGE HEAD ON TOP OF LAYER  4               20.539

   MAXIMUM HEAD ON TOP OF LAYER  4               28.777

   LOCATION OF MAXIMUM HEAD IN LAYER  3
         (DISTANCE FROM DRAIN)                  103.8 FEET

   PERCOLATION/LEAKAGE THROUGH LAYER  5           0.005610      2036.52515

   SNOW WATER                                     2.14        776934.3750


   MAXIMUM VEG. SOIL WATER (VOL/VOL)                      0.3504

   MINIMUM VEG. SOIL WATER (VOL/VOL)                      0.1147


    ***  Maximum heads are computed using McEnroe's equations.  ***

         Reference:  Maximum Saturated Depth over Landfill Liner
                     by Bruce M. McEnroe, University of Kansas
                     ASCE Journal of Environmental Engineering
                     Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 100

LAYER	(INCHES)	(VOL/VOL)
1	1.6334	0.2722
2	8.9659	0.2989
3	2.4793	0.2066
4	0.1500	0.7500
5	15.0897	0.2293
SNOW WATER	0.000	