Nevada
Environmental
Restoration
Project

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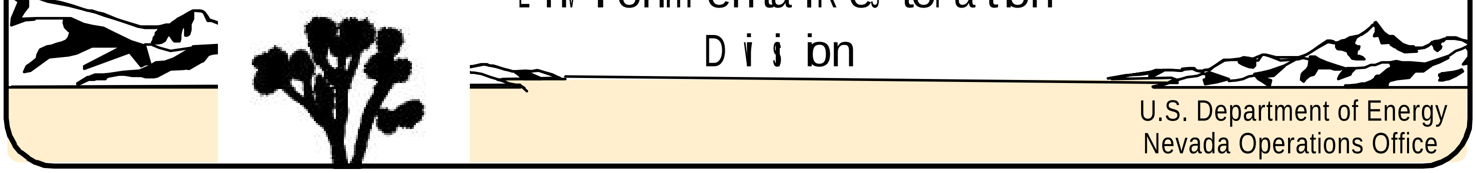
Salmon Site
Remedial Investigation Report

Volume I

Revision No.: 1

September 1999

Environmental Restoration
Division



U.S. Department of Energy
Nevada Operations Office

DOE/NV--494-VOL I/REV 1

SALMON SITE
REMEDIAL INVESTIGATION REPORT

DOE Nevada Operations Office
Las Vegas, Nevada

Revision No.: 1

September 1999

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SALMON SITE
REMEDIAL INVESTIGATION REPORT

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List of Acronyms and Abbreviations

AEC	U.S. Atomic Energy Commission
AOC	Area(s) of Concern
atm-m^3	Atmospheres-cubic meter
bgs	Below ground surface
CERCLA	*Comprehensive Environmental Response Compensation and Liability Act*
Ci	Curie(s)
cm	Centimeter(s)
cm/sec	Centimeter(s) per second
CPT	Cone Penetrometer Test(ing)
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
EPA	U.S. Environmental Protection Agency
ft	Foot (feet)
FS	Feasibility Study
gal	Gallon(s)
gpd/ft	Gallon(s) per day per foot
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HMCAA	Half Moon Creek Alluvial Aquifer
HQ	Hazard Quotient
ILCR	Incremental lifetime cancer risk
in.	Inch(es)
IRIS	Integrated Risk Information System
K	Hydraulic conductivity
K_d	Distribution coefficient
K_{oc}	Organic Carbon Partition Coefficient
K_{ow}	Octanol-water partition coefficient
km	Kilometer(s)
km^2	Square kilometer(s)
L	Liter(s)
m	Meter(s)
m^2/day	Square meter(s) per day
m^3	Cubic meter(s)

List of Acronyms and Abbreviations *(Continued)*

MCL	Maximum contaminant level
MCEQ	Mississippi Commission on Environmental Quality
MDEQ	Mississippi Department of Environmental Quality
mi	Mile(s)
mi^2	Square mile(s)
mg/kg	Milligram(s) per kilogram
mg/L	Milligram(s) per liter
MS	Mississippi
NCP	National Contingency Plan
NORM	Naturally Occurring Radioactive Material
PCB	Polychlorinated biphenyl(s)
pCi	Picocurie(s)
pCi/L	Picocurie(s) per liter
pCi/mL	Picocurie(s) per milliliter
pCi/g	Picocurie(s) per gram
PCOC	Potential contaminants of concern
ppm	Part(s) per million
PVC	Polyvinyl chloride
RAGS	*Risk Assessment Guidance for Superfund*
RBP	Rapid Bioassessment Protocols
REECo	Reynolds Electrical & Engineering Co., Inc.
RfD	Reference dose(s)
RI	Remedial Investigation
RME	Reasonable maximum exposure
SF	Slope factors
SGZ	Surface ground zero
SVOC	Semivolatile organic compound(s)
TCE	Trichloroethene
TDS	Total dissolved solids
TPH	Total petroleum hydrocarbon(s)
UCL	Upper confidence limit
UST	Underground Storage Tank
VOC	Volatile organic compound(s)

List of Acronyms and Abbreviations *(Continued)*

µg/L	Microgram(s) per liter
µg/kg	Microgram(s) per kilogram
°C	Degrees Celsius
°F	Degrees Fahrenheit

1.0 Introduction

The Salmon Site, formerly known as the Tatum Dome Test Site, is located in south-central Mississippi in Lamar County, near the city of Hattiesburg, and was the site of two nuclear and two gas explosions conducted deep underground in a salt dome. These tests, conducted between 1964 and 1970, were performed as part of the former U.S. Atomic Energy Commission's (AEC) Vela Uniform Program (DOE/NV, 1992). The Salmon Site is currently managed by the U.S. Department of Energy, Nevada Operations Office (DOE/NV).

Testing activities at the Salmon Site resulted in the release of radionuclides into the salt dome. During reentry drilling and other site activities, liquid and solid wastes containing radioactivity were generated resulting in surface soil and groundwater contamination at the Salmon Site. Most of the waste and the contaminated soil and water were disposed of either in the test cavity left by the tests or in an injection well. Other radioactive wastes were transported off the facility for disposal at the Nevada Test Site, located in southern Nevada. Nonradioactive wastes were disposed of in pits at the site, which were subsequently backfilled with clean soil and graded.

The U.S. Department of Energy (DOE) initiated a Remedial Investigation (RI) of the Salmon Site in 1992 to collect sufficient information to determine if the site poses a current or future risk to human health and/or the environment. The results of the RI will be used to develop and evaluate a range of risk-based remedial alternatives for a Feasibility Study (FS) if required. The purpose and scope of the RI are described in more detail in the *Remedial Investigation and Feasibility Study of the Tatum Dome Test Site, Lamar County, Mississippi*, Volume 1, Final Work Plan (DOE/NV, 1992) and in the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* (DOE/NV, 1995c). The purpose of this report is to present the results of the RI.

The first Salmon Site RI Report was prepared and submitted to the Mississippi Department of Environmental Quality (MDEQ) in February 1998 for review and comment. Results of the RI indicated that soil and water background values needed to be more accurately defined for the risk assessment, and the contaminants detected in the vicinity of the SGZ Mud Pits needed further investigation. These tasks were accomplished in December 1998. This document represents Revision 1 of the Salmon Site RI Report, and contains the additional background and SGZ Mud Pit information. The additional information is reflected in the results and conclusions presented in

Section 4.0 (Nature and Extent of Contamination), Section 5.0 (Contaminant Fate and Transport) and Section 6.0 (Risk Assessment).

1.1 Site Background

A brief overview of the Salmon Site is provided in the following section. This overview includes a description of the site location, a chronological history of site operations and activities, a discussion of the waste generation processes, potential contamination source areas, and previous investigation results and conclusions.

1.1.1 Site Location and Description

The Salmon Site is located in south-central Mississippi about 32 kilometers (km) (20 miles [mi]) southwest of Hattiesburg, Mississippi (Figure 1-1). The site encompasses approximately 595 hectares (1,470 acres) in Sections 11, 12, 13, and 14 of Township 2 North, Range 16 West, St. Stephens Meridian. Access to within 1.6 km (1 mi) of the site is via U.S. Highway 11 and other paved county roads. A network of graded gravel roads provides access to various locations on the site.

The Salmon Site was the location for two nuclear and two gas explosion tests conducted deep underground in the Tatum Salt Dome. These tests, conducted between 1964 and 1970, were part of the AEC's Vela Uniform Program which was conducted to improve the United States' ability to detect, identify, and locate underground nuclear detonations. The Salmon Site is owned and managed by the DOE/NV. Surface ground zero (SGZ), the ground surface point directly above the location where nuclear testing was conducted, is at latitude 31° 08' 32" north, longitude 89° 34' 12" west. A granite monument now marks the location of SGZ.

1.1.2 History of Operations

A complete history of the Salmon Site prior to 1990 is given in Section 2.1.2 of the RI/FS Work Plan (DOE/NV, 1992). Activities conducted after the issuance of the 1992 RI/FS Work Plan are summarized in Section 2.1.2 of the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site, November 1995* (DOE/NV, 1995c). Table 1-1 presents a summary of activities conducted at the Salmon Site from 1950 to 1999.

1.1.3 Waste Generation Processes

Waste was generated from a variety of activities that took place at the Salmon Site during testing of both nuclear and gas explosives. Following each of the tests, reentry holes (Post Shot Hole

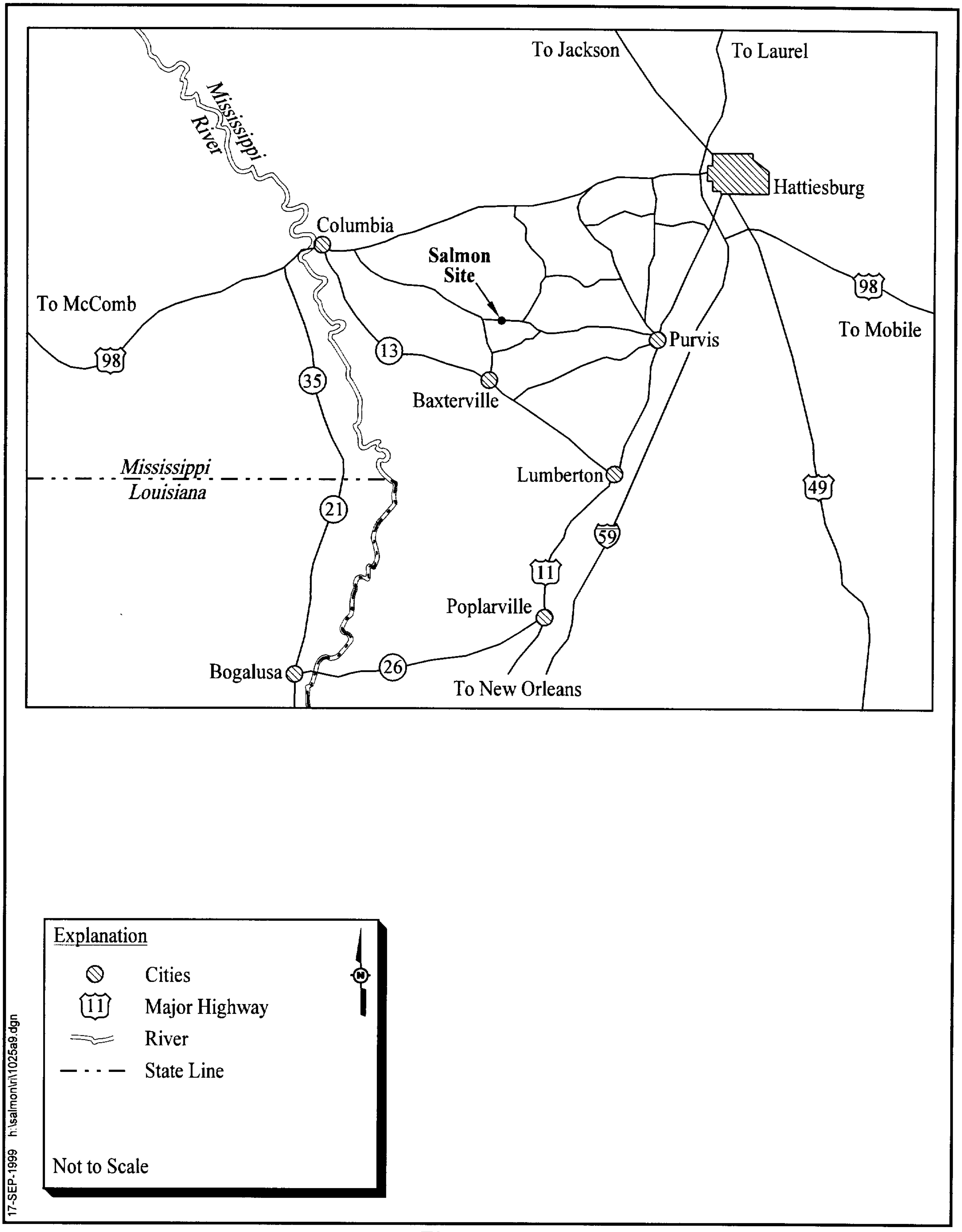


Figure 1-1
General Location Map of the Salmon Site

Table 1-1
Significant Events at the Salmon Site
(Page 1 of 2)

Date	Event
1950	Began disposal of oil field brine into the Cook Mountain limestone portion of Aquifer #5 near Baxterville, 8 km (5 mi) from the site
1959	U.S. Bureau of Mines surveyed 279 salt domes for potential nuclear test sites
1960	AEC's Site Evaluation Committee chose Tatum Dome as the experimental site
1961	Initiated the Vela-Uniform (Exploratory) Drilling Program for Projects Dribble and Miracle Play
1963	Initiated Meteorological Observation Program
1964	Salmon Test (Nuclear)/Project Dribble
1964	Began surface and groundwater sampling
1965	Began portable instrument surveys of radioactivity Began disposal of radioactive liquid waste into Aquifer #5 through Well HT-2
1966	Sterling Test (Nuclear)/Project Dribble
1968	AEC acquires mineral rights underlying the Tatum and Bass Pecan Leases
1969	Diode Tube Gas Explosion/Project Miracle Play Initiated site disposal safety studies
1970	Humid Water Gas Explosion/Project Miracle Play Reynolds Electrical & Engineering Co., Inc. began to identify and define contaminants Soil samples collected
1971	Began site cleanup
1972	Site cleanup and Decommissioned Returned Tatum Dome Site to the private landowner Mans Food Web sampled Initiated Long-Term Hydrologic Monitoring Program
1974	The Tatum Salt Dome Advisory Committee Formed
1977	Water and soil samples collected DOE completes special study of Tatum Dome
1978	Twelve wells added to the Hydrologic Monitoring Program
1979	DOE to reevaluate the Tatum Salt Dome Aquifer monitoring wells were drilled
1980	Six wells added to the Hydrologic Monitoring Program
1984	Began Tritium concentration monitoring Began infiltration studies

Table 1-1
Significant Events at the Salmon Site
(Page 2 of 2)

Date	Event
1988	DOE initiates preliminary assessment Preliminary assessment submitted to EPA Region IV
1989	Tatum Dome added to the Federal Agency Hazardous Waste Compliance Docket via *Federal Register*
1990	EPA installs/samples additional monitoring wells DOE receives Draft Administrative Order from Mississippi Department of Environmental Quality (MDEQ) Draft Agreement in Principle (DOE-MDEQ) prepared DOE holds public meetings DOE initiates preparation of RI/FS Work Plan Draft RI/FS Work Plan submitted to MDEQ
1992	April - Cultural Resources *National Environmental Policy Act* survey June - Submission of the Final RI/FS Work Plan July - Initiation of *National Environmental Policy Act* (NEPA) surveys: Threatened and Endangered Species and Wetlands and Flood Plains September - MDEQ approval of the Final RI/FS Work Plan October - Gopher Tortoise Survey November - Initial surface geophysical survey
1993	February - Surface water, sediment, biota sampling April and May - Soil, vegetation and groundwater sampling; continuation of the geophysical survey August - Miscellaneous construction activities including road maintenance/upgrading equipment decontamination area and storage areas September and October - Complete geophysical surveys October and November - Cone penetrometer testing and soil and groundwater sampling December - Trench Excavation
1994	December - DOE purchases the Salmon Site from the private land owner
1995	September - October - Expand geophysical survey to focus on identified anomalies October - December - Installed and sampled auger wells and soil borings October - Shallow groundwater sampling November - Preparation of RI/FS Work Plan Addendum
1996	September and December - Installed deep monitoring wells
1997	February - Completed well installation and first round of sampling of deep monitoring wells October - Second round of groundwater sampling from monitoring well network
1998	March - Background soil and groundwater sampling December - Direct-push soil and groundwater sampling in Source Area 1
1999	March - Groundwater sampling from deep monitoring well network[a]

[a] This data is presently not available and will be submitted under a separate cover.

No. 1 and Post Shot Hole No. 2) were drilled into the detonation cavity to collect scientific information and determine the effects of each explosion. These drilling operations generated the largest volume of waste including radioactively contaminated drill cuttings and drilling fluids. In addition, support activities generated wastes other than radioactively contaminated materials as part of the testing operations. Test site support operations required fuel, electricity, sanitation, waste storage, waste disposal, and use of hazardous materials. During site operations, the Salmon Site had a work force of more than 100 people.

Radioactive wastes, including contaminated soil and water, were disposed of in the cavity left by the tests, via Post Shot Holes Nos. 1 and 2 prior to them being plugged (DOE/NV, 1998). The HT-2 injection well was used following the first nuclear test to dispose of radiologically contaminated liquid wastes into Aquifer 5 (DOE/NV, 1980). This aquifer is also used for the disposal of oil-field brines near Baxterville, approximately 8 km (5 mi) from the site.

Significant cleanup and waste removal operations were conducted at the Salmon Site during the 1972 site decommissioning activities. During the decommissioning activities, contaminants were removed from the Post Shot No. 1 Slush Pit (Station 1-A Mud Pit) and the Post Shot No. 1 "Mouse Hole." In addition, all miscellaneous hardware and debris was removed from the Bleeddown Plant area, SGZ, drilling storage yard, west gate area, cable yard, junk yard and warehouse (storage) area (AEC, 1972a). During this cleanup, contaminated water and soils were mixed in a slurry and injected into the test cavity. The decommissioning equipment was decontaminated and transported to the Nevada Test Site for disposal. Nonradioactive wastes were disposed of in pits at the site, which were subsequently covered with clean soil and graded. The site was relatively inactive from 1972 to 1992 except for routine annual groundwater monitoring as part of the Long-Term Hydrologic Monitoring Program (DOE/NV, 1995c).

The RI field investigation, revealed that during the 1972 cleanup effort, residual contaminated material was left in the SGZ Mud Pits below the water table. Because of difficulty removing the saturated waste, only contaminated material above the water table was removed (AEC, 1972a). In addition, subsequent investigations concluded that no hazardous or radioactive waste was placed in the disposal pits during this cleanup. Only sanitary waste was encountered during trench sampling in the disposal pits (DOE/NV, 1995a).

Following decommissioning of the site, several additional issues were raised by concerned citizens, the State of Mississippi, and congressional leaders. The DOE initiated a series of studies in response to these concerns, that culminated in the issuance of a work plan for conducting a

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)-type investigation at the Salmon Site. Summary of the activities at the site prior to the initiation of the RI can be found in the RI/FS Work Plan (DOE/NV, 1992).

The RI/FS Work Plan (DOE/NV, 1992) was approved by the state of Mississippi in 1992. Results of the initial phase of the field investigation identified additional information that needed to be added to the original work plan to fulfill the objectives of the remedial investigation. After discussions with the MDEQ and Mississippi Department of Health concerning the initial phase results, the Work Plan Addendum (DOE/NV, 1995c) was prepared. The Work Plan Addendum included the additional information and added 16 areas of concern to the remedial investigation.

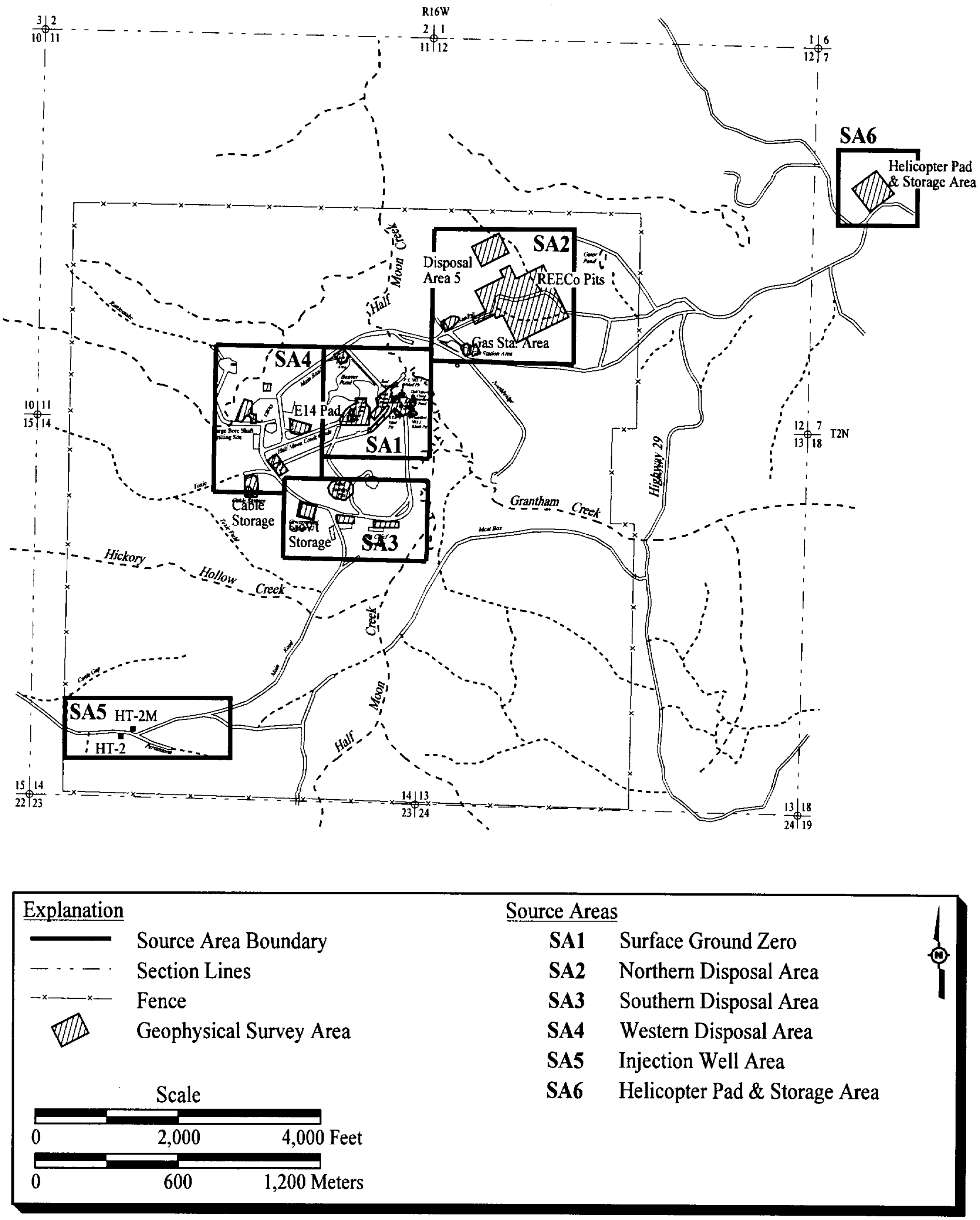
1.1.4 Source Areas and Operable Units

Based on the physical layout of the Salmon Site, and the types of activities conducted there, the site has been divided into six source areas:

- Source Area 1 - Surface Ground Zero
- Source Area 2 - Northern Disposal Area
- Source Area 3 - Southern Disposal Area
- Source Area 4 - Western Disposal Area
- Source Area 5 - Injection Well Area
- Source Area 6 - Helicopter Landing Pad and Storage Area

The locations of these areas are shown on Figure 1-2 and Plate 1. The general characteristics and rationale for defining the Areas of Concern (AOCs) and Source Areas are discussed in the *Remedial Investigation and Feasibility Study of the Tatum Dome Test Site, Lamar County, Mississippi* (DOE/NV, 1992) and the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* (DOE/NV, 1995c).

This RI report discusses the AOCs in terms of Operable Units (for the purpose of this RI, Operable Units are defined as geographical units with the same potential source of contamination). Three operable units have been established, based on three primary sources of potential contamination.



Source: DOE/NV, 1992

Figure 1-2
Salmon Site Source Area Locations

1.1.4.1 Operable Unit 1

Operable Unit 1 includes the surface soil and shallow aquifer system. Table 1-2 presents a list of the potential source areas, individual sites, and potential contamination sources that are associated with Operable Unit 1.

1.1.4.2 Operable Unit 2

Operable Unit 2 includes the test cavity and the intermediate depth aquifers. The test cavity is located in Source Area 1, approximately 826 meters (m) (2,710 feet [ft]) below ground surface (bgs) zero. Table 1-2 presents a list of the potential source areas, individual sites, and potential contamination sources that are associated with Operable Unit 2.

The detonations at the Salmon Site were fully contained and no releases to the surface environment occurred during any of the tests. Following testing, reentry borings were drilled into the test cavity that resulted from the detonations. Analysis of data from these borings led to the conclusion that most of the released radioactivity was contained in a solidified melt puddle in the bottom of the test cavity (DOE/NV, 1980; AEC, 1972a).

During nuclear testing, a number of fission by-products and other materials were released into the surrounding media immediately adjacent to the point of detonation. According to Borg et al. (1976), the by-products generated during underground nuclear testing may originate from three sources of radionuclides: (1) original nuclear material that did not undergo a fission or thermonuclear reaction; (2) fission products, including isotopic antimony, barium, cesium, strontium, and other radionuclides; and (3) activation products. Activation products include radionuclides or elemental isotopes produced by neutron activation in the immediate vicinity of the detonation and primarily include tritium, calcium, argon, and iron.

Other materials that may have been released include lead from shielding materials, traces of synthetic materials used in cables, and residuals from stemming materials (epoxies used to bond materials in the emplacement boring).

During site cleanup the test cavity was used for disposal of the soils excavated from contaminated areas. Material was transported and deposited into a holding pad adjacent to the reentry boring and then placed in a hopper at the borehole collar via a conveyor belt. Contaminated water from various on-site tanks and clean water from Half Moon Creek were

Table 1-2
List of Source Areas, Individual Sites, and Potential Contaminants of Concern for the Salmon Site, Lamar County, Mississippi

(Page 1 of 3)

Source Area Description	AOC	Site Name	Potential Contaminants of Concern
1. Surface Ground Zero	1-A	Station 1-A Mud Pit	Lead from shielding materials, synthetic materials used in cables, residuals from stemming materials, and drilling fluids[a]
	1-B	Beaver Pond	Tritium, fuels, and drilling fluids
	1-C	Half Moon Creek Overflow Pond	Tritium
	1-D	Post Shot No. 1 Slush Pit and ”Mouse Hole”	Tritium, radionuclides, and drilling fluids
	1-E	Bleed-Down Plant Area	Possible residual radioactive contamination from radioactive gas treatment plant
	1-F	East Electrical Substation	Potential contamination by PCBs[b] and generator fuel
	1-G	E-14 Pad and Mud Pits	Residual radioactive contamination from equipment storage and drilling fluids
	1-H	E-6 Decontamination Pad	Residual radioactive contamination from equipment decontamination rinsate
	1-I	Post Shot No. 2 Mud Pit	Contamination of the shallow aquifer by drilling fluids, tritium, and fuels
	1-J	E-3/E-9 Drill Site	Drilling mud, organics, metals

Table 1-2
List of Source Areas, Individual Sites, and Potential Contaminants of Concern for the Salmon Site, Lamar County, Mississippi
(Page 2 of 3)

Source Area Description	AOC	Site Name	Potential Contaminants of Concern
2. Northern Disposal Area	2-A	REECo[c] Disposal Pits	Tritium, materials of unknown (presumed nonradioactive) composition
	2-B	Debris Disposal Pits	Materials of unknown (presumed nonradioactive) composition
	2-C	Clean Burn Pit	Motor oils, solvents and other unknown materials
	2-D	Gas Station	Possible fuel spills and leakage of UST[d]
3. Southern Storage Area	3-A	Mud Storage Pits/South Borrow Pit	Possible organics, metals, and tritium contamination
	3-B	Big Chief Drilling Storage Area	Fuel and hydraulic equipment spills and storage of drill equipment
	3-C	E-2 and E-7 Area	Contamination from drilling fluids (metals and diesel) and tritium
	3-D	Government Storage Area 1 (drilling storage yard)	Possible tritium contamination from the storage of contaminated drilling equipment
	3-E	Government Storage Area 2	Unknown materials (presumed nonradioactive)
	3-F	Sewage Disposal Tank	Unknown wastes
	3-G	Station 4 and W.P. 4 Drilling Sites	Drilling fluids contaminated with metals and diesel

Table 1-2
List of Source Areas, Individual Sites, and Potential Contaminants of Concern for the Salmon Site, Lamar County, Mississippi
(Page 3 of 3)

Source Area Description	AOC	Site Name	Potential Contaminants of Concern
4. Western Disposal Area	4-A	Reserve Mud Pits	Contamination by drilling fluids (metals organics)
	4-B	Debris Burial Pit	Disposal of unknown materials
	4-C	West Electrical Substation	Potentially contaminated by PCBs and generator fuel
	4-D	CH Fuel Storage Area	Possible fuel spills
	4-E	Cable Storage Area	Possible contamination by residual products from burned cable
	4-F	South Electrical Substation	Potentially contaminated by PCBs and generator fuel
	4-G	North Electrical Substation	Potentially contaminated by PCBs and generator fuel
	4-H	E-5 Drill Site	Contamination by drilling fluids (metals and organics)
5. Injection Well Area	5-A	Well HT-2	Radiological contaminants resulting from injection operations of waste into Aquifer 5.
	5-B	Well HT-2m	Radiological contaminants resulting from injection operations of waste into Aquifer 5.
6. Helicopter Pad and Storage Area	6-A	Helicopter Pad and Storage Area	Possible fuel spills

[a] Drilling fluid potential contaminants of concern including primarily petroleum hydrocarbons (diesel) and chromium
[b] Polychlorinated Biphenyls
[c] Reynolds Electrical & Engineering Co., Inc.
[d] Underground storage tank

mixed with these soils to produce a slurry which was injected into the test cavity. An estimated 10,700 cubic meters (14,000 cubic yards) of contaminated soil and water were disposed of in this manner. Following disposal, the borehole was sealed with concrete and special plugging materials as well as 10-centimeter (cm) (4-inch [in.]) diameter steel pipe to prevent drilling into the plug (DOE/NV, 1972a).

1.1.4.3 Operable Unit 3

Operable Unit 3 includes the injection well and deep aquifers. Table 1-2 presents a list of the source areas, individual sites, and potential contamination sources that are associated with Operable Unit 3. This operable unit consists of deep injection Well HT-2 and monitoring Well HT-2m.

Well HT-2, located in Source Area 5, was used for the injection of radioactively contaminated material. Prior to injection of the waste, 7,600 liters (L) (2,000 gallons [gal]) of 15-percent hydrochloric acid were injected into the aquifer to increase the effective porosity and permeability of the Cook Mountain Limestone. Between March and July of 1965, 1,279,000 L (337,900 gal) of radioactively contaminated material were injected into the well. The waste had a total activity of 38 Curies of beta-gamma emitters and 3,253 Curies of tritium. Following injection of the waste, an additional 340,200 L (90,000 gal) of fresh water were injected.

1.2 Report Organization

This RI Report consists of eight sections, including the introduction. The document is organized following the EPA and Mississippi Department of Environmental Quality (MDEQ) guidance for conducting RIs (EPA, 1988a). The contents of each section are summarized below:

- Section 1.0 provides an introduction to the RI report and summarizes the history of operations and investigations at the Salmon Site.

- Section 2.0 presents the physical and environmental setting of the Salmon Site.

- Section 3.0 summarizes the field activities implemented for the RI investigation.

- Section 4.0 identifies potential site-related contamination and summarizes the nature and extent of that contamination.

- Section 5.0 describes the potential fate and transport of the contaminants of concern.

- Section 6.0 summarizes the human health risk assessment.

- Section 7.0 provides conclusions and a summary of the RI report.

- Section 8.0 provides a listing of the references cited in the report.

Appendices to the RI report include the following:

- Appendix A contains well completion and soil boring logs from subsurface investigations conducted at the Salmon Site. The Cone Penetrometer logs are presented in Exhibit 2. This appendix is indexed by Operable Unit.
- Appendix B contains the analytical results for environmental samples collected at the Salmon Site. This appendix is indexed by media sampled and type of investigation.
- Appendix C presents a detailed discussion of the human health risk assessment. A summary of this appendix is presented as Section 6.0.
- Appendix D presents the groundwater model input and output data.

At the request of the MDEQ, previous documents relating to Salmon Site environmental investigations have been included as exhibits to this report. These exhibits include the following:

- Exhibit 1 - *Preliminary Data Report of Investigations Conducted at the Salmon Site Lamar County, Mississippi* issued in April 1994
- Exhibit 2 - *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* issued in April 1995
- Exhibit 3 - *Task Summary for Cone Penetrometer Testing Sounding and Soil and Groundwater Sampling Salmon Site Lamar County, Mississippi* issued in October 1994
- Exhibit 4 - *Geophysical Investigation Salmon Site Lamar County, Mississippi* issued in February 1995
- Exhibit 5 - *Trench Sampling Report Salmon Site Lamar County, Mississippi* issued in July 1994

2.0 Physical Characteristics of the Salmon Site

This section provides a background of the site's geology, hydrogeology, surface water, and environmental resources. This background information constitutes the framework for understanding the occurrence and movement of contamination at the site, a prerequisite for evaluating the risk associated with that contamination. A more detailed discussion of the site's physical setting is presented in the RI/FS Work Plan (DOE/NV, 1992) and Work Plan Addendum (DOE/NV, 1995c).

2.1 Geology

The Salmon Site is situated in the low hills of the piney woods area of the Gulf Coast region of Mississippi. This area is characterized by narrow, flat-topped ridges and intervening valleys that trend predominantly in a south-southeast direction toward the Gulf of Mexico. The maximum relief at the site is about 30 m (100 ft) with elevations ranging from about 76 to 107 m (250 to 350 ft) above mean sea level. Southern Mississippi generally exhibits moderate relief (0 to 152 m [0 to 500 ft]) with typically low hills drained by broad stream drainages. The dense vegetative cover over most of the area reflects the moderate climate and high annual precipitation. The site is drained by Grantham Creek, Hickory Hollow Creek, and Half Moon Creek (Figure 2-1). Surface water flow at the Salmon Site is generally toward the north.

The Salmon Site is situated in a major regional geologic province referred to as the Mississippi Embayment. The Mississippi Embayment is a 259,000 square kilometer (km^2) (100,000 square mile [mi^2]) wedge-shaped region that extends from southern Illinois and southwestern Missouri to about 32 degrees north latitude in Texas, Louisiana, Mississippi, and Alabama. The Mississippi Embayment includes parts of nine states and adjoins the Gulf Coast Geosyncline south of 32 degrees north latitude.

Salt domes, such as Tatum Dome, occur in the southern third of the Mississippi Embayment. The Mississippi Salt Dome Basin, as defined by Spiers and Gandl (1980) and shown in Figure 2-2, contains more than 50 piercement-type salt domes. Tatum Salt Dome is somewhat unique in that it is a simple, unfaulted, cylindrical salt stock whereas the majority of the salt domes in the Mississippi Salt Dome Basin have some degree of faulting. The basin is bounded by a number of regional structural features, most notably the Pickens Gilbertown Fault System

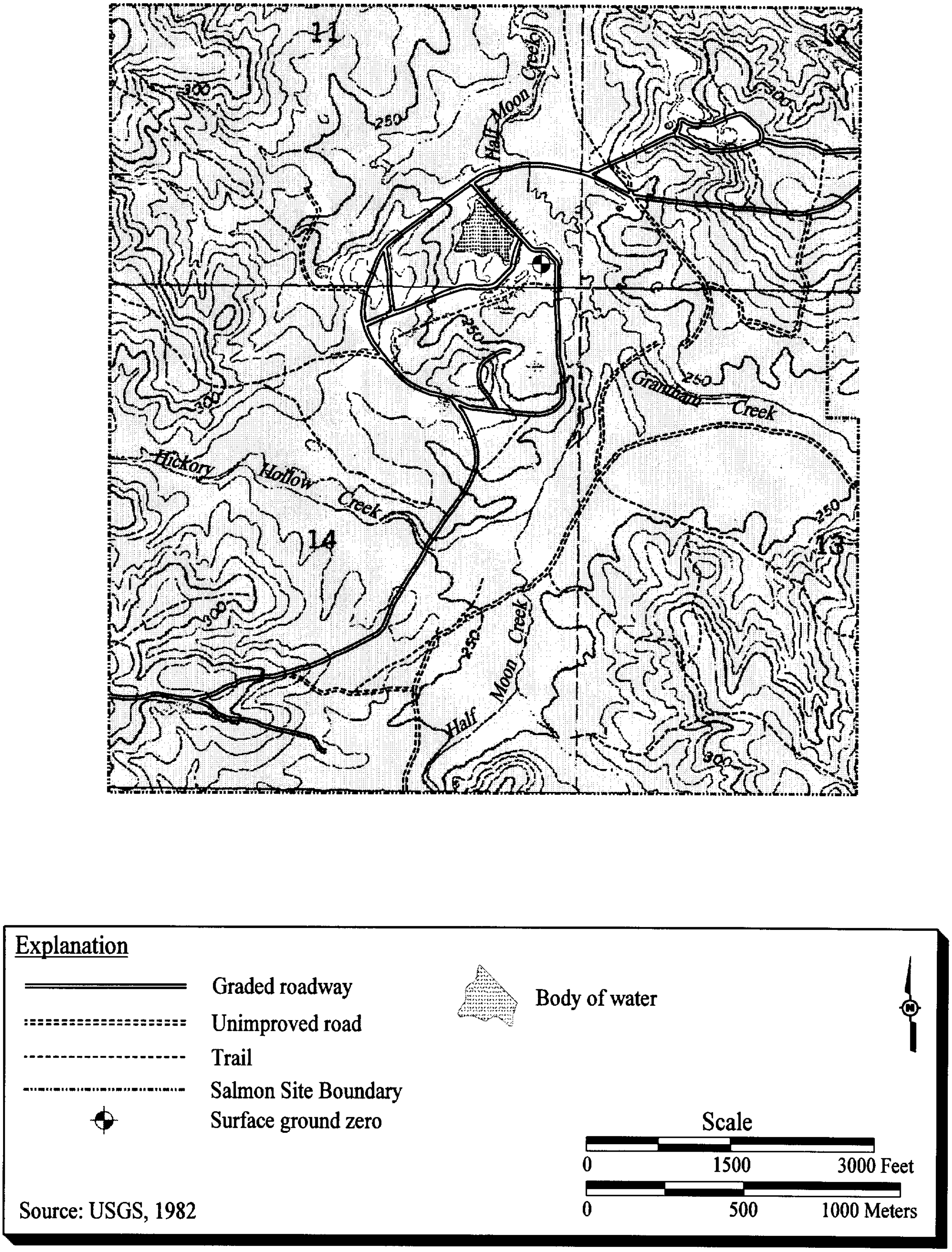
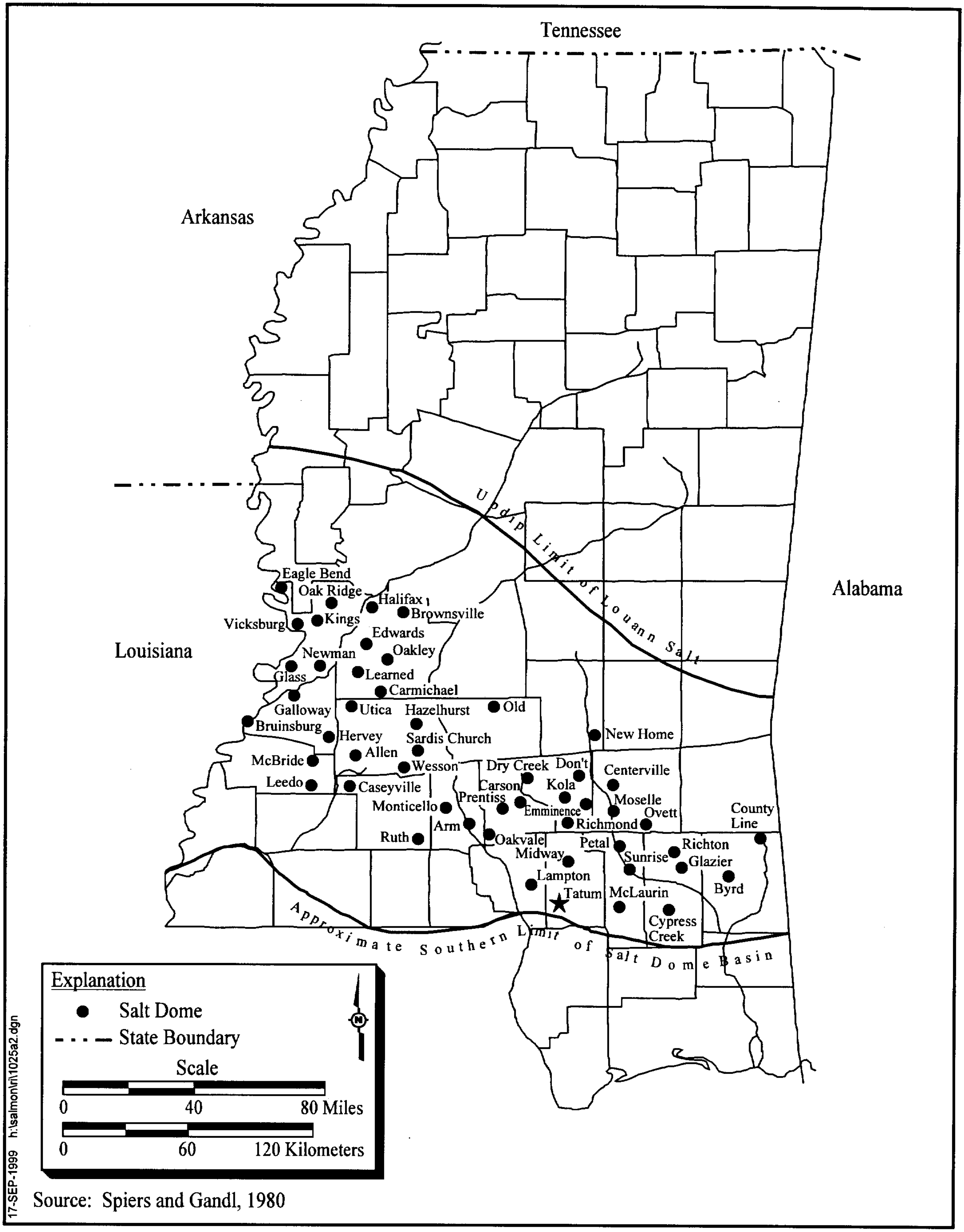


Figure 2-1
Topographic Map of Salmon Site



Source: Spiers and Gandl, 1980

Figure 2-2
Salt Dome Locations in Mississippi

on the north, the Monroe-Sharkey Uplift on the east, and the South Mississippi Uplift and Wiggins Anticline on the south.

The individual salt dome structures evolved from the uprising of salts from an extensive Jurassic formation through the overlying sediments. These piercement structures have caused deformation of the younger units. A conceptual representation of the relationship between the Tatum Dome and the surrounding and overlying sediments are shown in Figure 2-3.

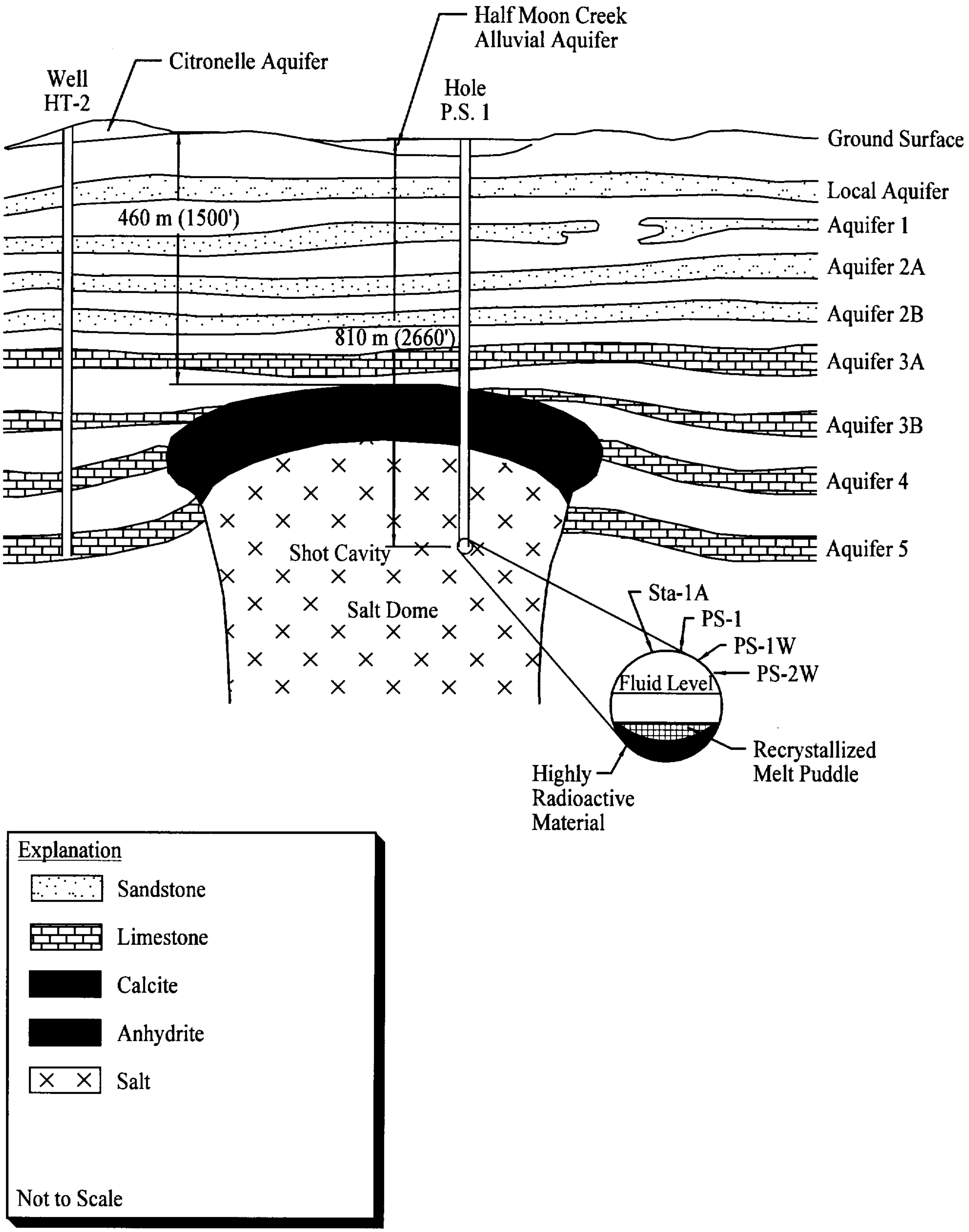
The geologic strata that have been deposited in the Mississippi Salt Dome Basin represent unconsolidated or poorly consolidated sediments comprising interbedded, discontinuous sandstone and shale with minor amounts of marls and limestones. The predominant lithology is shale in the southern portion of the basin, where the Salmon Site is located.

According to Spiers and Gandl (1980), the oldest unit penetrated by drilling is the Louann Salt, a thick Jurassic Age halite deposit. This deposit is overlain by upper Jurassic Sandstones followed by a thick sequence of Cretaceous Age deposits consisting primarily of sandstones, limestones, and shale. The Cretaceous deposits are overlain by Tertiary deltaic deposits and alluvium of Quaternary or Recent Age (DOE/NV, 1992).

2.2 Hydrogeology

In this section, the general regional and local hydrogeologic regimes at the site are summarized. A more complete discussion is contained in the RI/FS Work Plan which provided a conceptual model of the Salmon Site hydrogeologic regime and represented the DOE/NV’s level of understanding of this site (DOE/NV, 1992). The Salmon Site is located within the Mississippi Embayment Flow System, a major part of the Atlantic and Gulf Coastal Plain Ground-Water Region (Heath, 1984). This region is characterized by a series of unconsolidated deposits of gravel, sand, silt, and clay that are underlain by thick sequences of consolidated rock.

The groundwater regime at most locations within the Mississippi Embayment comprises two separate flow systems. On a regional scale, groundwater in the consolidated rock aquifers originates as recharge from precipitation over the outcrop areas, and flows down-dip southwest toward the axis of the embayment in the northeastern part of the embayment and south toward



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Source: DOE/NV, 1978

Figure 2-3
Test Cavity and Aquifers at the Tatum Dome Test Site

the Gulf Coast in the southeastern portions of the basin, including the Tatum Dome area. Superimposed on this regional system is a localized shallow flow regime comprising more recent unconsolidated deposits.

Although the regional flow of groundwater is generally toward the Gulf Coast, it is important to note that perturbations to the subregional and local groundwater levels lead to groundwater flow patterns that are different from the regional groundwater flow system. The effects of injection wells used by the oil industry for the disposal of brines generated during oil production have resulted in significant pressure increases and corresponding alterations in groundwater flow paths for tens of miles in the deeper aquifers of the region (Heath, 1984). On a somewhat more limited scale, water supply wells that withdraw groundwater from the shallower, freshwater aquifers, can create pumping centers that alter both regional and local groundwater flow directions and rates.

The presence of salt domes in the Mississippi Salt Dome Basin does not significantly affect regional groundwater flow in the basin, although local flow in the immediate vicinity of the dome may be altered (Spiers and Gandl, 1980). While the regional hydrogeologic conditions are more easily defined and relatively straightforward, the local, near-dome scale hydrogeologic conditions can be very complex as a result of the effect of the dome formation on the surrounding aquifers.

2.2.1 Local Hydrogeologic Regime

This section presents the general hydrology of the aquifers under the Salmon Site and their significance with respect to contaminant transport. Additional details regarding the local and regional hydrology are provided in the RI/FS Work Plan (DOE/NV, 1992). An understanding of the local hydrogeologic regime is an important element in the development of a site conceptual model. Groundwater can be an important mechanism by which contamination may migrate to potential receptors.

2.2.1.1 Alluvial Aquifer

Three near-surface aquifers identified at the Salmon Site include the Upper Aquifer, the Citronelle Aquifer, and the Half Moon Creek Alluvial Aquifer (Table 2-1). The Upper Aquifer, not specifically assigned to the Pliocene Age, Citronelle Formation, consists of discontinuous perched water zones in gravelly and sandy lenses and Holocene-Pleistocene Age terrace and alluvial deposits that occur along major drainages (ERDA, 1975; DOE/NV, 1980). The Citronelle Aquifer occurs at the contact of the Pascagoula/Hattiesburg and Citronelle formations. In the vicinity of the Salmon Site, this aquifer is primarily a red-orange silty sand. The

Table 2-1
General Stratigraphic Column for the Salt Dome Basin
(Page 1 of 2)

System	Series	Group	Formation/Member	Maximum Thickness m (feet)	Lithology	Aquifer Designation	Water-Bearing Characteristics
Quaternary	Holocene to Pleistocene		Alluvium	60 (200)	Clay, silt, sand, and gravel	Alluvial	Deposits in stream valleys furnish water supplies for small domestic wells. Supplies large irrigation along the Mississippi River.
			Loess	15 (50)	Brown calcareous silt with shells		Not an aquifer in this area
Tertiary	Pliocene		Citronelle Formation	45 (150)	Gray to mottled red-orange silty clay, sand, and gravel		Not an important aquifer. Supplies shallower domestic wells.
	Miocene		Pascagoula and Hattiesburg Formations undifferentiated	549 (1,800)	Greenish-gray-silty clay, sand, and gravelly sand	Local 1, 2a and 2b	Important aquifers. Largest potential source and groundwater in the State. Estimated hydraulic conductivity of 100 (cubic feet per day) per square foot. Supplies many municipal and industrial water users in the salt-dome basin.
			Catahoula Sandstone	853 (2,800)	Gray to olive sand, silt, and silty clay. Downdip–white to gray sandy limestone and marl; glauconitic, calcareous sand	3a and 3b Caprock Aquifer	
	Oligocene	Vicksburg	Chickasawhay Limestone	142 (470)	Gray to white sandy limestone and fossiliferous sandstone and clay	4	Not an aquifer in this area
			Byram Formation/ Bucatunna Clay Member		Calcareous clay and white to gray sandy limestone, marl (Glendon Limestone Member)		Not an important aquifer. Supplies some domestic wells in the northern part of the salt basin. Contains slightly saline water in the southern parts of the basin.
			Marianna Limestone	91 (300)	White to gray sandy limestone, marl		
			Forest Hill Sand/ Red Bluff Clay		Gray, fine sand and clay interbedded and soft fossiliferous limestone		
		Jackson	Yazoo Clay (Cocoa Sand Member)	166 (550)	Olive to gray calcareous clay	No Aquifer	Not an aquifer in this area. Cocoa Sand Member of Yazoo Clay is considered minor local aquifer in northeastern part of salt-dome basin.
			Moodys Branch Formation (Ocala Limestone to the south)		White sandy limestone, fossiliferous, glauconitic		

Table 2-1
General Stratigraphic Column for the Salt Dome Basin
(Page 2 of 2)

System	Series	Group	Formation/Member	Maximum Thickness m (feet)	Lithology	Aquifer Designation	Water-Bearing Characteristics
Tertiary (con't.)	Eocene	Claiborne	Cockfield Formation	166 (550)	Lignitic clay and fine sand	5	An important freshwater aquifer in northern half of salt-dome basin. Contains saline water in the south-half.
			Cook Mountain Formation	85 (280)	Hard to soft white calcareous sand and glauconitic, bentonitic clay		Not a freshwater aquifer in this area. When limestone is present, contains saline water.
			Sparta Sand	305 (1,000)	Gray shale and thin siltstone, interbedded		An important aquifer with moderate to large yields to industrial, municipal and domestic wells in the north-half of salt-dome basin. Contains saline water in the south-half.
			Zilpha Clay Winona Sand Tallahatta Formation	151 (500)	Glauconitic marl, green sand, and shale	No Aquifer	Not aquifers in this area
		Wilcox	Undivided	975 (3,200)	Gray, fine-grained sandstone and green to gray shale, interbedded Chalky white fossiliferous limestone		Important freshwater aquifer north of Jackson, but contains saline water in salt-dome basin.
	Paleocene	Midway	Naheola Formation Porters Creek Clay	320 (1,050)	Gray shale		Not an aquifer in this area
			Clayton Limestone	8 (25)	Limestone		Not an aquifer in this area

Citronelle Formation is about 24 m (80 ft) in maximum thickness and crops out on the slopes and tops of hills at the Salmon Site above the 75 m (250 ft) contour. The Half Moon Creek Alluvial Aquifer (HMCAA) consists of alluvial deposits with more coarse-grained gravels and sands predominating. The HMCAA is limited to the reaches of the major drainages.

In Lamar County, the near-surface aquifers are a minor source of water for domestic and stock wells and account for about two percent of the groundwater pumped in the Lamar County (TETC, 1986). Recharge to this aquifer is derived directly from precipitation over the aquifer. Flow is from the highland areas toward local discharge areas represented by springs, creeks, and ponds. This accounts for the large base flow common to streams in the area (DOE/NV, 1980). Downward leakage of water from the near-surface aquifers into the underlying Miocene aquifers also occurs (Spiers and Gandl, 1980).

In the vicinity of SGZ, the HMCAA extends from the top of the water table (generally less than 3 m [10 ft] bgs) to a depth of about 9 m (30 ft) bgs. Because this aquifer is discontinuous, a published map of the elevation of the top of the water table for the unconfined aquifer does not exist for the Salmon Site. Flow in this aquifer is assumed to generally coincide with topographic expressions, i.e., toward the streams that drain the area (Half Moon, Hickory Hollow, and Grantham Creeks) (DOE/NV, 1980).

The flow direction in the Upper Aquifer and Citronelle Aquifer is locally variable, reflecting the location of the upland areas where recharge occurs and the drainage where the aquifer discharges groundwater to the surface water regime. For example, in the vicinity of Source Area 1 (SGZ), groundwater flow is to the east, northeast, and southeast toward Half Moon Creek, while under Source Area 2 (Northern Disposal Area) groundwater flow is to the west-southwest toward Half Moon Creek.

The ability of the near-surface aquifers to transmit groundwater is an important consideration in evaluating contaminant transport at the Salmon Site.

For the purposes of this report, the Upper Aquifer, Citronelle Formation and Half Moon Creek Alluvial Aquifer will be combined and referred to as the Alluvial Aquifer.

2.2.2 Miocene Aquifer System (Local Aquifer and Aquifers 1, 2a, 2b, 3a, 3b, and Caprock Aquifer)

The Miocene series in Mississippi includes the undifferentiated Pascagoula and Hattiesburg Formations and the Catahoula Sandstone formation. These formations crop out over the southern third of the state except where it is overlain by the Citronelle Formation. The Miocene Aquifer System, which is made up of these formations, is a large regional aquifer system comprised of numerous interbedded sand and clay units (Table 2-1). The Miocene Aquifer System is the most important groundwater supply source in Lamar County. About 98 percent of all groundwater pumped in the county is from this aquifer system (TETC, 1986).

Based upon data collected during the drilling activities at the Salmon Site, this aquifer system may be differentiated into as many as eight discrete hydrostratigraphic zones, each representing a discrete aquifer. Summary descriptions of each of these zones are provided in the following sections.

2.2.2.1 Local Aquifer

The Local Aquifer comprises the uppermost water bearing zone of the Pascagoula/Hattiesburg Formation (undifferentiated), a Miocene Age unit of greenish-gray colored sand, silt, and silty clay (ERDA, 1975; Spiers and Gandl, 1980; DOE/NV, 1980). Recharge to this aquifer is derived from precipitation with discharge to major streams that drain southern Mississippi. The Local Aquifer is an important potable and non-potable water supply source in Lamar County.

The Local Aquifer occurs at depths of 46 m (150 ft) bgs in the vicinity of SGZ (DOE/NV, 1980) and is about 30 m (100 ft) thickness. On a regional basis, flow in this aquifer is generally to the southwest (TETC, 1986). In the vicinity of the Salmon Site, the groundwater flow direction in the Local Aquifer is approximately south, southwest and may be slightly influenced by local geologic conditions (DOE/NV, 1980).

The transmissivity of the Local Aquifer generally ranges from about 12.4 square meters per day (m^2/day) to 47.2 m^2/day (1,000 gallons per day per foot [gpd/ft] to 3,800 gpd/ft) (DOE/NV, 1980; ERDA, 1975). These transmissivity values are for wells completed at the Salmon Site.

2.2.2.2 Aquifers 1, 2a, and 2b

Aquifers 1, 2a, and 2b comprise individual water bearing zones of the undifferentiated deposits of the Pascagoula and Hattiesburg Formations (Chapman and Hokett, 1990; DOE/NV, 1980).

These units are believed to be continuous across the Salmon Site and are separated by discontinuous and less permeable clay beds that serve as aquitards (ERDA, 1975). Many water supply wells in Lamar County use groundwater from one or more of these aquifers.

In the vicinity of SGZ, the depth to the top of Aquifer 1 is approximately 104 m (340 ft) bgs and the aquifer is approximately 18 m (60 ft) thick. Aquifer 2a is approximately 24 m (80 ft) thick and begins at a depth of approximately 136 m (445 ft). The top of Aquifer 2b is approximately 183 m (600 ft) bgs and is approximately 27 m (90 ft) in total thickness.

The direction of groundwater flow through these aquifers is variable, reflecting both the regional flow system and local perturbations. Regional flow through this aquifer is to the southeast, south, and southwest (TETC, 1986). Locally, groundwater flow through Aquifers 1, 2a and 2b in the vicinity of the Salmon Site is easterly (DOE/NV, 1980).

Wells completed in Aquifers 1, 2a, and 2b have exhibited transmissivities ranging from 12.4 to over 2,484 m^2/day (1,000 to 200,000 gpd/ft) for wells completed at the Salmon Site (DOE/NV, 1980). Elsewhere in Lamar County, the transmissivity has been calculated to range from 55.9 to 2,062 m^2/day (4,500 to 166,000 gpd/ft) (TETC, 1986). This relatively high range in transmissivity may reflect lithologic and thickness variations, the depths of the wells tested, and/or the methods used in calculating transmissivity.

2.2.2.3 Aquifer 3a

Aquifer 3a is the upper part of the Catahoula Sandstone and occurs at a depth of about 236 m (775 ft) under SGZ where a total thickness of about 30 m (100 ft) is present (DOE/NV, 1980). Off the flanks of the dome, the aquifer thickens to about 60 m (200 ft) or more (ERDA, 1975). Aquifer 3a is the deepest freshwater aquifer in southern Lamar County and is the deepest water supply aquifer used in the area.

Regional groundwater flow in this aquifer is generally to the southeast, south, or southwest (TETC, 1986). At the Salmon Site the direction of groundwater flow in this aquifer is to the east-northeast (DOE/NV, 1980). This local perturbation may be related to the effects of local pumping.

The transmissivity of Aquifer 3a has been calculated to range from 22.4 to 298.1 m^2/day (1,800 to about 24,000 gpd/ft) at the Salmon Site (DOE/NV, 1980). Elsewhere in Lamar County, a range of 85.7 to 161.4 m^2/day (6,900 to 13,000 gpd/ft) has been reported (TETC, 1986).

2.2.2.4 Aquifer 3b

Aquifer 3b is the Tatum Limestone Member of the Catahoula Sandstone. This unit is not present over the Tatum Salt Dome, but does occur in the subsurface on the flanks of the dome at depths in excess of 267 m (875 ft). Its thickness ranges from about 30 m (100 ft) near the salt dome to about 61 m (200 ft) in thickness about 457 m (1,500 ft) away from the salt dome (ERDA, 1975).

No Salmon Site data are available on the direction of flow in Aquifer 3b. On a regional scale, the flow direction is reported to be to the southwest (DOE/NV, 1980). No aquifer tests have been conducted in Lamar County, in the Tatum Limestone Member. Therefore, transmissivity values are not available.

2.2.2.5 Caprock Aquifer

The Caprock Aquifer is present only over the Tatum Salt Dome and produces a mixture of fresh and saline water from fractures and solution cavities in limestone and anhydrite (DOE/NV, 1980). The aquifer’s areal extent is approximately the same as the salt dome, and may be hydrologically connected with Aquifers 3b and 4. The top of the Caprock Aquifer is about 460 m (1,500 ft) bgs in the vicinity of SGZ. The top surface of the Caprock Aquifer dips radially away from the center of the salt dome and ranges in thickness from 155 to 182 m (509 to 600 ft) (AEC, 1972a). Core recovered from Well E-7, indicates that the cap rock is primarily limestone, medium to dark gray, vuggy, and sandy. Interbedded sand units consist of fine to very fine, angular to subrounded sand with calcareous cement (USGS, 1963). Lost circulation problems reported in drilling records suggest that the Caprock Aquifer is very porous due to a combination of fractures and secondary porosity - primarily vugs and solution cavities in the vicinity of the borehole.

2.2.3 Oligocene Aquifer System (Aquifer 4)

The Oligocene Series in Mississippi includes the Vicksburg Group, and Forest Hill Formation, in descending order. The Paynes Hammock Sand and Chickasawhay Limestone members of the Vicksburg group are not aquifers. The Byram Formation/Bucatunna Clay Member, is a confining unit (Spiers and Gandl, 1980).

The underlying units of the Vicksburg Group, in descending order, are the Bryam, Glendon, Marianna, and Mint Spring Formations. Collectively, these formations are termed the Oligocene Aquifer System and at the Salmon Site, this system is referred to as Aquifer 4 (Table 2-1).

The Oligocene Aquifer System is a large aquifer in southern Mississippi, but because of its low groundwater production capacity, it is not as heavily developed as the shallower aquifers (Spiers and Gandl, 1980). Unlike the overlying Miocene Aquifer Systems and the Alluvial Aquifer, the Oligocene Aquifer System receives its recharge primarily over its outcrop area, a relatively narrow band extending from near Vicksburg on the west to central Wayne County on the east. Water in the Oligocene System (Aquifer 4) at the Salmon Site was derived from precipitation in Clarke and Jasper Counties. Flow in Aquifer 4 is to the south-southwest (DOE/NV, 1980; TETC, 1986). No aquifer tests have been conducted in Lamar County, in the Oligocene Aquifer System; therefore, transmissivity values are not available.

As previously stated, Aquifer 4 is not typically a source of drinking water in Lamar County; consequently, only a limited number of potential receptors may be currently withdrawing water from the aquifer. Aquifer 4 does qualifies as a drinking water source because the total dissolved solids (TDS) concentration of less than 3,000 parts per million (ppm), measured in the upper part of this aquifer at an elevation of about 488 m (1,600 ft) bgs (approximately 564 m [1,850 ft] bgs). Groundwater within this aquifer system has a TDS concentration of greater than 1,000 ppm (Spiers and Gandl, 1980).

2.2.4 Eocene Hydrostratigraphic Units (Aquifer 5)

Underlying the Oligocene Aquifer System is a sequence of Eocene sediments that include, in descending order, the Cockfield Formation, Cook Mountain Formation, and the Sparta Sand. Because of the salinity of the groundwater in these units, they are not considered drinking water aquifers in central and southern Lamar County. In more northern counties, the Cockfield Formation and Sparta Sand are important water supply aquifers, but the Cook Mountain Formation is not considered a freshwater aquifer (Table 2-1).

Two wells constructed in Source Area 5 by the AEC, HT-1 and HT-2, penetrate the full thickness of the Cook Mountain Formation (Aquifer 5). Typically, the Cook Mountain Formation is approximately 85 m (280 ft) thick in the Mississippi Salt Basin. Within the vicinity of the Salmon Site, this unit is approximately 61 m (200 ft) thick (Armstrong et al., 1971). In Well HT-2, the aquifer portion of the Cook Mountain Formation is 53 m (174 ft) thick and consists of interbedded gray, fine to coarse grained limestones and gray to greenish gray-clays. The limestones are fossiliferous in part (Armstrong et al., 1971). Water chemistry samples collected from HT-2, indicated that the water from Aquifer 5 had a TDS concentration of 31,000 ppm. In Well HT-2, the Cook Mountain Formation is overlaid by approximately 122 m (400 ft) of clay and limestone that separate Aquifer 4 from Aquifer 5.

Because of the saline groundwater present in Aquifer 5, this aquifer has been used for the injection of wastewater streams generated by the petroleum industry. Baxterville, Mississippi, located about 4.8 km (3 mi) southwest of the Salmon Site, has been an active center for injection activities for almost 40 years (DOE/NV, 1980). Injection activities have also occurred at Pistol Ridge, to the southeast in Forest County, but at a much lower rate (TETC, 1986). Because of the injection of wastes into Aquifer 5, the direction of flow may be altered. Under natural conditions, the flow through the Cook Mountain Formation is to the southeast. However, at the Salmon Site, the pressure gradient induced by the injection of wastes into Aquifer 5 has reversed, and the flow is to the northeast (DOE/NV, 1980). Two aquifer tests have been conducted in Lamar County in the Cook Mountain Formation, resulting in estimates of transmissivity ranging from 18.6 to 24.8 m^2/day (1,500 to 2,000 gpd/ft).

2.3 Surface Water

The Salmon Site is situated in the Pearl River Basin. This river, with a total drainage area of about 22,700 km^2 (8,760 mi^2), flows into the Gulf of Mexico. Three major streams, Half Moon Creek, Hickory Hollow, and Grantham Creek, drain the Salmon Site (Figure 2-1). These streams receive groundwater discharge from the surficial aquifer. Two ponds, the Beaver Pond and the Half Moon Creek Overflow Pond, are located at the Salmon Site. These ponds also receive runoff and groundwater discharge.

The streams and ponds at the site are expected to have a pronounced effect on the flow of groundwater in the Alluvial Aquifer. The streams receive discharge from the Alluvial Aquifer and the ponds represent groundwater recharge sources for the Alluvial Aquifers during high flow, precipitation events.

2.4 Climate

The climate in Lamar County is classified as semi-tropical with warm, humid summers and generally mild winters. In the Salmon Site area, the mean annual precipitation ranges from 145 to 200 cm (57 to 79 in.) with a long-term average of 150 cm (59 in.). The heaviest rainfalls occur in the summer and fall. Thunderstorms occur 70 to 80 days per year. Temperatures in the Salmon Site vicinity range from near freezing 0 degrees Celsius (°C) (32 degrees Fahrenheit [°F]) in December and January to 35° C (95° F) in July and August. The mean annual temperature for 1985 through 1989 was 18.6° C (65.5 °F). The average annual evapotranspiration rate in south-central Mississippi is 94 cm (37 in.), which amounts to about 63 percent of the precipitation. According to the U.S. Weather Bureau, the surface wind in the Salmon Site area in the summer is usually from a southerly direction which brings moisture from the Gulf of Mexico into the area, resulting in high humidity. Winter winds are more variable, alternately from southerly directions with warm moist air; then from northerly directions with dry, cold air (DOE/NV, 1980).

The Salmon Site is located close enough to the Gulf Coast to receive the effects of occasional Gulf hurricanes. Hurricane type effects occur in this area with a frequency of a little less than one per year (68 storms in 83 years).

2.5 Environmental Resources

Numerous environmental resources are present in Lamar County. Forests provide recreation, aesthetic enjoyment, and a habitat for wildlife. Timber harvesting is also an important component in both environmental and economic resources of Lamar County. The many creeks and streams provide habitats for riparian vegetation and animals. There are 16 flora species and 20 fauna species existing in Lamar County that are state or federal candidates for either proposed endangered, threatened, rare, or otherwise significant species. A Threatened and Endangered protected species study was completed in 1992 (IT, 1992). The Gopher Tortoise *(Gopherus polyphemus)* was the only species inhabiting this area identified as being threatened and endangered.

3.0 Study Area Investigation

Activities at the Salmon Site were conducted in accordance with the *Remedial Investigation and Feasibility Study of the Tatum Dome Test Site, Lamar County, Mississippi, Volume 1, Final Work Plan* (DOE/NV, 1992), and *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* (DOE/NV, 1995c). These activities included: surface water and sediment sampling; surface soil, vegetation, and biota sampling; surface geophysical surveys; cone penetrometer testing (CPT) and sampling; trench sampling; soil boring and sampling; monitoring well installation; and groundwater sampling. All RI field activities were performed in accordance with the RI Work Plan (DOE/NV, 1992) and the Work Plan Addendum (DOE/NV, 1995c).

Details, analytical results, and conclusions of the activities have been previously reported in a series of reports and have been included as exhibits. The exhibits include the following:

- Exhibit 1 - *Preliminary Data Report of Investigations Conducted at the Salmon Site Lamar County, Mississippi* (DOE/NV, 1994a)
- Exhibit 2 - *Baseline Ecological Risk Assessment for Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a)
- Exhibit 3 - *Task Summary for Cone Penetrometer Testing Sounding and Soil and Groundwater Sampling Salmon Site Lamar County, Mississippi* (DOE/NV, 1994b)
- Exhibit 4 - *Geophysical Investigation Salmon Site Lamar County, Mississippi* (DOE/NV, 1995b)
- Exhibit 5 - *Trench Sampling Report Salmon Site Lamar County, Mississippi* (DOE/NV, 1994c)

3.1 Methodology

The sections below describe the various investigation and sampling activities. The activities for each AOC are summarized in Table 3-1.

3.1.1 Surface Soil Sampling

Surficial soil samples were collected from identified AOCs at the site in April 1993 (DOE/NV, 1994a). These samples were collected from 18 individual sites and a location near the reference pond. Sample locations are presented on Figure 3-1. Samples were collected from

Table 3-1
Summary of Investigative Activities by Area of Concern
(Page 1 of 3)

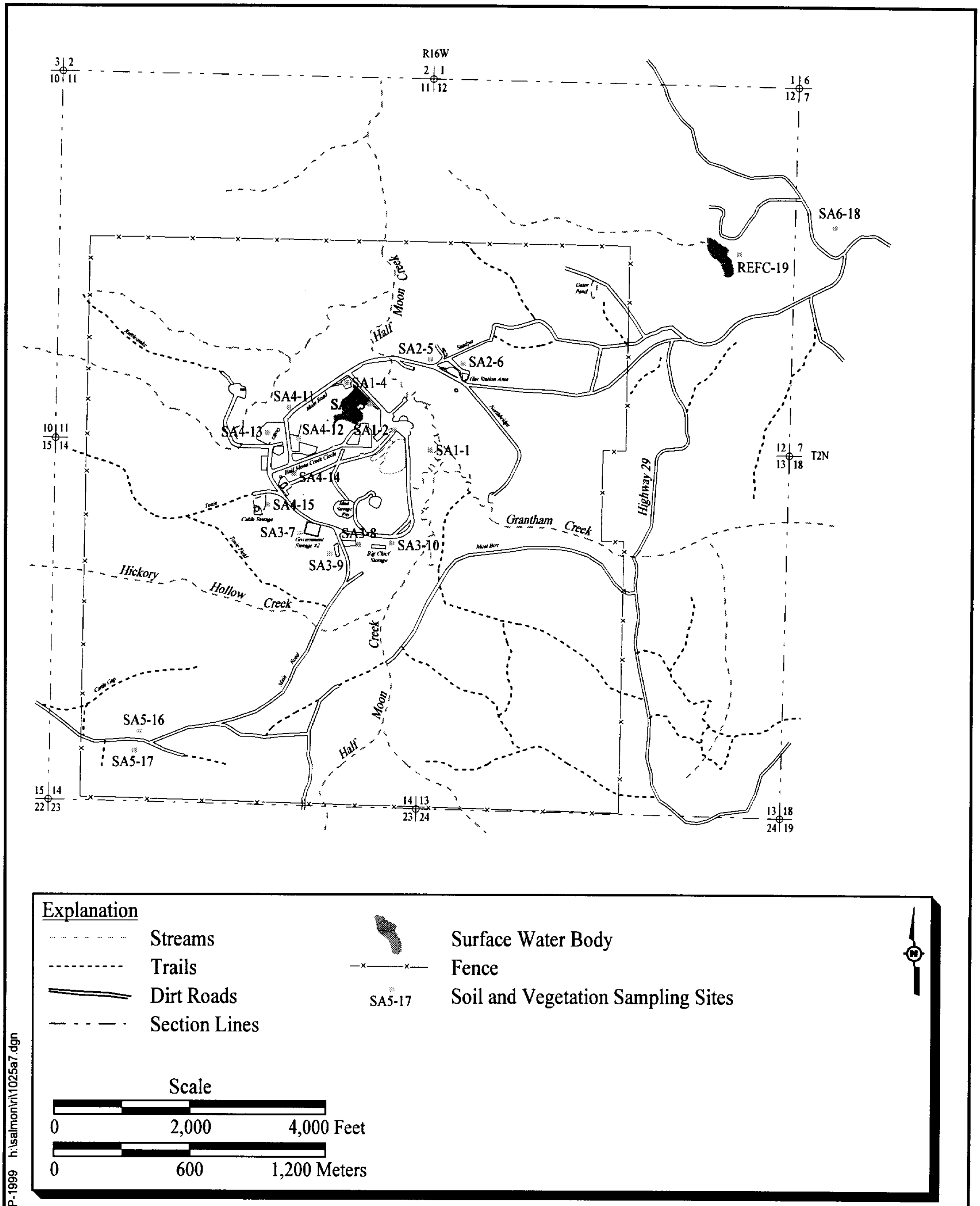
AOC	Site Name	Surface Soil	Geophysical Survey	CPT	Trench	Soil Borings	Auger Wells	Remarks
Source Area 1, Surface Ground Zero								
1-A	Station 1 Mud Pit		X	X		X		Direct-push soil samples collected
1-B	Beaver Pond							Sediment and surface water samples collected
1-C	Half Moon Creek Overflow Pond							Sediment and surface water samples collected
1-D	Post Shot No. 1 Slush Pit and Mouse Hole		X	X			X	
1-E	Bleed Down Plant Area	X	X					
1-F	East Electrical Substation	X						
1-G	E-14 Pad and Mud Pits		X	X		X	X	
1-H	E-6 Decontamination Pad	X	X					
1-I	Post Shot No. 2 Mud Pit	X		X		X	X	
1-J	E-3/E-9 Drilling Site					X		
Source Area 2, Northern Disposal Area								
2-A	REECo Disposal Pits		X	X	X			
2-B	Debris Disposal Pit		X	X	X	X		
2-C	Clean Burn Pit	X	X	X		X		
2-D	Gas Station	X	X	X	X			

Table 3-1
Summary of Investigative Activities by Area of Concern
(Page 2 of 3)

AOC	Site Name	Surface Soil	Geophysical Survey	CPT	Trench	Soil Borings	Auger Wells	Remarks
Source Area 3, Southern Storage Area								
3-A	Mud Storage Pits/South Borrow Pit		X	X		X	X	
3-B	Big Chief Drilling Storage Area	X	X					
3-C	E-2/E-7 Site	X	X	X		X		
3-D	Government Storage Area 1	X						
3-E	Government Storage Area 2	X	X					
3-F	Sewage Disposal Tank		X					Tank not identified
3-G	Station 4 and W.P. 4 Drilling Site		X				X	Mud pits not identified. Wells moved to the north and east
Source Area 4, Western Disposal Area								
4-A	Reserve Mud Pits		X			X	X	
4-B	Debris Burial Pit		X	X				Not identified by geophysics
4-C	West Electrical Substation	X						
4-D	CH Fuel Storage Area	X	X					
4-E	Cable Storage Area	X	X	X				Only surface debris identified
4-F	South Electrical Substation	X						
4-G	North Electrical Substation	X						
4-H	E-5 Drilling Site		X			X		

Table 3-1
Summary of Investigative Activities by Area of Concern
(Page 3 of 3)

AOC	Site Name	Surface Soil	Geophysical Survey	CPT	Trench	Soil Borings	Auger Wells	Remarks
Source Area 5, Injection Well Area								
5-A	Well HT-2	X		X		X	X	
5-B	Well HT-2M		X	X			X	
Source Area 6, Helicopter Pad and Storage Area								
6-A	Source Area 6, Helicopter Pad and Storage Area	X	X					



Source: DOE/NV, 1994a

Figure 3-1
Salmon Site Surface Soil and Vegetation Sampling Locations

approximately 15 cm (6 in.) below the ground surface. The samples were shipped to an off-site laboratory to be analyzed for the potential contaminants of concern (PCOCs) by the analytical methods listed in Table 3-2. Several of the AOCs were not sampled because they were either inaccessible or it was not possible to locate the site due to heavy vegetation. Additional information regarding surface soil sampling procedures is provided in *Preliminary Data Report of Investigations Conducted at the Salmon Site Lamar County, Mississippi* (Exhibit 1) (DOE/NV, 1994a).

3.1.2 Surface Geophysical Survey

Geophysical surveys were conducted at several of the AOCs. The purpose of the surveys was to identify potential buried structures, such as abandoned mud pits and waste sites (DOE/NV, 1995b). Magnetometer and electromagnetic conductivity surveys were conducted in several phases during 1992, 1993, 1994, and 1995. As additional information was gathered, the geophysical grids were expanded or reduced to accommodate the new information. The approximate locations of the geophysical study areas are shown on Figure 3-2. A ground-penetrating radar survey was conducted at several selected sites where anomalies were detected by the other geophysical methods. The overall results of the geophysical surveys were not always conclusive in defining abandoned mud pits, but were effective in identifying buried metallic objects. The ground-penetrating radar was not effective in defining the base of mud pits or buried objects. A detailed discussion regarding the geophysical techniques utilized for each area of study and the analysis of the data is presented in *Geophysical Investigation Salmon Site Lamar County, Mississippi* (DOE/NV, 1995b) (Exhibit 4).

3.1.3 Cone Penetrometer Testing and Sampling

Cone Penetrometer Testing was conducted at 25 locations within the Salmon Site in October and November 1993 (DOE/NV, 1994b). The locations for the CPT were based on the results of the geophysical investigations and historical information. The objectives of the CPT investigation included the following:

- Gather additional information about the geology of the subsurface
- Collect groundwater samples from shallow, water-bearing units
- Collect subsurface soil samples from immediately below the water-bearing units

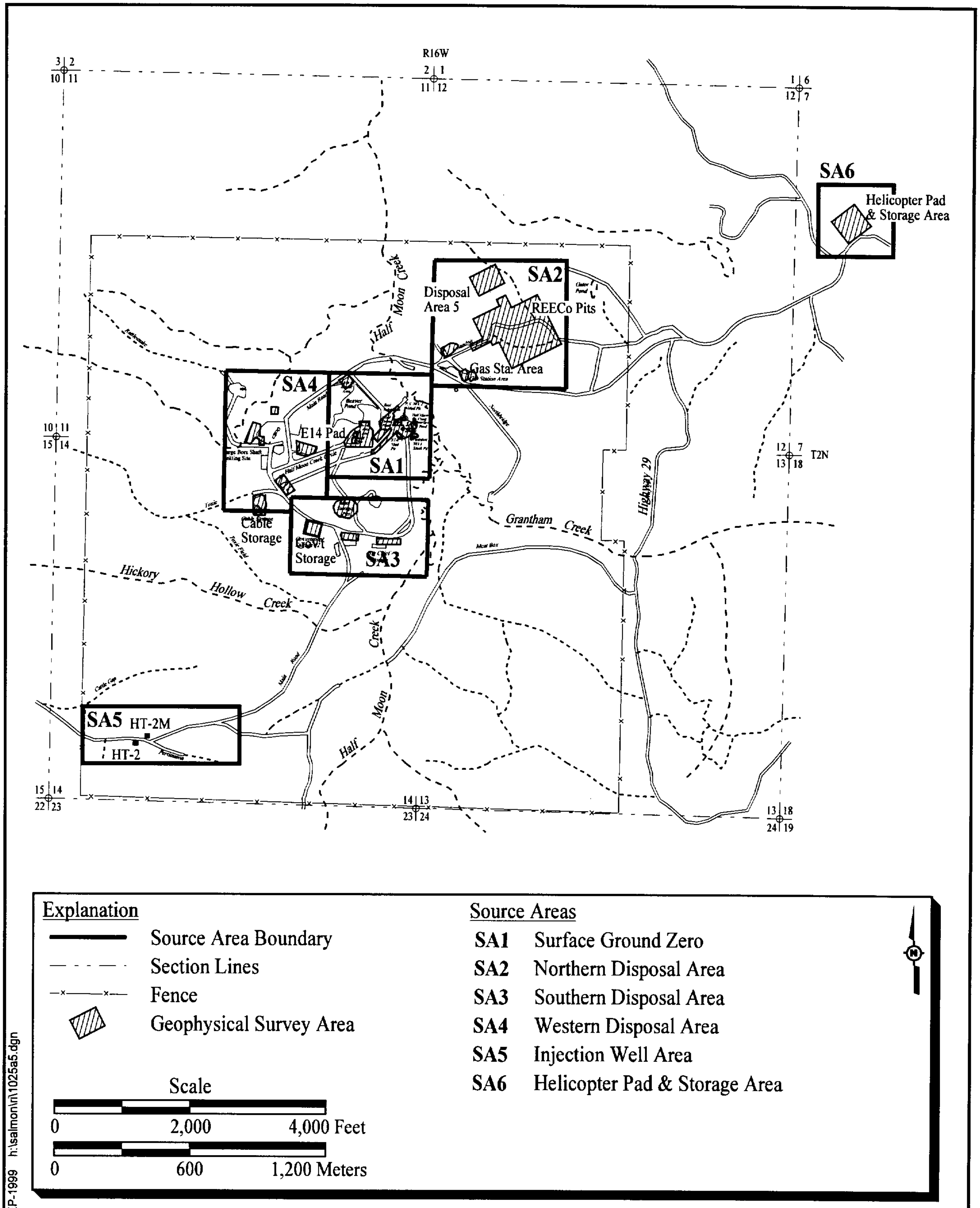
The soil and water samples were analyzed for PCOCs using the analytical methods presented in Table 3-2. The locations of the CPT borings are shown on Figure 3-3. Additional information regarding the CPT testing and sampling program is provided in *Task Summary for Cone*

Table 3-2
Salmon Site Remedial Investigation
Analytical Methods

Analysis	Analytical Method				
	Surface Soils[a]	CPT[b]	Trench[c]	Soil Borings	Groundwater
VOCs	CLP 88[d]	CLP 88	CLP 88	SW-846[e] 8240	SW-846 8240/CLP 90
SVOCs	CLP 88	CLP 88	CLP 88	SW-846 8270	SW-846 8270/BNA CLP90
Pesticides/ PCBs	CLP 88	CLP 88	NA	SW-846 8080	SW-846 8080
Dioxins/ Furans	NA	NA	SW-846 8280	NA	NA
TPH	NA	NA	SW-846 8015M	SW-846 8015M	SW-846 8015M
Metals	CLP 90[f]	CLP 90	CLP 90	SW-846 1311/6010/ 7470	SW-846 6010/7470 CLP MET
Tritium	NA	NA	NA	EERF H.01[g]	EPA 906.0[h]
Gross Alpha/ Gross Beta	SM 7110[i]	SM 7110	SM 7110	SM 7110	EPA 900.0
Gamma Emitters	HASL 300[j]	HASL 300	HASL 300	HASL 300	EPA 901.1

[a] *Preliminary Data Report of Investigation Conducted at the Salmon Site, Lamar County, Mississippi* (DOE/NV, 1994a)
[b] *Task Summary for Cone Penetrometer Testing, Soil and Groundwater, Salmon Site, Lamar County, Mississippi* (DOE/NV, 1994b)
[c] *Trench Sampling Report, Salmon Site, Lamar County, Mississippi* (DOE/NV, 1994c)
[d] *USEPA Contract Laboratory Statement of Work for Organics Analysis, Multi-Media, Multi-Concentration* (EPA, 1988b)
[e] *SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, 3rd Edition* (EPA, 1992)
[f] *USEPA Contract Laboratory Program Statement of Work for Inorganics Analysis, Multi-Media, Multi-Concentration* (EPA, 1990)
[g] *U.S. Environmental Protection Agency Eastern Environmental Radiation Facility Procedures Manual* (EPA, 1984)
[h] *Prescribed Procedures for Measurement of Radioactivity in Drinking Water* (EPA, 1980)
[i] *Standard Methods for the Examination of Water and Wastewater, 18th Edition* (APHA, 1992)
[j] *Environmental Measurements Laboratory Procedures, Manual HASL-300* (DOE, 1992)

NA = Not Analyzed
VOCs = Volatile organic compounds
SVOCs = Semivolatile organic compounds
PCBs = Polychlorinated biphenyls
TPH = Total petroleum hydrocarbons



Source: DOE/NV, 1995b

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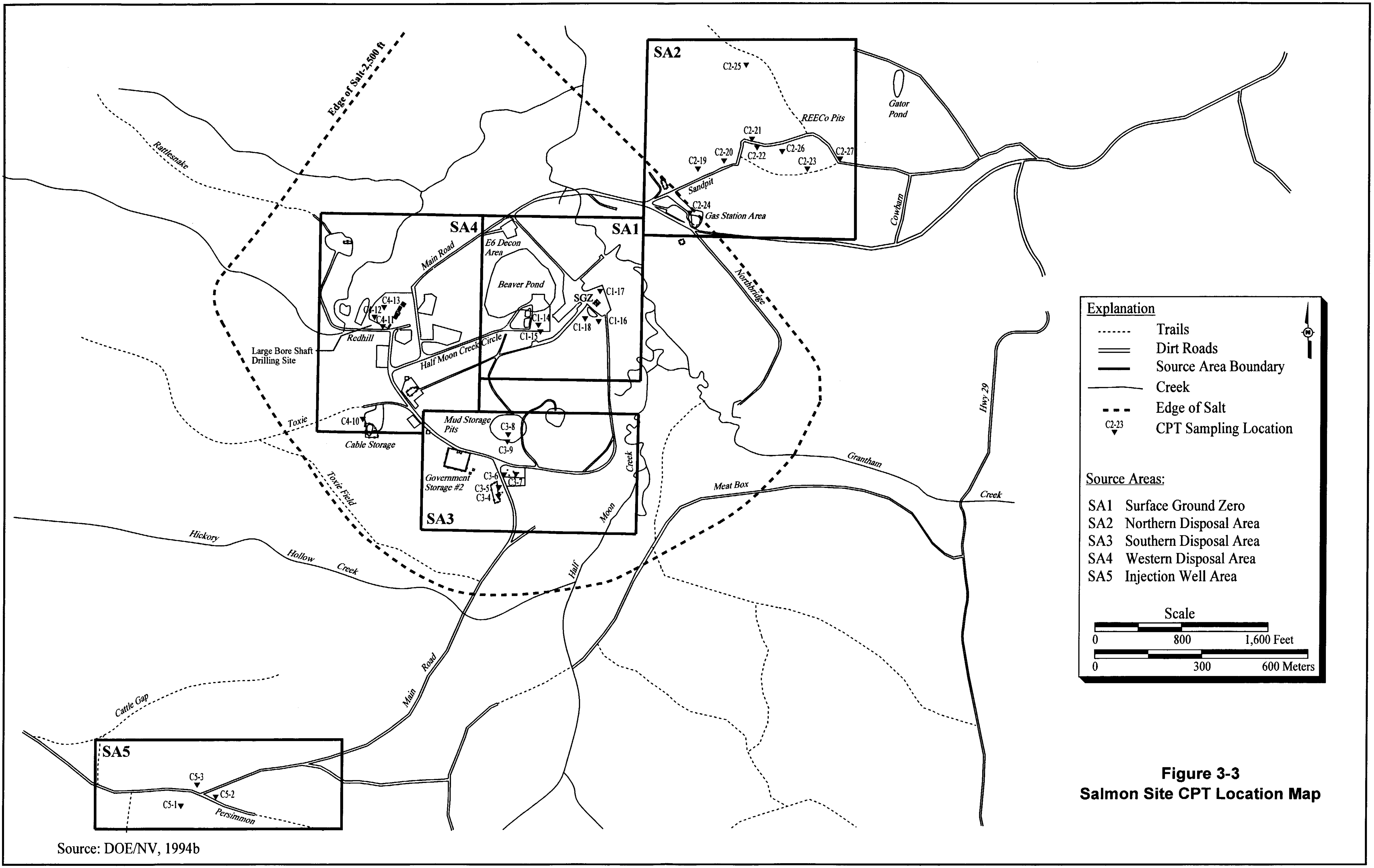
Figure 3-2
Salmon Site Geophysical Study Areas



Source: DOE/NV, 1994b

Figure 3-3
Salmon Site CPT Location Map

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Penetrometer Testing Sounding and Soil and Groundwater Sampling Salmon Site Lamar County, Mississippi (DOE/NV, 1994b) (Exhibit 3).

3.1.4 Trenching and Trench Sampling

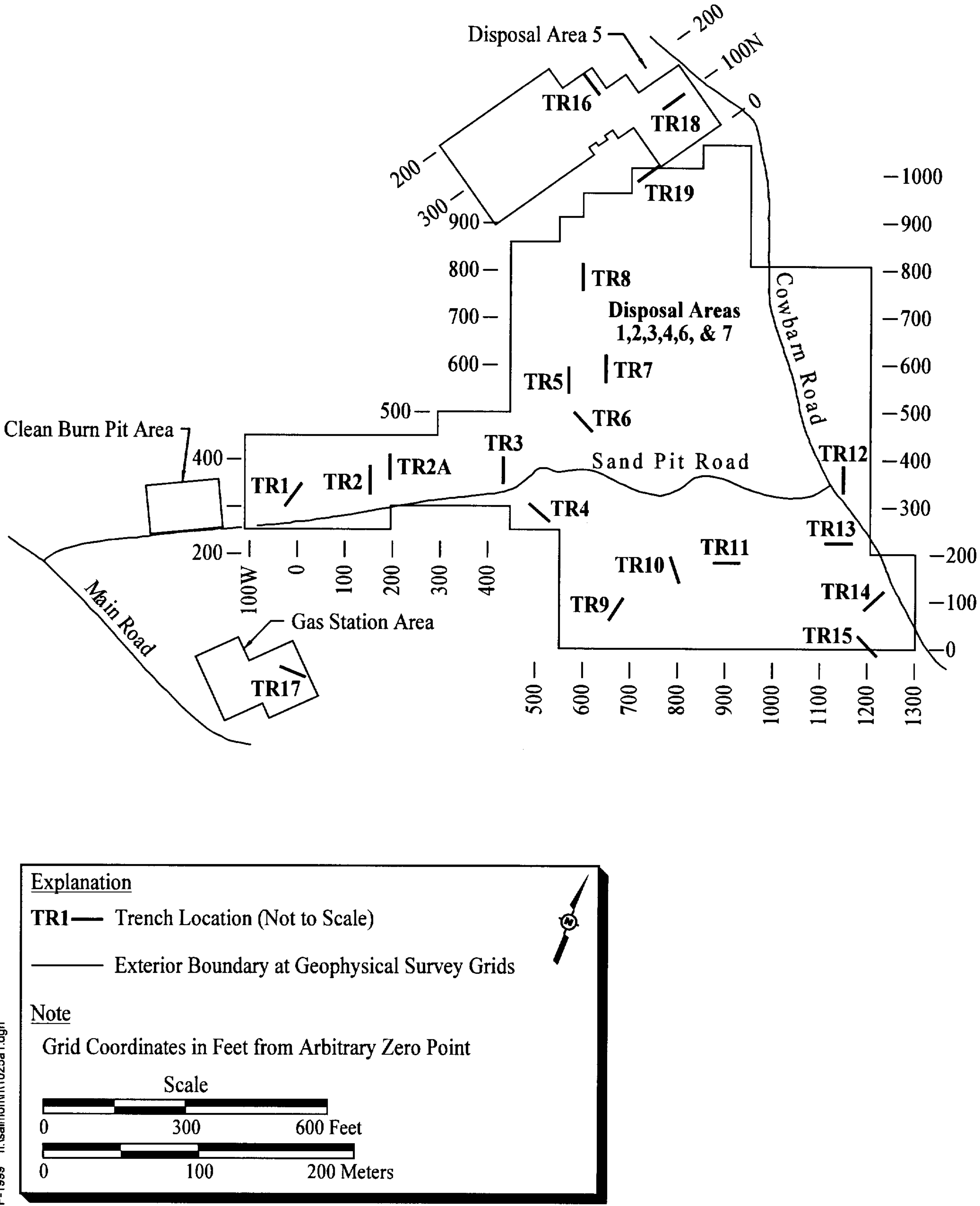
Based on the results of the geophysical investigations, several anomalies were identified at the Salmon Site. These were located primarily in the Reynolds Electrical & Engineering Co., Inc. (REECo) disposal pits in Source Area 2. To determine if the source of these anomalies was buried, potentially contaminated debris, a total of 18 test trenches were excavated to intersect the anomalies using a rubber tired backhoe equipped with an "extend a hoe" bucket (DOE/NV, 1994c). The approximate locations of the test trenches are shown in Figure 3-4. During the course of this investigation, 33 soil samples were collected and analyzed for PCOCs using the analytical methods presented in Table 3-2. A detailed discussion of excavation and sampling activities is provided in *Trench Sampling Report Salmon Site Lamar County, Mississippi* (DOE/NV, 1994c) (Exhibit 5).

3.1.5 Soil Borings

Based on the results of the geophysical investigation and the CPT results, 18 soil borings were advanced in areas where PCOCs were identified or suspected in 5 of the 6 source areas. Due to the limited potential for contamination in Source Area 6, no soil borings were advanced in this area. Borings were advanced using hollow stem auger drilling methods and samples were collected at 5-ft intervals using 3-in. outside diameter by 24-in. long Shelby tubes or 2-in. outside diameter by 24-in. long split-spoon samplers. The depths of these borings ranged from 6.7 to 17.4 m (22 to 57 ft) with the average depth being approximately 9.2 m (30 ft). During the course of this investigation, 105 soil samples were analyzed for PCOCs using the analytical methods presented in Table 3-2. This activity was completed in October 1995. The following sections describe the soil boring activities in the various source areas.

3.1.5.1 Source Area 1

Three soil borings (SB1-1, SB1-2, and SB1-3) were advanced in Source Area 1. The purpose of these borings was to investigate possible contaminants at the Post Shot Number 2 Mud Pit (AOC 1-I), E-14 Drilling Pad and Mud Pits (AOC 1-G), and the Station 1 Mud Pit (AOC 1-A). No boring was installed at the Post Shot No. 1 Slush Pit and "Mouse Hole" because the CPT analytical results indicated no PCOCs. The locations of the Source Area 1 soil borings are presented in Appendix A, Figure A-3.



Source: DOE/NV, 1994c

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Figure 3-4
Salmon Site SA2 Northern Disposal Area Trench Locations

3.1.5.2 Source Area 2

Four soil borings were advanced within Source Area 2. The purpose of these borings was to investigate possible contamination in the clean burn pit area (AOC C-2) and the debris disposal pit (AOC 2-B). The addendum to the work plan called for the installation of a soil boring at the clean burn pit (DOE/NV, 1995c). A review of the description of subsurface materials from this boring suggested that the boring may not have intersected the clean burn pit and a second boring was advanced. Two additional borings were installed near the debris burial pit because of concerns regarding burned material wastes disposed of within the pit (DOE/NV, 1994b). The location of the Source Area 2 soil borings is presented in Appendix A, Figure A-12.

3.1.5.3 Source Area 3

Four soil borings were advanced within Source Area 3. The purpose of these borings was to investigate the possible contaminants in the mud storage pits (AOC 3-A), the E-2/E-7 drilling site (AOC 3-C), and the Station 4 and WP-4 drilling site (AOC 3-G). Surface geophysics and field inspection failed to identify the mud pits at Station 4 and WP-4, so no soil borings could be advanced. The surface geophysics did identify two conductivity anomalies at the E-2/E-7 drilling site, so an additional soil boring was advanced in this area. One boring was proposed for the mud storage pits. An additional review of the geophysical data and field inspection suggested that a second boring was prudent. The Source Area 3 soil boring locations are presented in Appendix A, Figure A-13.

3.1.5.4 Source Area 4

Four soil borings were advanced within Source Area 4. The purpose of these borings was to investigate the possibility of contamination related to Tatum Dome Experiment drilling operations. Two borings were planned for the Reserve Mud Pits (AOC 4-A), and one for the E-5 drilling site. Prior to the drilling of the soil borings, a surface geophysical survey was conducted across the area. Based on the results of the geophysical survey, a third boring was advanced in the Reserve Mud Pits. The Source Area 4 soil boring locations are presented in Appendix A, Figure A-19.

3.1.5.5 Source Area 5

One soil boring was advanced within Source Area 5. The purpose of this boring was to investigate possible contamination related to drilling operations at Well HT-2. The location of the Source Area 5 soil boring is presented in Appendix A, Figure A-22.

3.1.6 Monitoring Well Installation

Monitoring wells were installed in accordance with the Addendum to the Work Plan (DOE/NV, 1995c). The following sections summarize the installation activities.

3.1.6.1 Shallow Well Installation, Operable Unit 1

Fifteen shallow (<15-m [50-ft] bgs) groundwater monitoring wells were installed during November and December 1995, as specified by the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* in Source Areas 1, 3, 4, and 5 (DOE/NV, 1995c). All of the wells were constructed of 13-cm (5-in.) inside diameter, schedule 80, polyvinyl chloride (PVC) well casing and 0.020 inch slotted PVC screen. Following well development, the wells were purged and sampled. Samples were analyzed for PCOCs by the analytical methods listed in Table 3-2. Table 3-3 summarizes the well installation activities in Operable Unit 1. All wells were completed in the Alluvial Aquifer.

Seven shallow wells were installed in Source Area 1. One proposed location in Source Area 1 had to be changed because of wetland intrusion considerations. The locations of Operable Unit 1 wells are shown in Appendix A, Figure A-4. Well completion diagrams for these wells are shown in Appendix A, Figures A-5 through A-11.

Four wells were installed in Source Area 3. The first attempt to install a well at the Mud Storage Pits was abandoned when no aquifer sands were encountered. A replacement well was installed northeast of the first location. The two wells proposed for the Station 4/WP-4 location were moved northeast from the proposed location because of wetland intrusion. Based on the results of these wells, an attempt was made to install another well east of the Big Chief drilling storage yard to evaluate potential contamination in the Alluvial Aquifer. No aquifer was encountered and the boring was abandoned. The locations for the wells installed in Source Area 3 are shown in Appendix A, Figure A-13. Well completion diagrams are included as Figures A-15 through A-18.

Only one of the two wells planned for Source Area 4 was completed. Two attempts failed to intersect aquifer sands, and the borings were abandoned. The locations of the well and the abandoned borings are shown in Appendix A, Figure A-20. A well completion diagram is included as Figure A-21.

Table 3-3
Shallow Monitoring Well Installation Data Summary

Well	Source Area	Depth m (ft)	Aquifer
SA1-1-H	1	9.1 (30)	Alluvial
SA1-2-H		9.1 (30)	
SA1-3-H		9.1 (30)	
SA1-4-H		9.1 (30)	
SA1-5-H		9.1 (30)	
SA1-6-H		7.0 (23)	
SA1-7-H		9.1 (30)	
SA3-1-M	3	12.2 (40)	
SA3-2-M			
SA3-3-M		15.2 (50)	
SA3-4-M		9.1 (30)	
SA3-5-M		9.1 (30)	
SA3-6-M			
SA4-1-M	4	15.2 (50)	
SA4-2-M			
SA4-3-M			
SA5-1-C	5	10.7 (35)	
SA5-2-C		10.7 (35)	
SA5-3-M		12.2 (40)	

Three wells were installed in Source Area 5. The locations for these wells are shown in Appendix A, Figure A-23. Well construction diagrams are shown in Figures A-24 through A-26. Following installation of the Operable Unit 1 wells sampled and the samples analyzed for the parameters identified in Table 3-2.

3.1.6.2 Deep Monitoring Well Installation, Operable Unit 2

During 1996 and 1997, twelve groundwater monitoring wells were installed and sampled at the Salmon Site as required under the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* (DOE/NV, 1995c). These wells ranged in depth from 60.4 to 285 m (198 to 934 ft) bgs and were installed to provide information about the geology, hydrology, and possible contaminants in the groundwater in the Local Aquifer, as well as Aquifers 1, 2a, 2b, and 3. The summary of these wells is provided in Table 3-4. Well SA1-8-L

Table 3-4
Monitoring Well Data Summary for Wells Installed in Operable Unit 2

Well	Location	Depth meters (ft)	Aquifer
SA1-8-L	Eastern Well Cluster (Southeast of Surface Ground Zero) Source Area 1	60.4 (198)	Local
SA1-9-2a		220 (722)	2a
SA1-10-2b		257 (844)	2b
SA1-11-3		285 (934)	3
SA2-1-L	Source Area 2	107 (351)	Local
SA2-2-L		104 (342)	
SA2-3-L		91 (299)	
SA2-4-L		80 (262)	
SA2-5-L		73 (238)	
SA3-8-1	Source Area 3	117 (385)	1
SA3-10-2		216 (710)	2a and 2b
SA3-11-3		263 (862)	3

was completed into the Local Aquifer using 15-cm (6-in.) PVC screen and casing. The other wells were installed using 17.8-cm (7-in.) fiberglass casing and 10-cm (4-in.) stainless steel screen and riser. Location maps, geological, geophysical and well construction data are presented in Appendix A (Figures A-28 to A-60) (DOE/NV, 1995c).

The addendum to the work plan proposed three wells would be installed into the Local Aquifer at two locations west of the disposal pit area and one to the east in Source Area 2. Upon further investigation of the expected groundwater flow direction, the locations were moved such that there were three locations to the east of the disposal pits, one to the north and one to the west. Five monitoring wells were installed in Source Area 2 in the Local Aquifer (Appendix A, Figure A-35).

The work plan addendum originally anticipated that five wells would be installed in Source Area 3. However, after drilling Well SA3-11-3, it was determined that the local aquifer was not present at this location and that it was not possible to differentiate between Aquifers 2a and 2b. Well SA3-10-2 was completed as a well monitoring a single aquifer.

Following installation and development of the wells installed into Operable Unit 2, permanent sampling pumps were installed. All of the wells were purged and sampled following completion. All groundwater samples collected from these wells were analyzed for PCOCs using analytical methods presented in Table 3-2.

During the fall of 1996 and winter of 1997, four existing monitoring wells (HT-2c, HT-4, HT-5, and E-7) were evaluated for structural integrity, and permanent sampling pumps were installed to allow them to be included in future sampling events. Well HT-2c is completed in the Local Aquifer, HT-4 in Aquifer 1, HT-5 in Aquifer 2, and E-7 is completed in the Caprock Aquifer. Appendix A includes well completion diagrams for these wells.

3.1.6.3 Deep Monitoring Well Installation, Operable Unit 3

To evaluate Aquifer 4, two monitoring wells were installed near the Salmon Site's injection well (HT-2 in Source Area 5) as required under the *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site* (DOE/NV, 1995c). Table 3-5 summarizes the well installations into Aquifer 4.

Table 3-5
Monitoring Well Data Summary for Wells Installed in Operable Unit 3

Well	Location	Depth meters (ft)	Aquifer
SA5-4-4	Source Area 5	640 (2,099)	4
SA5-5-4		635 (2,083)	

These two deep monitoring wells, SA5-4-4 and SA5-5-4, were installed and completed using fiberglass and stainless steel components. Well locations are shown in Figure A-61 and well completion diagrams are shown in Appendix A, Figures A-64 and A-65. Following installation and development of the wells, permanent sampling pumps were installed. All of the wells were purged and sampled following completion. All groundwater samples collected from these wells were analyzed for PCOCs using analytical methods presented in Table 3-2.

3.1.7 Surface Water and Sediment Sampling

As part of the field program for sampling activities at the Salmon Site, surface water samples were collected from 15 on-site locations. The sample locations are presented on Figure 3-5.

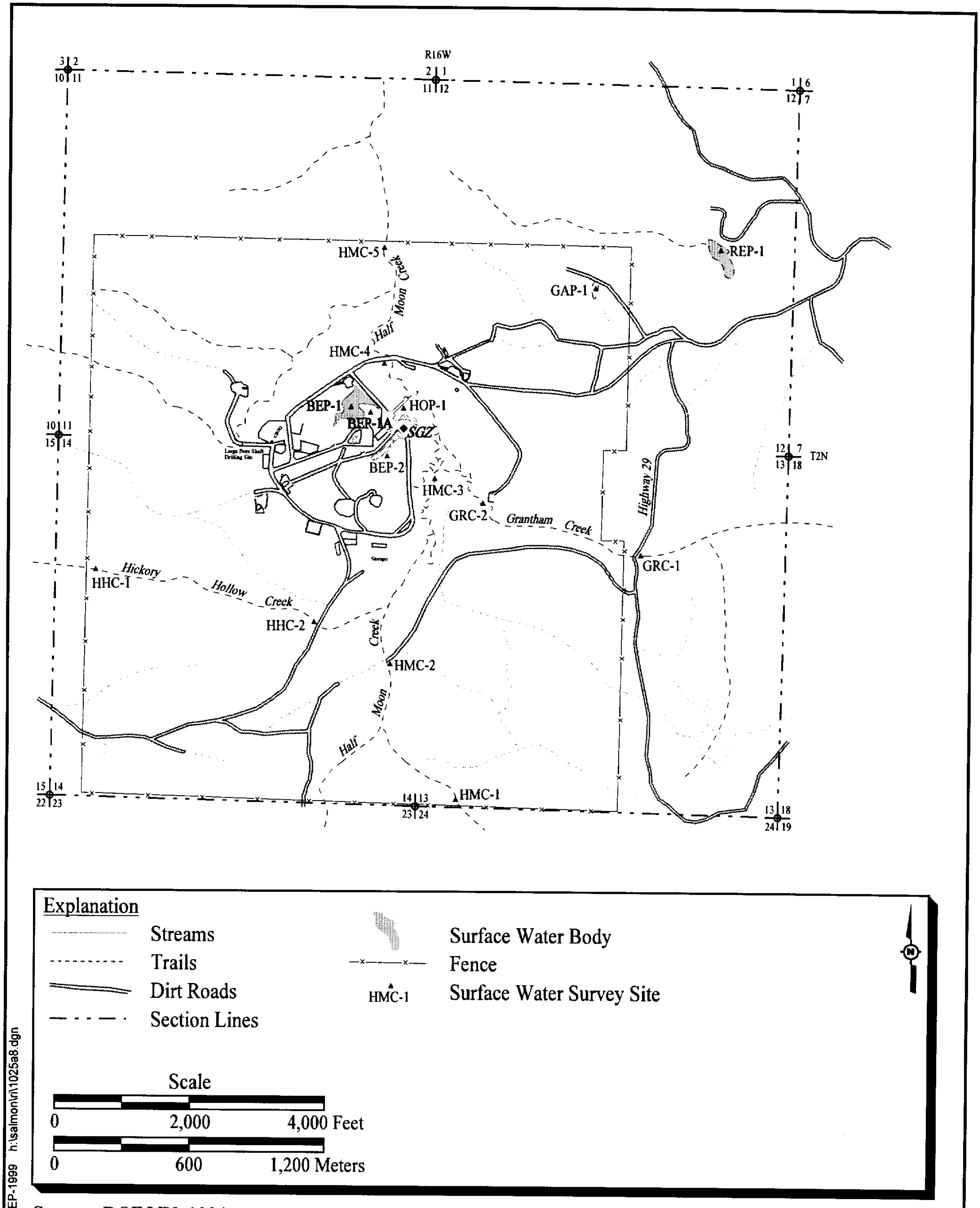

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Figure 3-5
Salmon Site Surface Water and Sediment Sampling Locations

Sampling activities were conducted from February 22 to 28, 1993, and samples were collected and analyzed according to the RI work plan (DOE/NV, 1992). A summary of the surface water samples and analyses performed on these samples is shown in Table 3-6. Additional information regarding sampling procedures are presented in *Preliminary Data Report of Investigations Conducted at the Salmon Site Lamar County, Mississippi* (DOE/NV, 1994a) (Exhibit 1). Analytical results for these samples are presented in Appendix B Table B-5.

Sediment samples were collected during the same time period as surface water samples and at the same locations. A summary of the sediment sample analyses performed is shown in Table 3-7. Sample analytical results are provided in Appendix B, Tables B-6 and B-7.

3.1.8 Background Soil and Groundwater Sampling

Between April 26 and 30, 1993, five soil samples were collected from the northeast portion of the Salmon Site and designated as background soil samples. The locations of these samples designated as REFC-19A through REFC-19E are shown on Figure 3-6. Soil samples were collected from 0 to 15 cm (0 to 6 in.) bgs. The analytical methods were the same as that used for the surface soil samples (Table 3-2).

Based on the analytical results, it was determined that additional background sampling was necessary to obtain a better representation of the background concentrations of metals and radionuclides for the Salmon Site. From April 23 to 25, 1998, soil samples were collected from six locations around the periphery of the site. Sample locations are shown on Figure 3-6. Seven samples were collected at each location from specified depths. At six of the locations, samples were collected from a depth of 0 to 30 cm (0 to 12 in.), and at the other location sampling depths were 0 to 30, 46 to 76, and 107 to 137 cm (0 to 12, 18 to 30, and 42 to 54 in.). A summary of the sample information is shown in Table 3-8. The analytical results for these background soil samples are shown in Appendix B, Table B-9.

Table 3-6
Surface Water Sampling Summary

Sample Number	Location	Composite (Yes/No)	Analyses								
			METALS	PEST	VOC	SVOC	GAB	GS	TRITIUM	GEN CHEM	BOD
BEP-1-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	X
BEP-1A-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	X
BEP-2-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	
GAP-1-SW-G-1	Gator Pond	No	X	X	X	X	X	X	X	X	X
GRC-1-SW-G-1	Grantham Creek	No	X	X	X	X	X	X	X	X	X
GRC-2-SW-G-1	Grantham Creek	No	X	X	X	X	X	X	X	X	X
HHC-1-SW-G-1	Hickory Hollow Creek	No	X	X	X	X	X	X	X	X	X
HHC-2-SW-G-1	Hickory Hollow Creek	No	X	X	X	X	X	X	X	X	X
HMC-1-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	X
HMC-2-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	X
HMC-3-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	X
HMC-4-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	X
HMC-5-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	X
HOP-1-SW-G-1	Half Moon Creek Overflow Pond	No	X	X	X	X	X	X	X	X	X
REP-1-SW-G-1	Reference Pond	No	X	X	X	X	X	X	X	X	X

PEST = Pesticides/polychlorinated biphenyls (PCBs)
VOC = Volatile organic compounds
SVOC = Semivolatile organic compounds
GAB = Gross alpha/beta
GS = Gamma spectroscopy
BOD = Biochemical oxygen demand (five-day)
GEN CHEM = General chemistry includes inorganic, nonmetallic analytes

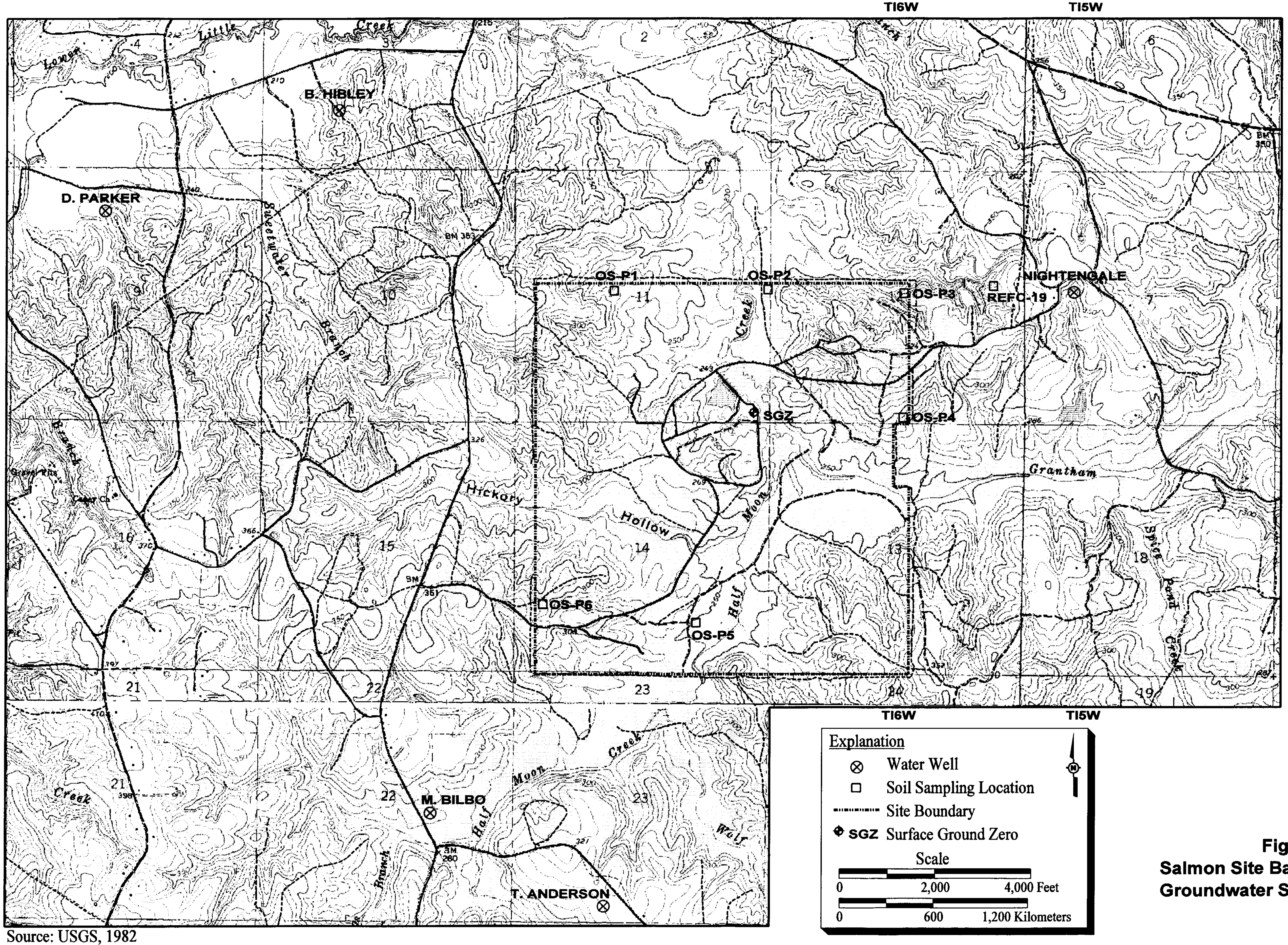
Note: Blank cell indicates no analysis performed.

Table 3-7
Sediment Sampling Summary

Sample Number	Location	Composite (Yes/No)	Analyses								
			METALS	PEST	VOC	SVOC	GAB	GS	TRITIUM	GEN CHEM	BOD
BEP-1-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	
BEP-1A-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	
BEP-2-SW-G-1	Beaver Pond	No	X	X	X	X	X	X	X	X	
GAP-1-SW-G-1	Gator Pond	No	X	X	X	X	X	X	X	X	
GRC-1-SW-G-1	Grantham Creek	No	X	X	X	X	X	X	X	X	
GRC-2-SW-G-1	Grantham Creek	No	X	X	X	X	X	X	X	X	
HHC-1-SW-G-1	Hickory Hollow Creek	No	X	X	X	X	X	X	X	X	
HHC-2-SW-G-1	Hickory Hollow Creek	No	X	X	X	X	X	X	X	X	
HMC-1-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	
HMC-2-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	
HMC-3-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	
HMC-4-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	
HMC-5-SW-G-1	Half Moon Creek	No	X	X	X	X	X	X	X	X	
HOP-1-SW-G-1	Half Moon Creek Overflow Pond	No	X	X	X	X	X	X	X	X	
REP-1-SW-G-1	Reference Pond	No	X	X	X	X	X	X	X	X	

PEST = Pesticides/polychlorinated biphenyls (PCBs)
VOC = Volatile organic compounds
SVOC = Semivolatile organic compounds
GAB = Gross alpha/beta
GS = Gamma spectroscopy
BOD = Biochemical oxygen demand
GEN CHEM = General chemistry includes inorganic, nonmetallic analytes

Note: Blank cells indicate no analysis performed.



Source: USGS, 1982

Figure 3-6
Salmon Site Background Soil and Groundwater Sampling Locations

Table 3-8
Summary of Background Soil Samples by Location, Depth and Sample Number
(Page 1 of 2)

Sample Location	Sample Point	Depth m (in.)	Sample No.(s)
OS-P1	A	0-0.3 (0-12)	SS-0522
OS-P1	A	0.5-0.8 (18-30)	SS-0523
OS-P1	A	107-137 (42-54)	SS-0524
OS-P1	B	0-0.3 (0-12)	SS-0525
OS-P1	C	0-0.3 (0-12)	SS-0526
OS-P1	D	0-0.3 (0-12)	SS-0527
OS-P1	E	0-0.3 (0-12)	SS-0528, SS-0529 (DUP)
OS-P2	A	0-0.3 (0-12)	SS-0532
OS-P2	A	0.5-0.8 (18-24)	SS-0533
OS-P2	A	107-137 (42-54)	SS-0534
OS-P2	B	0-0.3 (0-12)	SS-0535
OS-P2	C	0-0.3 (0-12)	SS-0536
OS-P2	D	0-0.3 (0-12)	SS-0537
OS-P2	E	0-0.3 (0-12)	SS-0538
OS-P3	A	0-0.3 (0-12)	SS-0539
OS-P3	A	0.5-0.8 (18-30)	SS-0540
OS-P3	A	107-137 (42-54)	SS-0541
OS-P3	B	0-0.3 (0-12)	SS-0542
OS-P3	C	0-0.3 (0-12)	SS-0543
OS-P3	D	0-0.3 (0-12)	SS-0544
OS-P3	E	0-0.3 (0-12)	SS-0545
OS-P4	A	0-0.3 (0-12)	SS-0547
OS-P4	A	0.5-0.8 (18-30)	SS-0548
OS-P4	A	107-137 (42-54)	SS-0549
OS-P4	B	0-0.3 (0-12)	SS-0550
OS-P4	C	0-0.3 (0-12)	SS-0551
OS-P4	D	0-0.3 (0-12)	SS-0552

Table 3-8
Summary of Background Soil Samples by Location, Depth and Sample Number
(Page 2 of 2)

Sample Location	Sample Point	Depth m (in.)	Sample No.(s)
OS-P4	E	0-0.3 (0-12)	SS-0553, SS-0554 (DUP)
OS-P5	A	0-0.3 (0-12)	SS-0555
OS-P5	A	0.5-0.8 (18-30)	SS-0556
OS-P5	A	107-137 (42-54)	SS-0557
OS-P5	B	0-0.3 (0-12)	SS-0558
OS-P5	C	0-0.3 (0-12)	SS-0559
OS-P5	D	0-0.3 (0-12)	SS-0560
OS-P5	E	0-0.3 (0-12)	SS-0561
OS-P6	A	0-0.3 (0-12)	SS-0515
OS-P6	A	0.5-0.8 (18-30)	SS-0516
OS-P6	A	107-137 (42-54)	SS-0517
OS-P6	B	0-0.3 (0-12)	SS-0518
OS-P6	C	0-0.3 (0-12)	SS-0519
OS-P6	D	0-0.3 (0-12)	SS-0520
OS-P6	E	0-0.3 (0-12)	SS-0521

Note: Depths are given as a range from below ground surface.
(DUP) indicates a field duplicate was taken at that location.

On April 25, 1999, background groundwater samples were collected from selected privately owned drinking water well locations to obtain data on groundwater quality. Initially, seven well locations had been selected for sampling; however, during well sampling activities, it was discovered that several of these wells were no longer in use or were unable to be sampled due to mechanical problems. This situation required the selection of alternate well locations. A summary of the well information is shown on Table 3-9. The intention of the sampling effort was to obtain groundwater samples from aquifers that occupied a similar stratigraphic structure as the Local Aquifer on the Salmon Site. Information regarding well construction and well depths were obtained from the land/well owner. Wells were sampled at the well-head but due to well configurations, static water levels could not be measured. In addition, since well volumes could not be accurately determined, wells were not purged prior to sampling; however, wells

Table 3-9
Background Well Data

St. Stephens Meridian							
Well Name	**Sample No.**	**Well Depth**	**Section**	**Township**	**Range**	**Quarter Section**	**Quarter Section**
R. Hibley	SS-0563	360	3	2N	16W	SE	SW
D. Parker	SS-0564	275	9	2N	16W	NE	NW
M. Bobo	SS-0565	200	22	2N	16W	NW	SE
T. Anderson	SS-0566 SS-0567	85	23	2N	16W	SE	SW
Nightengale	SS-0568	100	7	2N	15W	SW	NW

were sampled on a Saturday when water usage is typically high and wells were assumed to have reached stability with respect to water quality parameters. The only parameter analyzed was arsenic, using SW-846 Method 7060A (EPA, 1992). Analytical results are shown in Appendix B, Table B-2.

3.1.9 Direct-Push Soil and Groundwater Sampling

In an effort to obtain additional data regarding the horizontal and vertical extent of contamination in Source Area 1 near SGZ, additional soil and groundwater sampling was conducted utilizing direct-push technology. Locations for additional groundwater samples were established in a 50- by 50-ft grid pattern to determine the extent of elevated tritium concentrations in the shallow groundwater. Nine soil samples from 17 locations and 69 groundwater samples from 70 locations were collected in December 1998 at the locations shown on Figure 3-7. The direct push borings were advanced to an approximate depth of 9 m (30 ft) with the collection of continuous soil cores. Soil samples were analyzed for volatile and semivolatile organics, metals, and total petroleum hydrocarbons (TPH) while groundwater samples were analyzed for volatile and semivolatile organics, metals, TPH and Tritium. The analytical results for these samples are presented in Appendix B, Tables B-3 and B-4.

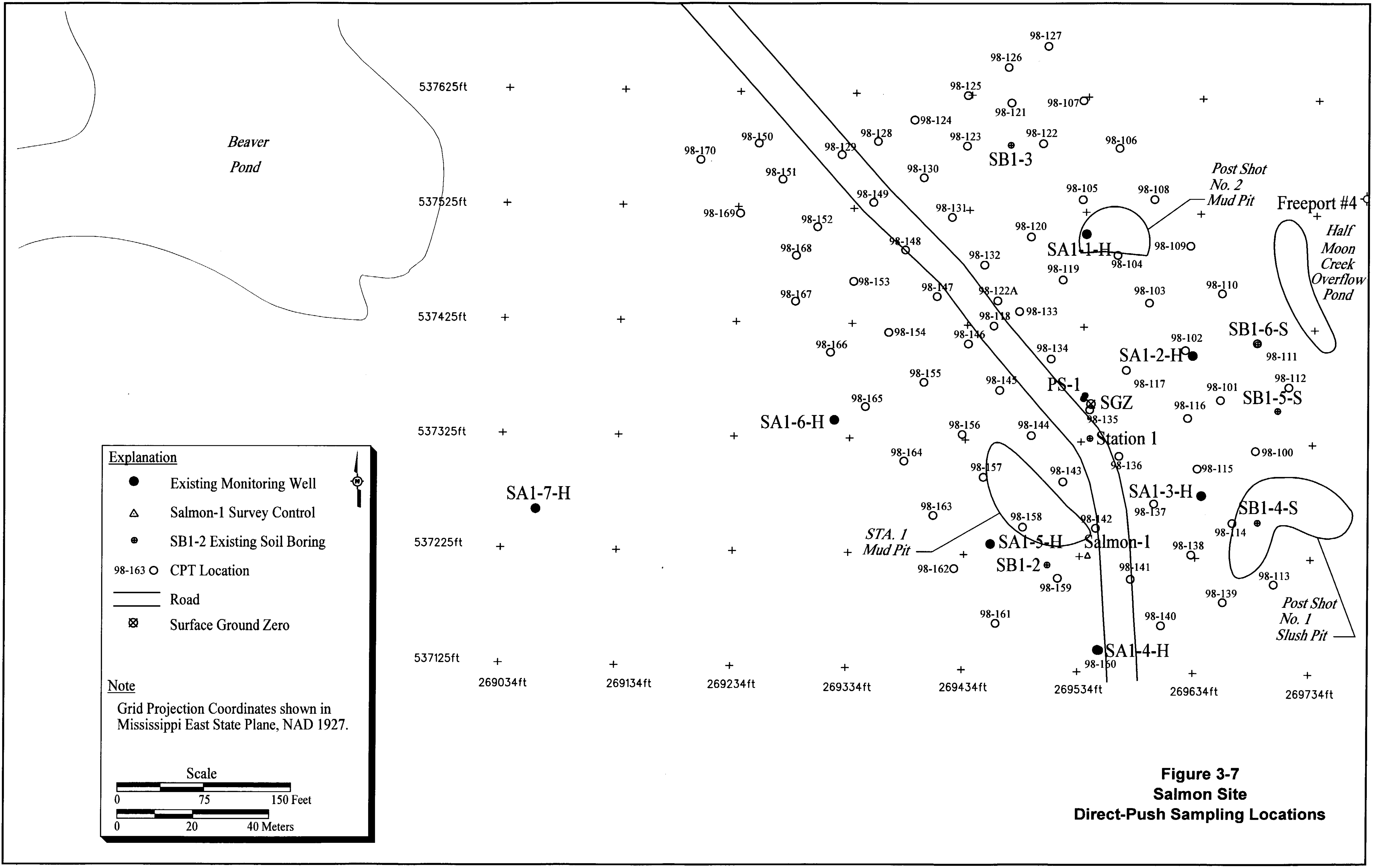


Figure 3-7
Salmon Site
Direct-Push Sampling Locations

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20-SEP-1999

4.0 Nature and Extent of Contamination

Section 3.0 presents the nature and extent of contamination at the Salmon Site. The purpose of this section is to identify potential site-related contaminants based on the analytical results for samples collected between 1993 and 1998. These potential contaminants are addressed further in Section 5.0, Contaminant Fate and Transport, and Section 6.0, Risk Assessment.

Laboratory results for the Salmon Site are presented in Appendix B. Appendix B is subdivided as follows:

B-1	Subsurface soil
B-2	Groundwater
B-3	Cone penetrometer testing - soil
B-4	Cone penetrometer testing - water
B-5	Surface water
B-6	Sediment
B-7	Surface soil
B-8	Trench samples
B-9	Background (all media)

Data verification/validation has been performed in accordance with the Quality Assurance Project Plan (Attachment A to the RI workplan [DOE/NV, 1995c]). The verification/validation process was performed on a subset of all analytical results to ensure that the concentrations of detected PCOCs are representative of site media and to ensure that the reported data are of known and documented quality.

The nature and extent of contamination discussion presented in Section 4.0 is organized by Operable Unit, and subdivided by media. Section 4.1 presents the nature and extent of contamination in Operable Unit 1 and is subdivided into soil (surface soil and subsurface soil), groundwater, surface water and surface sediments. Section 4.2 presents the nature and extent of contamination in Operable Unit 2, and only included groundwater. Section 4.3 presents the nature and extent of contamination in Operable Unit 3, and only included groundwater.

4.1 Operable Unit 1: Soils and Alluvial Aquifer

Operable Unit 1 includes the surface and subsurface soils, surface water, and sediment in all six Source Areas and the Alluvial Aquifer in Source Areas 1, 3, 4, and 5.

4.1.1 Soils

The approach for identifying potentially site-related contaminants that has been adopted for the Salmon Site surface and subsurface soils is described below. Under this approach, a contaminant is considered potentially site-related if:

- For inorganic substances, gamma-emitting radionuclides, and gross alpha and gross beta activity, the reported value exceeds the mean plus two standard deviations reported for the analyte in the five reference area surface soil samples (REFC-19A through REFC-19E) collected in 1993 (DOE/NV, 1994a; DOE/NV, 1995c), and the six background soil samples (OSP-1 through OSP-6) collected in April 1998, or the analyte was not detected in any of the reference area samples.
- For organic compounds and tritium (the reference area surface soil samples were not analyzed for tritium), the analyte was detected in the sample.

All soil sample analytical results are presented in Appendix B, subsection B-1 contains subsurface soil and subsection B-7 contains surface soil. The site-related PCOCs are addressed in the Human Health Risk Assessment (Section 6.0 and Appendix C).

The reference area samples were analyzed for inorganics gamma-emitting radionuclides, gross alpha and gross beta activity. While some sample results slightly exceeded the previously stated criteria ("reported value exceeds the mean plus two standard deviations, or were not present in the reference area samples") they were carried through this analysis even though they probably still represent background. In particular, with the exception of cesium-137, the gamma-emitting radionuclides detected in soil samples collected from both the reference area and the rest of the site are naturally occurring (potassium-40 and uranium and thorium daughters). The variability in the gamma results (including non-detects in some samples) may be more indicative of the natural variability in local natural background than radiological contamination caused by activities at the site. The sample analysis results for the background surface and subsurface soil samples are presented in Tables 4-1 and 4-2, respectively. These tables also include the statistical analysis results for mean and standard deviation for each PCOC.

Table 4-1
Surface Soil Background Constituent Concentrations

Analyte	Mean	Standard Deviation	Background Concentration (Mean + 2 × Standard Deviation)
Radiological (picocuries per gram)			
Actinium-228	0.41	0.18	0.77
Alpha	7.38	4.63	16.6
Beta	12.8	2.45	17.7
Bismuth-212	0.35	0.15	0.65
Bismuth-214	0.42	0.15	0.72
Cesium-137	0.32	0.21	0.74
Lead-210	0.51	0.42	1.35
Lead-212	0.53	0.19	0.91
Lead-214	0.69	0.25	1.19
Potassium-40	3.57	1.53	6.63
Radium-223	0.03	0.07	0.17
Radium-224	0.36	0.33	1.02
Radium-226	0.74	0.32	1.38
Radium-228	0.47	0.17	0.81
Thallium-208	0.25	0.12	0.49
Uranium-235	0.10	0.03	0.16
Uranium-238	0.30	0.09	0.48
Metals (milligrams per kilogram)			
Aluminum	5,912	4,119	14,150
Antimony	6.36	3.00	12.4
Arsenic	1.59	1.15	3.89
Barium	42.6	25.9	94.4
Beryllium	0.26	0.27	0.80
Cadmium	0.39	0.30	1.00
Calcium	208	200	608
Chromium	6.00	3.98	14.0
Cobalt	2.91	2.09	7.09
Copper	2.35	2.11	6.57
Cyanide	0.15	0.08	0.31
Iron	4,574	3,629	11,833
Lead	7.00	3.42	13.8
Magnesium	208	158	523
Manganese	365	355	1,075
Mercury	0.04	0.02	0.08
Nickel	4.25	2.08	8.41
Potassium	196	152	501
Selenium	0.35	0.25	0.85
Silver	0.63	0.18	0.99
Sodium	19.4	18.8	57.0
Thallium	0.32	0.09	0.50
Vanadium	9.90	7.02	23.9
Zinc	7.22	5.05	17.3

Table 4-2
Subsurface Soil Background Constituent Concentrations

Analyte	Mean	Standard Deviation	Background Concentration (Mean + 2 x Standard Deviation)
Radiological (picocuries per gram)			
Actinium-228	0.51	0.35	1.21
Bismuth-212	0.52	0.27	1.06
Bismuth-214	0.39	0.14	0.67
Cesium-137	0.01	0.01	0.03
Lead-210	0.34	0.21	0.76
Lead-212	0.63	0.18	0.98
Lead-214	0.69	0.24	1.17
Potassium-40	3.20	1.28	5.76
Radium-226	0.78	0.27	1.32
Thallium-208	0.30	0.14	0.58
Thorium-234	0.04	0.11	0.26
Uranium-235	0.12	0.04	0.20
Metals (milligrams per kilogram)			
Aluminum	7,801	6,613	21,027
Antimony	5.80	2.47	10.7
Arsenic	1.68	1.54	4.76
Barium	26.6	15.9	58.4
Beryllium	0.15	0.08	0.31
Cadmium	0.58	0.45	1.48
Calcium	74.4	58.0	190
Chromium	8.63	7.95	24.5
Cobalt	2.12	1.03	4.18
Copper	3.41	2.09	7.59
Iron	6,702	5,681	18,063
Lead	4.78	1.95	8.68
Magnesium	259	182	623
Manganese	40.0	29.3	98.6
Mercury	0.04	0.02	0.08
Nickel	5.13	2.93	11.0
Potassium	206	135	476
Selenium	0.33	0.18	0.69
Silver	0.62	0.04	0.70
Sodium	17.7	10.7	39.1
Thallium	0.35	0.02	0.39
Vanadium	13.8	11.3	36.4
Zinc	7.59	5.48	18.6

Five reports have been prepared that present portions of the analytical results for surface soil samples collected from trenches excavated in Source Area 2 and the subsurface soil samples collected using a cone penetrometer. The reports include:

- *Preliminary Data Report of Investigations Conducted at the Salmon Site Lamar County, Mississippi* (DOE/NV, 1994a) (Exhibit 1)
- *Baseline Ecological Risk Assessment for Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) (Exhibit 2)
- *Task Summary for Cone Penetrometer Testing Sounding and Soil and Groundwater Sampling Salmon Site Lamar County, Mississippi* (DOE/NV, 1994b) (Exhibit 3)
- *Geophysical Investigation Salmon Site Lamar County, Mississippi* (DOE/NV, 1995b) (Exhibit 4)
- *Trench Sampling Report Salmon Site County, Mississippi* (DOE/NV, 1994c) (Exhibit 5)

The following sections present PCOCs found in samples collected from the soil borings and auger wells installed in 1995, background soil samples collected in 1998, and direct-push soil samples collected in 1998. While most of the results presented were included in previous reports, some of the more recent results have not.

4.1.1.1 Source Area 1

Volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and TPH were detected in soil samples collected at several depths from Soil Boring SB1-2, which was drilled into the Station 1-A Mud Pit (AOC 1-A). The analytical results for these samples are presented in Table 4-3. Based on the available analytical data, it appears that the VOC contamination in the mud pit extends to a depth of 7 to 9 m (22 and 30 ft).

Low estimated concentrations of chloromethane (6 micrograms per kilogram [µg/kg]) and toluene (5 µg/kg) were detected in the sample collected from 1.5 to 2 m (5 to 7 ft) deep in Soil Boring SB1-1, which was drilled in the vicinity of the E-14 Pad and Mud Pits (AOC 1-G); and low estimated concentrations of 1,1-dichloroethene (2 µg/kg), chlorobenzene (1 µg/kg), toluene (1 µg/kg), and trichloroethene (1 µg/kg) were detected in the sample collected from 1.5 to 2 m (5 to 7 ft) deep in Soil Boring SBE-3-2, which was drilled in the vicinity of the E3/E9 Drill Site (AOC 1-J). No other organic PCOCs in concentrations greater than detectable levels and or

Table 4-3
Organic Compounds Detected in the Station 1-A Mud Pit
Source Area 1

Analyte	Soil Boring SB1-2 Sample Depth			
	5-7 ft	10-12 ft	15-17 ft	20-22 ft
Volatile Organic Compounds (µg/kg)				
Acetone	2,300J	23J	20J	30J
Benzene	840	U	U	U
Ethylbenzene	650	U	U	U
Tetrachloroethene	26,000D	2J	U	8
Toluene	1,000	U	U	1J
Trichloroethene	460J	U	U	U
Total xylenes	5,100	U	U	U
Semivolatile Organic Compounds (µg/kg)				
2-Methylnaphthalene	490,000D	320J	U	1,300
Acenaphthene	11,000	U	U	55J
Dibenzofuran	3,300	U	U	U
Fluorene	22,000	U	U	120J
N-nitrosodiphenylamine	1,800J	U	U	U
Naphthalene	53,000DJ	U	U	58J
Phenanthrene	7,100	U	U	64J
Total Petroleum Hydrocarbons (mg/kg)				
TPH	32,000	490	U	230J

U = Not detected above the detection limit
J = Estimated concentration
D = Sample was diluted prior to analysis
µg/kg = Microgram(s) per kilogram (or parts per billion)
mg/kg = Milligram(s) per kilogram (or parts per million)

above background concentrations were detected in the soil boring samples collected from Source Area 1.

Low levels of radionuclides above site-specific background levels were detected at three locations within Source Area 1. In Soil Boring SB1-2 and CPT location C1-16, in the Station 1-A Mud Pit, four radionuclides were detected. These included: lead-210 (1.23 pCi/g) lead-212 (1.25 to 1.48 picocuries per gram [pCi/g]), radium-228 (0.89 pCi/g), potassium-40 (6.5 to 14.8 pCi/g), bismuth-212 (1.16 pCi/g), bismuth-214 (0.94 pCi/g), and thallium-208 0.58 pCi/g. Depths of these constituents ranged from 1.5 to 9.2 m (5 to 30 ft) bgs. In the E-14 Pad and Mud Pits, five radionuclides were detected in Soil Boring SB1-1. These radionuclides were lead-210 (2.10 to 2.38 pCi/g), lead-212 (1.13 to 1.28 pCi/g), lead-214

(1.24 pCi/g), bismuth-214 (1.03 pCi/g), potassium-40 (10 pCi/g) and radium-228 (0.93 to 1.55 pCi/g). The depths of contamination ranged from 1.5 to 5.2 m (5 to 17 ft) bgs. Radionuclides were detected in the E3/E9 Drill Site area in Soil Boring SBE 3-1. Depth of contamination ranged from 3 to 5.2 m (10 to 17 ft) bgs. Radionuclides detected included: lead-210 (1.70 to 2.68 pCi/g), lead-212 (1.32 pCi/g), lead-214 (1.29 pCi/g), potassium-40 (10.7 pCi/g), and bismuth-214 (2.09 pCi/g). A complete tabulation of all analytical results are provided in Appendix B, Table B-1.

Several surface soil samples had radionuclide levels greater than background concentrations. The sampling locations are presented on Figure 3-1 and the analytical results are presented on Table 4-4.

Several samples from subsurface borings, surface soil, and sediments contained concentrations of metals above background levels. These results are presented on Table 4-5.

4.1.1.2 Source Area 2

No organic PCOCs in concentrations greater than detectable levels and/or above background levels were identified in the soil boring samples collected from Source Area 2.

Radionuclides were detected in three areas of concern in Source Area 2. The areas of concern include Clean Burn Area, the REECo Pits area, and the Debris Burial Pit. In the Clean Burn Area, radionuclides were detected in Soil Borings SB2-1 and C-19 from a depth of 1.5 to 9.2 m (5 to 30 ft) bgs. Soil Borings SB2-2, SB2-3, SB2-5, SB2-6, C2-25 and C2-27 in the REECo Pit area radionuclides were detected from 0.6 to 11.7 m (2 to 38.5 ft) bgs. In the Debris Burial Pit, samples from Soil Borings SB2-4 and C2-20 showed radionuclides above background concentrations from 2.3 to 17.4 m (7.5 to 57 ft) bgs. Table 4-6 presents the concentration for each contaminant in each area as well as the site-specific background concentration based on the data collected.

In the Clean Burn Area, surface soil locations SA2-5B through SA2-5E had radionuclide concentrations greater than background levels. Contaminants included: gross alpha (17.7 to 19.9 pCi/g), gross beta (18.0 to 20.4 pCi/g), lead-212 (0.98 to 1.49 pCi/g), radium-223 (0.37 pCi/g), radium-228 (1.04 to 1.25pCi/g), bismuth-212 (0.72 to 0.75pCi/g), thorium-228 (1.06 to 3.47 pCi/g) and uranium-238 (1.54 to 1.63 pCi/g).

Several surface soil and subsurface soil samples contained metals concentrations greater than background levels. These metals results are presented in Table 4-7.

Table 4-4
Radionuclide
Surface Soil Concentrations in Source Area 1

Analyte	Location	Concentration (pCi/g)	Background Concentration (pCi/g)
Lead-210	SA1-4A	1.53	1.34
Mercury-203	SA1-2C	0.03	NA
Protactinium-231	SA1-4A SA1-4B	0.83 0.64	NA
Protactinium-234	SA1-4B	2.96	NA
Tin-113	SA1-1E	0.02	NA
Thorium-228	SA1-1B SA1-4B	1.83 0.83	NA
Uranium-238	SA1-4A SA1-4B SA1-4D SA1-4E	0.96 0.56 0.61 0.60	0.47

NA = Background samples were not analyzed for this analyte.

Table 4-5
Surface and Subsurface Soil Metals Concentrations in Source Area 1

Analyte	Location - Concentration milligrams per kilogram (mg/kg) meters (feet)	Background Concentration
Subsurface Soil Samples		
Calcium	C1-18 1.8 - 2.3 m (6 - 7.5 ft) - 823B C1-16 2.3 - 2.9 m (7.5 - 9.5 ft) - 304B C1-15 5.8 - 6.1 m (19 - 20 ft) - 286B C1-17 3.7 - 4.7 m (12 - 15.5 ft) - 229B C1-14 7.0 - 7.5 m (23 - 24.5 ft) - 355B	190
Sodium	C1-14 7.0 - 7.5 m (23 - 24.5 ft) - 166 C1-17 3.7 - 4.1 m (12 - 13.5 ft) - 221B C1-16 2.3 - 2.9 m (7.5 - 9.5 ft) - 53.3B C1-18 1.8 - 2.3 m (6 - 7.5 ft) - 293B C1-15 5.8 - 6.1 m (19 - 20 ft) - 79.4B	39.1
Surface Soil Samples		
Lead	SA1-2D - 16.7J SA1-4E - 16.0J SA1-1A - 16.6J SA1-1C - 14.5J	13.8
Mercury	SA1-2E - 0.29	0.08
Potassium	SA1-4E - 765J SA1-1E - 835J SA1-10 - 878J SA1-1C - 858J	501
Chromium	SA1-1B - 44 SA1-2E - 16.6 SA1-15.0	14.0
Vanadium	SA1-1B - 25.1	23.9
Copper	SA1-3C - 8.8 SA1-4E - 8.80 SA1-1E - 8.20	6.57
Arsenic	SA1-2E - 11.90	3.89
Nickel	SA1-1E - 13.1	8.41
Antimony	SA1-4A - 14.5J SA1-4E - 14.6J SA1-4D - 13.7J SA1-4C - 12.7J SA1-4B - 13.6	12.4
Barium	SA1-4E - 208 SA1-4B - 152	94.4
Calcium	SA1-4E - 1350 SA1-1A - 1570 SA1-1B - 615J SA1-1E - 798J SA1-2E - 667J SA1-4B - 2230	608
Sodium	SA1-4E - 154J SA1-1A - 78J SA1-1E - 58J	57.0
Zinc	SA1-4B - 28.8 SA1-4E - 31.8 SA1-2E - 23.0 SA1-1C - 20.3	17.3
Sediment Samples		
Arsenic	BEP-1 - 7.7J	3.88
Barium	BEP-1 - 181J GAP-1 125J	94.3
Calcium	BEP-1 - 5630J BEP-1A - 1090J BEP-2 - 885J	608
Lead	BEP-1 - 20.2 GAP-1 - 17.0	13.8
Magnesium	BEP-1 - 1380J	523
Vanadium	BEP-1 - 27.7	23.9
Sodium	BEP-1 - 1230J BEP-1A - 232J BEP-2 - 144J HOP-1 - 112J HME-1 - 70.3J HME-2 - 73.2J HME-4 - 128J HMC-5 - 83.6J GRC-1 - 77.6B GRC-2 - 66.4J GAP-1 - 600J	57.0
Zinc	BEP-1 - 111 BEP-1A - 29.7 BEP-2 - 18.8	17.3
Cadmium	REP-1 - 90.J	1.00

Background concentration is the mean value plus two standard deviations.

J = Estimated value

B = A value that was less than the CRDL but greater than or equal to the IDL.

Table 4-6
Subsurface Soil Radionuclide Concentrations in Source Area 2

Analyte	Concentration (pCi/g)			Background Concentration
	Clean Burn Area	REECo Pits	Debris Burial Pit	
Gross Alpha	19.2	8.20 - 20.4	7.06 - 23.4	NA
Gross Beta	22.7	19.0 -28.8	12.00 - 22.0	NA
Lead-210	1.73 - 1.88	1.80 - 2.79	1.85 - 2.38	0.76
Lead-212	1.46 - 1.54	1.11 - 1.94	1.07 - 1.95	0.98
Lead-214	ND	1.40 - 1.54	ND	1.17
Radium-224	ND	1.71	ND	NA
Radium-226	1.64	1.52	ND	1.32
Radium-228	0.88 - 1.41	0.67 - 1.73	1.22 - 1.59	NA
Potassium-40	8.50 - 12.2	5.93 - 13.50	6.28 - 16.60	5.76
Thallium-208	ND	ND	0.68 - 0.92	0.58
Thorium-234	1.60 - 2.25	1.32 - 2.34	1.50 - 4.17	0.26
Bismuth-214	0.82 - 1.08	1.10 - 1.48	1.04 - 2.41	0.67

NA = Background samples were not analyzed for this analyte.
ND = All analyses were below the background level.

Note: One value indicates one sample had a concentration above background.
Range of values indicates minimum and maximum concentrations above background.

Table 4-7
Surface and Subsurface Soil Metals Concentrations in Source Area 2

Subsurface Soils

Analyte	Location - Concentration (mg/kg)					Background Concentration mg/kg
	Debris Burial Pit	Clean Burn	Gas Station	REECo Pits		
	Boring No. C2-20 7.5-9 ft	Boring No. C2-19 28.5-30 ft	Boring No. C2-24 53-54 ft	Boring No. C2-25A 20-22 ft	Boring No. C2-27 37-38.5 ft	
Beryllium	ND	ND	ND	1.70	ND	0.32
Barium	ND	ND	277	100	ND	58.4
Calcium	3,760	2,210	2,780	3,740	1,730	191
Cobalt	ND	ND	ND	7.4B	ND	4.17
Lead	ND	ND	ND	8.9	ND	8.68
Magnesium	ND	ND	ND	1,720	681	623
Barium	ND	ND	277	ND	ND	58.4
Nickel	ND	ND	ND	12.8	ND	11.0
Manganese	ND	451	1,250	ND	ND	98.5
Sodium	52.6	39.9	41.4	74.6	99.9	39.2

Surface Soils

Analyte	Clean Burn Pit				Gas Station		Background Concentration
	Boring No. SA2-5A	Boring No. SA2-5B	Boring No. SA2-5C	Boring No. SA2-5E	Boring No. SA2-6B	Boring No. SA2-6C	
Calcium	814J	1,790J	676J	ND	ND	ND	608
Cobalt	7.10J	ND	ND	9.30	ND	ND	7.09
Magnesium	ND	ND	615J	ND	ND	ND	523
Mecury	0.11J	ND	ND	ND	ND	ND	0.08
Cadmium	ND	ND	ND	ND	1.4	ND	1.00
Lead	ND	18.4	ND	ND	ND	18.4	13.8

J = Estimated value
ND = All analyses were below the background level.
mg/kg = Milligrams per kilogram

4.1.1.3 Source Area 3

Chloromethane was detected at an estimated concentration of 7 µg/kg in the sample collected from 4.6 to 5 m (15 to 17 ft) deep in Soil Boring SB3-2, which was drilled in the E-2 and E-7 Area (AOC 3-C). No other organic contaminants in concentrations above detectable levels and/or background concentrations were identified in the soil boring samples collected from Source Area 3.

Radionuclides were detected in concentrations greater than site-specific background levels in all the areas of concern in Source Area No. 3 with the exception of the Government Storage Area 1 and the Sewage Disposal Tank. In the Mud Storage Pits/South Borrow Pit, radionuclides were detected in Soil Borings SB3-3, SB3-4, and C3-8 from 1.5 to 11 m (5 to 36 ft). Boring SA3-6-H in the Big Chief Drilling Storage Area indicated radionuclide contamination at a depth of 10.7 m (35 ft) bgs. In the E-2 and E-7 area, Soil Borings SB3-1, SB3-2, C3-4, and C3-5 indicated contamination from 1.5 to 9.9 m (5 to 32.5 ft) bgs. Borings C3-6 and C3-7, in the Government Storage Area 2, indicated radionuclide contamination from 7.3 to 12.8 m (24 to 42 ft) in depth and at the Station 4 and WP-4 Drilling Sites, Boring Station 4 MP showed contamination at a depth of 0 to 0.5 m (0 to 2 ft) bgs.

Table 4-8 presents the radionuclide concentrations detected in each area above the established background concentration for each constituent detected. Metals concentrations in subsurface soils are shown in Table 4-9.

Radionuclides and metals were detected in surface soil samples in several areas of concern. These results are presented in Table 4-10.

4.1.1.4 Source Area 4

Total petroleum hydrocarbons were detected in soil samples from two depth intervals in Soil Boring SB4-2, which was drilled in the vicinity of the Reserve Mud Pits (AOC 4-A): 1.5 to 2 m (5 to 7 ft) (230 milligrams per kilogram [mg/kg]) and 3 to 3.5 m (10 to 12 ft) (36 mg/kg). Soil Boring SB4-2 also had an estimated benzoic acid concentration of 67 µg/kg, at a depth of 5 to 7 ft. Soil Boring SB4-3 had an estimated bis (2-ethylhexyl) phthalate concentration of 63 µg/kg and estimated Di-n-octyl phthalate concentration of 40 µg/kg at a depth of 5 to 7 ft.

Chloromethane was detected at an estimated concentration of 5 µg/kg in the sample collected from 1.5 to 2 m (5 to 7 ft) deep in Soil Boring SB4-1, which was drilled at the E-5 Drill Site (AOC 4-H). No other organic contaminants in concentrations above detectable levels and/or background concentrations were identified in the soil boring samples collected from Source Area 4.

Table 4-8
Subsurface Soil Radionuclide Concentrations in Source Area 3

Analyte	Concentration (pCi/g)					Background Concentration
	Mud Storage/ South Borrow	Big Chief Drilling Area	E-2 and E-7 Area	Govt. Storage Area No. 2	Sta. 4 and WP-4 Drilling Sites	
Gross Alpha	15.8	ND	12.9	16.7	22.2	NA
Gross Beta	23.2	ND	28.9	33.4	20.2	NA
Bismuth-214	.88 - 1.15	ND	0.8 - 0.87	ND	1.06 - 1.29	0.67
Lead-212	0.99 - 1.56	1.24	1.0 - 1.94	1.10 - 1.58	1.33	0.98
Lead-214	1.34	ND	2.14	ND	ND	1.18
Cesium-137	ND	ND	ND	ND	0.38 - 0.55	0.03
Radium-226	1.66	ND	1.50 - 2.05	ND	ND	1.33
Radium-228	0.92 - 1.51	1.79	1.18 - 1.63	1.46	1.29	NA
Potassium-40	7.88 - 16.10	14.9	6.07 - 16.8	17.5	ND	5.77
Thallium-208	0.57 - 0.61	ND	0.54 - 0.70	ND	ND	0.57
Thorium-234	1.71 - 1.94	1.78	1.11 - 1.40	1.41	2.16	0.25
Lead-210	1.50 - 1.94	ND	1.48	ND	2.08 - 2.59	0.76
Bismuth-212	1.56	ND	ND	ND	ND	1.06

NA = Background samples were not analyzed for this analyte.
ND = All analyses were below the background level.

Note: One value indicates one sample had a concentration above background.
Range of values indicates minimum and maximum concentrations above background.

Table 4-9
Metals Concentrations in Subsurface Soils in Source Area 3

Analyte	Location - Concentration (mg/kg)						Background Concentration
	E-2 & E-7 Area		Govt. Storage Area 2		Mud Storage Pit		
	Boring No. C3-4	Boring No. C3-5	Boring No. C3-6	Boring No. C3-7	Boring No. C3-8	Boring No. C3-9	
Arsenic	ND	18.9	11.5	10.0	9.8	ND	4.76
Barium	ND	ND	104	109	ND	ND	58.4
Beryllium	0.69B	0.82B	0.43B	0.98B	ND	ND	0.32
Calcium	6,100	1,870	3,380	6,890	3,960	863	191
Cobalt	11.4	56.9	ND	26.8	ND	ND	4.17
Copper	17.1	21.9	ND	12.9	ND	ND	7.58
Lead	18.8	15.6	ND	15.1	ND	ND	8.68
Magnesium	3,100	841	1,200	3,890	924	ND	623
Manganese	1,250	ND	310	2,690	ND	ND	98.5
Mercury	ND	0.18	ND	ND	ND	ND	0.09
Nickel	20.6	41.2	ND	29.2	ND	ND	11.0
Potassium	957	ND	ND	1,380	ND	ND	475
Sodium	147B	119B	108B	198B	60.8B	44.4B	39.2
Thallium	ND	ND	ND	0.46B	ND	ND	0.38
Zinc	35	ND	ND	47.6	ND	ND	18.6

B = A value that was less than the CRDL but greater than or equal to the IDL.
ND = All analyses were below the background level.

Table 4-10
Surface Soil Metals and Radionuclide Concentrations in Source Area 3
(Page 1 of 2)

Government Storage Area 1

Analyte	Location - Concentration (mg/kg)					Background Concentration
	Boring No. SA3-7A	Boring No. SA3-7B	Boring No. SA3-7C	Boring No. SA3-7D	Boring No. SA3-7E	
Arsenic	ND	ND	ND	4.6	6.1	3.88
Cobalt	7.20J	8.50J	ND	ND	ND	7.09
Calcium	ND	ND	ND	1,230	ND	608
Chromium	ND	ND	ND	16.4	ND	14.0
Iron	ND	ND	ND	15,400	ND	11,832
Lead	14.5	26.6	24.4J	85.2S[c]	40.3	13.8
Zinc	ND	54.3	17.5	278	76.4	17.3
Uranium-238	0.75	ND	ND	1.03	0.53	0.47

Government Storage Area 2

Analyte	Boring No. SA3-8A	Boring No. SA3-8B	Boring No. SA3-8D	Boring No. SA3-8E	Background Concentration
Calcium	686J	3,370	ND	801J	608
Cobalt	10.6J	ND	ND	7.3J	7.09
Iron	ND	ND	ND	12,900	11,832
Lead	20.1	ND	18.7J	ND	13.8
Magnesium	ND	ND	ND	647B	523
Radium-228	ND	ND	1.06	ND	0.81
Uranium-238	ND	ND	1.31	ND	0.47
Gross Beta	ND	ND	22.2	ND	17.7

E-2 and E-7 Area

Analyte	Boring No. SA3-9A	Boring No. SA3-9B	Boring No. SA3-9C	Boring No. SA3-9D	Boring No. SA3-9E	Background Concentration
Aluminum	18,800	ND	ND	ND	ND	14,149
Barium	ND	ND	ND	ND	236	94.3
Calcium	667J	1,000J	1,870	1,710	2,550	608
Chromium	18.2	ND	ND	ND	ND	14.0
Cobalt	ND	ND	ND	7.70J	7.8J	7.09
Iron	16,200	13,900	ND	ND	ND	11,832
Lead	13.9S	ND	13.9	15.7	24.2	13.9
Magnesium	1,180J	ND	ND	ND	ND	523
Nickel	11.8	ND	ND	ND	ND	8.4
Vanadium	34.0	27.4	ND	ND	ND	23.9
Zinc	17.9	ND	ND	ND	ND	17.3
Gross Alpha	37.9	17.5	ND	24.4	ND	16.6
Gross Beta	ND	17.8	ND	ND	ND	17.7
Radium-228	1.46	1.24	0.97	1.09	1.34	0.81

Table 4-10
Surface Soil Metals and Radionuclide Concentrations in Source Area 3
(Page 2 of 2)

Big Chief Drilling Storage Area						
Analyte	**Boring No. SA3-10A**	**Boring No. SA-10B**	**Boring No. SA3-10C**	**Boring No. SA-10D**	**Boring No. SA3-10E**	**Background Concentration**
Calcium	723J	ND	ND	ND	ND	608
Cadmium	ND	ND	ND	ND	1.3	1.00
Potassium	ND	ND	774J	ND	ND	501
Gross Alpha	22.5	16.8	ND	ND	ND	16.6
Radium-228	0.91	0.84	ND	ND	1.11	0.81
Thorium-234	ND	1.35	3.42	ND	3.56	NA

J = Estimated value
NA = Background samples were not analyzed for this analyte.
ND = All analyses were below the background level.
S = Value was determined by standard addition.

Radionuclides were detected in subsurface soil samples at concentrations above background levels in all areas of concern in Source Area No. 4, with the exception of the North and South Substations and the CH Fuel Storage Area. In the Reserve Mud Pit area, Soil Borings SB4-2, SB4-3 and SB4-4, had radionuclides detected from a depth of 1.5 to 10 m (5 to 32 ft) bgs. Boring C4-13 in the Debris Burial Pit had detected radionuclides at a depth of 5.5 to 5.9 m (18 to 19.5 ft). In the west Substation, Boring C4-11 had detected radionuclides at 8.5 to 9 m (28 to 29.5 ft) bgs. Boring C4-10 in the Cable Storage Area had detected radionuclides at a depth of 9.1 to 9.6 m (30 to 31.5 ft) and the E-5 Drill Site had detected radionuclides in Soil Boring SB4-1 at a depth of 3 to 9.8 m (10 to 32 ft). Table 4-11 shows the radionuclide concentrations above background levels as well as the site-specific background level for each constituent.

Several surface soil samples contained radionuclides above background levels. These results are shown in Table 4-12.

Metals were detected in surface and subsurface samples greater than background concentrations. These results are shown in Table 4-13.

Table 4-11
Subsurface Soil Radionuclide Levels in Source Area 4

Analyte	Concentration (pCi/g)					Background Concentration
	Reserve Mud Pits	Debris Burial Pits	West Electrical Substation	Cable Storage Area	E-5 Drill Site	
Gross Alpha	16.5 - 56.8	19.4	35.9	11.7	10.3	NA
Gross Beta	10.7 - 31.2	25.9	34.4	18.1	9.75 - 14.6	NA
Lead-210	3.02 - 5.46	ND	2.84	ND	1.64 - 2.2	0.76
Lead-212	1.03 - 1.80	1.61	1.19	1.62	1.07 - 1.51	0.98
Lead-214	1.24 - 4.96	ND	ND	ND	ND	1.18
Bismuth-212	1.64	ND	ND	ND	2.18	1.06
Bismuth-214	0.91 - 5.42	ND	ND	ND	0.17 - 0.86	0.67
Radium-226	2.02 - 5.15	ND	2.25	1.36	ND	1.33
Radium-228	1.01 - 1.69	ND	ND	ND	1.07 - 1.77	NA
Potassium-40	6.29 - 14.0	14.40	8.04	6.41	8.71 - 12.50	5.76
Thallium-208	0.57	ND	ND	ND	ND	0.58
Thorium-234	1.12 - 6.34	ND	2.56	ND	ND	0.26

NA = Background samples were not analyzed for this analyte.
ND = All analyses were below the background level.

Note: One value indicates one sample had a concentration above background.
Range of values indicates minimum and maximum concentrations above background.

Table 4-12
Surface Soil Radionuclide Concentrations, Source Area 4

Analyte	Location Concentration pCi/g					
	CH Fuel Storage	**South Electrical Substation**	**West Electrical Substation**	**North Electrical Substation**	**Cable Storage**	**Background Concentration**
Gross Alpha	ND	17.9 - 20.0	ND	ND	16.9 - 20.5	16.6
Gross Beta	ND	26.2 - 31.2	ND	ND	17.7 - 23.1	17.7
Bismuth-212	ND	1.01	ND	ND	0.71	0.66
Cesium-137	ND	ND	ND	ND	0.89	0.74
Lead-210	ND	1.62 - 1.72	1.36 - 1.44	ND	1.45 - 2.04	1.34
Lead-212	ND	1.46 - 1.85	ND	ND	0.94 - 1.23	0.92
Potassium-40	ND	6.83	ND	ND	ND	6.63
Protactinium-231	ND	0.96	ND	ND	0.61	NA
Radium-223	ND	0.32 - 0.42	ND	ND	0.22 - 0.27	0.18
Radium-224	ND	1.16 - 1.23	ND	ND	ND	1.01
Radium-228	ND	1.34 - 1.75	ND	ND	0.89 - 1.10	0.81
Thallium-207	ND	0.53	ND	ND	ND	0.48
Thorium-228	ND	2.56 - 4.35	ND	1.27	1.61 - 2.06	NA
Tin-113	0.03	ND	ND	ND	ND	NA
Uranium-234	ND	ND	ND	3.19	ND	NA
Uranium-238	0.51 - 0.71	1.80	ND	ND	ND	0.47

NA = Background samples were not analyzed for this analyte.
ND = All analyses were below the background level.

Note: One value indicates one sample had a concentration above background.
Range of values indicates minimum and maximum concentrations above background.

Table 4-13
Surface and Subsurface Soil Metals Concentrations in Source Area 4
(Page 1 of 2)

Subsurface Soils

Analyte	Location - Concentration (mg/kg)				Background Concentration
	Boring No. C4-13	Boring No. C4-12	Boring No. C4-11	Boring No. C4-10	
Beryllium	2.4	ND	0.46B	ND	0.32
Calcium	4,420	409B	1,890	2,430	191
Chromium	ND	99.6	ND	ND	24.5
Cobalt	43.1	ND	11.1	ND	4.17
Copper	12.8	21.4	ND	ND	7.58
Lead	14.6	ND	ND	ND	8.68
Magnesium	1,250	ND	ND	1,020	623
Nickel	29.8	27.0	ND	ND	11.0
Sodium	87.8B	93.9B	54.3B	109B	39.2
Zinc	26.4				

Surface Soils

West Electrical Substation

Analyte	Boring No. SA4-13B	Boring No. SA4-13C	Boring No. SA4-13D	Boring No. SA4-13E	Background Concentration
Calcium	657J	5,020	ND	755J	608
Chromium	ND	28.9	ND	ND	14.0
Lead	ND	16.6J	ND	ND	13.8
Nickel	ND	19.1	ND	ND	8.41
Zinc	ND	19.3	90.9	ND	17.3

CH Fuel Storage Area

Analyte	Boring No. SA4-11A	Boring No. SA4-11B	Boring No. SA4-11C	Boring No. SA4-11D	Boring No. SA4-11E	Background Concentration
Antimony	12.4J	12.8J	12.4J	13.3J	12.5J	12.4
Arsenic	ND	ND	ND	4.00	ND	3.88
Calcium	612J	712J	2,150	1,490	709J	608
Chromium	ND	ND	15.9	ND	ND	14.0
Copper	ND	ND	11.1	17.7	ND	6.56
Lead	ND	ND	54.3J	22.9J	ND	13.8
Mercury	0.14	0.21	ND	ND	ND	0.08
Zinc	ND	33.1	29.3	50.9	ND	17.3
Cyanide	ND	ND	ND	ND	0.49J	0.31

Table 4-13
Surface and Subsurface Soil Metals Concentrations in Source Area 4
(Page 2 of 2)

Cable Storage Area

Analyte	Boring No. SA4-15A	Boring No. SA4-15B	Boring No. SA4-15C	Boring No. SA4-15D	Boring No. SA4-15E	Background Concentration
Antimony	ND	ND	23.6	ND	ND	12.4
Arsenic	ND	ND	ND	5	ND	3.88
Calcium	ND	ND	937J	2790	658J	608
Copper	39J	50.7J	9,950J	73.9J	84.7J	6.56
Iron	ND	ND	ND	17,700	12,000	11,832
Lead	ND	34.6	120	16.8S[c]	ND	13.8
Magnesium	ND	ND	621J	ND	ND	523
Zinc	ND	ND	131	114	18.8	17.3

North Electrical Substation

Analyte	Boring No. SA4-14D	Background Concentration
Lead	78.9S	13.8

South Substation

Analyte	Boring No. SA4-12A	Boring No. SA4-12B	Boring No. SA4-12C	Background Concentration
Barium	ND	ND	429	94.3
Calcium	1,170J	ND	ND	608
Aluminum	14,200	ND	ND	14,150
Vanadium	29.1	ND	ND	23.9
Chromium	14.8	ND	ND	14.0
Iron	19,700	12,300	ND	11,832
Magnesium	1,300	773J	ND	523
Cyanide	ND	ND	0.68	0.31

B = A value that was less than the CRDL but greater than or equal to the IDL.
J = Estimated value
ND = All analyses were below the background level.
S = Value was determined by standard addition.

4.1.1.5 Source Area 5

No organic contaminants in concentrations greater than detectable levels and/or background concentrations were identified in any of the soil boring samples collected from Source Area 5. Radionuclides were detected greater than background levels at one boring location. In Soil Boring SB5-1, at a depth of 5 to 7 ft, 10 to 12 ft, and 15 to 17 ft, potassium-40 was detected at a concentration of 7.34, 10.2, and 7.97 pCi/g, respectively. Lead-212 was detected at 1.07 and 1.22 pCi/g at depths of 5 to 7 ft and 10 to 12 ft in Soil Boring SB5-1. Bismuth-214 and radium-228 were detected at 0.70 and 0.72 pCi/g, respectively, in Soil Boring SB5-1 at a depth of 15 to 17 feet. Surface soil samples indicated radionuclide concentrations greater than background levels. The results are shown in Table 4-14.

Several metals were detected in surface and subsurface soil samples greater than background levels. These results are presented in Table 4-15.

4.1.1.6 Source Area 6

The DOE sampling showed locations SA6-18A, 18B, and 18C has lead concentrations of 19.7, 16.1, and 23.1 mg/kg, respectively. Location SA6-18B also had a radium-224 concentration of 1.46, pCi/g. Based on the analytical results for the surface soil samples collected at Source Area 6 in 1993 (DOE/NV, 1994a; DOE/NV, 1995c), it was determined that additional sampling was not warranted (DOE/NV, 1995c).

4.1.2 Groundwater

Monitoring wells were installed into the shallow aquifer at Source Areas 1, 3, 4, and 5. Groundwater samples have been collected from these wells in December 1995, January 1997, and in October 1997. The analytical results for all of the groundwater sampling are included in Appendix B.

Due to uncertainties with respect to local background concentrations and naturally occurring radioactive material (NORM) and inorganic substances in the groundwater, all detected analytes have been addressed in the risk assessment (Section 6.0 and Appendix C). The following sections discuss concentrations of analytes detected in the monitoring well samples.

In April 1998, five background wells were sampled and analyzed for arsenic. The well names and sampling results are presented on Table 4-16.

Table 4-14
Surface Soil Radionuclide Concentrations, Source Area 5

Analyte	Location - Concentration (pCi/g)		Background Concentration
Gross A	SA5-17B - 18.8	SA5-16A - 18.1	16.6
Gross B	SA5-17E - 18.0	SA5-16A - 23.8	17.7
Cesium-137	SA5-17A - 0.92		0.74
Lead-210	SA5-17A - 16.0 SA5-17D - 1.53	SA5-17B - 1.36 SA5-17E - 1.37	1.34
Lead-212	SA5-17D - 0.97		0.92
Radium-223	SA5-17A - 0.25	SA5-17E - 0.19	0.18
Radium-228	SA5-17D - 0.82		0.81
Uranium-234	SA5-17C - 10.4		NA
Thorium-228	SA5-16D - 0.83		NA
Protactinium-231	SA5-16A - 0.73		NA

NA = Background samples were not analyzed for this analyte.

Table 4-15
Source Area 5 Metals Concentrations in Surface and Subsurface Soils

Surface Soils							
	Location - Concentration (mg/kg)						
Parameter	Boring No. SA5-17C	Boring No. SA5-17D	Boring No. SA5-17E	Boring No. SA5-16C	Boring No. SA5-16D	Boring No. SA5-16E	Background Concentration
Calcium	5,500	842J	775J	620J	ND[a]	9,480J[b]	608
Lead	36.3	ND	63.6	ND	ND	ND	13.8
Barium	ND	ND	107	ND	ND	ND	94.3
Manganese	ND	ND	1,150	ND	ND	ND	1,075
Magnesium	ND	ND	ND	ND	ND	553J	523
Chromium	ND	ND	ND	24.3	14.8	ND	14.0
Arsenic	ND	ND	ND	ND	5.70S[c]	ND	3.88
Zinc	24.4	ND	ND	ND	ND	ND	17.3

Subsurface Soils			
Parameter	Boring No. C5-1, 25-27 ft	Boring No. C5-3, 21.5-23 ft	Background Concentration
Chromium	73.5	ND	24.5
Beryllium	ND	0.43B	.32
Copper	16.5	ND	7.58
Nickel	20.2	ND	11.0
Calcium	319B	2,140	191
Magnesium	ND	1,010	623
Manganese	99.4	ND	98.5
Potassium	ND	501	475
Sodium	43.4B	54.1B	39.2

B = A value that was less than the CRDL but greater than or equal to the IDL.
J = Estimated value
ND = All analyses were below the background level.
S = Value was determined by standard addition.

Note: SA5-17A and SA5-17B had calcium concentrations of 746S and 738S mg/kg, respectively.

Table 4-16
Salmon Site 1998 Background Groundwater Metals Concentrations

Location	Arsenic (µg/L)
Billy Hibley	13
David Parker	10
Mike Bilbo	11
T. Anderson	0.77 U
T. Anderson	ND
Nightengale	0.63 U
Nightengale	ND

U = The analyte was analyzed for but not detected.
ND = All analyses were below the detection limit.
µg/L = Micrograms per liter

4.1.2.1 Source Area 1

A total of seven monitoring wells were installed into the Alluvial Aquifer at Source Area 1 (Wells SA1-1-H through -7-H). Suspected anomalous concentrations of tritium, trichloroethene, vinyl chloride, and trans-1,2-dichloroethene were detected in samples from six of the wells in 1995 (all Source Area 1 shallow wells except for SA1-7-H). The same PCOCs and tetrachloroethene were detected in samples collected from the wells in 1997. The analytical results for the Source Area 1 shallow groundwater samples are presented in Table 4-17. The likely source of these potential contaminants are the SGZ Mud Pits which intersect the Alluvial Aquifer within approximately 3 m (10 ft) of the ground surface.

In 1998, groundwater samples were collected in and around the SGZ Mud Pits to more accurately define the extent of contamination associated with this source area. The groundwater samples were collected using a direct-push method (DOE/NV, 1995c). During this investigation 72 direct-push borings were advanced and 68 groundwater samples collected and analyzed for tritium. The analytical results from this investigation are presented in Appendix B (Table B-4). Tritium concentration ranged from the laboratory detection limit to 88,200 picocuries per liter (pCi/L). Of the 68 groundwater samples analyzed, 20 did not detect tritium above the laboratory detection limit. The average concentration of tritium detected was approximately 9,500 pCi/L.

Figure 4-1 presents a contour map of the 1998 CPT groundwater samples concentrations. The 1998 results were comparable to what had been previous observed in monitoring well groundwater samples collected from monitoring wells in Source Area 1. The contours presented

Table 4-17
Potential Contaminants of Concern Detected in the Source Area 1 Alluvial Aquifer

Well	Tritium pCi/L	PCE µg/L	TCE µg/L	VC µg/L	1,2-DCE µg/L
SA1-1-H	23,600	5U	69	10U	8
	21,900	1J	26	10U	3J
	27,800	1U	30R	1U	4.5
SA1-2-H	6,040	5U	4J	6J	6
	3,900	2J	2J	3J	3J
	3,490	1U	2.3	1U	1.9
SA1-3-H	984	5U	5U	10U	5J
	909	5U	5U	10U	2J
	780	1U	0.8J	0.5J	5.3
SA1-4-H	274	5U	5U	10U	5U
	426	5U	5U	10U	5U
	220	1U	0.3J	1U	1U
SA1-5-H	1,090	5U	5U	10U	9
	514	5U	2J	10U	5J
	940	1U	1.5	1U	5.6
SA1-6-H	1,630	5U	3J	10U	5U
	769	1J	5U	10U	5U
	1,690	1U	1U	1U	1U
SA1-7-H	-30	5U	5U	10U	5U
	-57	2J	5U	10U	5U
	20U	1U	1U	1U	1U
HM-S	5,250	5U	7	10U	6
HM-S	2,960	0.5J	3.9	1U	0.9J

PCE = Tetrachloroethene
TCE = Trichloroethene
VC = Vinyl chloride
1,2-DCE = trans-1,2-Dichloroethene
U = Analyte not greater than the indicated value
J = Estimated concentration
pCi/L = Picocurie(s) per liter
µg/L = Microgram(s) per liter

Note: Multiple values indicate multiple samples collected from the monitoring well.

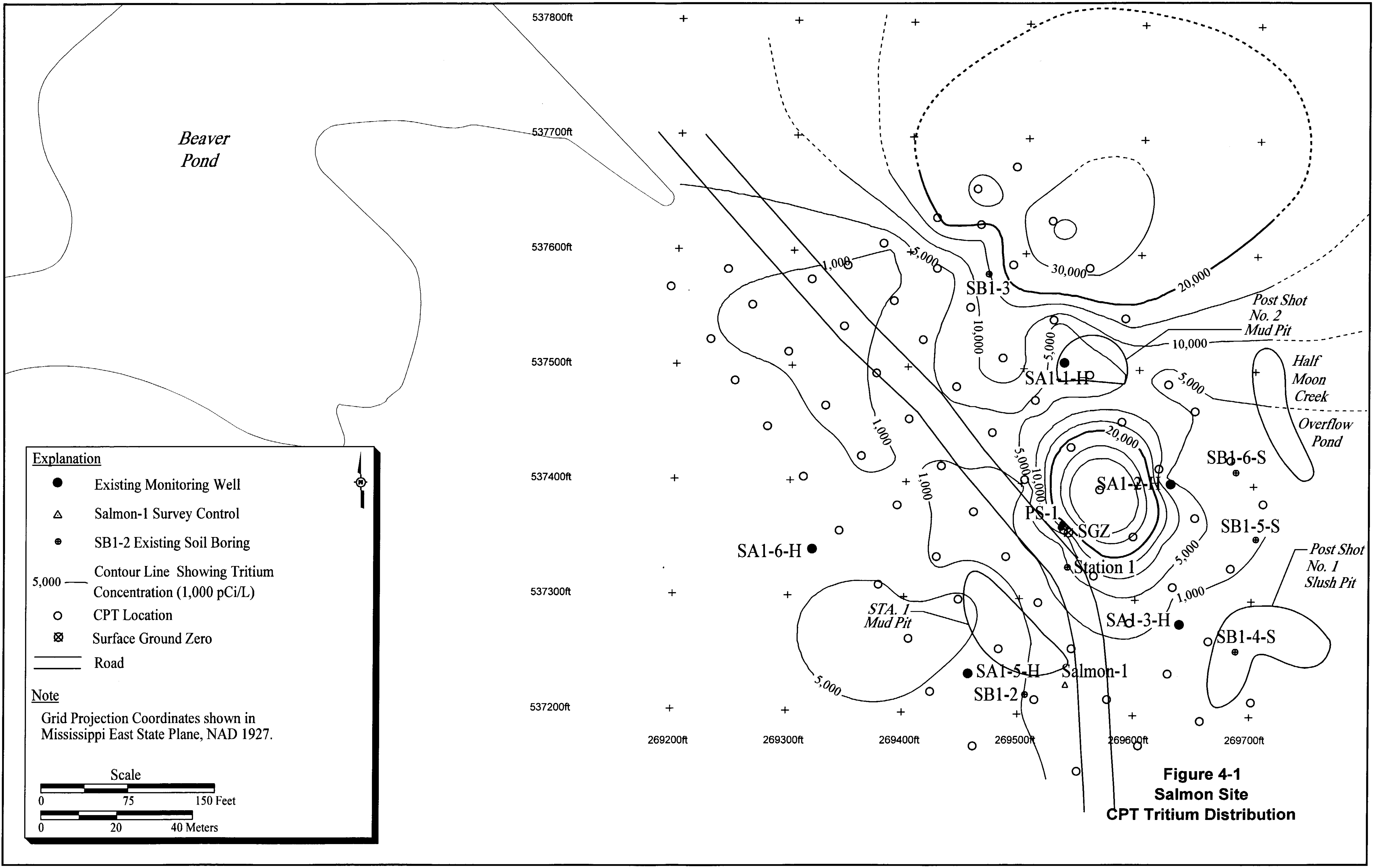

Figure 4-1
Salmon Site
CPT Tritium Distribution

on Figure 4-1 are much more refined than previous tritium contour maps prepared for Source Area 1.

4.1.2.2 Source Area 3

Four monitoring wells were installed into the Alluvial Aquifer at Source Area 3 (Wells SA3-1-M, -3-M, -4-H, and -5-H). Toluene was detected at an estimated concentration of 2 micrograms per liter (µg/L) in the sample collected from Well SA3-4-H in 1995, and tetrachloroethene was detected at an estimated concentration of 1 µg/L in the samples collected from Wells SA3-4-H and SA3-5-H in 1997.

4.1.2.3 Source Area 4

One monitoring well was installed into the Alluvial Aquifer at Source Area 4 (Well SA4-1-M). Bismuth-214 (31.9 pCi/L), lead-212 (6.42 pCi/L), lead-214 (26.7 pCi/L), and radium-226 (31.1 pCi/L) were detected in the sample collected from this well in 1995, but were not detected in the sample collected in 1997.

4.1.2.4 Source Area 5

Three monitoring wells were installed into the Alluvial Aquifer at Source Area 5 (Wells SA5-1-M, through -3-M). Carbon disulfide was detected at a concentration of 12 µg/L in the sample collected from Well SA5-3-M in 1997.

4.1.3 Surface Water

Surface water samples were collected at several locations at the Salmon Site (Figure 3-5). The purpose of the sampling was to support the *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) (Exhibit 3). For completeness, Table 4-18 lists the detected analytes that were above the laboratory detection limit. The surface water sampling results were not compared to site-specific background water samples because the extreme variability that can occur during surface water sampling. For example, surface water sample laboratory results may be higher (flushing) or lower (dilution) than normal during a significant precipitation event. A summary of the surface water analytical results are presented in Appendix B (Table B-5).

Table 4-18
Surface Water Analytical Results

Location		Beaver Pond	Grantham Creek	Half Moon Creek	Half Moon Creek Overflow Pond	Hickory Hollow Creek	Gator Pond	Reference Pond
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Aluminum	µg/L	228-416	87.8J-179J	113J-235	384	165J-201	110J	180J
Arsenic	µg/L	2.2J	ND	ND	ND	ND	ND	ND
Barium	µg/L	18.9J-31.3J	19.9J-25.6J	22.3J-29.8J	78.7J	29J-90.4J	32.6J	19.9J
Cadmium	µg/L	ND	ND	ND	3.0J	ND	ND	ND
Calcium	µg/L	2450J-3660J	594J-3070J	573J-798J	24600	615J-827J	3630J	1620J
Cobalt	µg/L	ND	10.1J	ND	9.1J	ND	ND	ND
Iron	µg/L	1440J-2690J	417J-654J	111J-421J	4190J	118J-206J	252J	677J
Lead	µg/L	1.2J	1.2J	ND	ND	1.1J	ND	ND
Magnesium	µg/L	560B-584J	417J-812J	363J-677J	2220J	405J-531J	1040J	566J
Manganese	µg/L	120-155	56.3-116	21.5-52.5	576	26.9-79.2	84.2J	213
Mercury	µg/L	ND	ND	ND	ND	ND	0.2J	0.2J
Silver	µg/L	ND	ND	3.5J-5.3J	ND	ND	ND	14.6
Sodium	µg/L	2440J-2910J	1740J-2160J	1610J-2120J	56400	1640J-1680J	18200	1220J
Tritium	pCi/mL	0.40-0.40	0.20-0.20	0.20	0.70	ND	ND	ND
Tin-113	pCi/L	ND	8.7	ND	ND	ND	ND	ND
Zinc	µg/L	ND	ND	5.2J	ND	5.1J	ND	ND

J = Estimated concentration
µg/L = Microgram(s) per liter
pCi/mL = Picocurie(s) per milliliter
pCi/L = Picocurie(s) per liter
ND = Not detected

Note: One value indicates one sample had a concentration above the detection limit. Range of values indicates minimum and maximum values above the detection limit. Blank indicates analyte not detected.

Other than naturally occurring elements, such as aluminum, calcium, manganese, and sodium, only tritium and Tin-113 were detected in surface water samples. Tin-113 was only detected in one sample in Grantham Creek at 8.7 picocuries per milliliter (pCi/mL). Tritium was detected in several surface water samples at concentrations ranging from less than the laboratory detection limit to 0.7 pCi/mL (700 pCi/L).

4.1.4 Sediment

Sediment samples were collected at several locations at the Salmon Site (Figure 3-5). The purpose of the sampling was to support the *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) (Exhibit 2). For completeness, Table 4-19 lists the nonradiological analytes that were detected above the laboratory detection limit and Table 4-20 lists the radiological analytes that were detected above the laboratory detection limit. A summary of the sediment analytical results are presented in Appendix B (Table B-6).

Nonradiological analytes detected in sediment samples are summarized on Table 4-19. The only analytes consistently detected were the naturally occurring elements, such as aluminum, calcium, manganese, and sodium. The other analytes detected were at or slightly above the laboratory detection limit, a review of the data does not reveal a pattern of contamination. This was the same conclusion reached in the ecological risk assessment. For completeness, the detected analytes are listed in this document but are discussed in detail in the *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) (Exhibit 2).

Radiological analytes detected in sediment samples are summarized on Table 4-20. While several analytes were detected at or slightly above the laboratory detection limit, a review of the data does not reveal a pattern of contamination. This was the same conclusion reached in the ecological risk assessment. For completeness, the detected analytes are listed in this document but are discussed in greater detail in the *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) (Exhibit 2).

4.2 Operable Unit 2: Test Cavity, Local Aquifer, and Aquifers 1, 2, and 3

Twelve monitoring wells were installed into the aquifers that comprise Operable Unit 2: six in the Local Aquifer, one in Aquifer 1, three in Aquifer 2, and two in Aquifer 3. Groundwater

Table 4-19
Detected Nonradiological Analytes
Sediment
(Page 1 of 4)

Location		Beaver Pond	Grantham Creek	Half Moon Creek	Half Moon Creek Overflow Pond	Hickory Hollow Creek	Gator Pond	Reference Pond
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Aluminum	µg/kg	4090-13000	84.4-214	195-1550	1780	560-2180	6490	6480
Antimony	µg/kg	ND	14.5NP-15NP	ND	ND	ND	ND	ND
Arsenic	µg/kg	3.0J-7.7J	.0014NP-0.3NP	0.3J-0.7J	0.9J	ND	1.5J	2.1J
Barium	µg/kg	21.1J-181J	2.4NP-5.9J	7.3J-51.7J	11.0J	16J-34.4J	125J	19.9J
Beryllium	µg/kg	ND	0.23NP-0.24NP	ND	ND	ND	ND	ND
Cadmium	µg/kg	9.0J	0.7NP-0.74NP	1.7	ND	ND	ND	ND
Calcium	µg/kg	885J-5630J	179NP-305NP	183J-579J	417J	451J-713J	3620J	369J
Chromium	µg/kg	5.5J-13.2J	0.1NP-1.2NP	1.2J-2.6J	14.8	2.2J-2.4J	7.8J	9.3
Cobalt	µg/kg	ND	1.6NP-1.6NP	ND	ND	ND	ND	ND
Copper	µg/kg	ND	1.0NP-1.0NP	ND	ND	ND	ND	ND
Iron	µg/kg	4700J-13000J	125NP-303J	102J-1040J	1280J	743J-1930J	12300J	19300J
Lead	µg/kg	3.9-20.2	0.0034NP-1.07NP	1.1-5.0	10.0	0.9J-2.4	17.0	5
Magnesium	µg/kg	279J-1380J	39.8NP-58.8J	46.6J-166J	106J	79.8J-174J	518J	152J
Manganese	µg/kg	28.2J-583J	6.3NP-85.1J	47.1J-90.8J	17.5J	32.2J-36.5J	136J	45.8J
Mercury	µg/kg	ND	0.06NP-0.07NP	0.12J	ND	0.11J	ND	ND
Nickel	µg/kg	ND	5.2NP-5.4NP	ND	ND	ND	ND	ND

Table 4-19
Detected Nonradiological Analytes
Sediment
(Page 2 of 4)

Location		**Beaver Pond**	**Grantham Creek**	**Half Moon Creek**	**Half Moon Creek Overflow Pond**	**Hickory Hollow Creek**	**Gator Pond**	**Reference Pond**
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Potassium	µg/kg	ND	701NP-727NP	ND	ND	ND	ND	ND
Silver	µg/kg	ND	0.91NP-0.95NP	ND	ND	ND	ND	ND
Selenium	µg/kg	ND	0.0014NP-0.26NP	ND	ND	ND	ND	ND
Sodium	µg/kg	144J-1230J	55.4NP-77.6B	70.3J-128J	112J	78.0J-96.8J	600J	80.8J
Thallium	µg/kg	ND	00014NP-0.26NP	ND	ND	ND	ND	ND
Vanadium	µg/kg	8.9J-27.7J	0.94NP-0.97NP	1.4J-1.8J	3.2J	3.6J	8.5J	43
Zinc	µg/kg	18.8-111	1.6NP-2.6NP	ND	ND	ND	ND	ND
2-butone	µg/kg	5J-170	ND	ND	ND	ND	ND	ND
Acetone	µg/kg	230B-920B	ND	41B-48B	ND	ND	250J	ND
Methylene Chloride	µg/kg	ND	2J-2J	1J-4BJ	ND	3J	ND	2J
4,4'-DDD	µg/kg	380NP	ND	ND	ND	ND	ND	ND
4,4'-DDE	µg/kg	380NP	ND	ND	ND	ND	ND	ND
4,4'-DDT	µg/kg	380NP	ND	ND	ND	ND	ND	ND
4-Mehtylphenol	µg/kg	2200J	ND	ND	ND	ND	ND	ND
Aldrin	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Alpha-BHC	µg/kg	190NP	ND	ND	ND	ND	ND	ND

Table 4-19
Detected Nonradiological Analytes
Sediment
(Page 3 of 4)

Location		Beaver Pond	Grantham Creek	Half Moon Creek	Half Moon Creek Overflow Pond	Hickory Hollow Creek	Gator Pond	Reference Pond
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Alpha-Chlordane	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Benzoic Acid	µg/kg	550J	ND	ND	ND	ND	ND	ND
Beta-BHC	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Delta-BHC	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Gamma-BHC	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Dieldrin	µg/kg	380NP	ND	ND	ND	ND	ND	ND
Endosulfan I	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Endosulfan II	µg/kg	380NP	ND	ND	ND	ND	ND	ND
Endosulfan Sulfate	µg/kg	380NP	ND	ND	ND	ND	ND	ND
Endrin	µg/kg	380NP	ND	ND	ND	ND	ND	ND
Endrin ketone	µg/kg	380NP	ND	ND	ND	ND	ND	ND
Gamma-Chlordane	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Heptachlor	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Heptachlor epoxide	µg/kg	190NP	ND	ND	ND	ND	ND	ND
Methoxychlor	µg/kg	1900	ND	ND	ND	ND	ND	ND
Toluene	µg/kg	11J-220	ND	ND	ND	ND	ND	ND

Table 4-19
Detected Nonradiological Analytes
Sediment
(Page 4 of 4)

Location		Beaver Pond	Grantham Creek	Half Moon Creek	Half Moon Creek Overflow Pond	Hickory Hollow Creek	Gator Pond	Reference Pond
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Toxaphene	µg/kg	3800NP	ND	ND	ND	ND	ND	ND
Aroclor-1016	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Aroclor-1221	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Aroclor-1232	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Aroclor-1242	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Aroclor-1248	µg/kg	1900NP	ND	ND	ND	ND	ND	ND
Aroclor-1254	µg/kg	3800NP	ND	ND	ND	ND	ND	ND
Aroclor-1260	µg/kg	3800NP	ND	ND	ND	ND	ND	ND

J = Estimated value
µg/kg = Micrograms per kilogram
NP = Result not validated
B = Analyte found is associated method and/or field blank as well as sample.
ND = Not detected

Note: One value indicates one sample had a concentration above the detection limit. Range of values indicates minimum and maximum values above the detection limit.
Blank indicates analyte not detected.

Table 4-20
Detected Radiological Analytes
Sediment

Location		Beaver Pond	Grantham Creek	Half Moon Creek	Half Moon Creek Overflow Pond	Hickory Hollow Creek	Gator Pond	Reference Pond
Analyte	**Units**	**Source Area 1**					**Source Area 2**	**Offsite**
Gross Alpha	pCi/g	17.2	ND	ND	ND	ND	22.48J	ND
Gross Beta	pCi/g	11.13-18.57	8.35-11.66	8.84-11.39	ND	11.23	23.69	ND
Be-7	pCi/g	2.4	ND	ND	ND	ND	ND	ND
K-40	pCi/g	ND	ND	ND	ND	ND	2.38	ND
Cd-109	pCi/g	ND	ND	0.74	ND	ND	ND	ND
I-131	pCi/g	ND	ND	ND	ND	ND	ND	0.10
Cs-137	pCi/g	0.17-0.61	0.012-0.013	0.08	0.16	0.07	1.09	ND
Ce-144	pCi/g	ND	ND	0.30	ND	ND	ND	ND
Ti-208	pCi/g	0.12	0.008-0.038	ND	ND	0.13	ND	0.39
Pb-210	pCi/g	2.04-9.56	ND	ND	ND	ND	ND	ND
Pb-212	pCi/g	0.85-0.88	.012-0.16	0.43	ND	0.39	1.05	1.42
Bi-212	pCi/g	0.43	0.11	0.09	ND	ND	ND	ND
Ra-224	pCi/g	1.31	ND	0.68	ND	ND	4.14	1.26
Ra-228	pCi/g	0.80-0.81	ND	0.36	ND	ND	ND	1.16
Pa-231	pCi/g	ND	ND	ND	ND	ND	ND	1.11
Pa-234	pCi/g	ND	ND	ND	ND	ND	ND	3.89
U-238	pCi/g	1.34-1.44	ND	ND	ND	ND	ND	ND
Tritium	pCi/g	0.48	ND	ND	ND	ND	ND	ND

J = Estimated value
pCi/g = Picocuries per gram
ND = Not detected

Note: One value indicates one sample had a concentration above the detection limit. Range of values indicates minimum and maximum values above the detection limit. Blank indicates analyte not detected.

samples were collected from these wells in January and October 1997. The analytical results for the well samples are presented in Appendix B.

As with the Alluvial Aquifer data, detected analytes have been addressed in the risk assessment (Section 6.0 and Appendix C). The following sections discuss the analytes detected in Operable Unit 2 monitoring well samples.

4.2.1 Local Aquifer

Six monitoring wells were installed into the local aquifer (Well SA1-8-L and Wells SA2-1-L through SA2-5-L). Gross beta activity was measured at 16.4 pCi/L in the sample from Well SA2-2-L in the January 1997 sampling event and 38.8pCi/L in the October 1997 sampling event. Tetrachloroethene and trans-1,3-dichloropropene were detected at an estimated concentration of 2 µg/L (each) in the sample from Well SA2-4-L, and TCE was detected at an estimated concentration of 2 µg/L (each) in the samples from Wells SA1-8-L and SA2-5-L. Arsenic was detected in the samples from the Local Aquifer wells at concentrations ranging from 9.3 µg/L to 44.2 µg/L.

4.2.2 Aquifer 1

One monitoring well was installed into Aquifer 1 (Well SA3-8-1). Carbon disulfide was detected at an estimated concentration of 2 µg/L in the sample from this well.

4.2.3 Aquifer 2

Three monitoring wells were installed into Aquifer 2 (Wells SA1-9-2a, SA1-10-2b, and SA3-10-2). Gross alpha and gross beta activities were measured at 22.4 pCi/L and 12.7 pCi/L, respectively, in the sample from Well SA1-10-2b. Carbon disulfide was detected in the samples from all three wells at estimated concentrations of 4 µg/L (Well SA1-9-2a), 5 µg/L (Well SA1-10-2b), and 3 µg/L (Well SA3-10-2).

4.2.4 Aquifer 3

Two monitoring wells were installed into Aquifer 3 (Wells SA1-11-3 and SA3-11-3). Gross beta activity was measured at 23.9 pCi/L in the sample from Well SA3-11-3. Carbon disulfide was detected in the samples from Wells SA1-11-3 and SA3-11-3 at estimated concentrations of 2 µg/L and 3 µg/L, respectively.

4.3 Operable Unit 3: Aquifers 4 and 5

Two monitoring wells were installed into Aquifer 4 (Wells SA5-4-4 and SA5-5-4). Two rounds of groundwater samples have been collected from these wells (the January 1997 and October 1997 sampling events). The analytical results for these samples are included in Appendix B, Table B-2. Tetrachloroethene (1 µg/L) and xylenes (2 µg/L) were detected at estimated concentrations in the sample from Well SA5-4-4.

5.0 Contaminant Fate and Transport

Previous sections presented physical characteristics of the study area and distributions of contaminants in each medium. This section uses that information to discuss the fate and potential transport of contaminants in each aquifer. This section consists of the following parts:

- Section 5.1 presents the groundwater flow and transport modeling objectives.
- Section 5.2 discusses potential routes of migration.
- Section 5.3 considers contaminant persistence in soils, surface water, sediment, and groundwater.
- Section 5.4 presents the factors that affect contaminant migration.
- Sections 5.5, 5.6, and 5.7 present an overview of factors affecting contaminant migration for each of the three Operable Units, and discusses the aquifer-specific flow and transport model.

Appendix D presents supporting data and documentation on the fate and transport models.

5.1 Modeling Objectives

The Salmon Site modeling objectives were as follows:

- To use analytical and numerical models to improve understanding of the local hydrogeology
- To estimate the potential for off-site movement of known contaminants from the Alluvial and the Local Aquifers
- A tritium concentration estimate was also calculated to estimate the amount of time required for tritium concentrations in the Alluvial and Local Aquifers to decay below the maximum contaminant level (MCL) for risk assessment purposes
- To estimate contaminant concentrations in the Alluvial and Local Aquifers for risk assessment purposes at the site boundary 100 years from the present
- To estimate the rate and direction of potential contaminant migration in Aquifers 1, 2a, 2b, and 3 given a scenario where contaminants from the test cavity migrate up from the test cavity through one of the sealed test holes and diffused laterally into an overlying aquifers
- To estimate the potential impact from tritium injected into Aquifer 5

5.2 Routes of Migration

This section delineates the potential routes of contaminant migration from source identified areas on the Salmon Site and vicinity. Potential migration pathways within each of the following media and among the different media include the following:

- Air, specifically the dispersion of volatile organic compounds from soil and surface water bodies (Section 5.2.1)
- Soil, primarily the potential leaching of contaminants from soil to underlying groundwater and nearby surface water, and the potential erosion of surface soil into adjacent surface water (Section 5.2.2)
- Surface water and sediments, including both the transport of surface water and sediment downstream and the potential transport of contaminants to groundwater via infiltration from ponds and creeks (Section 5.2.3)
- Groundwater, including both potential migration to off-site wells and potential transport of contaminants to surface water via groundwater discharge to ponds and creeks (Section 5.2.4).

Contaminant migration through biouptake by plants and animals is a potential pathway considered in the ecological risk assessment (DOE/NV, 1995a). This potential exposure scenario is evaluated as a contaminant transport process only as a secondary exposure pathway for human health risk. The reader is referred to the ecological risk assessment (Exhibit 2) for a more detailed discussion on biouptake.

5.2.1 Air Emissions

Volatile chemicals in near-surface soil and surface water have the potential for migration to the interface of soil and water with air at the land surface, followed by the subsequent volatilization to the air. Individual chemical rates of volatilization are a function of their vapor pressure, Henry's Law Constant, the relative chemical concentration in the two media, the temperature, and other factors such as the wind conditions. Volatile and semivolatile organic compounds, relative to the other classes of site chemicals, have the tendency to volatilize to the atmosphere because of their relatively high vapor pressures and air/water partitioning coefficients.

Because of the relatively low concentrations of VOCs and SVOCs in the surface soils at the Salmon Site, the air emissions pathway as a result of volatilization is not considered further. However, human inhalation of suspended solids contaminated with metals is one exposure pathway evaluated in the human health risk (Section 6.0).

5.2.2 Soil

Contaminants present in surface and subsurface soils may be released to the environment by one of the following mechanisms:

- Volatilization - This is not considered to be a primary release mechanism because of the relatively low concentrations of VOCs and SVOCs in the soil.

- Wind erosion of surface soil - Because of the surface vegetation and wet climate at the Salmon Site, the potential for this release mechanism is considered to be low (Section 6.0) discusses this release mechanism as a possibility for particulates in surface soils containing contamination).

- Water erosion and surface runoff - This release mechanism can transport contaminants contained in the site surface materials to other site locations influenced by surface drainage from heavy precipitation events. Such contaminants can eventually be transported off site by surface drainage or can be deposited in the sediments of Half Moon Creek and its site tributaries (Grantham Creek, Hickory Hollow Creek, and an unnamed creek in the northwest quadrant of the site).

- Leaching of subsurface contamination - This mechanism is controlled by contaminant solubility and sorption. Leaching of soil contaminants into groundwater can occur from any depth in the vadose zone. However, contaminant leaching is very slow when the site contaminants are contained in clays or drilling muds.

All soil sample concentrations of VOCs, SVOCs, polychlorinated biphenyls (PCBs), and pesticides in the 1993 and 1995 datasets except TPH were either significantly below published regulatory limits for the State of Mississippi (MDEQ, 1999) or were contained in less than five percent of the samples and were discarded as statistical outliers.

Total petroleum hydrocarbons (as diesel) were detected in the three samples obtained in 1995 from Soil Boring SB1-2. The highest concentration was 32,000 mg/kg, which occurred at the 1.5- to 2-m (5- to 7-ft) boring depth below land surface. This boring also contained diesel concentrations of 490 mg/kg at the 3- to 3.7-m (10- to 12-ft) interval and 230 mg/kg at the 6- to 6.7-m (20- to 22-ft) interval.

5.2.3 Surface Water and Sediment

The following primary surface water bodies and drainage features are associated with the Salmon Site (Figure 3-5):

- Beaver Pond in Source Area 1 which receives potential runoff from Source Area 1 and Source Area 3
- Half Moon Creek overflow pond in Source Area 1 which receives potential runoff from surface ground zero
- Half Moon Creek which receives potential runoff directly from Source Area 1, Source Area 2, Source Area 3, and Source Area 5
- Grantham Creek a tributary to Half Moon Creek, which receives potential runoff from Source Area 2
- An unnamed tributary to Half Moon Creek in the northwest quadrant of the site which receives potential runoff from Source Area 4
- Hickory Hollow Creek, a tributary to Half Moon Creek which receives potential runoff from Source Area 5

Surface water and sediments results obtained from site sampling in 1993 are presented in the ecological risk assessment (DOE/NV, 1995a). No pesticides or PCBs were detected in sediments along the surface drainage system at the Salmon Site.

5.2.4 Groundwater

Potential pathways for migration of dissolved contaminants with groundwater include the following:

- Shallow groundwater discharge to Half Moon Creek, Grantham Creek, the unnamed creek in the northwest quadrant of the site, Hickory Hollow Creek, the beaver pond in Source Area 1, and the Half Moon Creek overflow pond in Source Area 1
- Advective transport to water supply wells

5.3 Contaminant Persistence

Persistence is a measure of how long a given chemical will exist in a specific medium. Contaminant persistence in environmental media is a function of physical and chemical properties of a given class of compounds, the specific chemicals within each class found in the environment, and the properties of the media of concern (including the tendencies of each class of compounds to transfer among available media). Chemical and physical properties relevant to evaluation of transport and fate of organic primary contaminants include water solubility, vapor pressure, Henry's Law Constant, specific gravity, organic carbon partition coefficient, distribution coefficient, and half-life. The persistence of primary contaminants detected above the State of Mississippi (MDRH, 1996) MCL in surface water, sediment, soil, and groundwater is discussed in the following text.

5.3.1 Water Solubility

The solubility of a chemical in water is the maximum amount of the chemical that will dissolve in pure water at a specified temperature. Chemicals with high solubility are relatively mobile in water and are likely to leach from wastes and soils. These chemicals tend to have low volatilization potential, but tend to be biodegradable. Conversely, those chemicals with low solubility tend to adsorb on soils and sediments and are not readily biodegraded.

5.3.2 Vapor Pressure

Vapor pressure is a measure of the tendency of a substance to pass from a solid or a liquid to a vapor state. It is measured as the pressure of the gas in equilibrium with the solid or liquid at a given temperature. The vapor pressure determines the volatilization of a given chemical to the atmosphere from dry soils. Volatilization is dependent upon vapor pressure and the Henry's Law Constant for surface water and moist soils. A chemical with a vapor pressure less than 10^{-6} millimeters of mercury tends to associate with particulate matter; a chemical with a higher vapor pressure tends to associate with the vapor phase. Highly water-soluble compounds generally show little volatilization from water or moist soils unless they also have a high vapor pressure.

5.3.3 Henry's Law Constant

The Henry's Law Constant describes a linear relation between vapor pressure and water solubility, providing a measure of a chemical's ability to move from water or moist soils to air. Compounds with Henry's Law Constants greater than 10^{-3} atmospheres-cubic meter (atm-m^3) per mole can be expected to volatilize more readily from water. Compounds with values ranging from 10^{-3} to 10^{-5} atm-m^3/mole exhibit lower but moderate volatilization. Compounds with values less than 10^{-5} atm-m^3/mole show limited ability to volatilize from water or moist soils.

5.3.4 Specific Gravity

The specific gravity of a substance is the ratio of the weight of a given volume of that substance to the weight of the same volume of water. The normal water weight is usually measured at 4° C (39° F); the other substance is often measured at some other temperature, typically 20° C. If the specific gravity of a substance is less than 1.0, that free-phase substance will float on water; if specific gravity is greater than 1.0, the free-phase substance will sink in water. The specific gravity can sometimes be used to predict the vertical distribution of the immiscible or insoluble portion of a chemical within an aquifer or other body of water.

5.3.5 Organic Carbon Partition Coefficient

The organic carbon partition coefficient (K_{oc}) is a measure of the degree to which an organic substance will preferentially dissolve in water or in an organic solvent. The typical range of K_{oc} values is from 1 to 10^7 milliliters/gram, with higher values indicating a greater tendency to remain sorbed. Chemicals moving through the subsurface will alternately adsorb or desorb from available organic matter in the soil matrix. The higher the K_{oc} values are, the greater the tendency of a chemical to be attracted to the organic fraction of the soil and consequently the lower its mobility in the subsurface environment.

5.3.6 Distribution Coefficient

The distribution coefficient (K_d) is a measure of the concentration of a chemical sorbed onto a solid relative to the concentration of the same chemical in the associated liquid phase. The K_d is the slope of a linear sorption isotherm relating the concentrations in the two media. The larger the K_d is, the greater the sorption to the solid phase and the less in solution for a given solute. As with K_{oc}, the distribution coefficient measures the relative mobility of a chemical in the environment. A K_d value is estimated from the K_{oc} of the specific chemical and the fraction of organic carbon in the soil.

5.3.7 Half-Life

A half-life is the time required for the concentration of a substance to decrease from its initial level to one-half its initial level. The apparent decrease may be caused by various processes including radioactive decay, biodegradation, reactions with other substances, or mass removal of the constituent from the media in question.

5.3.8 Contaminant Identification

Four contaminants were identified as exceeding or being very near to the MCLs (MDEQ, 1995) in groundwater (see Section 6.0):

- Arsenic (soil and groundwater)
- Trichloroethene (TCE) (groundwater)
- Vinyl Chloride (groundwater)
- Tritium (groundwater).

This section addresses the fate and transport of those contaminants found in groundwater (arsenic, TCE, vinyl chloride, and tritium).

A. Arsenic is a ubiquitous, naturally occurring element often found in association with copper or lead. In the environment, arsenic can exist in several oxidation states. Under oxidizing conditions, the arsenate (V) form is the stable oxidation state, which gives way to the arsenite (III) form under transitional conditions and arsenic (I) form, or elemental arsenic, under reducing conditions. In a reducing environment and in the presence of sulfur, the relatively insoluble sulfides (As_2S_3 and AsS) form. Under oxidizing conditions, arsenic acid (H_3AsO_4) and its ionization products ($H_2AsO_4^{-1}$, $HAsO_4^{-2}$, AsO_4^{-3}) are of importance for arsenic transport over a wide range of pH. Therefore, arsenic mobility is expected under oxidizing conditions if a significant source is present.

B. Tetrachloroethene is a colorless, nonflammable, mobile liquid that is relatively soluble in water, with little tendency to partition onto organic carbon and other soil solids. Volatilization can be a significant process in surface and near-surface environments. Tetrachloroethene is subject to biodegradation under both aerobic and anaerobic conditions. Free-phase TCE will tend to move independently of the groundwater flow direction, generally sinking in the subsurface environment in response to its high specific gravity.

C. Vinyl chloride is a colorless, flammable, mobile liquid that is slightly soluble in water (2,700 mg/L). Based upon a high vapor pressure, volatilization in surface or near-surface environments would be rapid. Any vinyl chloride that does not evaporate should be highly mobile in soil and may leach to the groundwater. Vinyl chloride can be subject to biodegradation under anaerobic conditions such as exists in saturated soil and groundwater. Vinyl chloride is resistant to biodegradation in aerobic systems.

D. Tritium is an isotope of hydrogen that contains two neutrons in addition to a proton in the nucleus. As a hydrogen atom, it combines with oxygen to form water molecules. As such, it travels as part of the groundwater. Tritium has a half-life of 12.3 years (BNL, 1998).

While tritium, TCE, and vinyl chloride are considered site contaminants, arsenic is thought to be naturally occurring. Arsenic water analysis was performed on 123 water samples, 15 surface water and 108 groundwater. All the surface water results were less than the laboratory detection limit. Groundwater results ranged from less than the laboratory detection limit to 62.7 µg/L. Of the 108 groundwater samples analyzed, 18 (17 percent) had detections above the laboratory required detection limit (10 µg/L).

Background groundwater samples were collected for the Salmon Site. The mean of the background groundwater concentration for arsenic was calculated to be 1.59 µg/L, with a standard deviation of 1.15. The background concentration is less than the contract-required detection limit, but greater than the instrument detection limit.

Arsenic concentrations were compared between the various aquifers identified at the Salmon Site. Arsenic was not detected above the laboratory detection limit in the Aquifer 1, Aquifer 2a, Aquifer 2b, Aquifer 3a, and Aquifer 3b. Arsenic was detected in the Local and Alluvial Aquifers.

Published ranges of naturally occurring arsenic in groundwater range from less than the laboratory detection level of several mg/L (Hem, 1985). Typically, arsenic occurs at less than 100 µg/L (Matthess, 1982). Elevated arsenic concentrations in groundwater are typically associated with oil and gas deposits.

Statistical analysis performed on the arsenic detected in groundwater at the Salmon Site determined that the average concentration is 19 µg/L with a standard deviation of 32. All but two arsenic analyses are within one standard deviation of the average arsenic concentration. All but one arsenic analysis are within two standard deviations of the average arsenic concentration.

A review of Salmon Site historical site records, and process knowledge of activities conducted at similar sites, does not reveal a source for the arsenic detected. No records indicate that DOE used arsenic, or chemicals containing arsenic, in significant quantities at the site. The distribution of arsenic detected in soil and water samples does not delineate a distinct source and/or plume at the site, which also indicates that this compound is naturally occurring. However, because arsenic cannot be eliminated as part of the evaluation of PCOC, it has been carried through the contaminant fate and transport modeling process even though it is not suspected of being a site contaminant.

5.4 Factors Affecting Contaminant Migration

A number of factors affect the fate and transport of contaminants in groundwater. At the Salmon Site, many more monitoring wells are installed in the shallow aquifers than in the lower aquifers. Because of the limited number of deeper aquifer monitoring wells, the aquifer parameters are not as well defined. This section provides a discussion of the groundwater flow and solute transport model input parameters that exert the most control on groundwater flow and solute transport.

5.4.1 Groundwater Velocity

The average linear groundwater velocity, v, is related to the hydraulic conductivity (K), hydraulic gradient (i), and porosity (n) by the expression, $v = Ki/n$ commonly referred to as Darcy's Equation. This parameter is a dominant influence on the rate of advection of mass and the degree of dispersion. Groundwater velocity is used as a direct input to the analytical models and strongly influence the results.

5.4.2 Infiltration

Infiltration to the water table, occurring as recharge from the surface, is an important boundary condition in numerical models. It is a quantification of the amount of water that percolates through the vadose zone to the water table and becomes part of the groundwater flow system. For the Salmon Site numerical model, a uniform distribution across the study area as a percentage of the annual precipitation was assumed. The Salmon Site receives approximately 1.5 m (60 in.) of rain each year (Gardner and Downs, 1971). Considering the shallow depth to water in the Alluvial Aquifer, 8 to 33 percent of annual precipitation was assumed to be recharge to this aquifer. The thick clay layers between the Alluvial and Local Aquifers, inhibits infiltration to the deeper aquifers.

5.4.3 Groundwater/Surface-Water Interaction

Half Moon Creek and Grantham Creek are the two primary sources of surface water that exist at the Salmon Site (Plate 1). The shallow depth (approximately 1.5 m [5 ft] or less) to groundwater in wells in the Alluvial Aquifer make it likely that there is a significant hydraulic connection between the Alluvial Aquifer and the creeks. This is important because Half Moon Creek is hydraulically downgradient of SGZ and may be a mechanism for dilution and transport of contaminants from the Alluvial Aquifer. Note that no contaminants have ever been detected in surface water and sediment samples taken from either creek (DOE/NV, 1995a).

5.4.4 Source Term

Zheng and Bennett (1995) describe the source term as “solute mass dissolved in water which enters the flow domain through fluid sources.” The flow rates and concentrations of sources can be either calculated within the model or specified. For example, tritium found in the Alluvial Aquifer probably reached the water table by transport from the SGZ Mud Pits, which were used for reentry drilling at the site. The distribution of tritium in the groundwater, indicates there is not a continuous source; therefore, this source term was estimated.

At the request of MDEQ, the lower aquifers were modeled to evaluate effects if contamination migrated up from the test cavity and diffused laterally into more shallow aquifers. In this case, the source term is simulated as a constant flux rate and an initial concentration was estimated.

5.4.5 Dispersivity

Dispersivity is used to calculate dispersion, D, as follows:

$$D = V\alpha + D_m \tag{5-1}$$

Where:

V = The average linear groundwater velocity

α = The dispersivity (either longitudinal or transverse to the direction of flow)

D_m = Molecular diffusion (usually assumed to be insignificant in aquifers with reasonable velocities)

Dispersivity controls the amount of contaminant movement exclusive of advection and results in the dilution and dispersion of a plume. Longitudinal dispersivity is often thought of in terms of the scale of the transport distance (Gelhar et al., 1992). For the Salmon Site, the transverse dispersivity was assumed to be a factor of 10 less than the longitudinal dispersivity.

5.4.6 Decay

Decay is the process by which contaminants are physically degraded from their original concentration. Radioactive decay is well-documented and half-lives are known for all radionuclides. Nonradioactive constituents also degrade via chemical and biological decomposition. Radioactive decay was simulated based on published half-life (e.g., Howard et al., 1991) or decay constants. Because of uncertainty with determining a chemical and biological decay constant, the transport modeling conservatively assumed no chemical or biological decay of contaminants.

5.5 Operable Unit 1: Alluvial Aquifer

Contamination was detected in the soils samples from the Source Area 1, SGZ Mud Pits, and groundwater samples from the Alluvial Aquifer. The contamination in the soil is addressed in the human health risk assessment (Section 6.0). The results of modeling flow and transport in the Alluvial Aquifer are discussed below.

5.5.1 Modeling Methods

The groundwater flow model in the Alluvial Aquifer was developed and implemented with the U.S. Geological Survey code, MODFLOW (McDonald and Harbaugh, 1988). The creation and editing of MODFLOW input files were facilitated with the software packages “ModelCAD” (Geraghty and Miller, 1993) and Visual MODFLOW (Guiger and Franz, 1997). The Alluvial Aquifer is known to be of limited areal extent and found only in the valley or lower elevation area around SGZ; therefore, no-flow boundaries were specified to describe the limits of the aquifer. The model was two-dimensional (horizontal) with a uniform vertical thickness of 9 m (30 ft). The active area of the aquifer is depicted by the gray area in Figure 5-1, which generally outlines the Valleys of Half Moon and Grantham Creeks. There were 5,444 active cells in the model. The largest and smallest of the cells had both x and y dimensions of 30 m (100 ft) and 15 m (50 ft), respectively. Porosity was uniform at 0.3; the aquifer was treated as unconfined, and the model was assumed to be steady-state. Seven different hydraulic conductivity zones were used in the model, ranging from 0.6 m (2 ft) per day to 30 m (100 ft) per day. Four different recharge zones were distributed across the top surface of the model, varying from 13 to 51 cm (5 to 20 in.) per year. Both Half Moon Creek and Grantham Creek were simulated using MODFLOW’s “River Package.” The thickness of the bed material in both creeks was assumed to be 0.3 m (1 ft) with a vertical hydraulic conductivity of 1.5 to 2.4 m (5 to 8 ft) per day.

The flow model was calibrated to the hydraulic heads in nine target wells. The absolute mean of the residuals (i.e., the difference between the model-predicted head and the actual head) in the final calibration run was 0.08 m (0.25 ft) (Appendix D). A plot of actual hydraulic head versus model head is presented in Appendix D, Figure D-1. Figure 5-2 shows the calibrated hydraulic heads in the Alluvial Aquifer and the approximate direction of groundwater flow.

Groundwater contaminant transport was simulated for tritium, arsenic, TCE, vinyl chloride, and the PCOCs determined using standard EPA risk assessment procedures (EPA, 1989a) is discussed in detail in Section 6.0. The transport model was implemented with versions of the MT3D code by Papadopulous and Associates (1992) which is based on a 1996 U.S. Army Corps

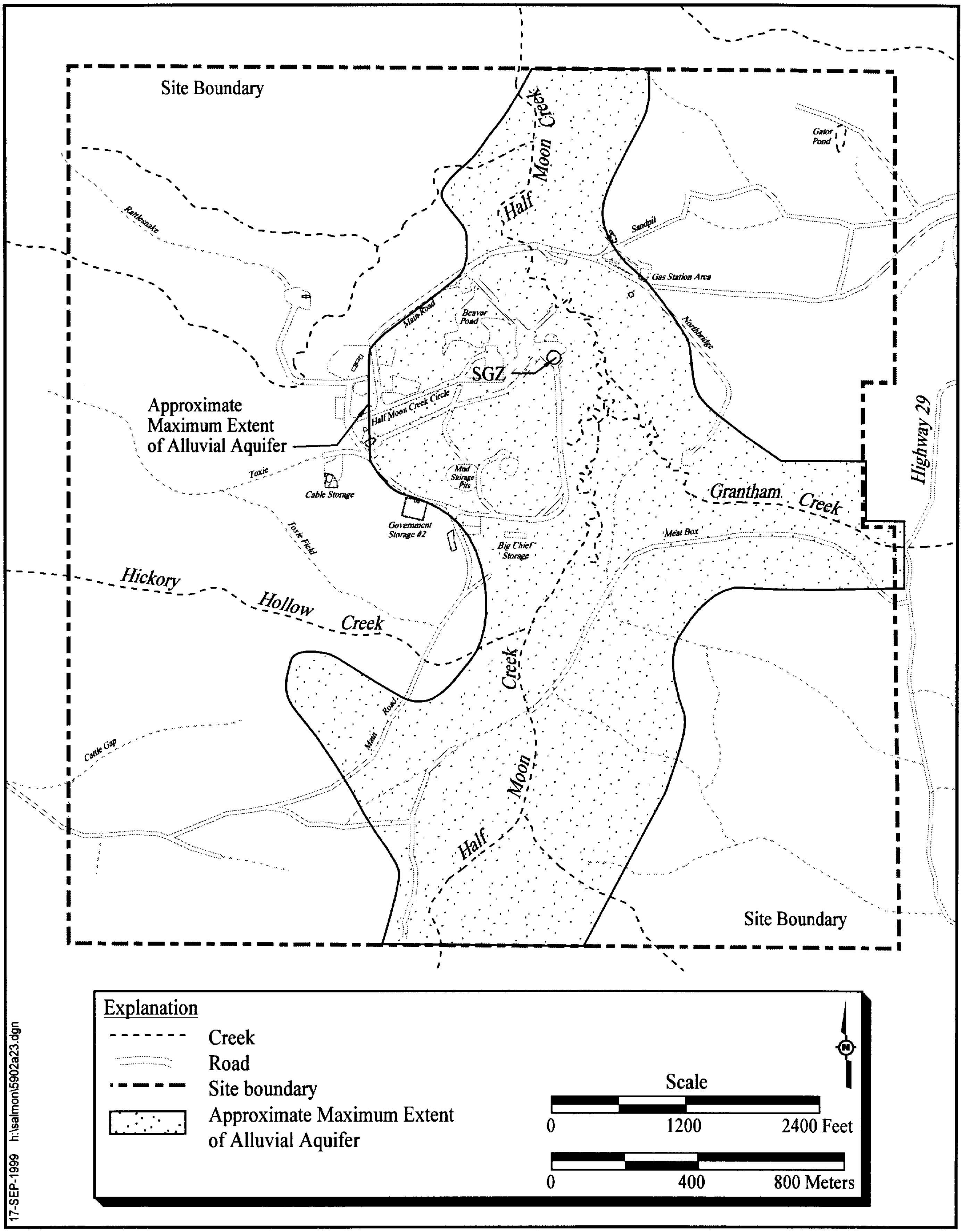

Figure 5-1
Plan View of Salmon Site Showing Approximate Lateral Boundary of Alluvial Aquifer

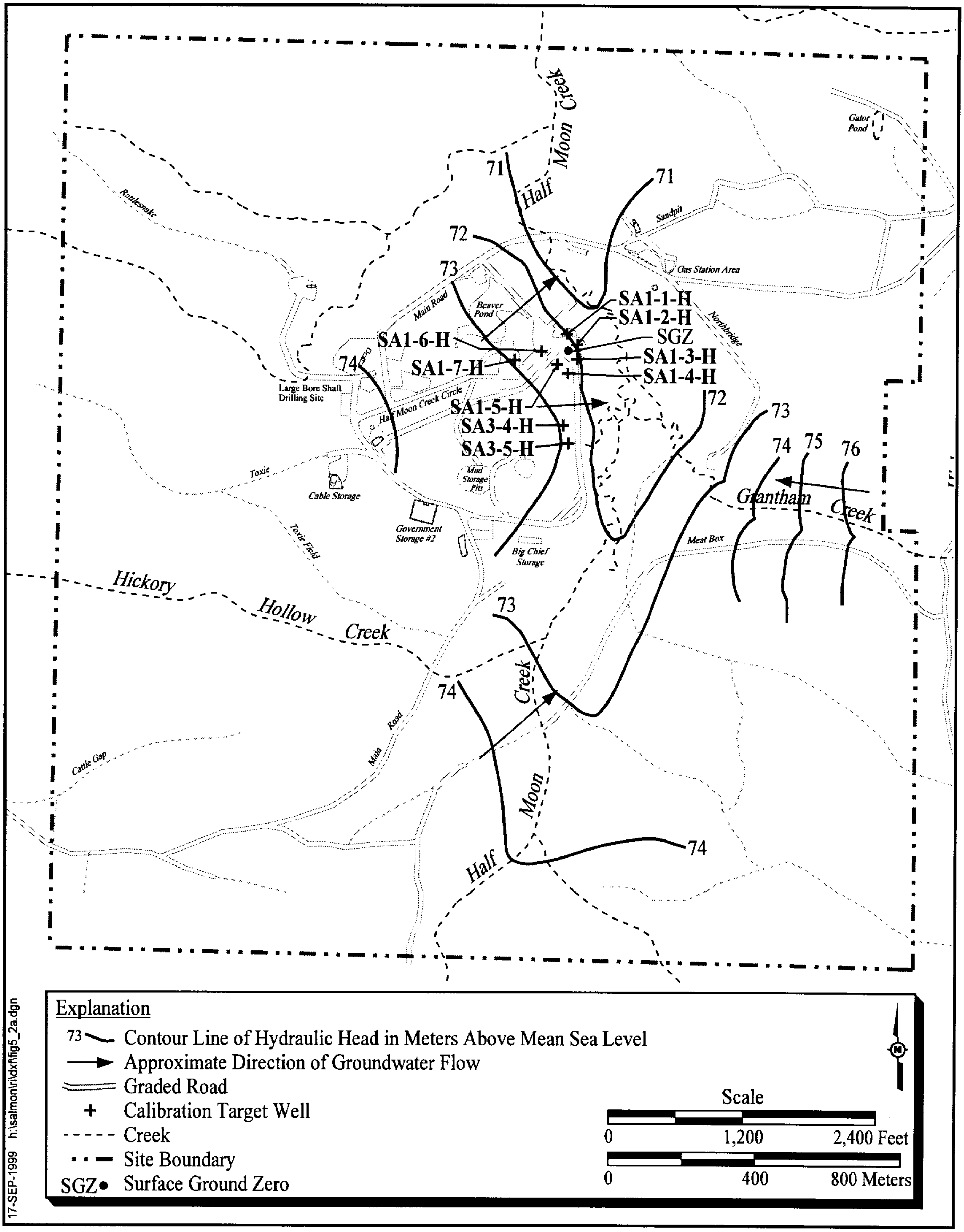

Figure 5-2
Calibrated Hydraulic Heads in the Alluvial Aquifer Model

of Engineers developed code. Longitudinal dispersivity was set at 15 m (50 ft) a transverse dispersivity at 1.5 m (5 ft). This is consistent with the recommended dispersivity for a problem of this scale that Gelhar et al. (1992) reported. Retardation was assumed to be zero (i.e., the retardation factor was one), the decay constant was 0.056 year^{-1} for tritium, and zero for all other PCOCs. Contour maps showing the initial concentration distributions of tritium, arsenic, and TCE in the Alluvial Aquifer can be seen in Figures 5-3, 5-4, and 5-5, respectively. The maximum initial concentration used for tritium was 88,200 pCi/L, which was the maximum reported value in groundwater at the Salmon Site between 1993 and 1998. The maximum initial concentration used for arsenic was 7.7 µg/L, which was the maximum reported value in groundwater. Vinyl chloride and TCE were detected in levels near or above the respective MCLs in Monitoring Wells SA1-1-4 and SA1-2-4, respectively. The maximum initial concentrations for TCE and vinyl chloride were 26 µg/L and 3 µg/L, respectively. Except for tritium, all PCOCs were conservatively assumed to be nonsorbing and nondecaying. Tritium was modeled to allow for decay in accordance with its 12.3-year half-life.

A detailed description (generated by Visual MODFLOW) on the entire Alluvial Aquifer model can be found in Appendix D.

5.5.2 Model Results

Figures 5-6 through 5-11 show the transport model results for tritium, arsenic, TCE, and vinyl chloride as distribution maps. Figures 5-6 and 5-7 show contour plots of tritium concentration after two years and six years. The maximum concentration of tritium was predicted to decline to a level below the MCL of 20,000 pCi/L after a period of between one and two years. After two years, the maximum level was below 10,000 pCi/L, and after six years, the maximum level was below 2,000 pCi/L (Table 5-1). Figures 5-8 and 5-9, show contour plots of arsenic concentrations. Figures 5-10 and 5-11 show contour plots of TCE contamination after one year and after five years, respectively. Maximum concentration of each of the PCOCs was predicted to decline by over 99 percent at the end of 100 years to levels significantly less than the MCL (Table 5-1). Note that in the case of tritium, approximately 60 percent of the solute mass was lost via discharge to Half Moon Creek. For arsenic, about 70 percent of the initial solute migrated into the river nodes representing Half Moon Creek. This is a higher percentage than tritium because tritium was simulated to radioactively decay as it migrated. In the case of TCE and vinyl chloride, approximately 37 and 43 percent, respectively, of the total contaminant mass discharged to Half Moon Creek.

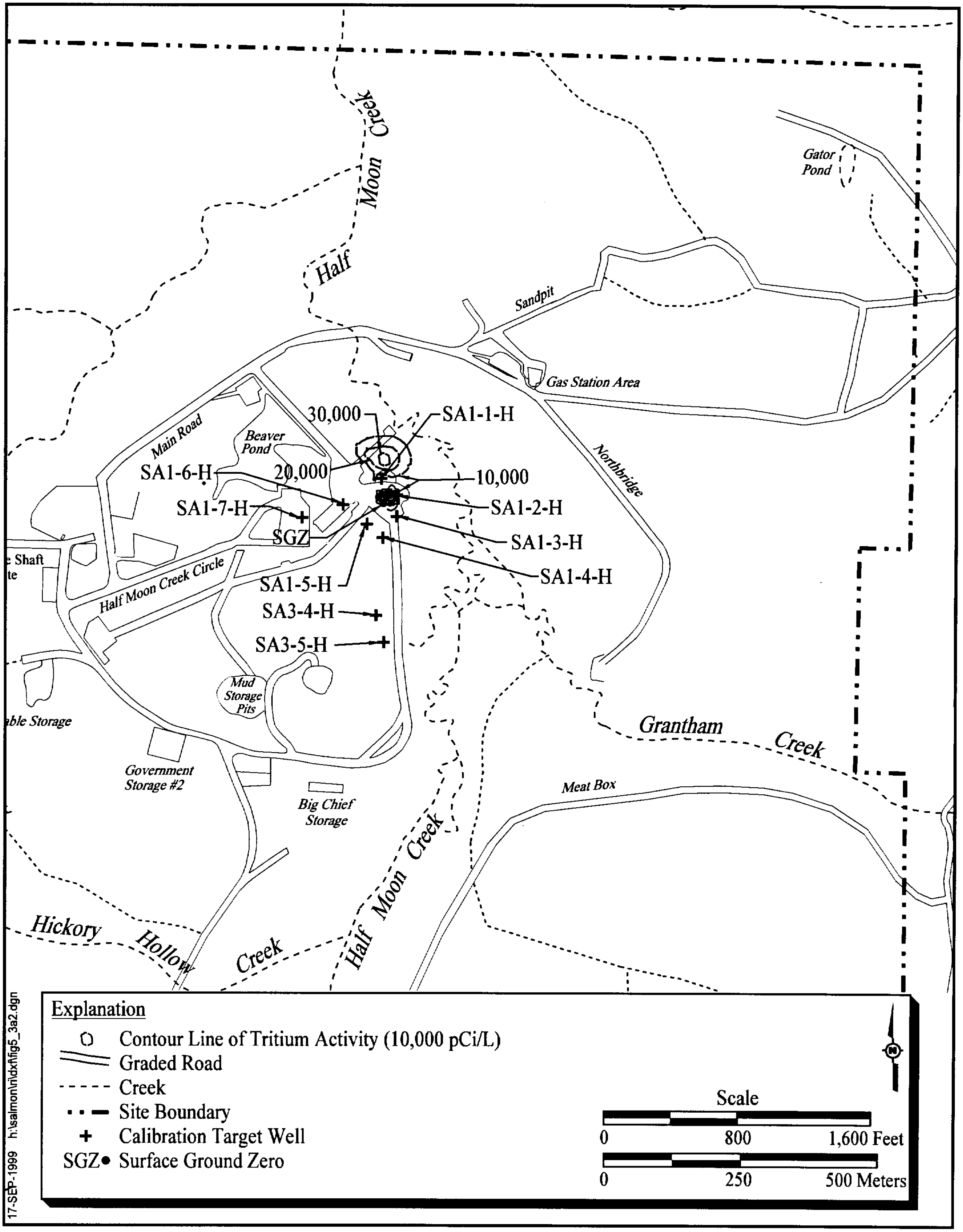

Figure 5-3
Initial Tritium Distribution in the Alluvial Aquifer

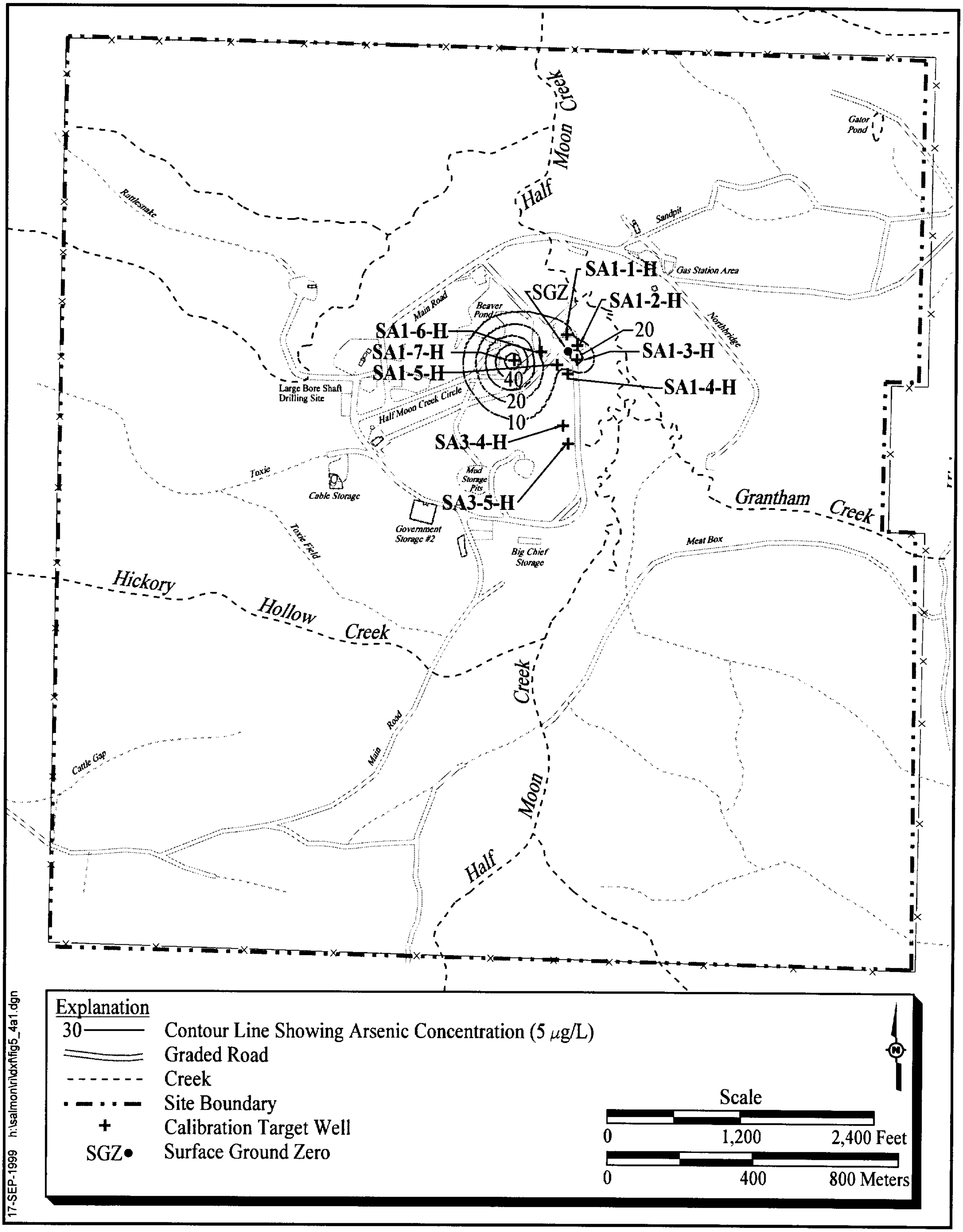

Figure 5-4
Initial Arsenic Distribution in the Alluvial Aquifer

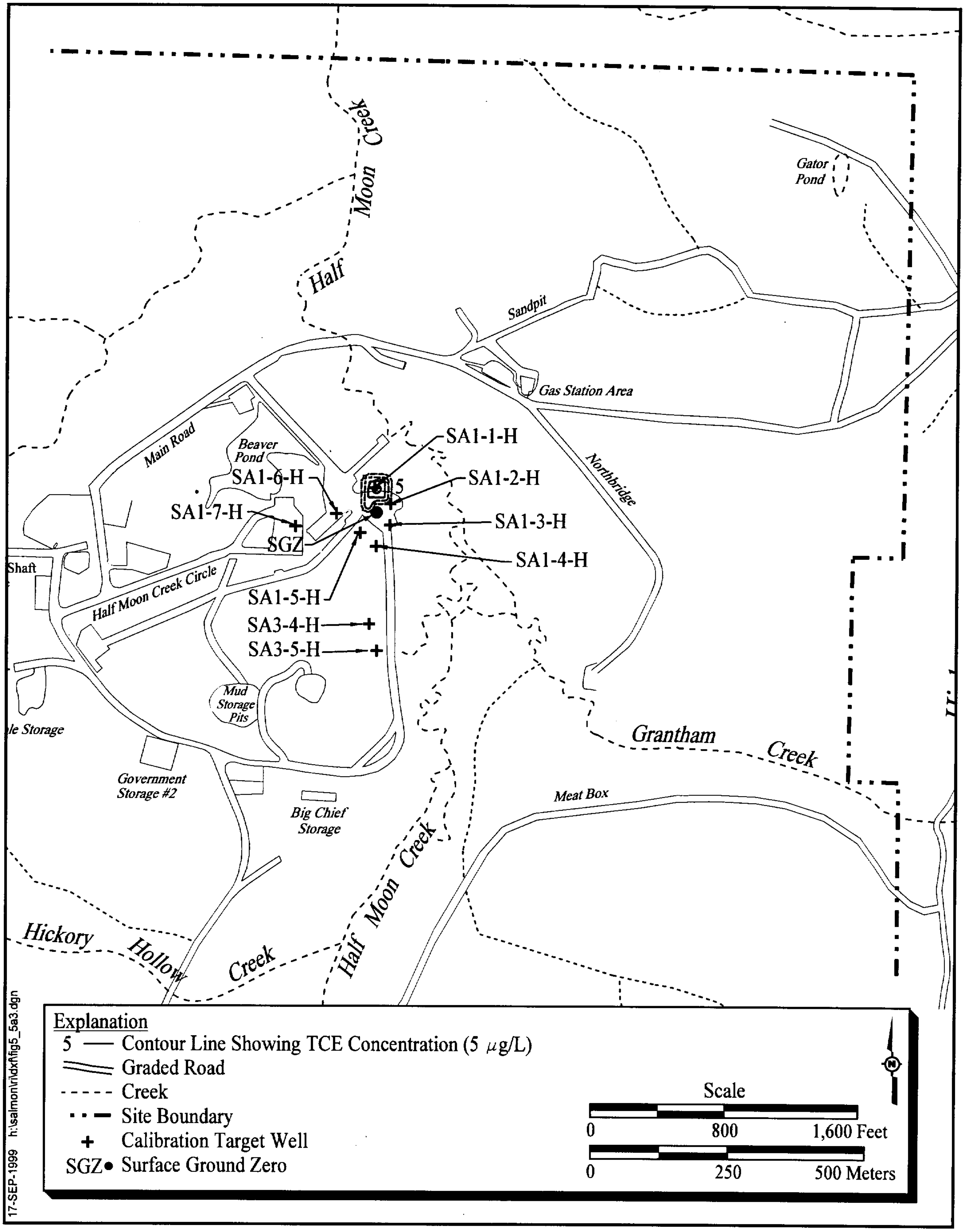

Figure 5-5
Initial TCE Distribution in the Alluvial Aquifer

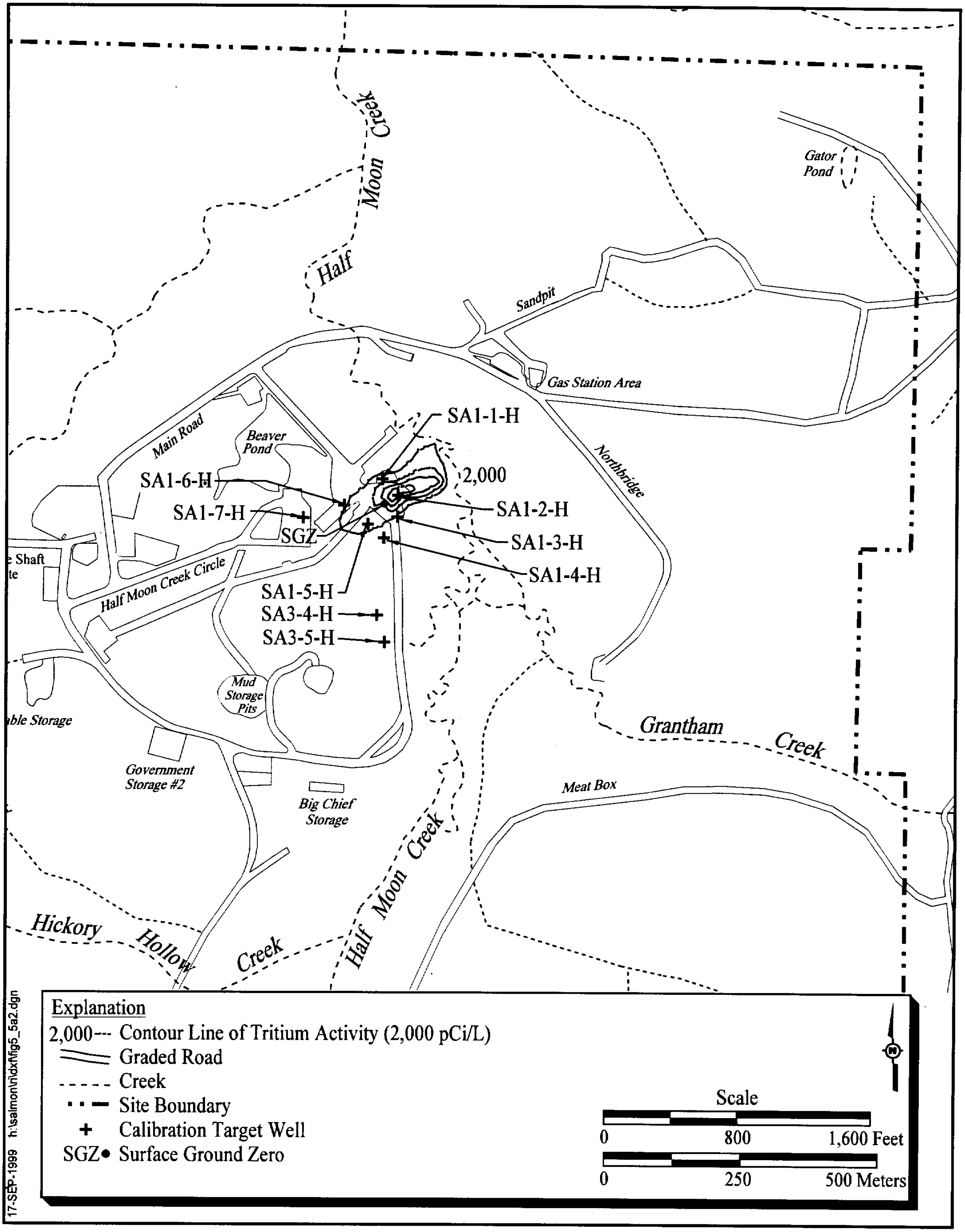

Figure 5-6
Tritium Distribution in the Alluvial Aquifer After 2 Years

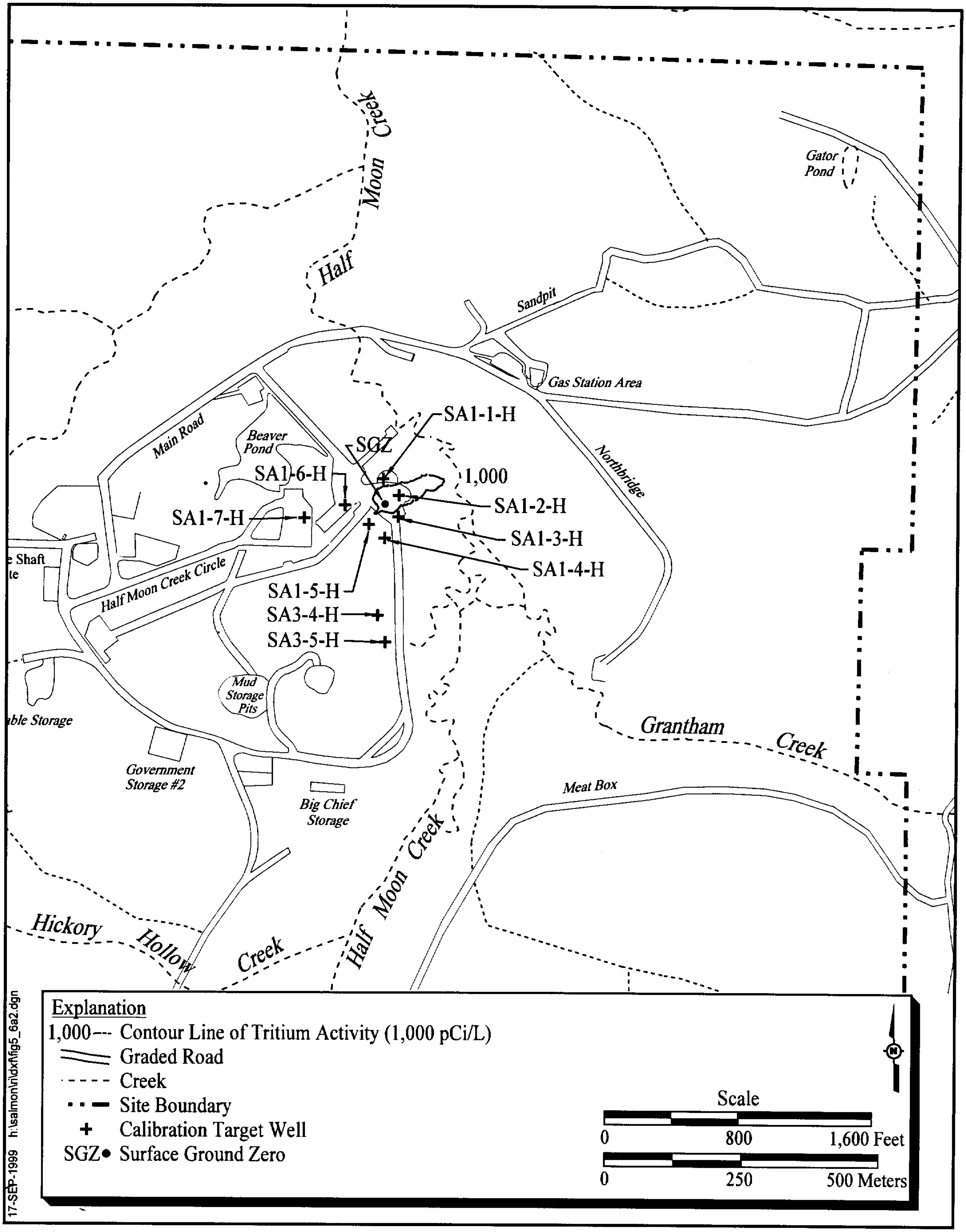

Figure 5-7
Tritium Distribution in the Alluvial Aquifer After 6 Years

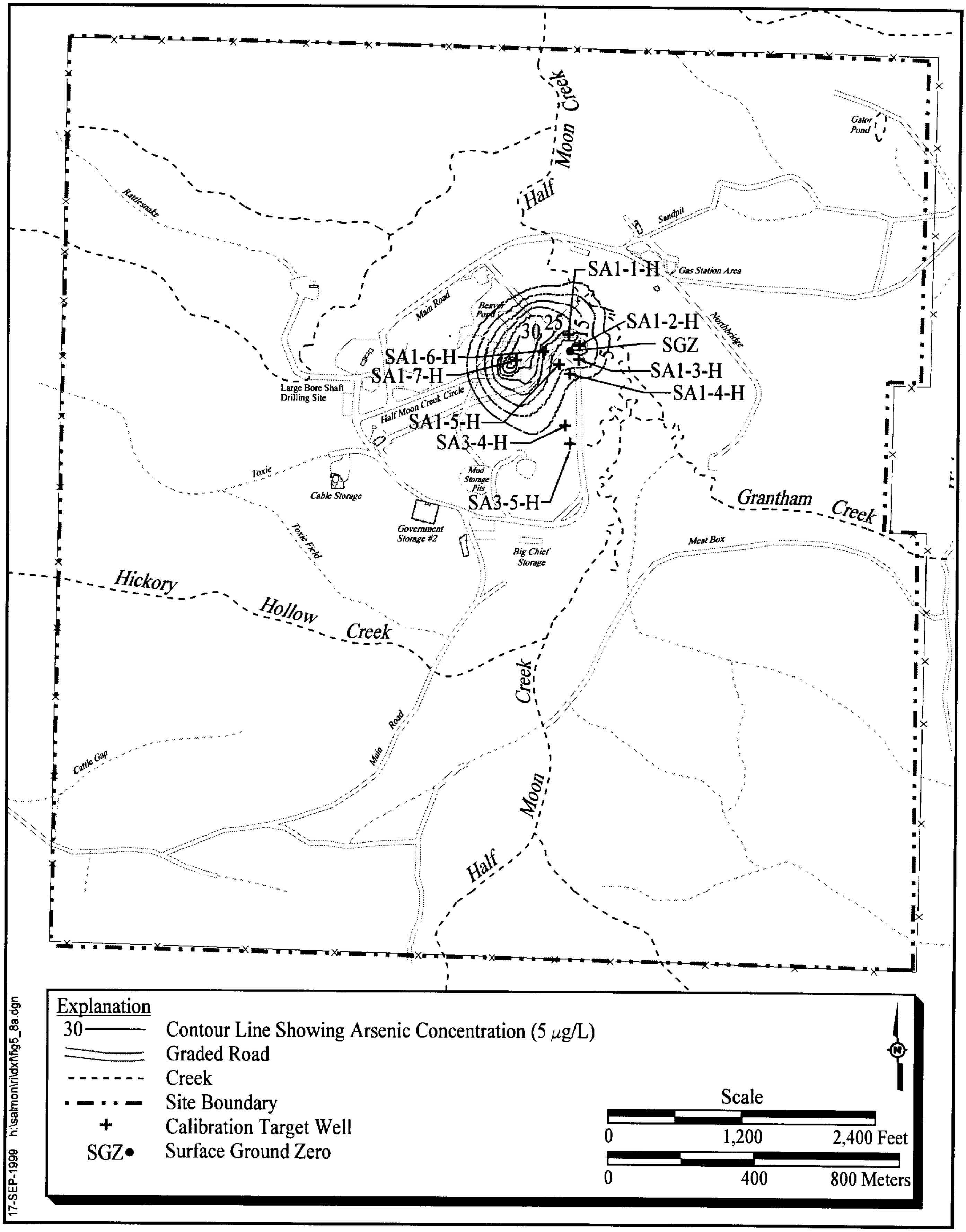

Figure 5-8
Arsenic Distribution in the Alluvial Aquifer After 1 Year

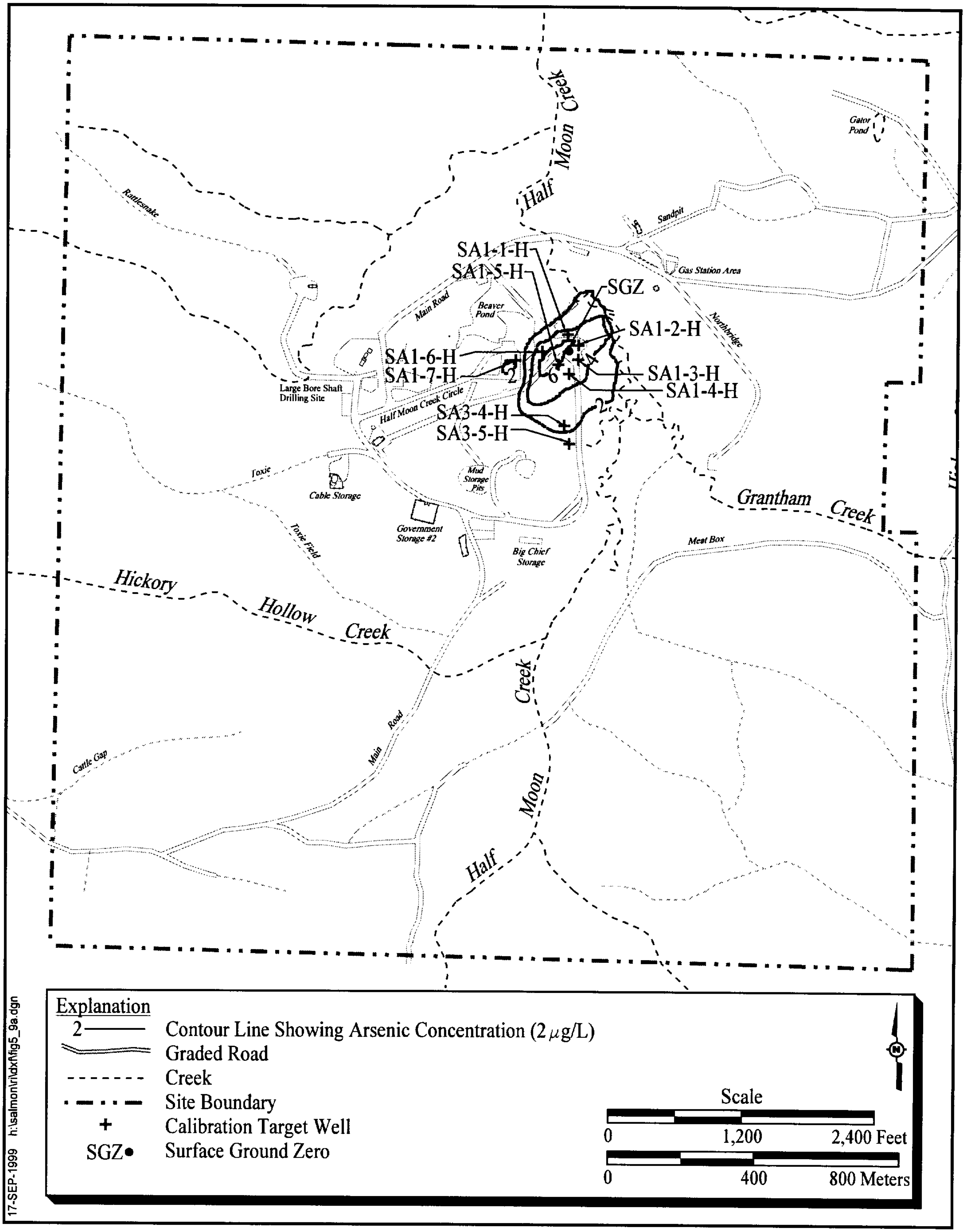

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Figure 5-9
Arsenic Distribution in the Alluvial Aquifer After 8 Years

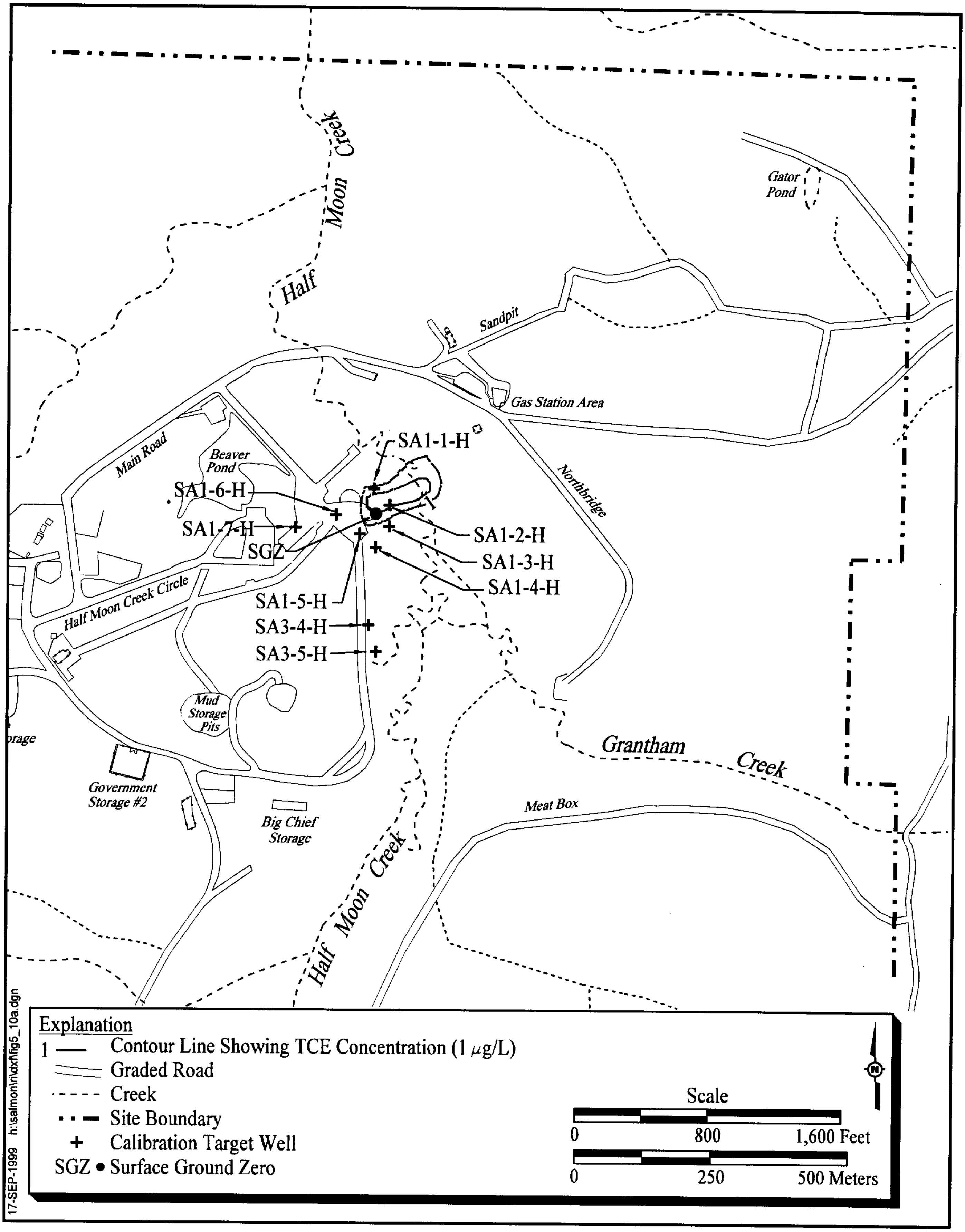

Figure 5-10
TCE Distribution in the Alluvial Aquifer After 2 Years

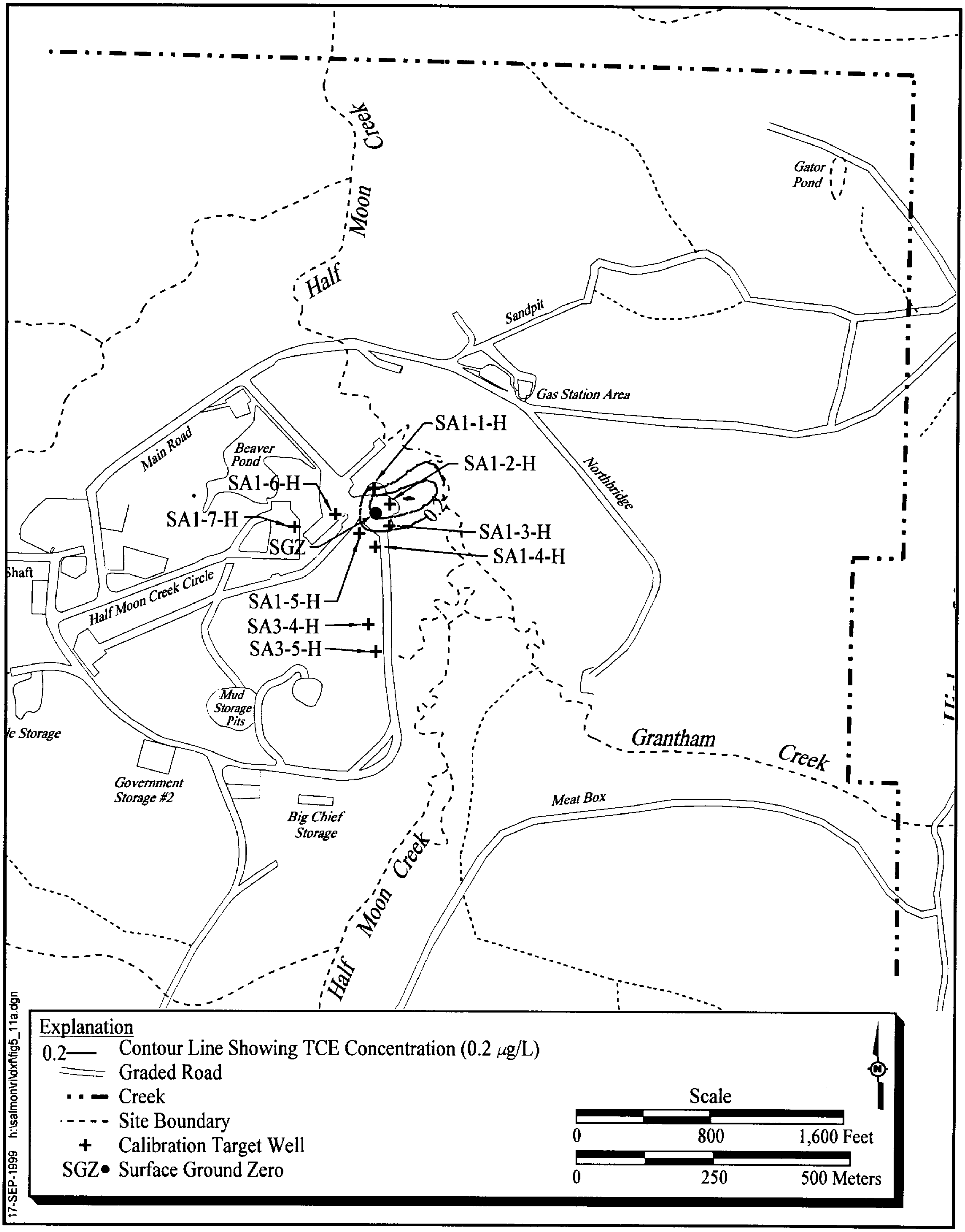

Figure 5-11
TCE Distribution in the Alluvial Aquifer After 5 Years

Table 5-1
Initial Predicted Concentration for Modeled Contaminant in the Alluvial Aquifer

Potential Contaminants of Concern		Maximum Concentration Within the Contaminant Plume						
		Initial	Years					
			1	2	5	6	8	100
Tritium	pCi/L	88,200		<10,000		<2,000		$<1 \times 10^{-12}$
Arsenic	µg/L	62.7	<40				<8	$<1 \times 10^{-12}$
TCE	µg/L	26.0		<3	<0.6			4.8×10^{-12}

Tetrachloroethene and vinyl chloride are assumed to be point sources because they were detected in only one well each. It is important to note that these were conservative simulations because no retardation or contaminant degradation was assumed. In reality, these processes are occurring (at various rates) and the actual PCOC concentrations off site would be lower than those predicted. These contaminants have not been detected in surface water or sediment samples collected.

5.6 Operable Unit 2: Aquifers Local, 1, 2a, 2b, 3, and the Test Cavity

In the area directly over Tatum Dome, the Alluvial Aquifer is underlain by six additional water-bearing units (Figure 2-3). Operable Unit 2 consists of the Local Aquifer, Aquifer 1, Aquifers 2a and 2b, Aquifers 3a and 3b, and the Caprock Aquifer. Because of geologic discontinuities and limited monitoring well control data from Aquifer 3b and the Caprock Aquifer they were grouped with 3a and simply called "Aquifer 3" for this modeling effort. Operable Unit 2 also includes the test cavity. When testing was completed at the Salmon Site in 1966, the test holes were plugged with cement and grout (AEC, 1972b). It is possible that as the test cavity creeps closed, small amounts of radioactive fluid could seep upward and diffuse laterally into one of the upper freshwater aquifers. While this transport scenario is possible, it is unlikely to occur because of the following:

- The last 9 m (30 ft) of the test hole (above the roof of the test cavity) were uncased. Therefore, as this part of the borehole crept closed, it would effectively pinch off the only avenue for upward migration. Moreover, work by Gardner and Downs (1971) suggests that even a chimney collapse (i.e., the roof of the cavity catastrophically caves in) would conservatively extend upward less than 91 m (300 ft) and still be nearly 305 m (1,000 ft) below the top of the salt dome.

- The grout and cement used to plug the holes would have to completely fail to create a vertical pathway.

- The caprock is fractured calcite and anhydrite and assumed to have a high porosity and hydraulic conductivity (DOE/NV, 1980). In the unlikely event that all of the man-made safeguards failed and contaminants did migrate through 366 m (1,200 ft) of halite to the top of the dome, it is probable that they would then migrate horizontally into the caprock rather than continue upward.

While the chance that contaminant migration from the test cavity is remote, the MDEQ requested that this scenario be analyzed. This scenario was evaluated with a diffusion rate calculated for tritium released into Aquifers 1 through 3 and its fate modeled analytically over 100 years. Section 5.6.1.2 addresses the methods and results.

5.6.1 Modeling Methods

The modeling methods used for the aquifers composing Operable Unit 2 are discussed in the following text.

5.6.1.1 The Local Aquifer

Some contamination has been detected in the Local Aquifer (Section 4.2.1) at concentrations significantly lower than those found in the Alluvial Aquifer. Since contaminants have not been detected in Aquifer 1, the contamination in the Local Aquifer was assumed to have leached down from above. Like the Alluvial Aquifer, a simple model of the Local Aquifer was designed and executed with MODFLOW and ModelCAD or Visual MODFLOW. Unlike the Alluvial Aquifer, the Local Aquifer model covers the entire site. There were 100 cells in the x-direction and 100 cells in the y-direction (i.e., 10,000 cells total). Each cell was 30 by 30 m (100 by 100 ft). The two-dimensional model had a uniform vertical thickness of 7.6 m (25 ft), the aquifer was assumed to be confined, and the model simulated steady state flow. There were six different hydraulic conductivity zones in the model ranging from 3.5×10^{-5} to 3.5×10^{-2} centimeters per second (cm/sec) (0.1 to 100 ft/day) (Stover et al., 1981). Porosity was set at 0.3 (Gardner and Downs, 1971) across the entire aquifer and recharge was zero. Boundary conditions consisted of constant heads around the perimeter of the model. These were determined by contouring water levels in wells in the Local Aquifer (measured in December 1996) and projecting the interpolated values to the boundary cells.

The flow model was calibrated to the hydraulic heads in nine target wells. The wells used in this flow model are presented in Appendix D. The absolute mean of the residuals (i.e., the difference between the model-predicted head and the actual head) was 0.28 ft (Appendix D). A plot of actual hydraulic heads versus model heads is presented in Appendix D (Figure D-2). Figure 5-12 shows the calibrated model hydraulic heads in the Local Aquifer and the approximate direction of groundwater flow.

Contaminant transport in the Local Aquifer was simulated for tritium and arsenic. Note that the maximum reported concentrations of tritium (960 pCi/L) and arsenic (44.2 mg/L) in groundwater were below their respective MCLs of 20,000 pCi/L and 50 µg/L. Vinyl chloride and TCE were not detected in groundwater samples from the Local Aquifer above the contract-required quantitation limit. The maximum reported concentrations of tritium and arsenic were found in Monitoring Wells HM-L and SA2-2-L, respectively. As was the case with the Alluvial Aquifer, the dissolved concentrations of tritium and arsenic were imported into ModelCAD or Visual MODFLOW for use by MT3D as initial conditions. Figures 5-13 and 5-14 display the initial concentration contours for tritium and arsenic in the Local Aquifer, respectively.

Longitudinal and transverse dispersivities were specified with values of 15 and 1.5 m (50 and 5 ft), respectively. As previously stated (see Section 5.5.1), these values are consistent with dispersivities reported for transport distances of this scale (Gelhar et al., 1992). No retardation of tritium was assumed to have occurred, but the standard tritium half-life of 12.3 years was used. No retardation or decay of arsenic was assumed to have occurred.

Appendix D contains the inputs and outputs for the Local Aquifer model.

5.6.1.2 Aquifers 1, 2a, 2b, and 3

Aquifers 1 through 3 comprise the remaining water-bearing units in Operable Unit 2. With only three monitoring wells in each of the aquifers, there were limited hydraulic data to justify the use of anything more than a simple analytical model to simulate the hypothetical migration of tritium as it diffused laterally into an aquifer. The hypothetical two-dimensional analytical solution by Wilson and Miller (1978) used for this effort describes the concentration distribution resulting from injection of mass into an aquifer by any number of wells. Calculated solute concentrations are subject to the attenuation mechanisms of dispersion, first-order decay, and linear, equilibrium absorption. Individual wells may be operated at different injection rates for any period of simulated time independent of one another. For the purpose of simulations at the Salmon Site, one injection well with a constant mass injection rate was considered appropriate for each of the transport models of the aquifers. Tritium was the only PCOC considered. Other

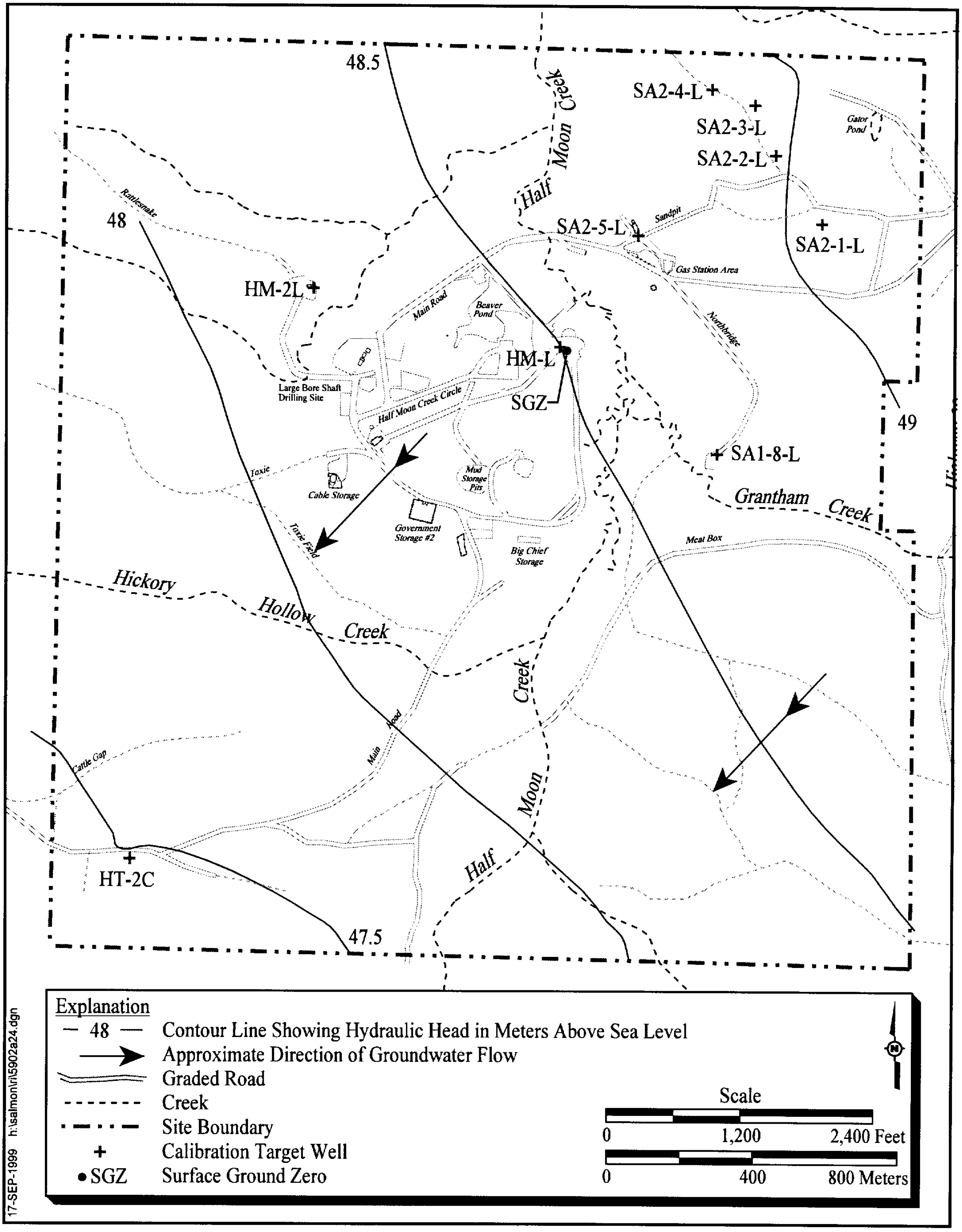

Figure 5-12
Calibrated Hydraulic Heads in the Local Aquifer Model

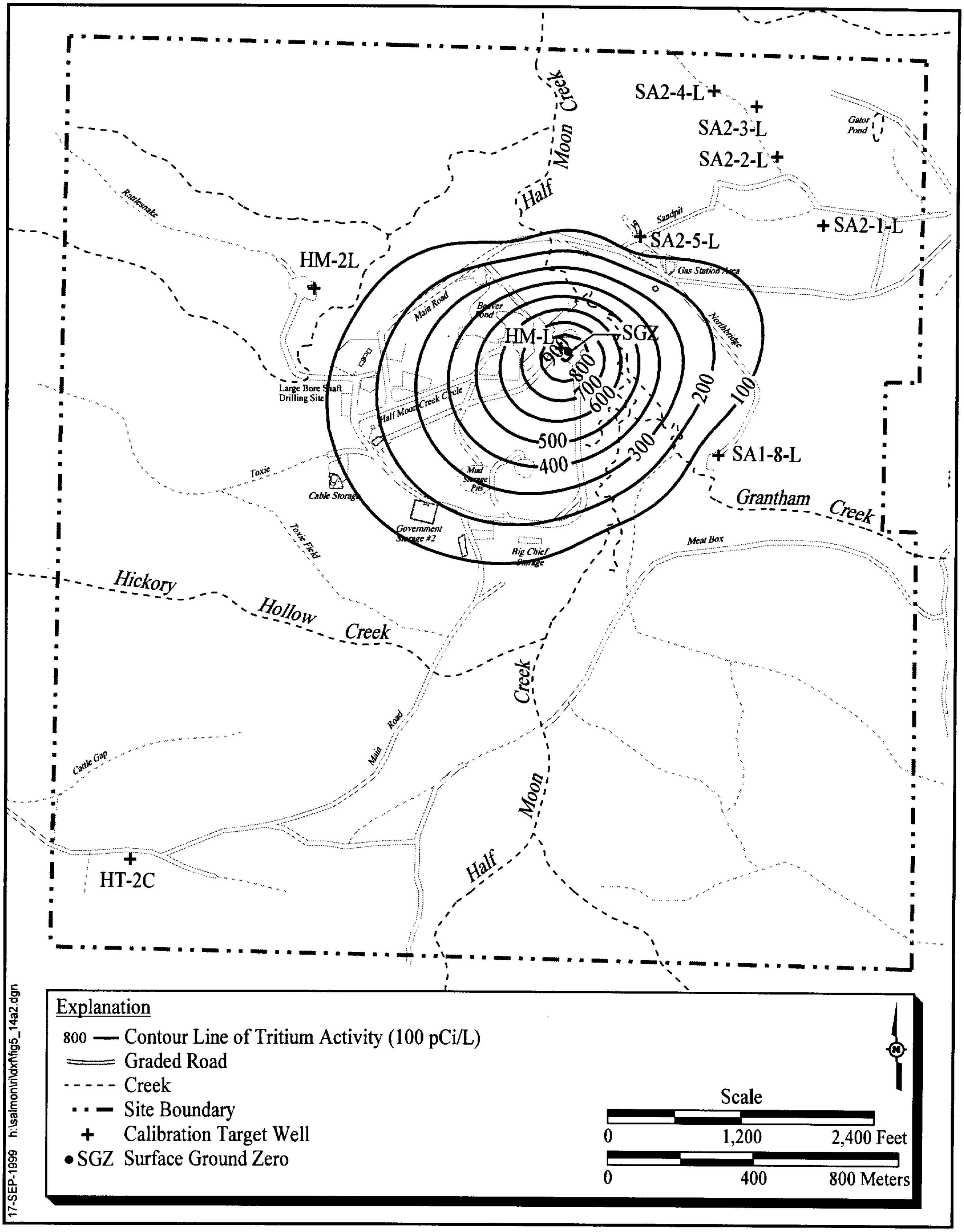

Figure 5-13
Initial Tritium Distribution in the Local Aquifer

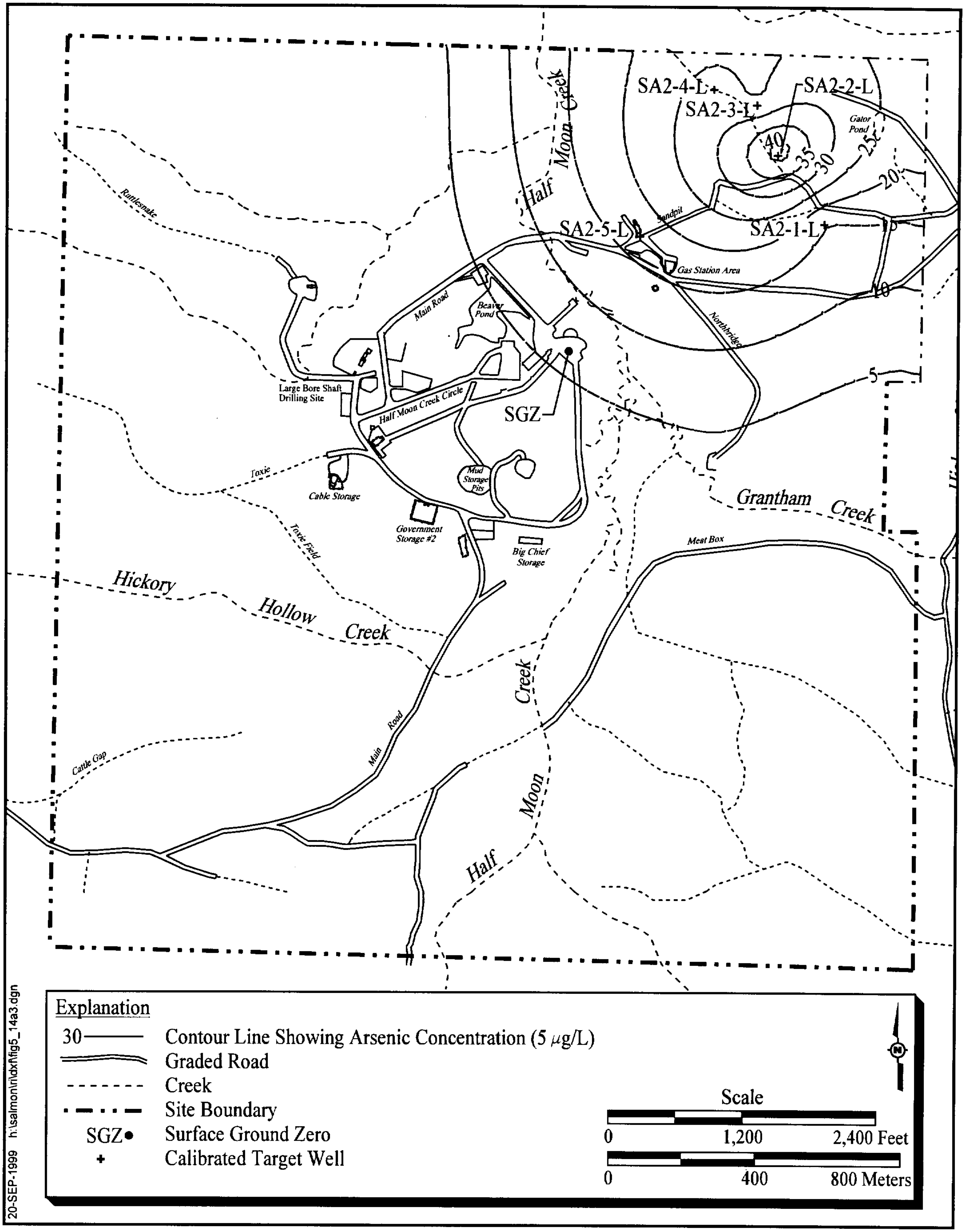

Figure 5-14
Initial Arsenic Distribution in the Local Aquifer

radionuclides are also present in the test cavity but were not modeled. Tritium is the most mobile of radionuclides present in a test cavity and would represent a worst case most conservative scenario.

Major assumptions and limitations of the Wilson and Miller (1978) solution include the following:

- The porous medium is homogeneous and isotropic.
- Groundwater flow is at steady-state and horizontal.
- Although solute concentration may vary areally, it is uniform (or well mixed) throughout the aquifer's thickness.
- The volume of injected fluid is small enough to have an insignificant effect on the volume of water in the aquifer or on the uniform groundwater velocity.
- Adsorption is linear. For tritium, there is no retardation.
- Decay of mass is first-order. For tritium, the half-life is 12.3 years (BNL, 1998).

Key input to the models includes the thickness of the aquifer, the hydraulic conductivity, the effective porosity, and the source strength (source term). For all except the source strength, averages from Koopman et al. (1963) and Gardner and Downs (1971) were used in the models. The source strength is given by the expression (Cleary and Ungs, 1994):

$$G = (QC_o) / b \tag{5-2}$$

Where:

Q = The volumetric injection rate
C_o = The injected tritium concentration
b = The vertical length of the injection source

The length of the injection source in each model was defined to be equal to one percent of the aquifer thickness. Although an actual well screen does not exist, this was considered a reasonable conservative representation of the vertical opening associated with any possible breach of integrity in the plugged well casing or grout seals.

Fick’s First Law was employed to estimate the magnitude of the tritium source strengths in the models. Transfer of tritium from the “injection” well to the surrounding aquifers was assumed to be only by molecular diffusion. This approach is consistent with the conceptual model that has tritium seeping slowly around the failed cement and grout in a plugged test hole and diffusing laterally into an aquifer. Fick’s First Law states that the chemical mass flux rate, F, is the product of a diffusion coefficient, D_d, and a concentration gradient, ∇C, and is expressed for a simple aqueous nonporous system as (Fetter, 1993):

$$F = -D_d \nabla C \tag{5-3}$$

where the mass flux rate has units of mass per unit time per unit area. The resultant mass flux rate was then multiplied by the assumed casing circumferences used in each of the transport models to derive the requisite source strengths in units of mass per time per unit vertical length of casing.

Values of the aqueous diffusion coefficient range in magnitude from approximately 2.8×10^{-5} to 8.4×10^{-5} m^2/day (3×10^{-4} to 9×10^{-4} square ft per day) (Fetter, 1993). To be conservative, the largest value in the range of diffusion coefficients was used for calculation of the mass flux rate.

The concentration gradient was defined as the difference between the maximum reported tritium concentration at the site and the tritium concentration in the aquifers (assumed to be equal to zero), across an assumed 0.3-m (1-ft) width of the annular space.

The exact quantity and chemical composition of radionuclides remaining in the test cavity after a test are not available. However, estimates of cavity fluid concentrations for tests done at the Nevada Test Site, and assuming a cavity porosity at Tatum Dome of 40 percent, suggest a mean tritium activity of $8 \times 10^{+8}$ pCi/L is appropriate. The strength of the tritium source was maintained at a constant value in all of the transport simulations. This served to add an additional level of conservatism to the models because the total mass of tritium contained in the source actually would be progressively reduced by radioactive decay.

Table 5-2 summarizes the input data.

Table 5-2
Analytical Model Input Parameters for Aquifers 1, 2a, 2b, and 3

Model	**Aquifer Thickness** m (ft)	**Porosity** Percent (%)	**Hydraulic Conductivity** cm/sec (ft/d)	**Hydraulic Gradient** dimensionless	**Groundwater Velocity** cm/sec (ft/d)	**Longitudinal Dispersivity** m (ft)	**Transverse Dispersivity** m (ft)	**Volumetric Injection Rate** m^3/day (ft^3/d)	**Injection Well Screen Length** m (ft)	**Source Strength** (pCi/d/ft)
Aquifer 1	46 (150)	0.30	5.3×10^{-3} (15)	0.006	7.1×10^{-6} (0.02)	61 (200)	6 (20)	3.9×10^{-13} (1.37×10^{-11})	0.5 (1.5)	2.23×10^{-3} (0.0073)
Aquifer 2a	38 (125)	0.30	4.7×10^{-2} (134)	0.022	3.5×10^{-3} (9.83)	61 (200)	6 (20)	3.2×10^{-13} (1.12×10^{-4})	0.4 (1.25)	2.19×10^{-3} (0.0072)
Aquifer 2b	30 (100)	0.30	3.3×10^{-2} (94)	0.036	4.0×10^{-3} (11.28)	61 (200)	6 (20)	2.5×10^{-13} (8.75×10^{-12})	0.3 (1)	2.13×10^{-3} (0.0070)
Aquifer 3 (3a + 3b)	43 (140)	0.30	3.5×10^{-3} (10)	0.062	7.3×10^{-4} (2.07)	61 (200)	6 (20)	3.5×10^{-13} (1.24×10^{-11})	0.4 (1.4)	2.16×10^{-3} (0.0071)

ft^3/d = Cubic feet per day
pCi/d/ft = Picocuries per day per foot
ft/d = Feet per day
cm/sec = Centimeters per second
% = Percent

5.6.2 Model Results

The modeling results for each aquifer in Operable Unit 2 are discussed in this section.

5.6.2.1 Local Aquifer

Table 5-3, Figure 5-15, and Figure 5-16, present the results of 100 years of tritium and arsenic transport in the Local Aquifer. The maximum tritium activity concentration within the plume was calculated to be 2.8 pCi/L, a decrease in activity of over 99 percent from the initial concentration of 960 pCi/L. In the case of arsenic, the maximum concentration declined by approximately 33 percent from 44.2 µg/L to 29.4 µg/L. The difference in mass reduction between arsenic and tritium is attributed to radioactive decay during the simulation. It is also important to note that, despite the conservative assumption of no solute retardation, neither of the plumes ever moved off site.

Table 5-3
Initial Concentration, Final Concentration, and Percent Change for Each Contaminant Modeled in the Local Aquifer After 100 Years

Contaminant of Potential Concern	Maximum Initial Concentration	Maximum Final Concentration	Concentration Reduction (%)
Tritium	960 pCi/L	2.8 pCi/L	99.7
Arsenic	44.2 µg/L	29.4 µg/L	33

5.6.2.2 Aquifers 1, 2a, 2b, and 3

The following sections discuss the simulated tritium migration through each aquifer. Results are reported graphically for each aquifer in the form of a contour plot of concentration and a breakthrough curve at the site boundary.

5.6.2.2.1 Aquifer 1

The extent of tritium migration within Aquifer 1 was limited. After 100 years of transport, the leading edge of the hypotheical plume extended approximately 110 m (360 ft) downgradient from SGZ and did not reach the site boundary (see Figure 5-17). This limited amount of migration is a result of the relatively low groundwater velocity and resultant advection rate in Aquifer 1. The maximum concentration of tritium in the plume was calculated to be 1.6 × 10^{+6} pCi/L after 100 years, which is two orders of magnitude less than the initial injected concentration of 8.0 × 10^{+8} pCi/L.

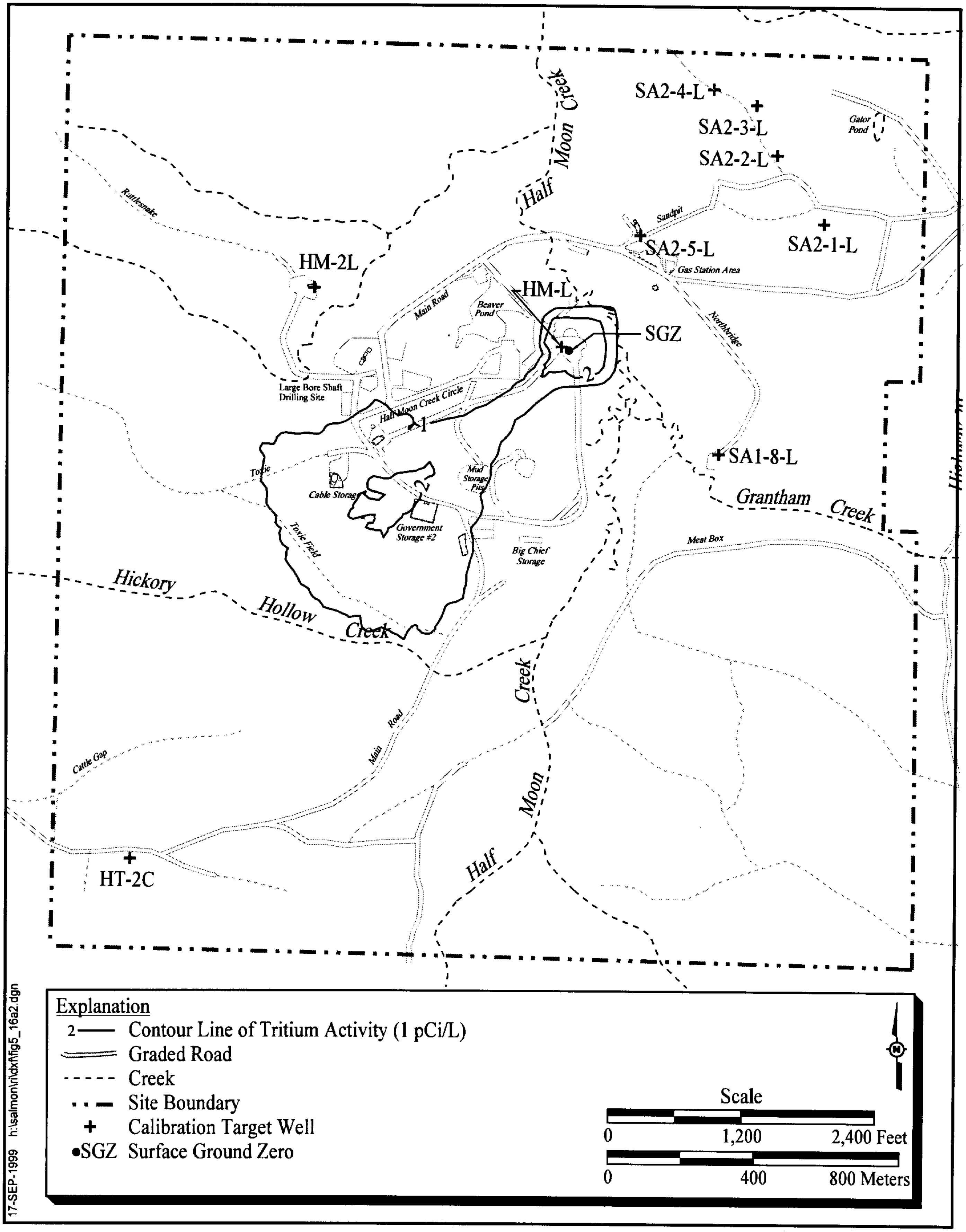

Figure 5-15
Tritium Distribution in the Local Aquifer After 100 Years

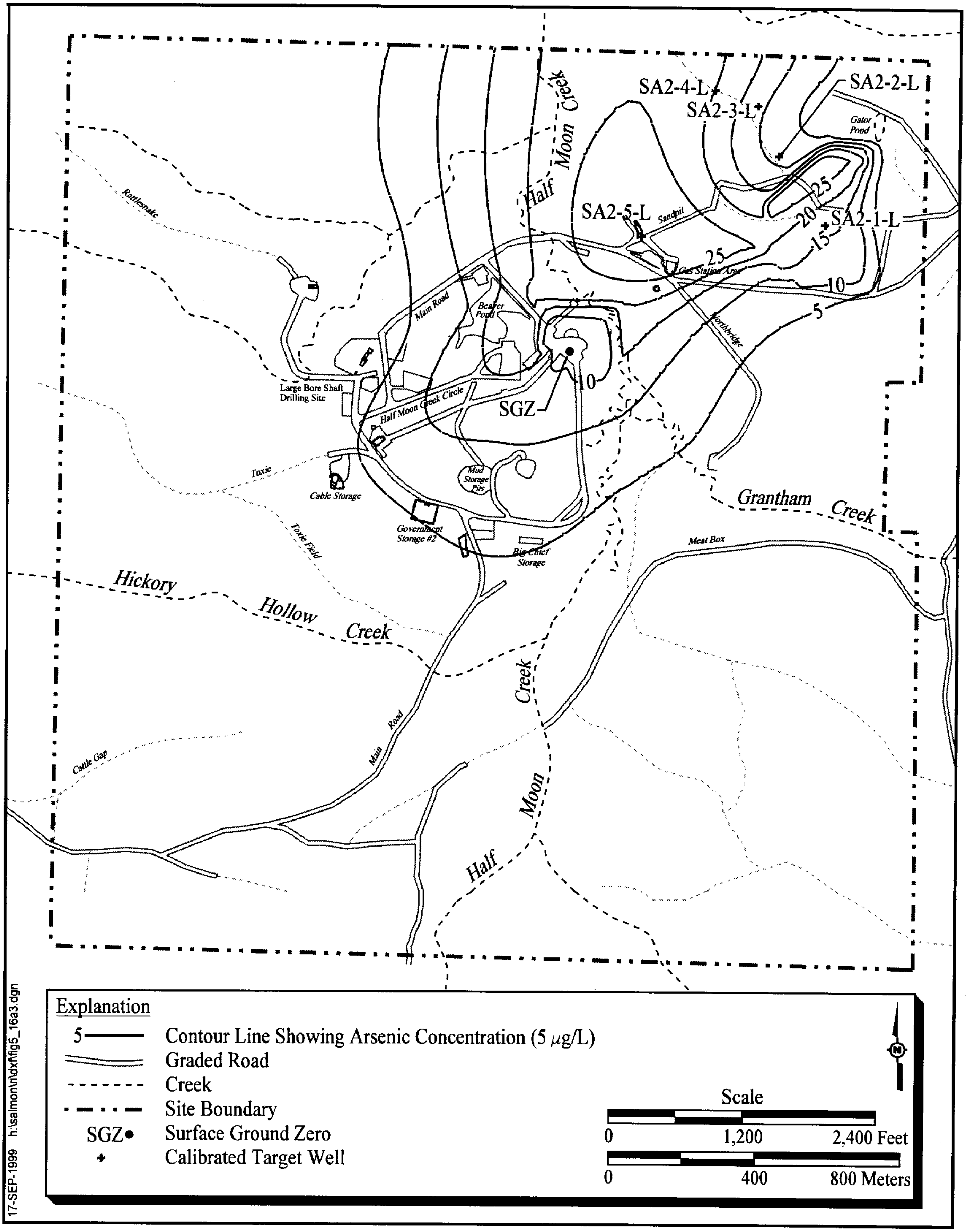

Figure 5-16
Arsenic Distribution in the Local Aquifer After 100 Years

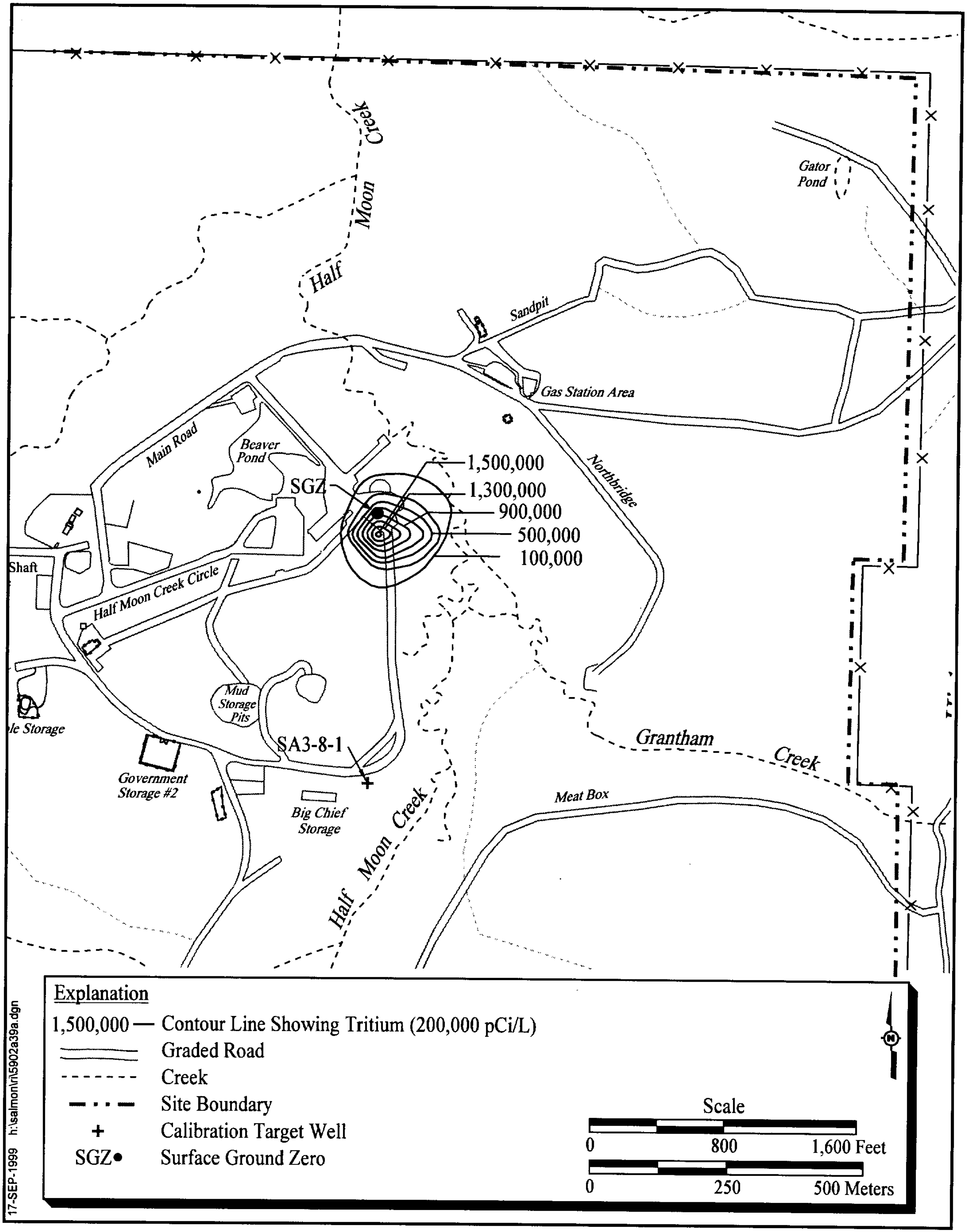

Figure 5-17
Tritium Distribution in Aquifer 1 After 100 Years

5.6.2.2.2 Aquifer 2a

Tritium in Aquifer 2a migrated to the site boundary after approximately 470 simulated days (1.3 years) of transport. Arrival time was defined as the number of elapsed days that correspond to the mid-point of the tritium breakthrough curve at the site boundary (Figure 5-18). The site boundary location is directly downgradient of the source, in the center of the plume, where the maximum tritium concentration occurs. The site boundary was located approximately 1,419 m (4,655 ft) west-southwest of SGZ (Figure 5-19). The maximum concentration of tritium at any point in the plume was calculated to be 9,946 pCi/L after 100 years, which was five orders of magnitude less than the initial concentration and approximately one-half the MCL for tritium.

5.6.2.2.3 Aquifer 2b

Tritium in Aquifer 2b reached the site boundary in approximately 300 days (Figure 5-20). The assumed site boundary was located approximately 902 m (2,960 ft) northeast of SGZ (Figure 5-21). The maximum concentration of tritium in the plume was calculated to be 1,507 pCi/L after 100 years, which was five orders of magnitude less than the initial concentration and approximately eight percent of the MCL for tritium.

5.6.2.2.4 Aquifer 3

Tritium in Aquifer 3 extended to the site boundary after approximately 2,850 days (7 years) (Figure 5-22). The assumed point of compliance was located approximately 1,829 m (6,000 ft) south-southeast of SGZ (Figure 5-23). The maximum tritium concentration was calculated to be 8,622 pCi/L after 100 years, which was five orders of magnitude lower than the initial injected concentration and approximately one-half the MCL for tritium.

In summary, all of the analytical simulations of the lower aquifers in Operable Unit 2 suggest that the concentrations at the site boundary would be significantly below the MCL for tritium. Given the conservativeness inherent to these models, the actual concentration, if tritium ever even leaked into these aquifers, would be even lower.

5.7 Operable Unit 3: Aquifers 4 and 5

Aquifers 4 and 5 are interrupted by Tatum Dome, and are not present beneath SGZ. The aquifers are separated by approximately 91 m (300 ft) of clay aquitard. Aquifer 5 has been historically used by the oil industry in the Baxterville region (about 6 miles southwest of the site) to dispose of waste brines used in secondary oil recovery. Aquifer 5 is naturally saline and does not produce potable water (DOE/NV, 1980). Liquid radioactive waste generated during the nuclear

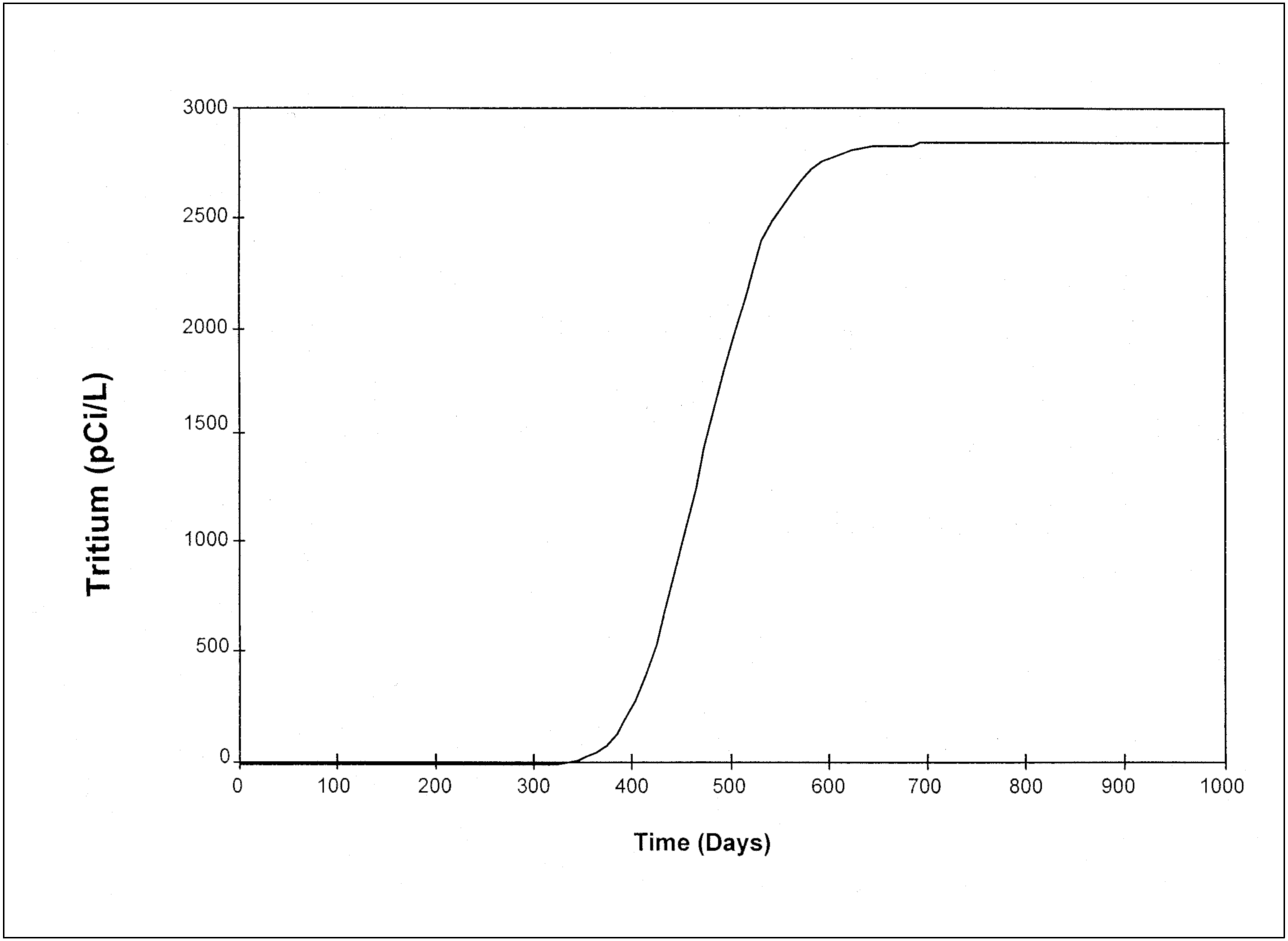

Figure 5-18
Tritium Concentration Versus Time at Downgradient Site Boundary in Aquifer 2a

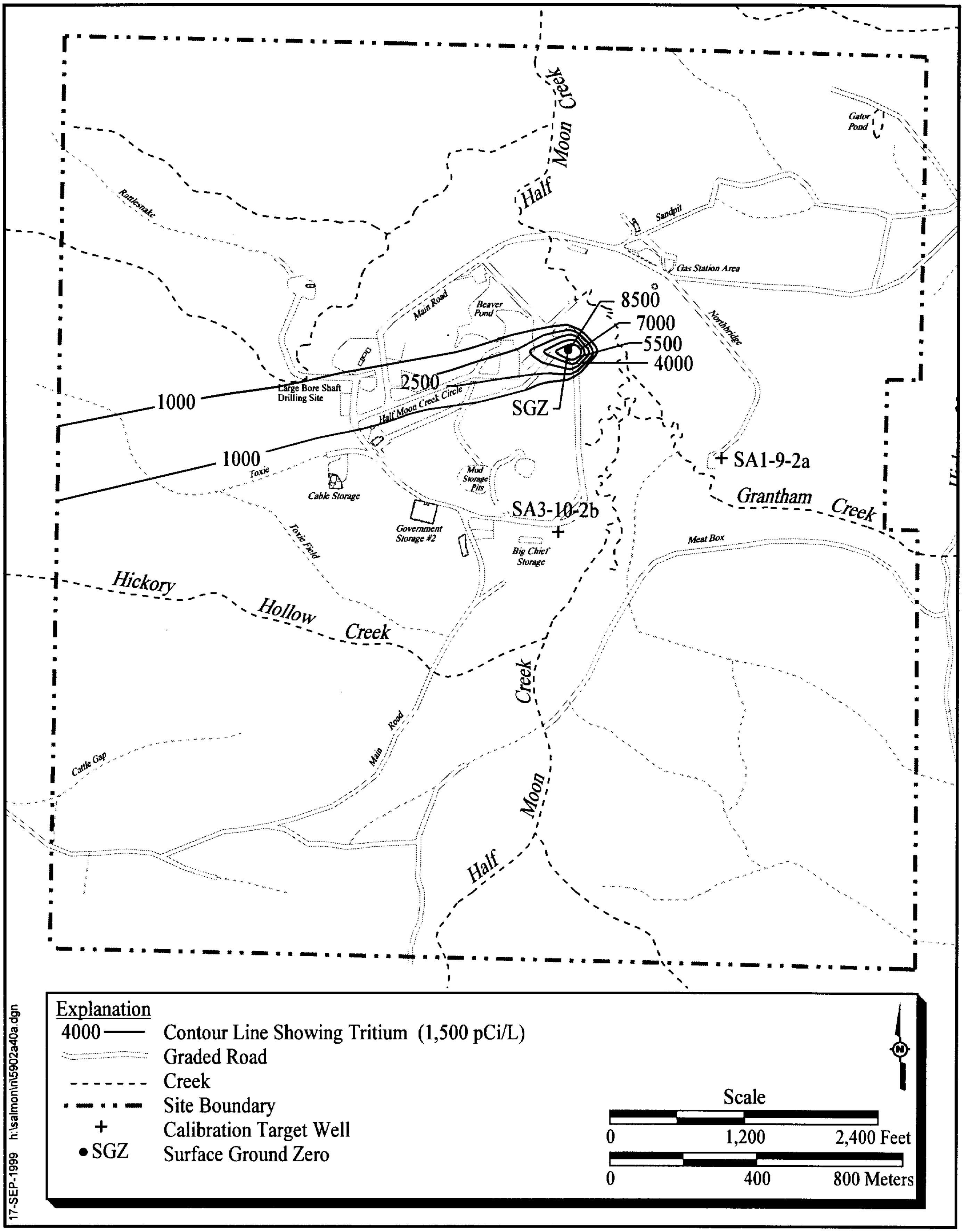

Figure 5-19
Tritium Distribution in Aquifer 2a After 100 Years

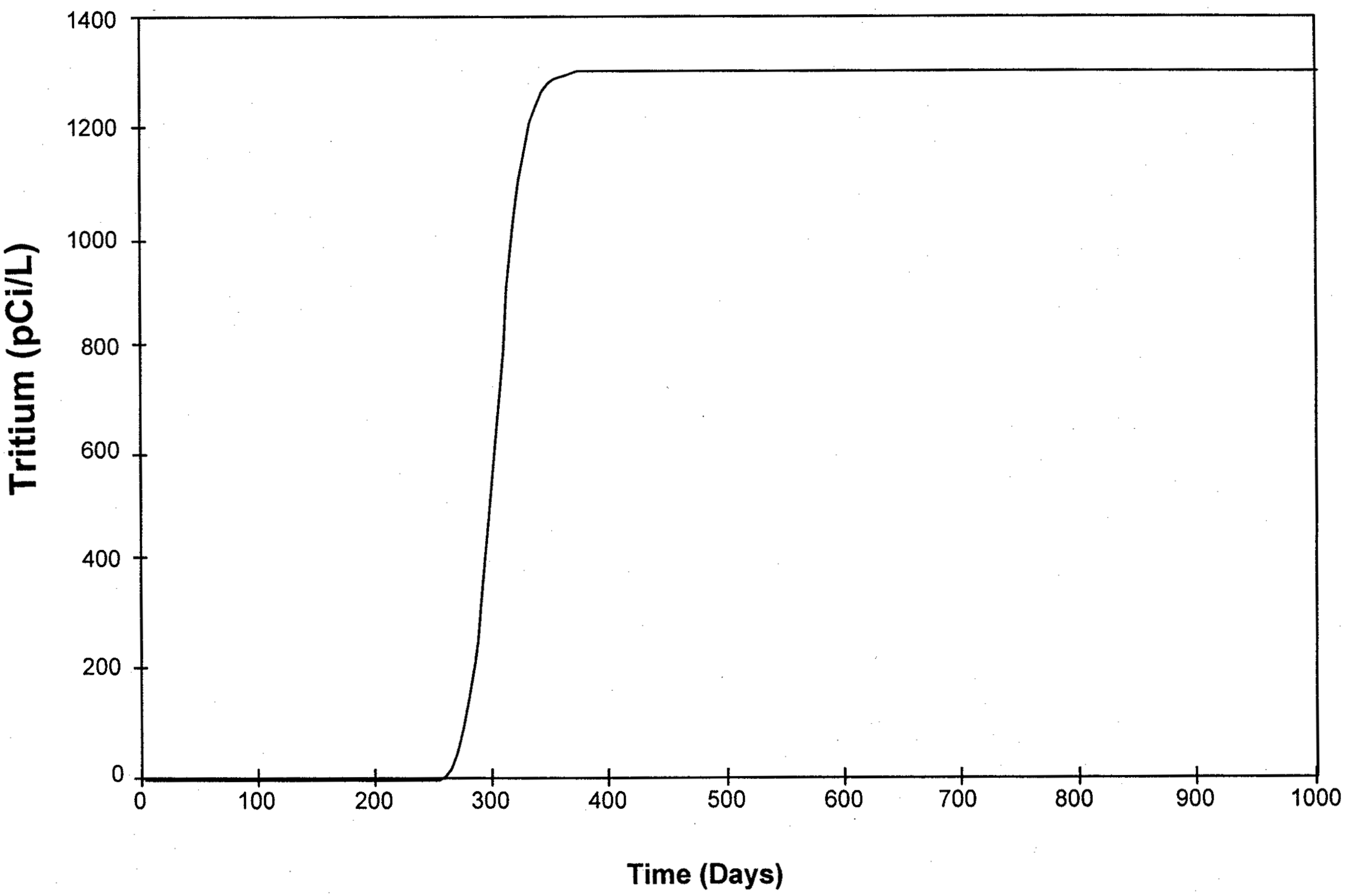

Figure 5-20
Tritium Concentration Versus Time at Downgradient Site Boundary in Aquifer 2b

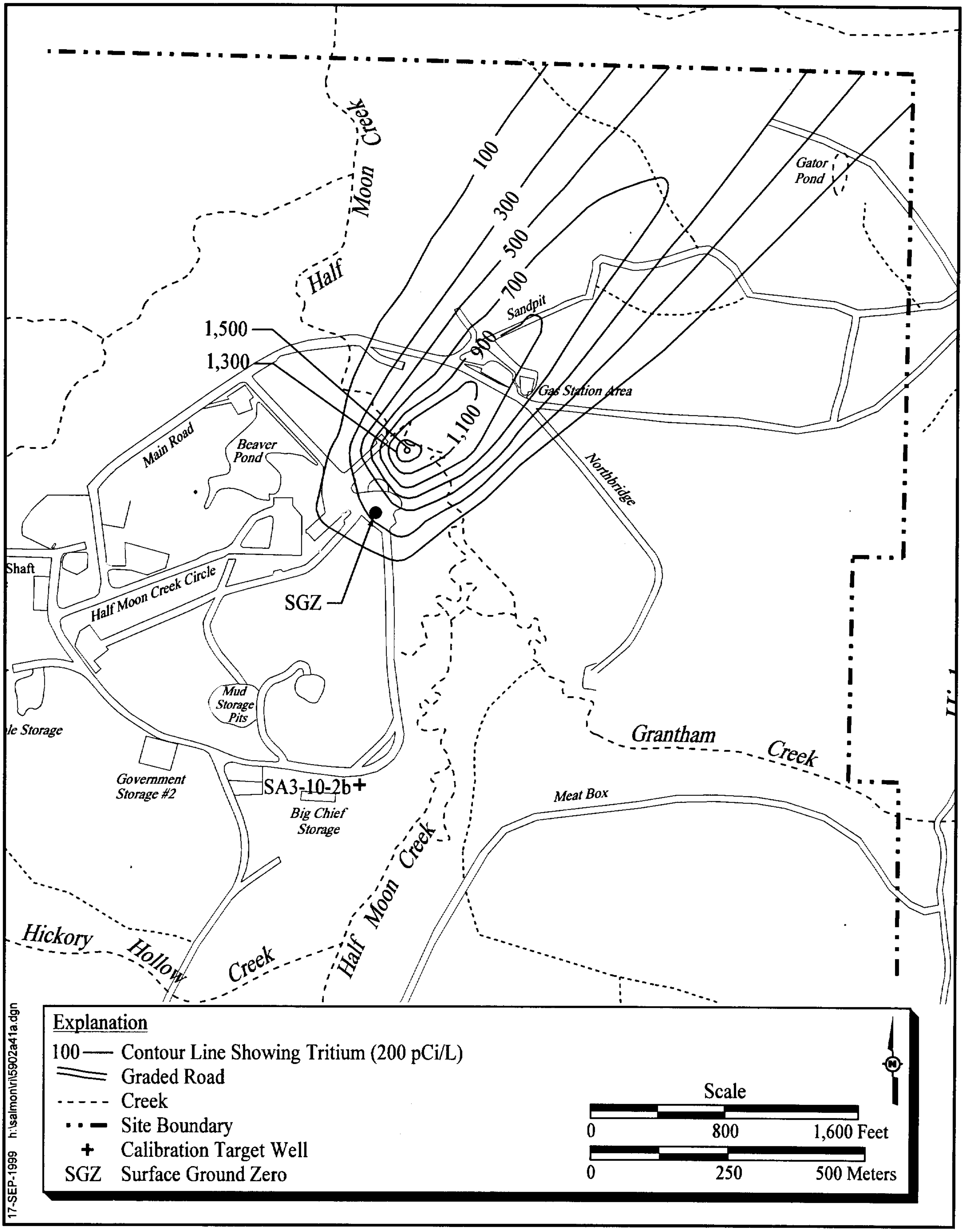

Figure 5-21
Tritium Distribution in Aquifer 2b After 100 Years

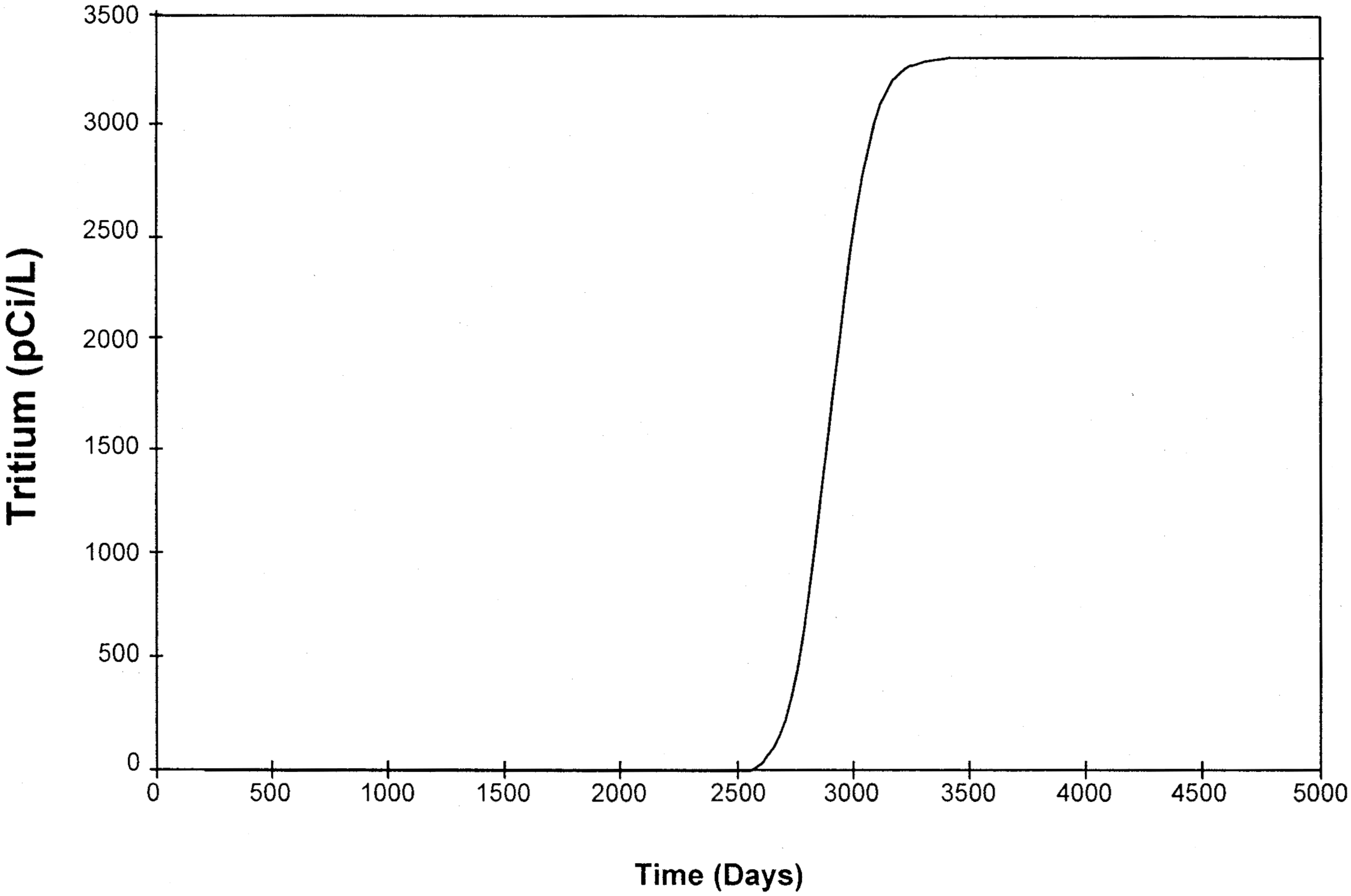

Figure 5-22
Tritium Concentration Versus Time at Downgradient Site Boundary in Aquifer 3

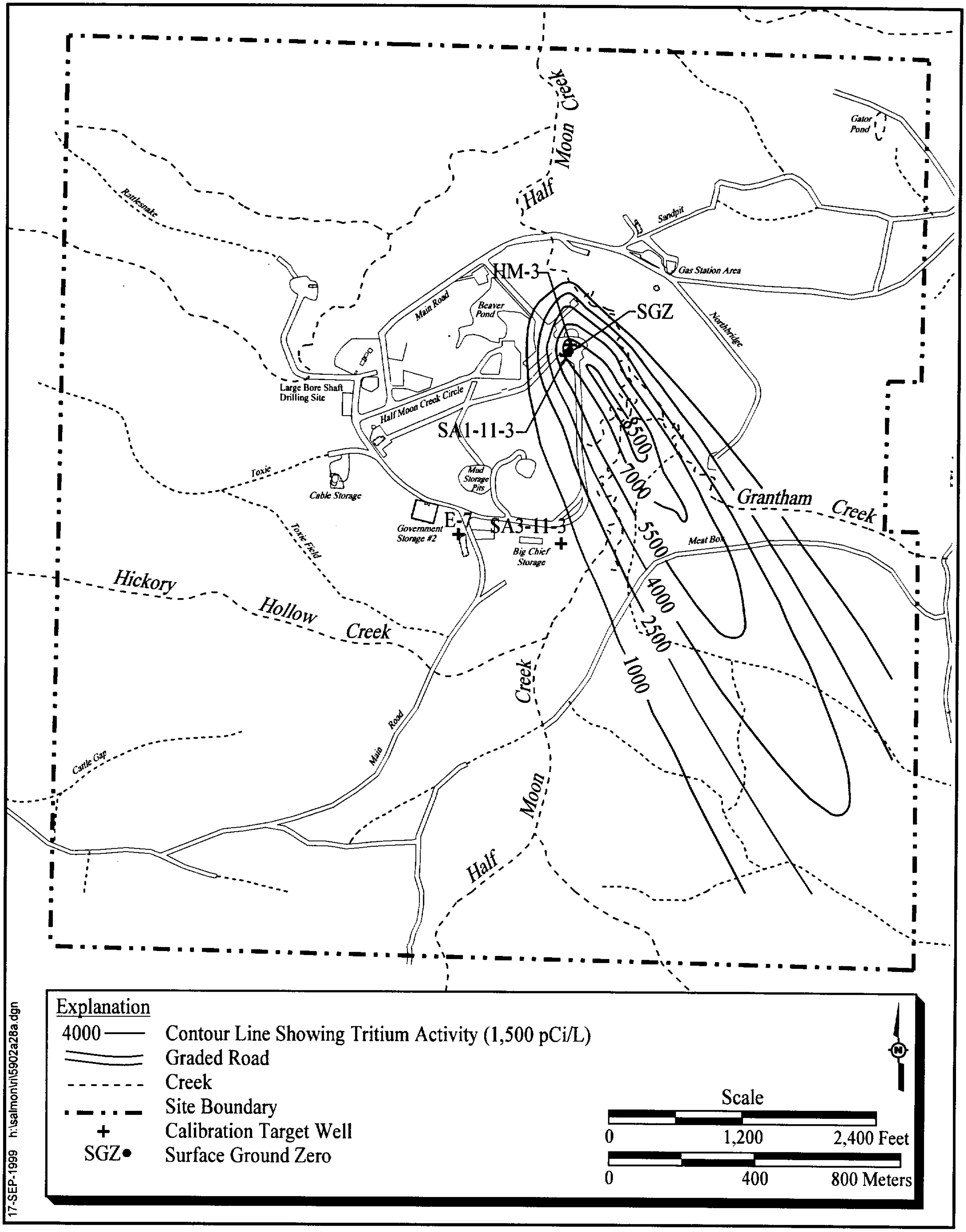

Figure 5-23
Tritium Distribution in Aquifer 3 After 100 Years

tests was disposed of into Aquifer 5 through Well HT-2 (at a depth of about 671 m [2,200 ft] below sea level) as follows (DOE/NV, 1980):

- Well HT-2 was acidized with 7,570 liters (2,000 gal) of 15-percent hydrochloric acid.
- Approximately 1,279,000 liters (337,900 gal) slurry of waste and water that contained 38 curies (Ci) of beta and gamma activity and 3,253 Ci of tritium was injected.
- Approximately 340,600 liters (90,000 gal) of fresh water injected. Well HT-2 was plugged to the surface in June, 1971. In March 1972, tritium was detected in Well HT-2M (also in Aquifer 5) approximately 91 m (300 ft) from HT-2. The purpose of the model was to determine whether it is likely that tritium could have moved through the aquitard and into Aquifer 4.

5.7.1 Modeling Methods

Modflow was used to simulate groundwater flow for Operable Unit 3, Aquifers 4 and 5. In addition, Path3D (Papadopulous and Associates, 1991) was used to calculate and illustrate groundwater flow paths. The model domain was two-dimensional in the x-z plane, oriented along a northeast-to-southwest transect, and based primarily on hydraulic data from Well HT-2 (DOE/NV, 1980; Gardner and Downs, 1971). Aquifer 4 is about 76 m (250 ft) thick, primarily limestone, and with a horizontal hydraulic conductivity of about 1.8×10^{-3} cm/sec (5 ft/day) (Figure 5-24). Below Aquifer 4, the Red Bluff and Yahoo clays are approximately 61 m (200 ft) thick total and have an assumed hydraulic conductivity of 5.6×10^{-6} cm/sec (0.016 ft/day) (Carsel and Parrish, 1988). The Red Bluff and Yahoo Clays are underlain by the Moody's Branch Limestone which is relatively thin (15 m [50 ft]) and has a hydraulic conductivity on the order of 1.1×10^{-3} cm/sec (0.016 ft/day). Beneath Moody's Branch Limestone is the Cockfield Formation, composed of lignitic clay and fine sand. The Cockfield Formation has an assumed hydraulic conductivity of 5.6×10^{-6} cm/sec (0.016 ft/day) and is 31 m (100 ft) thick. Aquifer 5 (the Cook Mountain limestone) is at the bottom of the profile and is about 61 m (200 ft) thick at HT-2. Gardner and Downs (1971) reported a horizontal hydraulic conductivity for Aquifer 5 to be 4.9×10^{-3} cm/sec (14 ft/day). The layer thicknesses presented are from Gardner and Downs (1971), specifically at Well HT-2. The estimated hydraulic conductivities for Aquifers 4 and 5 were also from Gardner and Downs (1971). Hydraulic conductivities for the clay aquitards are from Carsel and Parrish (1988) for a silty clay. The vertical hydraulic conductivity was assumed to be one-tenth of the horizontal valve. Density effects as a result of saline groundwater were not considered.

Gardner and Downs (1971) estimated the hydraulic gradient between Aquifers 4 and 5 to be vertically upward at 0.070 (dimensionless). The horizontal gradients are 0.0002 (dimensionless) to the southwest and 0.002 (dimensionless) to the northeast in Aquifers 4 and 5, respectively.

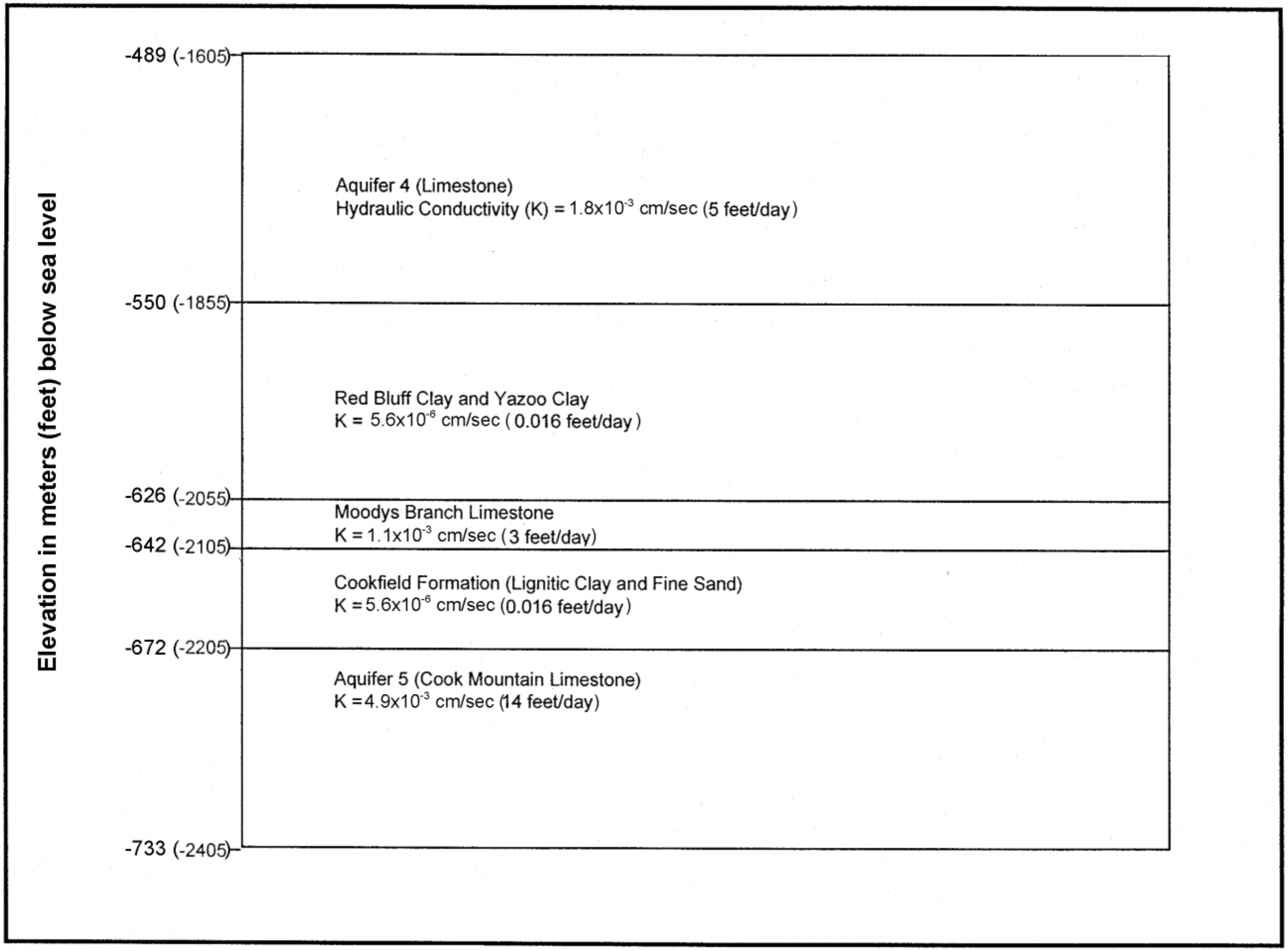

Figure 5-24
Profile of Aquifers 4 and 5 and Confining Units Near Former Well HT-2

Porosity is assumed to be 0.25 percent in all limestone units and 0.35 percent in all clay units. Recharge from the land surface was assumed to be zero. The model grid was two-dimensional in the vertical plane and consisted of 24 cells in the x-direction and 16 cells in the z-direction. The z-axis was 244 m (800 ft) in length with all cell widths equal to 15 m (50 ft). The x-axis was 305 m (1,000 ft) long with cell widths varying from 5.1 to 15 m (16.7 to 50 ft). The 305-m (1,000-ft) length of the x-axis represents slightly less than half the 732-m (2,400-ft) distance from HT-2 to the point where Aquifer 5 is interrupted by Tatum Dome.

Groundwater flow model calibration was performed to match the historical record. Tritium was discovered in Well HT-2M, 91 m (300 ft) downgradient of HT-2, seven years following injection. To calibrate the groundwater flow model, the hydraulic conductivity of Aquifer 5 was increased to 4.9×10^{-3} cm/sec (14 ft/day) until particles travel time was approximately 91 m (300 ft) downgradient in seven years. This change in hydraulic conductivity is within the range reported in the literature (e.g., Freeze and Cherry, 1979) for fractured limestone.

Following the groundwater flow model calibration, seven hydraulic scenarios were evaluated:

- Scenario 1 (the “base case” or initial conditions, as described above). The hydraulic conductivity of the clay aquitards were 5.6×10^{-6} cm/sec (0.016 ft/day).

- Scenario 2. A single column of cells was delineated at a point 98 m (320 ft) downgradient from the left-hand (x = 0) model boundary. The column extended from the bottom of Aquifer 5, up through the intervening clays to the bottom of Aquifer 4. The column was given a uniform hydraulic conductivity of 1.1×10^{-5} cm/sec (0.032 ft/day (a factor of two greater than the clay) and is intended to represent an old, plugged borehole in which the grout seals may have failed enough to allow vertical migration.

- Scenario 3. Scenario 2 was repeated except the borehole conductivity was increased to 1.7×10^{-5} cm/sec (0.048 ft/day).

- Scenario 4. Scenario 2 was repeated except the borehole conductivity was increased to 2.3×10^{-5} cm/sec (0.064 ft/day).

- Scenario 5. Scenario 2 was repeated except the borehole conductivity was increased to 2.8×10^{-5} cm/sec (0.080 ft/day).

- Scenario 6. Scenario 2 was repeated except the borehole conductivity was increased to 4.0×10^{-5} cm/sec (0.112 ft/day).

- Scenario 7. Scenario 2 was repeated except the borehole conductivity was increased to 5.6×10^{-5} cm/sec (0.160 ft/day).

In each case, the travel distance after 35 years (the approximate time from injection to the present) was computed using Modflow and Path3D. Section 5.7.2 presents the results.

5.7.2 Model Results

Figures 5-25 through 5-31 show the results for each scenario. The flow lines represent the path a particle of water would follow from release to 35 years. Figure 5-26 presents the base case (Scenario 1) and shows that the modeled particles stay completely within Aquifer 5. In Scenario 2 (Figure 5-26), the simulated borehole is given a hydraulic conductivity of 0.01 m (0.032 ft) per day. The water particle tracks generally look identical to those in Scenario 1 except for a slight ripple in the uppermost particle where it crosses the borehole. In Scenario 3 (Figure 5-27), the uppermost particle moves upward until it encounters the Moody's Branch Limestone, after which the water particle moves laterally. Note that only the uppermost particle is affected, the lower three particles remain exclusively in Aquifer 5. Figures 5-28 and 5-29 show the results from Scenarios 4 and 5. These scenario simulation results look similar to Scenario 3 in that the uppermost simulated water particle moves up to, and then laterally within, the Moody's Branch Limestone while the lower three simulated water particles remain within Aquifer 5. In Scenario 6 (Figure 5-30), when the borehole conductivity is increased by a factor of 7 to 4.0×10^{-5} cm/sec (0.112 ft/day), some significant vertical movement is seen through the aquitard beneath Aquifer 4 (although after 35 years, the simulated water particle had not yet reached Aquifer 4). In Scenario 7 (Figure 5-31), the borehole conductivity is increased by a factor of 10 for the clay to 5.6×10^{-6} cm/sec (0.16 ft/day). In Scenario 7, the uppermost simulated water particle moves upward to Aquifer 4 and then begins to move southwestward according to the horizontal gradient in that aquifer. Note that even though the borehole extends to the bottom of Aquifer 5, only the uppermost particle is affected by changing the borehole conductivity. The lower three simulated water particles remain in Aquifer 5 for the entire 35-year simulation.

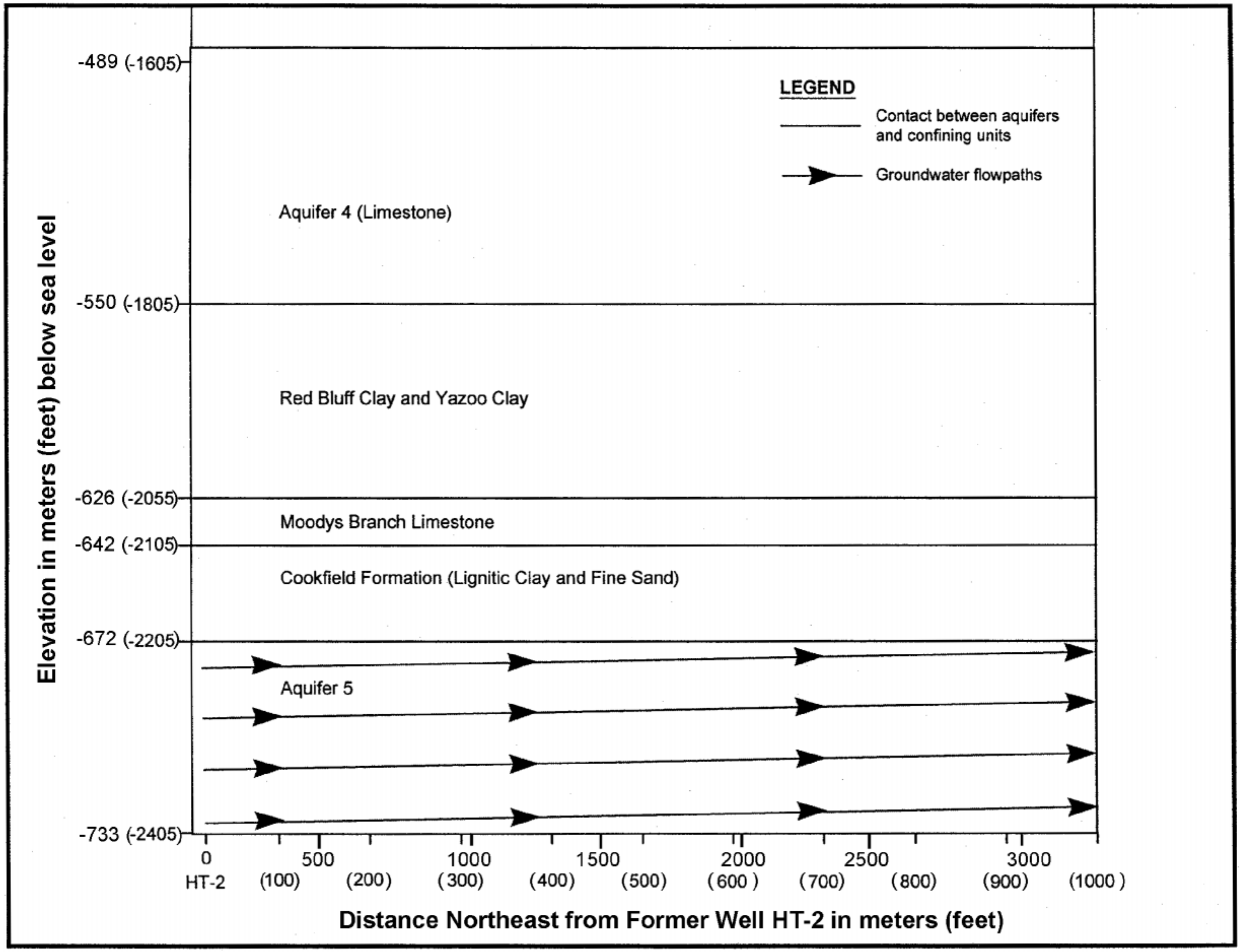

Figure 5-25
Scenario 1 (no borehole) Showing Flowpaths 35 Years After Injection

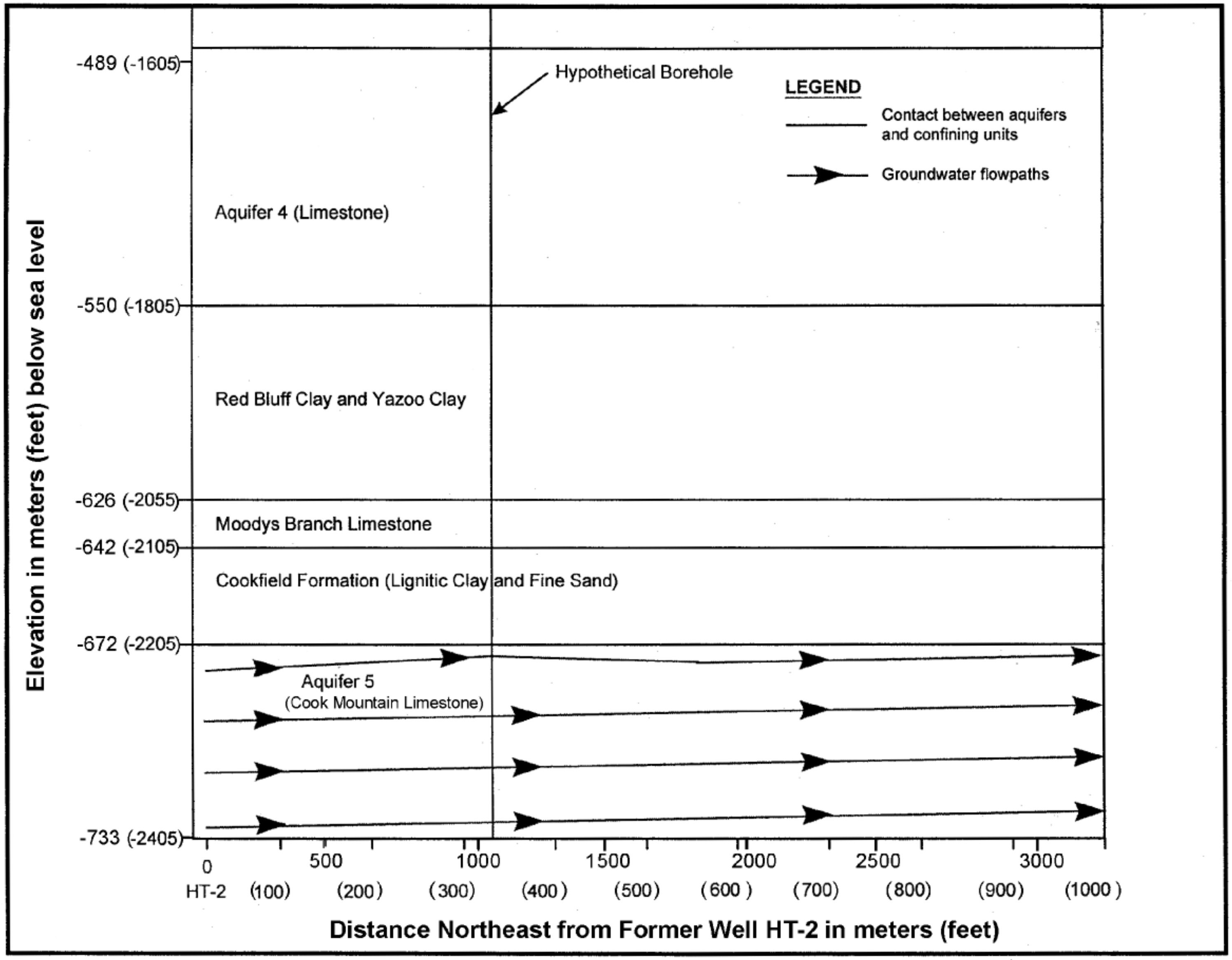

Figure 5-26
Scenario 2 (Borehole K = 1.1×10^{-6} cm/sec [0.032 feet/day])
Showing Flowpaths 35 Years After Injection

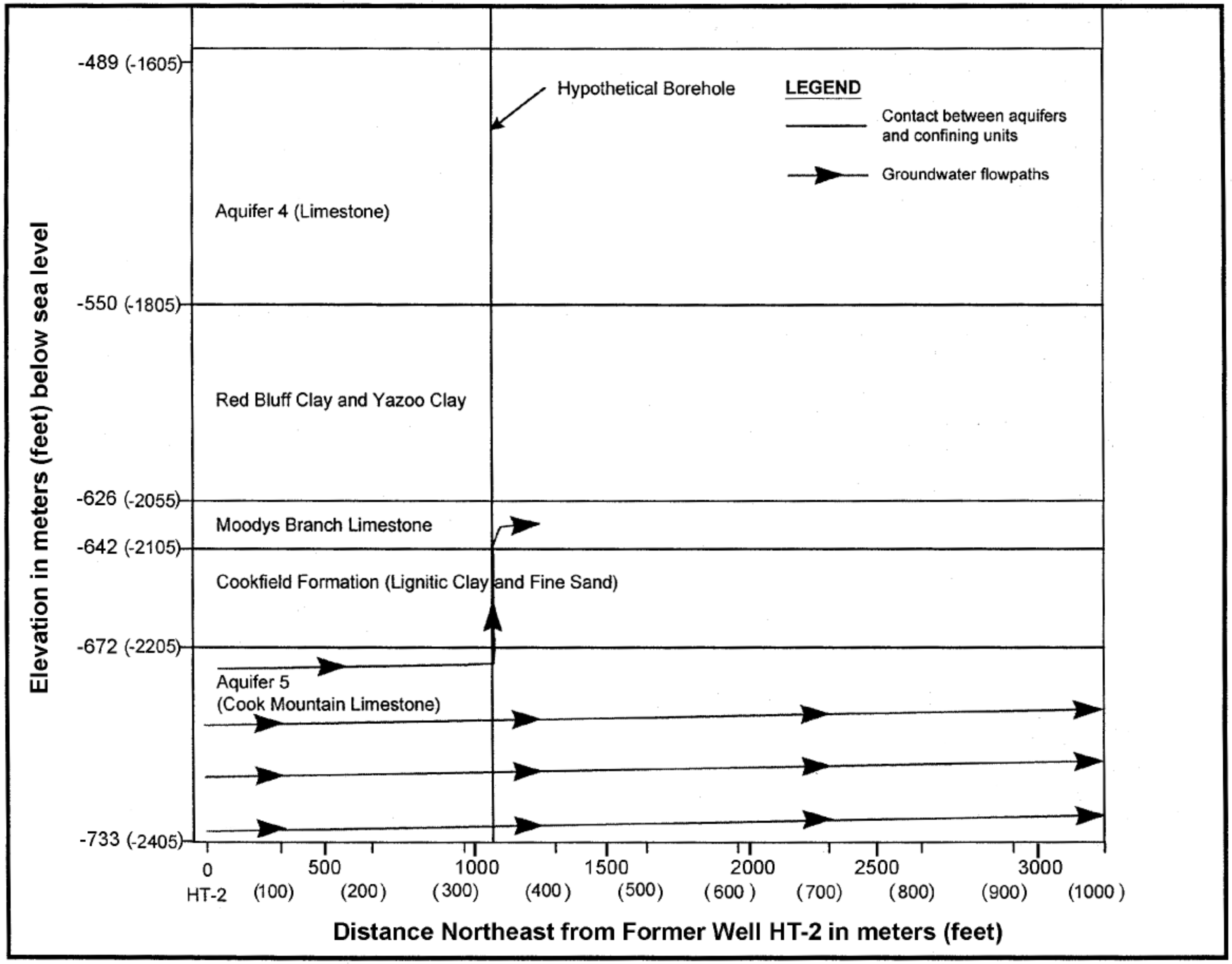

Figure 5-27
Scenario 3 (Borehole K = 1.7×10^{-5} cm/sec [0.048 feet/day])
Showing Flowpaths 35 Years After Injection

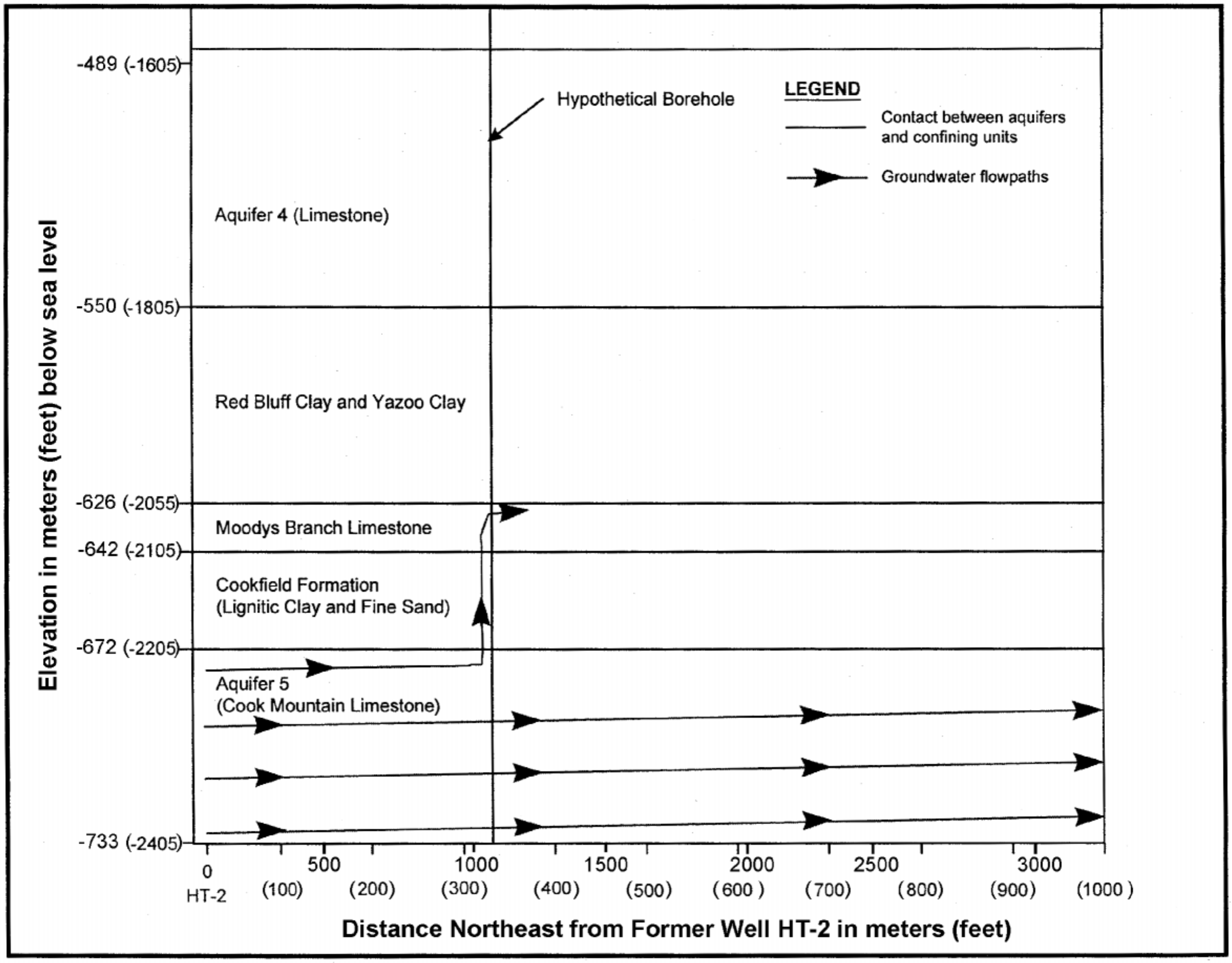

Figure 5-28
Scenario 4 (Borehole K = 2.3 × 10^{-5} cm/sec [0.064 feet/day])
Showing Flowpaths 35 Years After Injection

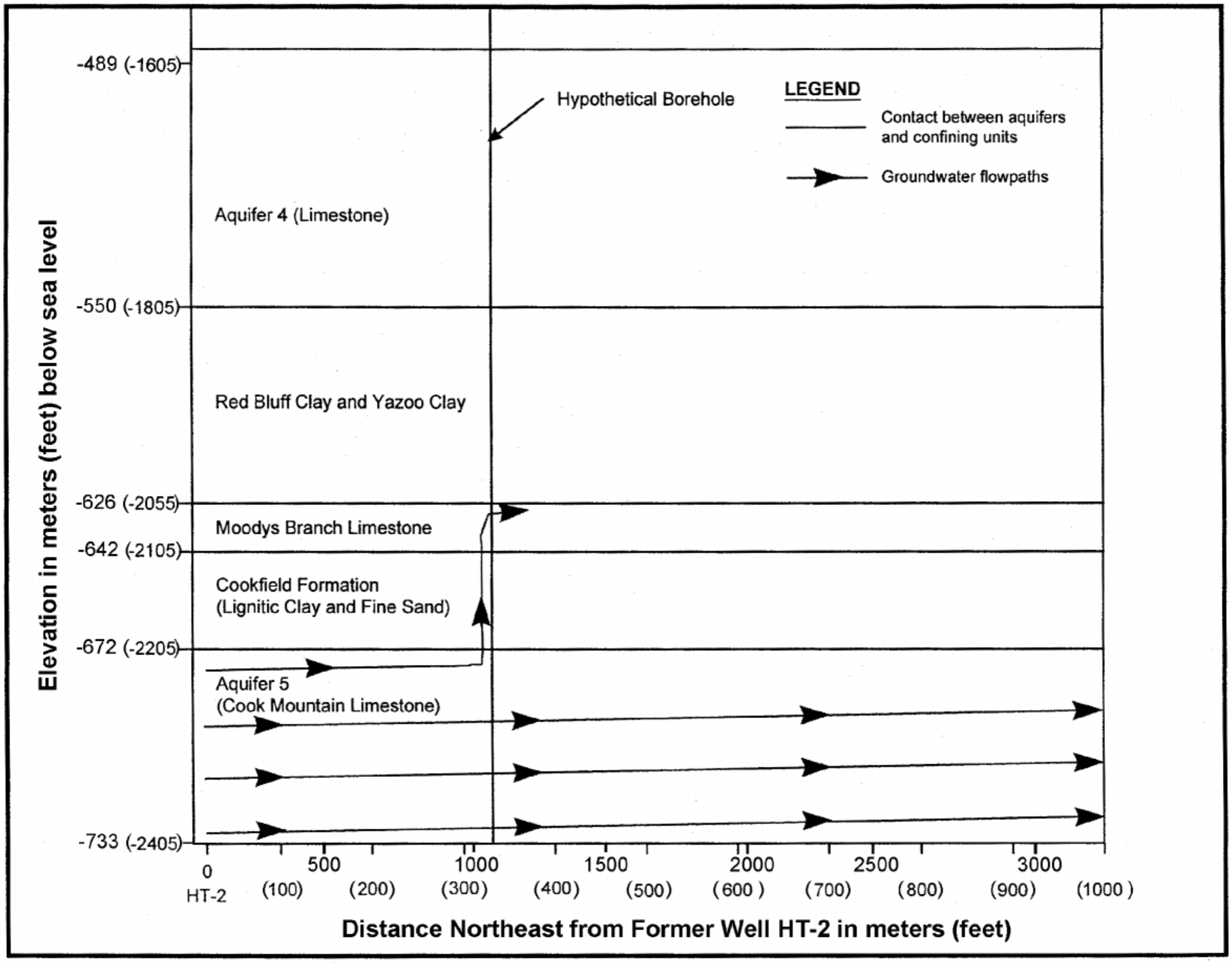

Figure 5-29
Scenario 5 (Borehole K = 2.8 × 10^{-5} cm/sec [0.080 feet/day])
Showing Flowpaths 35 Years After Injection

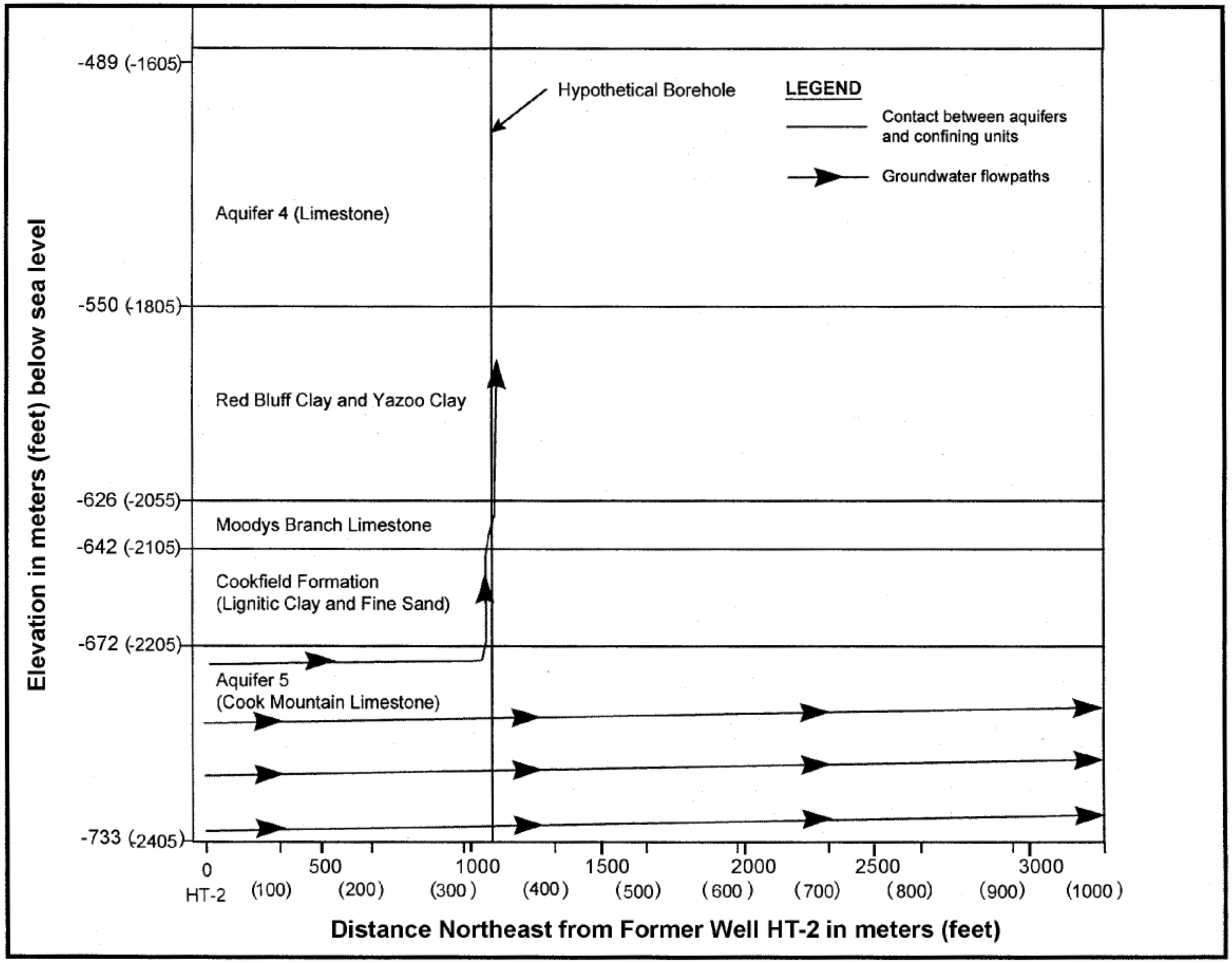

Figure 5-30
Scenario 6 (Borehole K = 4.0 × 10^{-5} cm/sec [0.112 feet/day])
Showing Flowpaths 35 Years After Injection

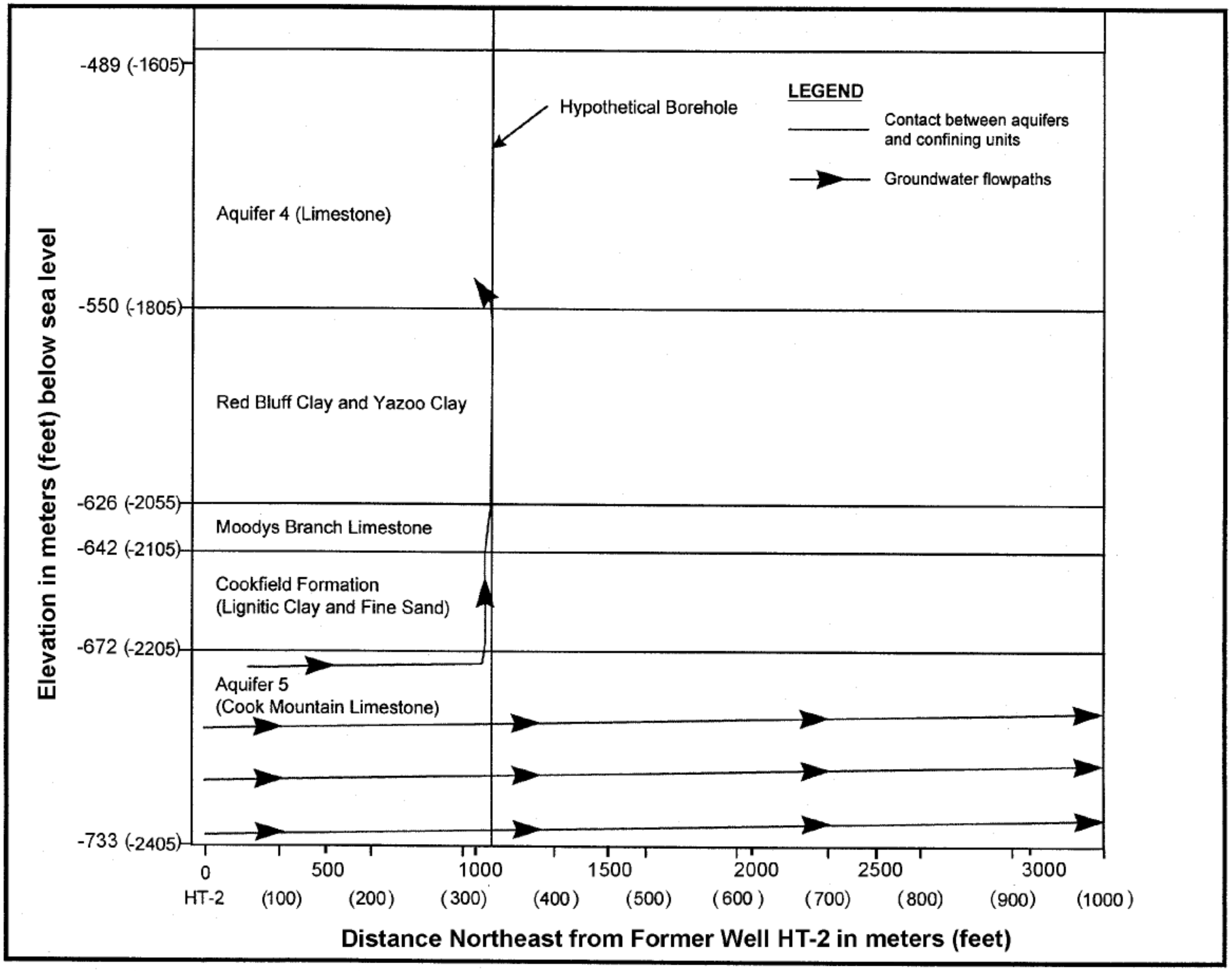

Figure 5-31
Scenario 7 (Borehole K = 5.6 × 10^{-5} cm/sec [0.160 feet/day])
Showing Flowpaths 35 Years After Injection

6.0 Risk Assessment

This section summarizes the overall human health and ecological effects of exposure to PCOCs, for both chemicals and radionuclides, in surface soil, sediment, subsurface soil, surface water, and groundwater at the Salmon Site. The complete Human Health Risk Assessment is included as Appendix C. The Baseline Ecological Risk Assessment is included as Exhibit 2.

A risk assessment is an interpretive link between a remedial investigation and site remediation. Risk assessments are designed to use historical information and data generated by an RI to evaluate potential health effects at a site and to formulate the goals to be used in selecting remedial actions, if required, and to provide one of several components of the overall risk management decision process.

6.1 Human Health Risk Assessment

The following is a brief summary of the human health risk assessment for the Salmon Site with a complete assessment presented in Appendix C. This risk assessment was performed in accordance with the U.S. Environmental Protection Agency's *Risk Assessment Guidance for Superfund* (RAGS) (EPA, 1989a). This section consists of the human health evaluation and includes the following major elements: data evaluation (Section 6.1.1), exposure assessment (Section 6.1.2), toxicity assessment (Section 6.1.3), and risk characterization (Section 6.1.4).

6.1.1 Identification of Chemicals/Radioisotopes of Potential Concern

The PCOCs for the Salmon Site were selected based on an evaluation of available information. This process evaluated historical site information, sample collection and analytical methods, analytical data results of samples collected, and quality of the data. Contaminants evaluated in this analysis were selected based on process knowledge of contaminants handled at this site, background results and site characterization results.

The initial list of PCOCs are the same as those summarized in Section 4.0 and Appendix B. This list of PCOCs was further reduced based on the following screening criteria presented in RAGS (EPA, 1989a):

- Blank contamination
- Comparison of background
- Frequency of detection

- Essential nutrients
- Short half-life radionuclides

Appendix C, Section C.2.1, presents a more complete description of each of the screening criteria. The summary statistics compiled for each of the six source areas depended on the media and PCOC type (chemical or radionuclide). Each of these differences are summarized in the following sections.

6.1.1.1 Surface and Subsurface Soil

For risk assessment purposes, surface soil is defined as 0 to 15 cm (0 to 6 in.) bgs and subsurface soil is defined as an soil deeper than 15 cm (6 in.). The MDEQ defines surface soil as 0 to 1.8 m (0 to 6 ft). Because groundwater is shallow at the Salmon Site, DOE/NV used a more restrictive definition of surface soil. For chemical constituents, the initial list of PCOCs is the same as summarized in Section 4.0 and Appendix B. The initial analytical data sets for each PCOC by source area and sampling location were compiled from the *Baseline Ecological Risk Assessment Salmon Site Lamar County, Mississippi* (DOE/NV, 1995a) for hazardous constituents. One half of the detection limit was used for all non-detects. For radionuclides, the initial list of radionuclides is the same as summarized in Section 4.0 and Appendix B. Short half-life daughters were eliminated from risk consideration as long as the parent toxicity values included risks due to the radioactive daughters. The analytical data for the radiological PCOCs are summarized in Section C.2.2. Using the Statistica® statistical software package, the following statistics were calculated for each source area and PCOC, assuming a normal distribution: maximum detected value, minimum detected value, mean, standard deviation, and 95 percent upper confidence limit (UCL) of the mean.

The statistics for soil and sediment samples at the six source areas are summarized in Appendix C, Section C.2.2. For each of the six source areas, the PCOC surface soil statistics are summarized in Tables C.2-1 through C.2-6; the PCOC subsurface soil statistics are summarized in Tables C.2-7 through C.2-11; and the PCOC sediment statistics are summarized in Table C.2-13.

6.1.1.2 Surface Water

Surface water at the Salmon Site was not separated into source areas. Therefore, the statistical analysis for the surface water summarized in the *Baseline Ecological Risk Assessment, Salmon Site, Lamar County, Mississippi* (DOE/NV, 1995a) will be used in this human health risk assessment. The surface water analytical data are summarized in Appendix C, Section C.2.2 (Table C.2-12).

6.1.1.3 Groundwater

Groundwater at the Salmon Site was not separated into the six different source areas. For this risk assessment, the groundwater PCOC and corresponding concentrations are the same as those developed in Section 5.0 of this report. For on-site concentrations, the maximum detected groundwater concentration for each PCOC was carried through this risk analysis. As part of the fate and transport analysis, groundwater concentrations were modeled to calculate when the concentration dropped below the respective regulatory limit, and to the site boundary. The site boundary calculation was made as a conservative measurement because DOE/NV is intending to expand an existing water supply system to the area surrounding the Salmon Site. Concentrations of contaminants modeled at the site boundary were extremely low. The maximum groundwater concentrations for each PCOC are summarized in Section 5.0 and Appendix C, Section C.2.2 (Table C.2-14).

6.1.2 Exposure Assessment

The exposure assessment estimates the type and magnitude of exposure to humans from the PCOC. The exposure pathways and calculations of chemical intakes are presented in this section.

For exposure and potential risks to occur, complete exposure pathways must exist. A complete pathway requires the following elements (EPA, 1989b):

- A source and mechanism for release of contamination
- A transport or retention medium
- A point of potential human contact (exposure point) with the contaminated medium
- An exposure route at the exposure point.

If any one of these elements is missing, the pathway is not considered complete.

6.1.2.1 Exposure Pathways at the Salmon Site

Exposure points are locations of human contact with contaminated media. Exposure points consider human activity patterns and the location of potentially exposed individuals relative to the location of contaminated media. For this assessment, contact with potentially contaminated media takes place as a result of recreational, residential, and occupational exposure. To maintain the conservative methodology of RAGS (EPA, 1989a), the contact point for soil contamination with all exposure scenarios is located at the contaminant source, and maximum on-site groundwater concentrations were carried through the risk analysis.

Depending on the exposure scenario, the following five exposure routes were examined:

- Ingestion
- Inhalation of dust
- Dermal contact
- External exposure (radionuclides only)
- Ingestion of home-grown produce

The current Salmon Site land-use restrictions are intended to limit site access and minimize inadvertent exposure to an intruder. For the risk assessment calculations, the current land use assumed there is the potential for a recreational user (e.g., hunter or hiker) to be found on site. Currently, there are no on-site residents. The potential complete exposure pathways include exposure to surface soil, subsurface soil due to the removal of the surface soil, and off-site groundwater (see Section 5.0 for the groundwater transport modeling to an off site location). Table 6-1 lists the complete human exposure pathways for recreational land use. This table indicates which pathways have been selected for risk characterization and presents the rationale for inclusion or exclusion of each pathway.

To maintain the conservative methodology of RAGS (EPA, 1989b), a future on-site residential pathway is considered as the worst-case scenario. The potential complete exposure pathways include exposure to surface soil, subsurface soil due to the removal of the surface soil, and on-site and off-site groundwater (refer to Section 5.0 for the groundwater transport modeling to an offsite location). Table 6-2 lists the complete human exposure pathways for future land use. This table indicates which pathways have been selected for risk characterization and presents the rationale for inclusion or exclusion of each pathway.

A second realistic potential site use is an adult periodically being on site performing occupational duties. An example of this would be a game warden, site caretaker, or individual conducting ecological research. This land-use scenario is the most reasonable with the assumption that the Salmon Site will eventually become a wildlife refuge. For the park ranger scenario, it was assumed the individual would be an adult and be on site eight hours per week. The potential

Table 6-1
Potentially Complete Human Exposure Pathways for Current Land Use at the Salmon Site

Environmental Medium	Exposure Route	Potentially Exposed Population	Pathway Selected for Evaluation	Reason for Selection or Exclusion
Surface Soil	Inhalation Ingestion Dermal Contact	Residents Park Ranger	No	No current on-site residents or long term on-site workers are at the Salmon Site.
Surface Soil	Inhalation Ingestion Dermal Contact	Recreational	Yes	Potential intermittent recreational exposure is currently feasible.
Surface Water	Inhalation Ingestion Dermal Contact	Residents Park Ranger	No	No current on-site residents or long term on-site workers are at the Salmon Site.
Surface Water	Ingestion	Recreational	Yes	Potential intermittent recreational exposure is currently feasible.
Air[a]	Inhalation	Residents Recreational Park Ranger	No	No air sampling occurred.
Groundwater	Inhalation Ingestion Dermal Contact	Recreational	Yes	Current groundwater analytical data were used in the calculation of risk. The groundwater pathway is considered at the site boundary due to a lack of current residential wells in the potentially affected area.
Groundwater	Inhalation Ingestion Dermal Contact	Residents Park Ranger	No	No current on-site residents or long term on-site workers are at the Salmon Site.
Subsurface Soil	Inhalation Ingestion Dermal Contact	Recreational/Park Ranger	No	Direct or indirect exposure to subsurface soil at depth of contamination is improbable (i.e., no complete exposure pathway exists).
Subsurface Soil	Inhalation Ingestion Dermal Contact	Residents	No	No current on-site residents or long term on-site workers are at the Salmon Site.

[a] Air refers specifically to evaluating exposure using air sample data. Potential exposure by inhalation to constituents from other media (e.g., soil) is presented with those media.

Table 6-2
Complete Human Exposure Pathways for Potential Future Land Use at the Salmon Site

Environmental Medium	Exposure Route	Potentially Exposed Population	Pathway Selected for Evaluation	Reason for Selection or Exclusion
Surface Soil	Inhalation Ingestion Dermal Contact	Recreational	No	No future long-term on-site workers are planned at the Salmon Site. Recreational exposure is considered a current pathway. Future residential exposure is conservative.
Surface Soil	Inhalation Ingestion Dermal Contact Ingestion of Home-grown Produce	Residents/Park Ranger[a]	Yes	Potential future residential exposure is feasible and conservative.
Surface Water	Inhalation Ingestion Dermal Contact	Recreational	No	Potential intermittent recreational exposure is feasible.
Surface Water	Ingestion	Residents	Yes	Potential intermittent residential and Park Ranger exposure is feasible and conservative.
Air[b]	Inhalation	Residents Recreational/Park Ranger	No	No air sampling occurred.
Groundwater	Inhalation Ingestion Dermal Contact	Residents	Yes	Current groundwater analytical data were used in the calculation of risk. The future groundwater pathway is considered both on site and at the site boundary.
Groundwater	Inhalation Ingestion Dermal Contact	Recreational/Park Ranger	No	No future, long-term on-site workers are planned at the Salmon Site. Recreational exposure is considered a current pathway. Future residential exposure is conservative.
Subsurface Soil	Inhalation Ingestion Dermal Contact Ingestion of Home-grown Produce	Residents/Park Ranger	Yes	Direct or indirect exposure to subsurface soil at depth of contamination is improbable (i.e., no complete exposure pathway exists). However, upon removal of surface soil, a future residential receptor is the most conservative.
Subsurface Soil	Inhalation Ingestion Dermal Contact	Recreational/Park Ranger	No	No future, long-term on-site workers are planned at the Salmon Site. Recreational and Park Ranger exposure is not considered a current pathway. Future residential exposure is conservative.

[a] Park Ranger, subsurface soil exposure does not include ingestion of home-grown produce.
[b] Air refers specifically to evaluating exposure using air sample data. Potential exposure by inhalation to constituents from other media (e.g., soil) is presented with those media.

exposure pathways included exposure to surface soil and surface waters. It was also assumed that all food and water consumed would be brought to the site. Table 6-2 lists the complete human exposure pathways for this future land use. The table indicates which pathways have been selected for risk characterization and presents the rationale for inclusion or exclusion of each pathway.

6.1.2.2 Quantification of Exposure

This section describes the estimation of exposures for the PCOCs that may come in contact with human receptors. The process involves the following:

- Identification of applicable human exposure models and input parameters
- Determination of the concentration of each constituent in environmental media at the point of human exposure
- Estimation of human intakes

For each potentially complete exposure pathway identified above, a reasonable maximum exposure (RME) scenario has been developed. The RME is the highest exposure that is reasonably expected to occur at a site (EPA, 1989a). The intent of the RME, as defined by the EPA, is to estimate a conservative exposure case (i.e., well above the average case) that is still within the possible range of exposures. The RME is both protective and reasonable, but is not the worst possible case (EPA, 1991a).

The primary source for the exposure models used in this baseline risk assessment is RAGS (EPA, 1989a). Shown below is the generalized equation for calculating chemical intakes:

$$I = C \frac{CR \times EFD}{BW \times AT} \tag{6-1}$$

where:

I = Intake; the amount of chemical at the exchange boundary mg/kg body weight-day

C = Chemical concentration at the exposure point; the concentration contacted over the exposure period (e.g., mg per liter [mg/L] water or mg/kg soil)

CR = Contact rate; the amount of contaminated medium contacted per unit time or event (e.g., mg per day soil ingestion rate or cubic meter [m^3] per hour air inhalation rate)

EFD = Exposure frequency and duration; describes how often and how long exposure occurs; often calculated using two terms (EF times ED)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight; the average body weight over the exposure period (kilogram)

AT = Averaging time; period over which exposure is averaged (days)

The calculation of radiological intakes are similar to the calculation of chemical intakes. The primary differences are that body weight and averaging time are eliminated from the chemical intake equation. Pathway-specific exposure models are summarized Appendix C, Section C.3.2.1.

Two types of parameters are used in exposure models to estimate intake (EPA, 1989b):

- Constituent-related parameters (i.e., octanol-water partition coefficient [K_{ow}]), summarized in Table C.3-3

- Parameters that describe the exposed population (e.g., contact rate, exposure frequency and duration, and body weight), summarized in Table C.3-4

The exposure parameters used in the Salmon Site risk calculations are summarized in Tables C.3-3 and C.3.4. All values shown in the tables apply to the RME scenario. The exposure parameters have been taken from EPA guidance (EPA, 1991a) and are based on best professional judgment using site-specific information, where available. Upper-bound values are generally the 90th or 95th percentile values, depending on the data available for each parameter. Combinations of upper-bound and average exposure parameters were used to estimate the RME for each scenario. The RME input parameters are from current EPA guidance.

Noncarcinogenic and carcinogenic intakes of PCOCs and pathways at the Salmon Site are tabulated in Appendix C, Section C.5.0.

6.1.3 Toxicity Assessment

Toxicity information is given in the same units provided by the source material (dose rates and concentrations are primarily used). The EPA weight-of-evidence classification (cancer class) system for carcinogenicity is presented here for reference. The classification is as follows (EPA, 1989a):

- Class A—Human carcinogen
- Class B1—Probable human carcinogen; limited human data available
- Class B2—Probable human carcinogen; sufficient evidence in animals; inadequate or no evidence in humans
- Class C—Possible human carcinogen
- Class D—Not classifiable as to human carcinogenicity
- Class E—Evidence of noncarcinogenicity for humans

Slope factors (SF) are typically calculated for potential carcinogens in Classes A, B1, and B2. A quantitative estimation of slope factors for chemicals in Class C proceeds on a case-by-case basis.

For chemicals, the primary source for toxicity values, both reference doses (RfD) and SF, is the *Integrated Risk Information System (IRIS)* (EPA, 1998a). If a toxicity value for a given chemical is not available in IRIS, the secondary source is the *Health Effects Assessment Summary Tables (HEAST)* listing (EPA, 1995). No surrogate values were developed for chemicals for which no toxicity information existed in either of the above references.

The EPA classifies all radionuclides as Group A carcinogens. The HEAST (EPA, 1995) lists ingestion, inhalation, and external exposure cancer SF for radionuclides in units of risk per picocurie (pCi). Ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk/pCi. External exposure slope factors are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and these are expressed as risk/year per pCi/gram soil. When combined with site-specific media concentration data and appropriate exposure assumptions, SF can be used to estimate lifetime cancer risks to members of the general population due to radionuclide exposures. In most cases, cancer risks are limiting, exceeding both mutagenic and teratogenic risks.

Selected radionuclides and radioactive decay chain products are designated in HEAST with the suffix "+D" (e.g., uranium-238+D, radium-226+D, cesium-137+D) to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment. Where possible, the "+D" SF were used to calculated risk at the Salmon Site. However, if the parent radionuclide was not detected (above the reference site concentrations) and short-lived decay products of the parent radionuclide were detected (above background), the slope factors for the short-lived daughters were used in the calculation of risk.

Table C.4-1 summarizes the radiological toxicity information, including the radionuclides of potential concern half lives and the ingestion, inhalation, and external exposure SF. Table C.4-2 summarizes the chemical toxicity information including the potential contaminants of concern RfDs, SF, and EPA cancer classification.

6.1.4 Risk Characterization

This section provides a characterization of the potential health risks associated with the intake of PCOCs. Risk characterization compares estimated potential cancer risks with reasonable levels of risk (SF) for carcinogens and compares estimated daily intake (rate) with reference levels (RfD) for noncarcinogens. Carcinogens may also pose a systemic (noncarcinogenic) hazard, and these potential hazards are characterized in the same manner as other noncarcinogens.

Estimation of potential risk from exposure to the PCOCs is based on RAGS (EPA, 1989a). This assessment employs a health-protective bias that leads to a conservative estimation of the risk. The exposure of individuals to an RME is described in Section C.3.1 and evaluated in Section C.3.2 to provide estimates of daily intakes. These estimated intakes (rates) are evaluated with the individual chemical toxicological values (Table C.4.2) to determine the potential carcinogenic risks and the potential hazards to human health.

6.1.4.1 Estimation of Carcinogenic Risk

In evaluating the calculated residential exposure from a potentially carcinogenic PCOC, a reasonable level of risk must be selected. The EPA used an incremental lifetime cancer risk

(ILCR) (also referred to as excess cancer risk) of one in one million (1×10^{-6}) as the lower bound of an acceptable range. The upper bound of an acceptable ILCR recommended by the EPA for drinking water is 1 in 10,000 (1×10^{-4}) (EPA, 1987). In addition, the EPA specifies a risk range of 10^{-6} to 10^{-4} associated with the consideration and selection of remedial alternatives for contaminated media in the National Contingency Plan (NCP) (CFR, 1996a). The MDEQ uses 10^{-6} as a target level for remedial actions for carcinogenic chemicals (MCEQ, 1999 and MDEQ, 1999).

Based on the regulatory precedents cited above, a reasonable and appropriate ILCR range would be from 10^{-6} to 10^{-4}. As implemented under the NCP, pathway risks greater than 10^{-6} ILCR must receive risk management consideration (CFR, 1996a). The quantitative risk assessment is one of many factors that is considered in the decision-making process for remediation. Therefore, there is no single risk value that defines "acceptable" and "unacceptable" risk. The purpose of this risk assessment is to present quantitative and qualitative estimates of potential risk; therefore, all pathway risks greater than the lower bound of 10^{-6} will be examined.

Cumulative site ILCR were developed for subsurface soil and groundwater PCOCs. These cumulative ILCRs included all media and pathways that were appropriate to combine. These pathways occur when there is potential for an individual to be exposed to multiple pathways at the same given instant in time. Where the cumulative ILCR site risk to an individual based on the RME for both current and future land use is less than 10^{-4}, action generally is not warranted unless there are adverse environmental impacts (EPA, 1991b).

The carcinogenic risk is estimated as the probability of an additional incidence of cancer. This risk is:

$$\text{ILCR} = \text{SF} \times \text{Intake} \qquad (6\text{-}2)$$

where:

ILCR = Incremental lifetime cancer risk (unitless)

SF = Carcinogenic SF [$(\text{mg/kg-day})^{-1}$ for chemicals; for radionuclides $(\text{pCi})^{-1}$ or $(\text{pCi-year/g})^{-1}$ for external exposure]

Intake = Chronic daily intake (mg/kg-day) for chemicals or (pCi and pCi-year/g) for radionuclides

The carcinogenic SF for the PCOC are presented in Tables C.4-1 and C.4-2. For chemicals, these are the most recent values cited in the EPA's IRIS (EPA, 1998a), and the HEAST (EPA, 1995). For radionuclides, all of the SF are from HEAST (EPA, 1995). Surrogate values for constituents were not derived if no SF existed in the IRIS or the HEAST.

For a given pathway and medium with exposure to several carcinogens, the following equation was used to sum the cancer risk:

$$\text{Risk}_{t,p} = \sum_{i=1}^{I} \text{ILCR}_p\ (\text{chem}_i) \qquad (6\text{-}3)$$

where:

$\text{Risk}_{t,p}$ = Total cancer risk for pathway p (unitless)

$\text{ILCR}_p(\text{chem}_i)$ = Individual cancer risk for constituent I through exposure pathway p (unitless)

Estimates of ILCRs are provided for each exposure scenario and pathway in Section C.5.3.

6.1.4.2 Estimation of Noncarcinogenic Risk

Constituents that pose a health threat other than cancer were evaluated by comparing an exposure level or intake to an acceptable level or RfD. The ratio of estimated daily intake to the RfD is termed the hazard quotient (HQ) and is defined as

$$\text{HQ}_{i,p} = \frac{I_{i,p}}{\text{RfD}_i} \qquad (6\text{-}4)$$

where:

$\text{HQ}_{i,p}$ = Individual HQ for exposure to constituent I through exposure pathway p (unitless)

$I_{i,p}$ = Daily intake via a specific pathway p for constituent I (mg/kg-day)

RfD_i = RfD for exposure by the specific pathway (limited to oral and inhalation values) for constituent I (mg/kg-day)

The RfD is an estimate of the intake level to which a human population, including sensitive subpopulations, may be chronically exposed without a significant risk of adverse health effects

(EPA, 1989a). The RfDs for the PCOCs are listed in Table C.4-2. Because the HQ does not define intake response relationships, its numerical value should not be construed as a direct estimate of risk, but it does suggest that a given situation should be more closely scrutinized. The concept of the HQ implies the existence of a threshold for systemic health effects. The HQ is a numerical indication of the fraction of acceptable limits of exposure or the degree to which acceptable exposure levels are exceeded. As this quotient increases toward unity, concern for the potential hazard of the constituent increases. A value above unity is an indication of risk, although a direct correlation to the magnitude of the risk cannot be drawn. The RfD used in this risk assessment are the most recent values cited in the IRIS (EPA, 1998a) and HEAST (EPA, 1995). No surrogate values were derived.

In the case of simultaneous exposure to several constituents, the hazard index (HI) is calculated to evaluate the potential risk from exposure to the mixture by summing the HQ for each chemical, medium, and pathway. The total HI incorporates the assumption of additive effects when dealing with a mixture of components. The HI formula is as follows (EPA, 1989b):

$$HI = \sum_{i=1}^{I} HQ_i \qquad (6\text{-}5)$$

where:

HI = Hazard index (unitless)

HQ_i = Hazard quotient for exposure to constituent I (unitless)

Summation of the individual HQ could result in an HI that exceeds 1, even if no single chemical exceeds its acceptable level. Mechanistically, it is not appropriate to sum HQ unless the constituents that make up the mixture have similar effects on the identical organ. Consequently, the summing of HQ for a mixture of compounds that are not expected to include the same type of effects could overestimate the potential risk. The EPA recommends that if the total HI is greater than unity, the components of the mixture should be grouped by critical effect, and separate hazard indices should be calculated for each effect.

6.1.4.3 Results of the Human Health Risk Assessment

The results of the human health risk assessment are summarized below. Tables C.5-1 through C.5-12 are the surface soil results for each of the six source areas. Tables C.5-13 through C.5-24 are the subsurface results for each of the six source areas. Tables C.5-25 and C.5-26 are the surface water results and Tables C.5-27 and C.5-28 are the groundwater results. All tables are located in Appendix C, at the end of Section C.5.3.

6.1.4.3.1 Source Area 1

Potential risks due to surface soil at Source Area 1 are summarized in Tables C.5-1 (lifetime cancer risks) and C.5-2 (hazard quotients). The surface soil pathways identified at Source Area 1 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with highest risk is external exposure to radionuclides. The ILCR for the recreational scenario, external exposure to radionuclides, is 2.7×10^{-5}, with protactinium-234 (1.8×10^{-5}) contributing most of the risk. The ILCR for the residential scenario external exposure to radionuclides is 6.6×10^{-4}, with protactinium-234 (4.5×10^{-4}) contributing most of the risk. The ILCR for the park ranger scenario external exposure pathway to radionuclides is 1.4×10^{-5}, with protactinium-234 (9.3×10^{-6}) contributing most of the risk. Note that protactinium-234 is a daughter of naturally occurring uranium-238 (Faur, 1977). The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 1.0×10^{-4} for the residential scenario. However, protactinium-234, which is naturally occurring, contributes most of the risk. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 1 does not pose a potential significant carcinogenic risk (EPA, 1991b).

For the recreational scenario, only the external exposure pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway, the ILCR is 2.7×10^{-5} for radionuclides with protactinium-234 (1.8×10^{-5}) contributing most of the risk.

For the residential scenario, the pathways that exceed the RME risk of 10^{-6} include incidental soil ingestion, dermal contact, ingestion of home-grown produce and external exposure. For the incidental soil ingestion pathway the ILCR is 7.3×10^{-6} for chemicals, with arsenic (7.3×10^{-6}) contributing most of the risk. For the dermal contact with soil pathway the ILCR is 2.5×10^{-6} for chemicals, with arsenic (2.5×10^{-6}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 3.7×10^{-5} for radionuclides, with radium-228+D

(1.5×10^{-5}) and radium-224 (7.9×10^{-6}) contributing most of the risk. For the external exposure pathway the ILCR is 6.6×10^{-4} with thallium-208 contributing most of the risk.

For the park ranger scenario, only the external exposure pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway, the ILCR is 1.4×10^{-5} for radionuclides with protactinium-234 (9.3×10^{-6}) contributing most of the risk.

Potential risks due to contact with subsurface soil at Source Area 1 are summarized in Tables C.5-13 (lifetime cancer risks) and C.5-14 (hazard quotients). The residential scenario is the only scenario where the subsurface soil pathway is applicable. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for the external exposure and ingestion of home-grown produce. For the external exposure pathway the ILCR is 2.0×10^{-4} for radionuclides, with radium-226+D (1.0×10^{-4}) contributing most of the risk. For the ingestion of home-grown produce the ILCR is 2.4×10^{-4} for radionuclides with lead-210+D (2.1×10^{-4}) contributing most of the risk. Note that protactinium-234 and lead-210+D are daughters of naturally occurring uranium-238 (Faur, 1977). None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 1 does not pose a potential significant carcinogenic risk (EPA, 1991b).

The subsurface soil cumulative site ILCR based on the RME is less than 10^{-6} for all pathways except external exposure, ingestion of home-grown produce, and incidental ingestion of soil. For the external exposure pathway the ILCR is 2.0×10^{-4} with radium-226+D (1.0×10^{-4}), radium-228+D (7.3×10^{-5}), and bismuth-212 (1.8×10^{-5}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 6.5×10^{-6} for chemicals, with benzene (5.8×10^{-6}), contributing most to the risk and 2.4×10^{-4} for radionuclides, with lead-210+D (2.1×10^{-4}) radium-226+D (1.1×10^{-5}), radium-228+D (1.4×10^{-5}) and lead-212 (1.9×10^{-6}) contributing most to the risk. For the incidental soil ingestion pathway, the ILCR is 2.3×10^{-6} for radionuclides, with lead-210+D (1.7×10^{-6}) contributing most of the risk. Note that radium-226 and lead-210 are daughters of naturally occurring uranium-238 and radium-228, lead-212 and bismuth-212 are daughters of naturally occurring thorium-232.

The residential scenario exposure pathway to subsurface soil at Source Area 1 does not pose a significant potential carcinogenic risk. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. The subsurface soil cumulative site ILCR to an individual based on the RME, is less than 10^{-4} except for naturally occurring radionuclides. Therefore, the exposure pathway to subsurface soil at Source Area 1 does not pose a potential significant carcinogenic risk (EPA, 1991b).

6.1.4.3.2 Source Area 2

Potential risks due to surface soil at Source Area 2 are summarized in Tables C.5-3 (lifetime cancer risks) and C.5-4 (hazard quotients). The surface soil pathways identified at Source Area 2 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure pathway (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with the highest risk is external exposure pathway to radionuclides. The ILCR for the recreational scenario external exposure pathway to radionuclides is 2.2×10^{-5}, with thorium-228+D (2.0×10^{-5}) contributing most of the risk. The ILCR for the residential scenario, external exposure pathway to radionuclides, is 5.5×10^{-4}, with thorium-228+D (4.9×10^{-4}) contributing most of the risk. The ILCR for the park ranger scenario to external exposure pathway to radionuclides is 1.2×10^{-5}, with thorium-228+D (1.0×10^{-5}) contributing most of the risk. Note that thorium-228+D is a daughter of naturally occurring thorium-232. The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 10^{-4} for the residential scenario. However, thorium-228+D, which is naturally occurring, contributes most of the risk. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 2 does not pose a potential significant carcinogenic risk (EPA, 1991b).

For the recreational scenario, only one pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway, the ILCR is 2.2×10^{-5} for radionuclides with radium-228+D (2.3×10^{-6}) and, thorium-228+D (2.0×10^{-5}) contributing most of the risk.

For the residential scenario, the pathways that exceed the RME risk of 10^{-6} include incidental soil ingestion, inhalation of dust, ingestion of home-grown produce and external exposure. For the incidental soil ingestion pathway the ILCR is 1.4×10^{-6} for radionuclides with thorium-228+D (1.0×10^{-6}) contributing most of the risk. For the inhalation of dust pathway the ILCR is 1.0×10^{-6} for radionuclides, with thorium-228+D (9.9×10^{-7}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 2.9×10^{-5} for radionuclides, with radium-223 (5.1×10^{-6}), radium-228+D (1.1×10^{-5}), and thorium-228+D (1.1×10^{-5}) contributing most of the risk. For the external exposure pathway the ILCR is 5.5×10^{-4} with radium-223 (2.1×10^{-6}), radium-228+D (5.6×10^{-5}), thorium-228+D (4.9×10^{-4}), and uranium-238+D (1.3×10^{-6}) contributing to the risk.

For the park ranger scenario, the pathway that exceeds the RME risk of 10^{-6} is the external exposure. For the external exposure pathway the ILCR is 1.2×10^{-5} for radionuclides with radium-228+D (1.2×10^{-6}) and thorium-228+D (1.0×10^{-5}) contributing most of the risk.

Potential risks due to contact with subsurface soil at Source Area 2 are summarized in Tables C.5-15 (lifetime cancer risks) and C.5-16 (hazard quotients). The residential scenario is the only scenario where the subsurface soil pathway is applicable. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for the external exposure and ingestion of home-grown produce pathways. For the external exposure pathway the ILCR is 3.7×10^{-4} for radionuclides, with radium-226+D (1.2×10^{-4}), radium-228+D (1.0×10^{-4}), and thorium-228 (1.2×10^{-4}) contributing the most to the risk. For the ingestion of home-grown produce, the ILCR is 4.7×10^{-4} for radionuclides with lead-210+D (4.1×10^{-4}) contributing most of the risk. Note that radium-226 and lead-210+D are daughters of naturally occurring uranium-238 and radium-228 and thorium-228 are daughters of naturally occurring thorium 232. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways, except for a single occurrence of manganese (1.7). Therefore, excluding naturally occurring radionuclides and manganese, Source Area 2 does not pose a potential significant carcinogenic risk (EPA, 1991b).

The subsurface soil cumulative site ILCR, based on the RME, is greater than 10^{-6} for all paths. For the incidental soil ingestion pathway the ILCR is 7.7×10^{-6} for chemicals, with arsenic (6.0×10^{-6}) and beryllium (1.7×10^{-6}) contributing most of the risk and 4.6×10^{-6} for radionuclides, with lead-210+D (3.4×10^{-6}) contributing most of the risk. For the inhalation of dust pathway the ILCR is 1.2×10^{-6} for chemicals, with arsenic (1.1×10^{-6}) contributing most of the risk. For the dermal contact with soil pathway the ILCR is 2.2×10^{-6} for chemicals, with arsenic (2.0×10^{-6}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 4.7×10^{-4} for radionuclides, with cerium-141 (2.4×10^{-6}), cesium-137+D (3.0×10^{-6}), lead-210+D (4.1×10^{-6}), lead-212 (2.4×10^{-6}), radium-224 (1.5×10^{-5}), radium-226+D (1.4×10^{-5}), and radium-228+D (1.9×10^{-6}). For the external exposure pathway, the ILCR is 3.7×10^{-4} with cesium-137+D (1.7×10^{-5}), lead-212 (5.9×10^{-6}), radium-226+D (1.2×10^{-5}), radium-228+D (1.0×10^{-4}) and thallium-208 (1.2×10^{-4}) contributing most of the risk.

The residential scenario exposure pathway to subsurface soil at Source Area 2 does not pose a significant potential carcinogenic risk. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways, except for a single occurrence manganese (1.7) inhalation of dust. The subsurface soil cumulative site ILCR, to an individual based on the RME, is less than 10^{-4} except for naturally occurring radionuclides. Therefore, the exposure pathway to subsurface soil at Source Area 2 does not pose a potential significant carcinogenic risk (EPA, 1991b).

6.1.4.3.3 Source Area 3

Potential risks due to surface soil at Source Area 3 are summarized in Tables C.5-5 (lifetime cancer risks) and C.5-6 (hazard quotients). The surface soil pathways identified at Source Area 3 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure pathway (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with highest risk is external exposure pathway to radionuclides. The ILCR for the recreational scenario external exposure pathway to radionuclides is 7.1×10^{-6}, with thallium-208 (3.8×10^{-6}) contributing most of the risk. The ILCR for the residential scenario external exposure pathway to radionuclides is 1.8×10^{-4}, with thallium-208 (9.4×10^{-5}) contributing most of the risk. The ILCR for the park ranger scenario external exposure pathway to radionuclides is 3.6×10^{-6}, with thallium-208 (1.6×10^{-6}) contributing most of the risk. Note that thallium-208 is a daughter of naturally occurring thorium-232. The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 10^{-4} for the residential scenario. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, and the occurrence of benzo(a)pyrene and dieldrin (discussed below) Source Area 3 does not pose a potential significant carcinogenic risk (EPA, 1991b). Note that benzo(a)pyrene and dieldrin have an ILCR greater than 1.0×10^{-4}, and a HQ less than one.

For the recreational scenario only the external exposure pathway exceeds the RME risk of 1.0×10^{-6}. For the external exposure pathway, the ILCR is 7.1×10^{-6} for radionuclides with thallium-208 (3.8×10^{-6}) contributing most of the risk.

For the residential scenario the pathways which exceed the RME risk of 10^{-6} include incidental soil ingestion, dermal contract, ingestion of home-grown produce and external exposure. For the incidental soil ingestion pathway the ILCR is 4.0×10^{-6} for chemicals, with benzo(a)pyrene (2.7×10^{-6}) and dieldrin (1.3×10^{-6}) contributing most of the risk and 2.6×10^{-6} for radionuclides, with lead-210+D (2.0×10^{-6}) contributing most of the risk. For the dermal contact with soil pathway the ILCR is 3.8×10^{-6} for chemicals, with benzo(a)pyrene (3.1×10^{-6}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 2.6×10^{-4} for chemicals with benzo(a)pyrene (2.3×10^{-4}) and dieldrin (3.0×10^{-5}) contributing most to the risk and 2.7×10^{-4} for radionuclides, with lead-210+D (2.4×10^{-4}), lead-212 (2.1×10^{-6}), radium-224 (8.5×10^{-6}), and radium-228+D (1.3×10^{-5}) contributing most of the risk. For the external exposure pathway, the ILCR is 1.8×10^{-4} with bismuth-212 (6.3×10^{-6}), lead-212 (5.2×10^{-6}), radium-228+D (6.8×10^{-5}), thallium-208 (9.4×10^{-5}), and uranium-238+D (1.2×10^{-6}) contributing most of the risk.

For the park ranger scenario, only the external exposure pathway exceeds the RME risk of 10^{-6}. For the external exposure pathway, the ILCR is 3.6×10^{-6} for radionuclides with radium-228+D (1.4×10^{-6}) and thallium-208 (1.9×10^{-6}) contributing most of the risk.

Potential risks due to contact with subsurface soil at Source Area 3 are summarized in Tables C.5-17 (lifetime cancer risks) and C.5-18 (hazard quotients). The residential scenario is the only scenario where the subsurface soil pathway is applicable. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for the external exposure and ingestion of home-grown produce. For the external exposure pathway the ILCR is 2.9×10^{-4} for radionuclides, with radium-228+D (1.0×10^{-4}) and thallium-208 (1.8×10^{-4}) contributing most of the risk. For the ingestion of home-grown produce the ILCR is 3.2×10^{-4} for radionuclides with lead-210+D (3.0×10^{-4}) contributing most of the risk. Note that lead-210 are daughters of naturally occurring uranium-238 and radium-228 and thallium-208 is a daughter of naturally occurring thorium-232. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 3 does not pose a potential significant carcinogenic risk (EPA, 1991b).

The subsurface soil cumulative site ILCR, based on the RME, is less than 10^{-6} for all pathways except external exposure, ingestion of home-grown produce, and incidental ingestion of soil. For the external exposure pathway the ILCR is 2.9×10^{-4}, with lead-212 (8.6×10^{-6}), radium-228+D (1.0×10^{-4}), and thallium-208 (1.8×10^{-4}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 3.2×10^{-4} for radionuclides, with lead-210+D (3.0×10^{-4}), lead-212 (3.5×10^{-6}), and radium-228+D 0 (1.9×10^{-5}) contributing most to the risk. For the incidental soil ingestion pathway, the ILCR is 3.0×10^{-6} for radionuclides, with lead-210+D (2.5×10^{-6}) contributing most of the risk. Note that lead-210 is a daughter of naturally occurring uranium-238 and radium-228, lead-212 and thallium-208 are daughters of naturally occurring thorium-232.

The residential scenario exposure pathway to subsurface soil at Source Area 3 does not pose a significant potential carcinogenic risk. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for naturally occurring radionuclides. Therefore, exposure pathway to subsurface soil at Source Area 3, does not pose a potential significant carcinogenic risk (EPA, 1991b).

6.1.4.3.4 Source Area 4

Potential risks due to surface soil at Source Area 4 are summarized in Tables C.5-7 (lifetime cancer risks) and C.5-8 (hazard quotients). The surface soil pathways identified at Source Area 4 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (radionuclides), external exposure pathway (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with highest risk is external exposure pathway to radionuclides. The ILCR for the recreational scenario external exposure pathway to radionuclides is 2.2×10^{-5}, with thorium-228+D (1.9×10^{-5}) contributing most of the risk. The ILCR for the residential scenario external exposure pathway to radionuclides is 5.5 × 10^{-4}, with thorium-228+D (4.8 × 10^{-4}) contributing most of the risk. The ILCR for the park ranger scenario the external exposure pathway to radionuclides is, 1.1 × 10^{-5} with thorium-228+D (1.0 × 10^{-5}) contributing most of the risk. Note that thorium-228 is the daughter of naturally occurring thorium-232. The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 10^{-4} for the residential scenario. However, naturally occurring thorium-228+D contributes most to this risk. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 4 does not pose a potential significant carcinogenic risk (EPA, 1991b).

For the recreational scenario, only one pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway the ILCR is 2.2 × 10^{-5} for radionuclides, with thorium-228+D (1.9 × 10^{-5}) and radium-228+D (2.3 × 10^{-6}) contributing most of the risk.

For the residential scenario, the pathways that exceed the RME risk of 10^{-6} include incidental soil ingestion, ingestion of home-grown produce and external exposure. For the incidental soil ingestion pathway, the ILCR is 1.7 × 10^{-6} for radionuclides with thorium-228+D (9.9 × 10^{-7}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 3.8 × 10^{-5} for radionuclides, with cesium-137+D (1.9 × 10^{-6}), protactinium-231 (2.7 × 10^{-6}), radium-223 (4.6 × 10^{-6}), radium-228+D (1.1 × 10^{-5}), thorium-228+D (1.1 × 10^{-5}), uranium-234 (5.4 × 10^{-6}), and uranium-238+D (1.3 × 10^{-6}) contributing most of the risk. For the inhalation of dust pathway the ILCR is 1.2 × 10^{-6}, with thorium-228+D (9.7 × 10^{-7}) contributing most of the risk. For the external exposure pathway, the ILCR is 5.5 × 10^{-4} with cesium-137+D (1.1 × 10^{-5}), radium-223 (1.9 × 10^{-6}), radium-228+D (5.8 × 10^{-5}), and thorium-228+D (4.8 × 10^{-4}), contributing most of the risk.

For the park ranger scenario, only the external exposure pathway exceeds the RME risk of 10^{-6}. For the external exposure pathway the ILCR is 1.1 × 10^{-5} for radionuclides, with thorium-228+D (1.0 × 10^{-5}) and radium-228+D (1.2 × 10^{-6}) contributing most of the risk.

Potential risks due to contact with subsurface soil at Source Area 4 are summarized in Tables C.5-19 (lifetime cancer risks) and C.5-20 (hazard quotients). The residential scenario is the only scenario where the subsurface soil pathway is applicable. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for the external exposure and ingestion of home-grown produce pathways. For the external exposure pathway the ILCR is 9.0 × 10^{-4} for radionuclides, with radium-226+D (5.5 × 10^{-4}), radium-228+D (1.3 × 10^{-4}), and thallium-208 (1.8 × 10^{-4}) contributing most of the risk. For the ingestion of home-grown produce the ILCR is 9.5 × 10^{-4} for radionuclides, with lead-210+D (8.5 × 10^{-4}) contributing most of the risk. Note that radium-226 and lead-210+D are daughters of naturally occurring uranium-238 and radium-228 and thallium-208 are daughters of naturally occurring thorium-232. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 4 does not pose a potential significant carcinogenic risk (EPA, 1991b).

The subsurface soil cumulative site ILCR based on the RME is less than 10^{-6} for all pathways except external exposure pathway ingestion of home-grown produce, and incidental ingestion of soil. For the external exposure pathway the ILCR is 9.0 × 10^{-4} with bismuth-212 (2.5 × 10^{-5}), cesium-137+D (7.7 × 10^{-6}), lead-212 (1.0 × 10^{-5}), radium-226+D (5.5 × 10^{-4}), radium-228+D (1.3 × 10^{-4}), and thallium-208 (1.8 × 10^{-4}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 9.5 × 10^{-4} for radionuclides, with cesium-137+D (1.3 × 10^{-6}), lead-210+D (8.5 × 10^{-4}), lead-212 (4.0 × 10^{-6}), radium-226+D (6.2 × 10^{-5}), radium-228+D (2.6 × 10^{-5}), and thorium-234 (1.7 × 10^{-7}) contributing most of the risk. Note that all the mentioned Source Area 4 radionuclides are daughters of either naturally occurring uranium-238 or thorium-232, except cesium-137+D. Also note that the contribution of cesium-137+D to the subsurface soil total ILCR at Source Area 4 is less than one percent. Therefore, it has been concluded that cesium-137+D is not significant to potential carcinogenic risk to the site as a whole.

The residential scenario exposure pathway to subsurface soil at Source Area 4 does not pose a significant potential carcinogenic risk. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for naturally occurring radionuclides. Therefore, the exposure pathway to subsurface soil at Source Area 4 does not pose a potential significant carcinogenic risk (EPA, 1991b).

6.1.4.3.5 Source Area 5

Potential risks due to surface soil at Source Area 5 are summarized in Tables C.5-9 (lifetime cancer risks) and C.5-10 (hazard quotients). The surface soil pathways identified at Source Area 5 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure pathway (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with highest risk is external exposure pathway to radionuclides. The ILCR for the recreational scenario external exposure pathway to radionuclides is 7.7×10^{-6}, with thorium-228+D (4.7×10^{-6}) contributing most of the risk. The ILCR for the residential scenario external exposure pathway to radionuclides is 1.9×10^{-4}, with thorium-228+D (1.2×10^{-4}) contributing most of the risk. The ILCR for the park ranger scenario to external exposure pathway to radionuclides is 4.0×10^{-6}, with thorium-228+D (2.4×10^{-6}) contributing most of the risk. Note that thorium-228 is the daughter of naturally occurring thorium-232. The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 10^{-4} for the residential scenario. However, naturally occurring thorium-228+D contributes most to this risk. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 5 does not pose a potential significant carcinogenic risk (EPA, 1991b).

For the recreational scenario, only the external exposure pathway exceeds the RME risk of 10^{-6}. For the external exposure pathway the ILCR is 7.7×10^{-6} for radionuclides, with thorium-228+D (4.7×10^{-6}) and radium-228+D (1.9×10^{-6}) contributing most of the risk.

For the residential scenario, the pathways exceed the RME risk of 10^{-6} include incidental soil ingestion, ingestion of home-grown produce and external exposure. For the incidental soil ingestion pathway, the ILCR is 1.3×10^{-6} for radionuclides with uranium-234 (5.8×10^{-7}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 3.9×10^{-5} for radionuclides, with cesium-137+D (4.2×10^{-6}), protactinium-231 (2.0×10^{-6}), radium-223 (3.4×10^{-6}), radium-228+D (9.2×10^{-6}), thorium-228+D (2.6×10^{-6}), and uranium-234 (1.8×10^{-5}) contributing most of the risk. For the external exposure pathway, the ILCR is 1.9×10^{-4} with cesium-137+D (2.4×10^{-5}), radium-223 (1.4×10^{-6}), radium-228+D (4.7×10^{-5}), and thorium-228+D (1.2×10^{-4}) contributing most of the risk.

For the park ranger scenario, only the external exposure pathway exceeds the RME risk of 10^{-6}. For the external exposure pathway, the ILCR is 4.0×10^{-6} for radionuclides with thorium-228+D (2.4×10^{-6}) contributing most of the risk.

Potential risks due to contact with subsurface soil at Source Area 5 are summarized in Tables C.5-21 (lifetime cancer risks) and C.5-22 (hazard quotients). The residential scenario is the only scenario where the subsurface soil pathway is applicable. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for the external exposure and ingestion of home-grown produce pathways. For the external exposure pathway the ILCR is 1.2×10^{-4} for radionuclides, with radium-226+D (1.2×10^{-4}) contributing most of the risk. For the ingestion of home-grown produce the ILCR is 2.0×10^{-4} for radionuclides, with lead-210+D (1.9×10^{-4}) contributing most of the risk. Note that radium-226 and lead-210+D are daughters of naturally occurring uranium-238. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 5 does not pose a potential significant carcinogenic risk (EPA, 1991b).

The subsurface soil cumulative site ILCR based on the RME is less than 10^{-6} for all pathways except external exposure, ingestion of home-grown produce, and incidental ingestion of soil. For the external exposure pathway the ILCR is 1.2×10^{-4}, with radium-228+D (1.2×10^{-4}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 2.0×10^{-4} for radionuclides, with lead-210+D (1.9×10^{-4}) and radium-226+D (1.4×10^{-5}) contributing most of the risk. For the incidental ingestion of soil pathway, the ILCR is 1.9×10^{-6} with lead-210+D (1.6×10^{-6}) contributing most of the risk. Note that radium-226 and lead-210 are daughters of naturally occurring uranium-238 and radium-228 is a daughter of naturally occurring thorium-232.

The residential scenario exposure pathway to subsurface soil at Source Area 5 does not pose a significant potential carcinogenic risk. None of the subsurface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. The subsurface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} except for naturally occurring radionuclides. Therefore, the exposure pathway to subsurface soil at Source Area 5, does not pose a potential significant carcinogenic risk (EPA, 1991b).

6.1.4.3.6 Source Area 6

Potential risks due to surface soil at Source Area 6 are summarized in Tables C.5-11 (lifetime cancer risks) and C.5-12 (hazard quotients). The surface soil pathways identified at Source Area 6 include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure pathway (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The surface soil pathway with highest risk is external exposure pathway to radionuclides. The ILCR for the recreational scenario external exposure pathway to radionuclides is 2.6×10^{-8}, with radium-224 the contributor to the risk. The ILCR for the residential scenario external exposure pathway to radionuclides is 6.5×10^{-7}, with radium-224 the contributor to the risk. The ILCR for the park ranger scenario to external exposure pathway to radionuclides is 1.3×10^{-8}, with radium-224 the contributor to the risk. Note that radium-224 is the only isotope contributing to the radiological risk and that it is the daughter of naturally occurring thorium-232. The surface soil cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational, residential and park ranger scenarios. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, Source Area 6 does not pose a potential significant carcinogenic risk (EPA, 1991b).

For the residential scenario, only the ingestion of home-grown produce pathway exceed the RME risk of 10^{-6}. For the ingestion of home-grown produce pathway, the ILCR is 1.0×10^{-5} for radionuclides, with radium-224 (1.0×10^{-5}) the contributor to the risk.

There is not a subsurface soil pathway for Source Area 6; and therefore, there is no potential risk.

6.1.4.4 Other Media of Concern (Surface Water, Sediment, and Groundwater)

Potential risks due to surface water at the Salmon Site are summarized in Tables C.5-23 (lifetime cancer risks) and C.5-24 (hazard quotients).

The recreational, residential, and park ranger scenario exposure pathways to surface water, all source areas, do not pose a potential carcinogenic risk. None of the surface water PCOCs exceeded a HQ of 1.0 for any of the exposure pathways. The surface water cumulative site ILCR to the future individual based on the RME is less than 10^{-6}. Therefore, the exposure pathway to surface water at the Salmon Site does not pose a potential significant carcinogenic risk (EPA, 1991b).

Sediment

Potential risks due to sediment from all source areas at the Salmon Site are summarized in Tables C.5-25 (lifetime cancer risks) and C.5-26 (hazard quotients). The sediment pathways include incidental soil ingestion (chemicals and radionuclides), dermal contact (chemicals), inhalation of dust (chemicals and radionuclides), external exposure (radionuclides), and ingestion of home-grown produce (chemicals and radionuclides). The ingestion of home-grown produce pathway is only applicable to the residential scenario.

The sediment pathway with highest risk is external exposure to radionuclides. The ILCR for the recreational scenario, external exposure to radionuclides is 5.7×10^{-6}, with thallium-208 (1.8×10^{-6}) and radium-226+D (2.7×10^{-6}) contributing most of the risk. The ILCR for the residential scenario, external exposure to radionuclides, is 1.4×10^{-4}, with thallium-208 (4.5×10^{-5}) and radium-226+D (6.6×10^{-5}) contributing most of the risk. The ILCR for the park ranger scenario external exposure pathway to radionuclides is 2.9×10^{-6}, with thallium-208 (9.2×10^{-7}) and radium-226+D (1.4×10^{-6}) contributing most of the risk. Note that thallium-208 is a daughter of naturally occurring thorium-232 and radium-226+D is a daughter of naturally occurring uranium-238. The sediment cumulative site ILCR to an individual based on the RME is less than 10^{-4} for the recreational and park ranger scenarios. The surface soil cumulative site ILCR to an individual based on the RME is greater than 10^{-4} for the residential scenario. However, thallium-208 and radium-226+D, which is naturally occurring, contributes most of the risk. None of the surface soil PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, excluding naturally occurring radionuclides, sediment does not pose a potential significant carcinogenic risk at the Salmon Site (EPA, 1991b).

For the recreational scenario, only the external exposure pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway the ILCR is 5.6×10^{-6} for radionuclides, with thallium-208 (1.8×10^{-6}) and radium-226+D (2.7×10^{-6}) contributing most of the risk.

For the residential scenario the pathways that exceed the RME risk of 10^{-6} include incidental soil ingestion, ingestion of home-grown produce, and external exposure. For the incidental soil ingestion pathway the ILCR is 5.5×10^{-6} for radionuclides, with lead-210+D (5.0×10^{-6}) contributing most of the risk. For the ingestion of home-grown produce pathway the ILCR is 6.5×10^{-4} for radionuclides, with cadmium-109 (1.4×10^{-5}), cesium-137+D (3.0×10^{-6}), lead-210+D (6.1×10^{-4}), radium-224+D (1.3×10^{-5}), radium-226+D (7.5×10^{-6}), and uranium-238+D (1.8×10^{-6}) contributing most of the risk. For the external exposure pathway, the ILCR is 1.4×10^{-4} with beryllium-7 (9.5×10^{-6}), bismuth-212 (1.7×10^{-6}), cesium-137+D (1.7×10^{-5}), radium-226+D (6.6×10^{-5}), thallium-208 (4.5×10^{-5}), and uranium-238+D (1.1×10^{-6}) contributing most of the risk.

For the park ranger scenario only the external exposure pathway exceeded the RME risk of 10^{-6}. For the external exposure pathway the ILCR is 2.9×10^{-6} for radionuclides, with radium-226 (1.4×10^{-6}) contributing most of the risk.

Note that beryllium and cadmium are naturally occurring radionuclides, radium-226 and lead-210 are daughters of naturally occurring uranium-238 and bismuth-212, thallium-208, radium-224 and radium-228 are daughters of naturally occurring thorium-232. Also note that the contribution of cesium-137+D to the total sediment ILCR at Salmon Site is less than one percent. Therefore, it has been concluded that cesium-137+D is not significant to potential carcinogenic risk to the site as a whole. None of the sediment PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways. Therefore, it has been concluded that cesium-137+D is not significant to potential carcinogenic risk to the site as a whole.

Groundwater

Potential risks due to groundwater at the Salmon Site are summarized in Tables C.5-27 (lifetime cancer risks) and C.5-28 (hazards quotients). Currently, there are no on-site wells, and fate and transport modeling show that extremely small PCOC concentrations reached the site boundary. The only complete groundwater scenario is the potential for a future resident to drill a domestic well for household use in either the Alluvial or the Local Aquifer on the Salmon Site.

The residential scenario is the only scenario where the groundwater pathway is applicable. The groundwater pathways identified at the Salmon Site include incidental groundwater water ingestion (chemicals and radionuclides), dermal contact (chemicals and radionuclides), inhalation of VOCs (chemicals), and ingestion of home-grown produce (chemicals and radionuclides).

For Alluvial Aquifer, residential scenario, the incidental groundwater ingestion pathway the ILCR is 2.1×10^{-4} for chemicals, with arsenic (1.4×10^{-4}) contributing the most to the risk and 1.3×10^{-4} for radionuclides, with tritium (1.3×10^{-4}) the contributor to the risk. None of the groundwater PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways.

The Alluvial Aquifer, groundwater cumulative site ILCR based on the RME is less than 10^{-6} for all pathways except ingestion of groundwater and ingestion of home-grown produce. For the ingestion of groundwater pathway the ILCR is 2.1×10^{-4} for chemicals, with arsenic (1.4×10^{-4}), trichloroethene (4.6×10^{-6}), and vinyl chloride (6.7×10^{-5}) contributing to the risk and 1.3×10^{-6} for radionuclides, with tritium (1.3×10^{-4}) the contributor to the risk. For the ingestion of home-grown produce pathway the ILCR is 1.7 × 10^{-6} for chemicals, with vinyl chloride (1.5 × 10^{-6}) contributing most to the risk.

For Local Aquifer, residential scenario, the incidental groundwater ingestion pathway, the ILCR is 7.7 × 10^{-4} for chemicals, with arsenic (7.7 × 10^{-4}) the contributor to the risk. The HQ for arsenic is 4.0 for the ingestion of groundwater from the local aquifer.

The Local Aquifer groundwater cumulative site ILCR based on the RME is less than 10^{-6} for all pathways except ingestion of groundwater and dermal contact while showering. For the ingestion of groundwater pathway the ILCR is 7.7 × 10^{-4} for chemicals, with arsenic (7.7 × 10^{-4}) the contributor to the risk. For the dermal contact with groundwater while showering pathway, the ILCR is 2.2 × 10^{-6} for chemicals, with arsenic (2.2 × 10^{-6}) the contributor to the risk.

The residential scenario exposure pathway to groundwater at the Salmon Site does not pose a significant potential carcinogenic risk for either the Alluvial or the Local Aquifers. None of the groundwater PCOCs exceeded a HQ of 1.0 for any of the potential exposure pathways except arsenic (4.0), Alluvial Aquifer, ingestion of groundwater (Table C.5-28). The groundwater cumulative site ILCR to a future individual based on the RME is less then 10^{-4} except for arsenic (1.4 × 10^{-4}) and tritium (1.3 × 10^{-4}) Alluvial Aquifer, Ingestion of groundwater pathway and arsenic (7.7 × 10^{-4}) Local Aquifer, ingestion of groundwater (Table C.5-27).

6.1.4.5 General Uncertainties

The overriding uncertainties associated with the risk characterization are as follows:

A. Short half-life daughters were carried through the risk analysis when no analytical information was available for the parents (i.e., the parents were either below background or not detected). Many of these remaining daughters may have been below background.

B. Radiological decay was not considered in the risk models. Many of the radionuclides detected at the Salmon Site have half-lives less then the assumed residential exposure duration of 30 years.

C. The extrapolation of toxic effects observed at the high doses necessary to conduct animal studies to effects that might occur at much lower, more realistic doses is uncertain.

D. The extrapolation from toxic effects in laboratory animals to toxic effects in humans (i.e., responses of animals may be different from responses of humans) is uncertain.

E. The conservative estimation of receptor concentrations for PCOC are above the true average and include maximum values and upper 95 percent confidence limits.

F. The pathways selected are the most conservative (i.e., residential).

G. Currently there is limited receptor point of contact at any area of concern or media.

H. Pathway analyses have been conservative and generally do not include fate and transport considerations (e.g., dispersion, adsorption) in the estimates.

I. The groundwater risk for each aquifer was calculated with the maximum detected concentration for each PCOC. This assumes that these concentrations all occur at the same location and that the potential receptor installs a water-supply well at this location. The probability of both these events occurring is very low.

6.2 Ecological Risk Assessment

The following is a brief summary of the conclusions for the baseline ecological risk assessment for the Salmon Site. The complete Baseline Ecological Risk Assessment for the Salmon Site is in Exhibit 2.

For the ecological assessment at the Salmon Site, the following assumptions were made:

A. PCOCs and their respective concentrations in on-site media were appropriate indicators of overall contamination.

B. Bioassay tests performed with media collected from the site were appropriate indicators of gross biological effect.

C. Field observations made on a qualitative basis were indicative of overall community and individual stress.

D. The reference sites selected were similar to the study areas with regard to environmental characteristics, but were relatively unaffected by site-related activities and contamination.

E. Only those constituents with site concentrations greater than reference area concentrations (for organics and inorganics) were considered further as possible PCOCs.

Risks posed by PCOC concentrations within the surface water, sediment, soil, and biological tissues were assessed through comparisons with benchmarks. These benchmarks were criteria or standards gathered through review of the scientific literature. Contaminant concentrations exceeding benchmarks are indicative of potentially stressful conditions.

Toxicity test response data from the on-site samples and reference sample were compared, and any on-site sample showing statistically significant adverse responses relative to the reference sample was considered to show measurable toxicity.

Comparisons between on-site community conditions and reference conditions or expected conditions were made using biological data gathered from benthic macroinvertebrate analyses or terrestrial site observations. In addition, chemical concentrations within biotic tissue could offer evidence of exposure, which may be detrimental or lead to food chain transfers.

The Ecological Risk Assessment (Exhibit 2) of this report describes the exposure pathways and the factors relating to them. Five pathways have the potential to expose biota to PCOCs: water, sediment, soil, air, and biota via food chain transfers. The following sections describe the potential risk to ecological receptors posed by each pathway, within the aquatic and terrestrial ecosystems.

6.2.1 Aquatic Ecosystem

The aquatic ecosystems at the Salmon Site were assessed using two assessment endpoints: benthic macroinvertebrate community viability, and probability of subacute effects in pelagic organisms.

6.2.1.1 Water Pathway

Some impairment of benthic communities according to Rapid Bioassessment Protocols (RBP) III metrics (EPA, 1989b) was detected at stations HMC-2, HMC-3, HMC-5, BeP-1, BeP-1a, and BeP-2. Impairment of benthic communities was also detected at stations HMC-5, BeP-1, BeP-1a, and BeP-2, as well as stations HMC-4, HOP-1, and GaP-1. This impairment could be due to elevated contaminant concentrations or to habitat factors. Impairment based on acute toxicity testing was not observed at any stations.

There is strong evidence for absence of contaminant-induced risk at both GrC-2 and HHC-2 since impairment was not detected according to analytical data, bioassay tests, or field observations. The slight impairment at HMC-2 and HMC-3 is probably not due to contaminants because the PCOC concentrations were not elevated with respect to the reference areas. The measured contaminants in the Half Moon Creek Overflow Pond, the Gator Pond, and HMC-4, though elevated, may not be bioavailable to organisms because no impairment was found. Station HMC-5 had a high concentration of aluminum (235 µg/L). This exceeds the chronic criteria of 87 µg/L by a factor of almost three. Although no acute toxicity was found in these surface waters, elevated aluminum may be causing chronic risk to organisms, thus, may be the cause of the slight impairment in benthic macroinvertebrate communities there, according to RBP III metric interpretation. Risk to the fish population due to aluminum or iron would appear to be negligible because the site tissue samples had lower concentrations than the reference sample.

Tritium contributed the entire internal dose to fish; but the total dose, including that received from sediments, was still well below the protective criterion for aquatic populations. The dose to the great blue heron was also extremely low and within protective dose rates. Therefore, radiation poses no risk to aquatic biota through the water pathway.

6.2.1.2 Sediment Pathway

The Beaver Pond had high levels of many contaminants. Although surface waters were not found to be acutely toxic, the benthic macroinvertebrate community appeared stressed relative to the reference area. The elevated levels of PCOCs in the sediments may be causing chronic effects on aquatic biota in the Beaver Pond.

On an over-all basis, the only apparent potential for risk would be related to the presence of elevated levels of barium and manganese. However, although site fish tissues had elevated concentrations of these elements compared to the reference sample, adverse effects would not be expected in the aquatic life on the site because neither barium nor manganese exists in high soluble (bioavailable) concentrations in fresh water. Neither chemical was considered a PCOC in surface water. Because these two metals are widely found in nature and manganese is a micronutrient, it is likely that the concentrations in the fish are within normal ranges and do not represent a site-wide risk. However, the lack of effects data for manganese and barium in fish tissue could be considered a data gap.

Radiation, as discussed above, was calculated as a total dose to fish and Herons from water and sediment sources and poses no risk to aquatic biota.

6.2.2 Terrestrial Ecosystems

The terrestrial ecosystems at the Salmon Site were assessed using two assessment endpoints: change in floral community diversity and probability of chronic effects in the faunal community.

6.2.2.1 Soil Pathway

The Salmon Site tissue results for lead and copper were compared to literature reference values and calculations of dose to a top predator. Based on this comparison, it was concluded that no adverse effects would be expected for terrestrial receptors on a site-wide basis. The same is true for radiation sources, for which the calculated dose to the mouse was well below the protective criterion for terrestrial populations. It is reasonable to extrapolate these results to the Bachman’s sparrow, game birds, and Gopher Tortoise because of the similarity in their diets. The birds would have less contact with soils than the mouse. Although the Gopher Tortoise may have more soil contact, its shell is an effective shield against radiation (Cosgrove, 1971).

There were no observed signs of stress at any of the sites except for the physical alterations due to DOE-related activities. Based on laboratory toxicity tests, there was no evidence of acute toxicity to flora in the surficial soils; however, PCOCs were present at a few sites. The Clean Burn Pit in SA-2 and the HT-2 Well Area in SA-5 had high levels of both alpha and beta activity and some other radionuclides. The West Substation in SA-4 also had high measurements of gross alpha, beta activity, other radionuclides, and also had high levels of copper. Although the potential for risk to terrestrial receptor populations site-wide is negligible, there may be risk of chronic effects to individuals in these localized areas.

6.2.2.2 Air Pathway

There is no expected ecological risk related to the air pathway. The only release mechanism to air for lead and copper would be through adsorption to soil-particles and mobilization to air as fugitive dust. A similar mechanism is also possible for radionuclides. Minor levels of noble gases, such as krypton and argon, may have been emitted during reentry drilling operations. However, intake via this mechanism is probably minimal relative to other pathways. PCOCs absorbed by this pathway would have been accounted for in the tissue analyses, which concluded that risk is negligible.

6.2.3 Uncertainty Analysis

The assumption used for this assessment was that all site receptors were exposed to all site contaminants within an ecosystem (i.e., habitat was not delineated by source area). The following are uncertainties that may affect the outcome of risk characterization:

- Impacts to individual organisms on a site-wide basis are considered in this assessment as a predictor of impacts to populations. Generally, except for threatened and endangered species, assessments need only evaluate population effects. Evaluating risks to individual organisms tends to overestimate risks to populations.

- In estimating effects to red-tailed hawks from lead and copper, a conservative calculation was used, and no depuration losses were assumed.

- Applicability of literature-derived data depends on types of results presented and methods used to arrive at these results. Test endpoints produced by laboratory and field tests may be reported as formally defined toxicological endpoints or as less stringently defined measures of mortality or sublethal effect; variations in format introduce a source of error when subsumed into a single acceptable level value. Thus, seemingly equivalent values may in fact be significantly different due to differences in test protocols, test conditions, or responses of individual organisms.

- Regulatory standards, criteria, and/or toxicological data were not available for every PCOC (i.e., barium and manganese); thus, they could not be evaluated for potential impacts. These data gaps may cause an underestimate of risk because unevaluated PCOCs could be unrecognized sources of risk.

- Tissue concentrations may only represent one, two, or more animals of different species and may lead to either over- or underestimations of exposure to a population. No samples representative of avian tissue PCOC concentrations were sampled, and extrapolations from mammalian values were used. Also, no reference sources were sampled, and comparisons had to be made to literature-derived values.

- Synergistic, additive, and antagonistic interactions between chemicals were not explored.

6.3 Human Health Risk Assessment Results

The section summarizes the human health risk assessment results for the Salmon Site. The Salmon Site ecological risk assessment is presented, and summarized in, *Baseline Ecological Risk Assessment, Salmon Site, Lamar County, Mississippi* (DOE/NV, 1995a).

6.3.1 Remedial Investigation Results

Based on results of the Baseline Ecological Risk Assessment, the RI groundwater flow and transport model, and human health risk assessment, the risk to existing and future land-use scenarios at the Salmon Site are minimal. The summed ILCR for all sources and pathways for the recreational and park ranger scenarios are less than 10^{-6}. The summed ILCR for all sources and pathways for the residential scenario are slightly greater than 10^{-6}. However, when some of the residential scenario conservative assumptions are replaced with more realistic assumptions, the ILCR for the residential scenario is less than 10^{-6}. The sources of contaminated media that were part of the human health risk assessment are in the subsurface at the SGZ Mud Pits and shallow groundwater in the immediate vicinity of the SGZ Mud Pits. The test cavity contaminants, within the underground salt dome, were not included in the human health risk assessment because it is extremely unlikely there would ever be a human exposure.

Near-surface contaminants at the Salmon Site that are contributing to the risk are primarily associated with the SGZ Mud Pits. The SGZ Mud Pits are located within approximately 100 m from SGZ. As stated in Section 1.1.2, remedial actions completed in 1972 included removal and off-site disposal of the source of contamination at all the source areas at the Salmon Site. During the 1972 remedial action, sources of the contaminants were removed from the SGZ Mud Pits to approximately the water table. The only significant residual contamination remaining at the Salmon Site is below the water table, in the SGZ Mud Pits. The SGZ Mud Pits excavation was backfilled with clean soil that caps the residual material and serves as an effective barrier between the residual material and the surface. This soil barrier supports a vegetative cover and significantly reduces the potential for accidental contact with the residual material below the groundwater table.

Based on sample results and other RI evidence, the residual material that remains in the SGZ Mud Pits is contained. Soil and water laboratory results and groundwater flow and transport model calculations indicate that the contaminants in the SGZ Mud Pits are slightly hydraulically connected with the Alluvial and Local Aquifers. Contaminants detected inside the SGZ Mud Pits are at significantly higher concentration inside the SGZ Mud Pits than outside the SGZ Mud Pits, indicating the transport of contaminants between the SGZ Mud Pits and aquifer is minimal. Sample laboratory analysis also indicates that the detected chemical constituents, primarily TCE, is reducing in concentration through natural attenuation and radioisotope, (tritium) are radiologically decaying. The identified effected groundwater plume will naturally attenuate and/or decay below the regulatory limit in approximately two years. The groundwater plume will not migrate beyond the risk-based site compliance boundary.

Based on the well installation data and sampling of soil and groundwater throughout the subsurface horizons, the test cavity within the salt dome was determined not to be leaking radioactivity into the less shallow groundwater aquifers (Aquifers 1, 2a, 2b, and 3). Historical data collected through the implementation of the Long-Term Hydrological Monitoring Program, conducted by the EPA since the 1970s, and by the Mississippi Department of Health (MDOH) supports this conclusion.

6.3.2 Human Health Risk Assessment

A human health risk assessment was performed for the identified PCOCs at all the source areas. The scenario selected was the existing site use, a recreational scenario, and future land uses. The future site use scenarios evaluated were the conservative case scenario (a permanent resident) and a reasonable case (a park ranger). For the existing recreational and future residential scenarios, both the child and adult were evaluated. For the park ranger, only an adult was evaluated. The Summed ILCR results for the three scenarios are summarized on Tables 6-3, 6-4, and 6-5. Table 6-3 and Table 6-4 summarize the surface and subsurface soil summed ILCRs for

Table 6-3
Summary of Surface Soil Summed ILCR

Source Area	Risk	Recreational	Residential	Park Ranger
1	Total Risk (Summed ILCR)	2.8×10^{-5}	7.1×10^{-4}	1.4×10^{-5}
	Percent External Exposure	98	93	97
	Percent Home-Grown	NA	5	NA
	Percent All Other Risk	2	2	3
2	Total Risk (Summed ILCR)	2.2×10^{-5}	5.8×10^{-4}	1.2×10^{-5}
	Percent External Exposure	100	95	100
	Percent Home-Grown	NA	5	NA
	Percent All Other Risk	<1	<1	<1
3	Total Risk (Summed ILCR)	7.7×10^{-6}	7.2×10^{-4}	4.1×10^{-6}
	Percent External Exposure	93	25	87
	Percent Home-Grown	NA	74	NA
	Percent All Other Risk	7	1	13
4	Total Risk (Summed ILCR)	2.2×10^{-5}	5.9×10^{-4}	1.1×10^{-5}
	Percent External Exposure	100	93	99
	Percent Home-Grown	NA	6	NA
	Percent All Other Risk	< 1	1	1
5	Total Risk (Summed ILCR)	7.8×10^{-6}	2.3×10^{-4}	4.1×10^{-6}
	Percent External Exposure	99	82	99
	Percent Home-grown Produce	NA	17	NA
	Percent All Other Risk	1	1	1
6	Total Risk (Summed ILCR)	3.5×10^{-8}	1.1×10^{-5}	1.9×10^{-8}
	Percent External Exposure	0	6	68
	Percent Home-grown Produce	NA	92	NA
	Percent All Other Risk	100	2	32

Note: Summed ILCR is the sum of all site sources and pathways.
Percent external exposure is the percent contribution of external exposure (radiological) to the total summed ILCR.
Percent home-grown produce is the percent contribution of consumed produce (chemical and radiological) to the total summed ILCR.
Percent all other risk sources is the percent contribution of all risk sources except external exposure and the consumption of home-grown produce to the total summed ILCR.

Table 6-4
Summary of Subsurface Soil Summed ILCR

Source Area	Risk	Residential
1	Total Risk (Summed ILCR)	4.5×10^{-4}
	Percent External Exposure	45
	Percent Home-Grown Produce	55
	All Other Risk Sources	<1
2	Total Risk (Summed ILCR)	8.6×10^{-4}
	Percent External Exposure	43
	Percent Home-Grown Produce	55
	Percent All Other Risk Sources	2
3	Total Risk (Summed ILCR)	6.1×10^{-4}
	Percent External Exposure	47
	Percent Home-Grown Produce	52
	Percent All Other Risk Sources	1
4	Total Risk (Summed ILCR)	1.9×10^{-3}
	Percent External Exposure	48
	Percent Home-Grown Produce	51
	Percent All Other Risk Sources	1
5	Total Risk (Summed ILCR)	3.2×10^{-4}
	Percent External Exposure	37
	Percent Home-Grown Produce	62
	Percent All Other Risk Sources	1

Note: Summed ILCR is the sum of all site sources and pathways
Percent external exposure is the percent contribution of external exposure (radiological) to the total summed ILCR.
Percent home-grown produce is the percent contribution of consumed produce (chemical and radiological) to the total summed ILCR.
Percent all other risk sources is the percent contribution of all risk sources except external exposure and the consumption of home-grown produce to the total summed ILCR.

Table 6-5
Summary of Surface Water, Sediment and Groundwater Summed ILCRs

Source	Risk	Recreational	Residential	Park Ranger
Surface Water	Total Risk (Summed ILCR)	2.9×10^{-9}	1.1×10^{-8}	2.9×10^{-9}
Sediment	Total Risk (Summed ILCR)	5.9×10^{-6}	8.0×10^{-4}	3.0×10^{-6}
Groundwater Alluvial Aquifer	Total Risk (Summed ILCR)	NA	3.4×10^{-4}	NA
Groundwater Local Aquifer	Total Risk (Summed ILCR)	NA	7.7×10^{-4}	NA

each source area. Table 6-5 summarizes the surface water, sediment, and groundwater summed ILCR, by the respective source areas.

A review of the human health risk assessment results for the surface and subsurface soil sources indicate that the constituents that most influence the soil risk is naturally occurring radioactive material (NORM), see Appendix C, Tables C.5-1 through C.5-22. These naturally occurring isotopes are primarily mercury, protactinium, radium, thallium, tin and uranium and are not typical associated as fission products from a nuclear explosion. These isotopes are detected throughout the site, in all source areas, without a definable source or emanating contaminant plume. Reviewing the human health risk assessment calculations, in all land-use scenarios, NORM accounts for greater than 95 percent of the total risk for the surface and subsurface soil source.

The human health risk assessment calculations were performed with the assumption that institutional controls would not be maintained, either in the surface or subsurface. However, it is anticipated that as a minimum, existing surface institutional controls and subsurface restrictions will be maintained. By maintaining existing surface institutional controls at the Salmon Site, the incidental ingestion, dermal contact, ingestion of home-grown produce (only applicable for the residential scenario) and external exposure pathways will be minimized and/or eliminated.

As previously stated in the introduction of Section 6.0, the human health risk assessment follows EPA RAGS (EPA, 1989a) which generally requires a conservative case be utilized for the risk calculations. Therefore, the Salmon Site human health risk calculations assumed that current and future institutional controls would not exist and there would be exposure by the existing and future scenarios to contaminants. With existing and future institutional controls, the realistic sources would be surface soil, sediment and surface water. The subsurface contaminant source would be a source of risk only applicable for the residential scenario. With existing or future institutional controls, the pathway that remains includes direct contact and incidental ingestion of surface soil, sediment and surface water, and the inhalation of dust (which is extremely limited because of the vegetative cover, high seasonal humidity, low ambient dust at the site).

Surface Soil

The surface soil summed (all sources and all pathways) ILCR for the recreational scenario ranged from 3.5×10^{-8} (Source Area 6) to 2.8×10^{-5} (Source Area 1). The percent contribution of external exposure to radiation ranged from 98 to approximately 100 percent of the total risk excluding Source Area 6 which has a total risk summed ILCR of 3.5×10^{-8}. Maintaining surface institutional controls, the summed ILCR minus the surface radiation source would be reduced to range from 3.5×10^{-8} (Source Area 6) to 5.6×10^{-7} (Source Area 3). With the removal of all pathways, except inhalation of dust, the summed ILCR would range from 3.0×10^{-10} (Source Area 6) to 4.8×10^{-8} (Source Area 4). The MDEQ guidance uses a summed ILCR of 1×10^{-6} as a target risk level for remedial actions (MDEQ, 1999).

The surface soil summed ILCR for the residential scenario ranged from 1.1×10^{-5} (Source Area 6) to 7.1×10^{-4} (Source Area 1). The percent contribution of external exposure to radiation and consumption from home-grown produce ranged from 98 to approximately 100 percent of the total risk. Maintaining surface institutional controls the summed ILCR minus the surface radiation and consumption of home-grown produce sources would be reduced to a range from 2.2×10^{-7} (Source Area 6) to 1.0×10^{-5} (Source Areas 1 and 3). With the removal of all pathways except inhalation of dust, the summed ILCR would range from 7.6×10^{-9} (Source Area 6) to 1.2×10^{-6} (Source Area 4).

The surface soil summed ILCR for the park ranger scenario ranged from 1.9×10^{-8} (Source Area 6) to 1.4×10^{-5} (Source Area 1). The percent contribution of external exposure to radiation ranged from 87 to approximately 100 percent of the total risk. Maintaining surface institutional controls, the summed ILCR minus the surface radiation source would be reduced to a range from 5.7×10^{-9} (Source Area 6) to 5.2×10^{-7} (Source Area 3). With the removal of all pathways, except inhalation of dust, the summed ILCR would range from 1.6×10^{-10} (Source Area 6) to 2.5×10^{-8} (Source Area 4).

Subsurface Soil

The subsurface soil pathway is only applicable to the residential scenario. The subsurface soil summed ILCR for the residential scenario ranged from 3.2×10^{-4} (Source Area 5) to 1.9×10^{-3} (Source Area 4). The percent contribution of external exposure to radiation and consumption from home-grown produce ranged from 98 to 99 percent of the total risk. Maintaining surface institutional controls, the summed ILCR minus the surface radiation and consumption of home-grown produce sources would reduce the summed ILCR range from 1.9×10^{-6} (Source Area 5) to 1.6×10^{-5} (Source Area 2). With the removal of all pathways, except inhalation of dust, the summed ILCR would range from 4.4×10^{-10} (Source Area 1) to 9.7×10^{-8} (Source Area 4).

The summed ILCR for the residential scenario (the most conservative scenario), is slightly greater than the MDEQ target value. However, with institutional controls in place the residential scenario would not occur, would only be allowed to occur either after the contaminants have naturally attenuated to below the regulatory limit, or would be restricted to a designated area of the Salmon Site. Therefore, it can be reasoned that the summed ILCR for the surface and subsurface pathways are below the MDEQ target value with institutional controls.

Surface Water

The surface water summed ILCR are presented on Table 6-5. The summed ILCR for the recreational scenario was 2.9×10^{-9}, the residential scenario was 1.1×10^{-8} and for the park ranger was 2.9×10^{-9}. Note that the recreational and park ranger results are identical because of the identical sources and pathways and all the ILCR values are below the MDEQ target value.

Sediment

The sediment summed ILCR are presented on Table 6-5. The sediment summed ILCR is 5.9×10^{-6} for the recreational scenario, 8.0×10^{-4} for the residential scenario and 3.0×10^{-6} for the park ranger scenario. The percent contribution from external exposure for these scenarios due to external radiation is 96 and 95 percent of the recreational and park ranger scenarios, respectively, of the total risk. For the residential scenario, the percent contribution from external exposure and consumption of home-grown produce is 99 percent of the total risk. Maintaining surface institutional controls, the summed ILCR minus just the external exposure source for the recreational and park ranger scenario would be reduced in range to 2.2×10^{-7} and 1.4×10^{-7}, respectively. With institutional controls, the summed ILCR for the residential scenario minus just external radiation and the consumption of home-grown produce sources would be reduced to 5.6×10^{-6}.

A conservative, worst case, assumption made with the sediment pathway calculation was that there would be direct contact with the sediment in the creeks and ponds and that the sediment would be dry to create the dust pathway. In addition, it was assumed that home-grown produce would be grown in/on the sediments and consumed. If a more realistic assumption were made that the sediments would remain wet for most of the year and produce would not be grown on the sediment, which historical records indicate is valid. The only realistic pathway for sediment contaminants is incidental direct contact. The sediment source total summed ILCR would be reduced to significantly below the MDEQ target value of 10^{-6} if the realistic case was assumed.

Groundwater

The groundwater summed ILCR are presented on Table 6-5. The groundwater pathway is only applicable for the residential scenario utilizing groundwater in the Alluvial Aquifer. The summed ILCR for the resident recreational scenario utilizing the Alluvial Aquifer is 3.4×10^{-4}, and for the Local Aquifer is 7.7×10^{-4}. As previously stated, maintaining institutional controls at the site will restrict the installation of water wells at the potable use of groundwater at the site. In addition, a water supply system in the immediate vicinity of the Salmon Site is being proposed by the DOE, further eliminating this pathway. Groundwater flow and transport modeling results predict that the PCOC identified in groundwater will naturally decay to below regulatory limits within two years. This decay was observed with groundwater samples analytical results. Through the DOE’s remedial measures to install the water supply system, and the natural decay of the contaminants, this pathway and source will be eliminated.

Results from the human health risk assessment indicate that if surface and subsurface institutional controls are maintained, and there are no significant risks to human health and the environment above the MDEQ target level.

7.0 Conclusions and Recommendations

Results of the Salmon Site RI indicate that contaminants were detected at the site in concentrations that do not present a significant risk to existing and/or future land users, if surface institutional controls and subsurface restrictions are maintained. Soil and water sampling results determined that contamination, primarily TCE and tritium, were present at the SGZ Mud Pits at a depth below the water table. Surface contamination was not encountered at the SGZ Mud Pits. No other significant surface or shallow subsurface contamination was detected at a source area. The test cavity resulting from the experiment is contaminated and presently cannot be economically remediated with existing technologies. The ecological sampling did not detect a biological uptake of contaminants in the plants or animals sampled.

Arsenic was detected in soil and groundwater samples collected throughout the site and appears to be naturally occurring. Arsenic was detected in groundwater samples collected in Source Area 2 above the MCL. For completeness, arsenic was modeled and included in the human health risk assessment even though there are no suspected arsenic contamination sources at the Salmon Site as a result of DOE activities.

Tritium and TCE laboratory results from soil samples collected inside and outside of the SGZ Mud Pits indicate that the contaminants are at a higher concentration inside the SGZ Mud Pits than outside. This means that the SGZ Mud Pit contamination is contained, and contaminants are not being readily transported into the Alluvial Aquifer. The laboratory results over time also show that the contaminants are naturally decaying (decreasing in concentrations). Groundwater flow and transport modeling confirmed this observation and calculated that the tritium and TCE will naturally decay to below the respective MCLs, within two years. The two years are significantly less than the time required for the contaminants to reach the site compliance boundary.

It is intended that as a minimum, existing surface institutional controls and subsurface restrictions will be maintained at the Salmon Site. The future land use for the site is the release of the surface land area to the State of Mississippi for use as a wildlife refuge and working demonstration forest. This action was instituted and mandated by the Public Law (Section 2851[b] of Part IV of the *National Defense Authorization Act* for Fiscal Year 1997, Public Law 104-201 - Sept. 23, 1996). Agreements will be enacted with the State of Mississippi for the acceptance and transfer of the surface land area. The agreements will be completed prior to the completion of the site closure.

7.1 Remedial Investigation Results

Based on results of the Baseline Ecological Risk Assessment, the RI groundwater flow and transport model, and human health risk assessment, the risk to existing and future land-use scenarios at the Salmon Site are minimal. The summed ILCR for all sources and pathways for the recreational and park ranger scenarios are less than the MDEQ target level of 10^{-6} (MDEQ, 1999). The summed ILCR for all sources and pathways for the residential scenario are slightly greater than 10^{-6}. However, when some of the residential scenario conservative assumptions are replaced with more realistic assumptions, the ICLR for the residential scenario is less than 10^{-6}. The sources of contaminated media that were part of the human health risk assessment are in the subsurface at the SGZ Mud Pits and shallow groundwater in the immediate vicinity of the SGZ Mud Pits. The test cavity contaminants, within the underground salt dome, were not included in the human health risk assessment because it is extremely unlikely there would ever be a human exposure.

Contaminants detected at the Salmon Site are primarily associated with the SGZ Mud Pits. This area is approximately 100 m from SGZ. As stated in Section 1.1.2, remedial actions completed in 1972 removed and disposed of contamination sources from all the source areas at the Salmon Site. During the 1972 remedial action, sources of contaminants were removed from the SGZ Mud Pits to the water table (approximately 2 m [6 ft]). The only significant residual contamination remaining at the Salmon Site in the SGZ Mud Pits is below the water table. During the 1972 remedial action, the SGZ Mud Pits excavation was backfilled with clean soil that provides an effective barrier between the remaining material and the surface. This soil barrier supports a vegetative cover and minimizes the potential for accidental contact with the contaminated residual material below the groundwater table.

Based on sample results and other RI evidence, the residual material remains in the SGZ Mud Pits and contaminant transport into the shallow aquifers is minimal. The chemical constituents, primarily TCE, are being reduced in concentration through natural attenuation and the radioisotope (tritium) is naturally decaying. Soil and water laboratory results and groundwater flow and transport model calculations, in the area surrounding SGZ, indicate that contaminant transport from the SGZ Mud Pits to the Alluvial and Local Aquifers is minimal. The identified groundwater plume will naturally attenuate and/or decay below the regulatory limit in approximately two years and will not migrate beyond the site boundary.

The test cavity within the salt dome was determined, based on the installation and sampling of soil and groundwater throughout the subsurface horizons, not to be leaking radioactivity into the Alluvial Aquifer, Local Aquifer, or Aquifers 1, 2a, 2b, and 3. Therefore, the radioisotopes are confined to the test cavity. Historical data collected through the implementation of the Long-Term Hydrological Monitoring Program, conducted by the EPA since the 1970s, and by the Mississippi Department of Health supports this determination.

7.2 Human Health Risk Assessment

A human health risk assessment was performed for the identified PCOCs at all the source areas and the results are summarized in Section 6.3. The scenarios selected were the existing site use, a recreational scenario, and the future land uses. The future site use scenarios evaluated were the conservative case (a resident) and a reasonable case (a park ranger). For the existing recreational and future residential scenarios both the child and adult were evaluated. For the park ranger only an adult was evaluated. The summed ILCR results are summarized on Tables 6-3, 6-4, and 6-5. The human health risk assessment calculations were performed with the assumption that existing institutional controls and subsurface restrictions would not be maintained. Maintaining institutional controls of the site would minimize and/or eliminate the incidental ingestion, dermal contact, ingestion of home-grown produce (only applicable for the residential scenario) and external exposure pathways.

A review of the human health risk assessment results for the surface and subsurface soil sources indicate that the most influence on soil risk is from daughters of naturally occurring radionuclides. These daughters are primarily bismuth, protactinium, radium, thallium, thorium, and uranium and are not typical fission products associated with a nuclear explosion. In addition, these isotopes are detected throughout the site, in all source areas, without a definable source or emanating contaminant plume. In all land-use scenarios, daughters of naturally occurring isotopes account for more than 95 percent of the total risk for the surface and subsurface soil source.

7.2.1 Surface Soil

The site wide surface soil summed ILCR (which includes all sources, from all source areas and via all pathways) for the recreational scenario is 8.7×10^{-5}. The percent contribution of external exposure to radiation was 98 percent of the total risk. Maintaining surface institutional controls the summed ILCR minus the surface radiation source would be reduced to 1.4×10^{-6}. With the removal of all pathways, except inhalation of dust, the summed ILCR is 1.3×10^{-7}. The MDEQ guidance uses 10^{-6} as a target summed ILCR risk level for remedial actions (MDEQ, 1999). For the residential scenario the summed ILCR was 2.8×10^{-3}. For this future land use, the percent contribution from the consumption of home-grown produce and external exposure was 99 percent. Maintaining surface institutional controls, all sources and pathways except inhalation of dust would no longer apply. The revised summed ILCR minus external exposure and the consumption of home-grown produce would be reduced to 2.9×10^{-5}. The revised summed ILCR minus all pathways except the inhalation of dust is reduced to $3.2 \times 10^{-6.}$ The park ranger scenario results were very similar to the recreational scenario with the summed ILCR is 4.6×10^{-5}. The percent contribution from external exposure to radiation is 98 percent. Maintaining surface institutional controls the summed ILCR minus the surface radiation source would be reduced to 1.1×10^{-6}. The revised summed ILCR minus all pathways except the inhalation of dust is reduced to 6.5×10^{-8}.

7.2.2 Subsurface Soil

The subsurface soil source is applicable to only the residential scenario. For the residential scenario, the summed ILCR was 4.1×10^{-3}. For this future land use, the percent contribution from home-grown produce and external exposure was 99 percent. Maintaining existing surface institutional controls all sources and pathways except inhalation of dust would no longer apply. The revised summed ILCR minus the surface radiation source and home-grown produce would be reduced to 3.2×10^{-5}. The revised summed ILCR minus all pathways except the inhalation of dust is reduced to 1.4×10^{-6}.

The residential (most conservative) scenario, is slightly greater than the MDEQ target summed ILCR value of 10^{-6}. However, with institutional controls in place, the residential scenario would not occur, or would only be allowed to occur either after the contaminants have naturally attenuated to below the regulatory limit, or be restricted to a specific area of the Salmon Site. Therefore, it can be reasoned that the summed ILCR for the surface and subsurface pathways are below the MDEQ target value with institutional controls (MDEQ, 1999).

7.2.3 Surface Water

The surface water summed ILCR are presented on Table 6-5. The summed ILCR for the recreational scenario was 2.9×10^{-9}, the residential scenario was 1.1×10^{-8}, and the park ranger was 2.9×10^{-9}. Note that the recreational and park ranger results are identical because of the identical sources and pathways. The summed ILCR for this pathway is below the MDEQ target summed ILCR value of 10^{-6} (MDEQ, 1999).

7.2.4 Sediment

The sediment summed ILCR are presented on Table 6-5. The sediment summed ILCR is 5.9×10^{-6} for the recreational scenario, 8.0×10^{-4} for the residential scenario, and 3.0×10^{-6} for the park ranger scenario. The percent contribution of external exposure for these scenarios due to external radiation is 96, 99 and 95 percent of the total risk, respectively. Maintaining surface institutional controls, the summed ILCR minus the external exposure source for the recreational and park ranger scenario would be reduced to 2.2×10^{-7} and 1.4×10^{-7}, respectively. With institutional controls, the summed ILCR minus the ingestion of home-grown produce and external exposure sources for the residential scenario would be reduced to 5.6×10^{-6}. The revised summed ILCR minus all pathways except the inhalation of dust is reduced to 3.4×10^{-9}, 9.1×10^{-8}, and 1.8×10^{-9} for the recreational, resident and park ranger scenarios, respectively.

A conservative, worst case, assumption made with the sediment pathway calculation was that there would be direct contact with the sediment in the creeks and ponds and that the sediment would have to be dry for the dust pathway to exist. If the less conservative assumption were made that the sediments would remain wet for most of the year, which historical records indicate they are, the total summed ILCR would be reduced to significantly below the target value of 10^{-6}.

Based on the results of the Baseline Ecological Risk Assessment and the human health risk assessment there is a remote potential future risk from sediments for exposure to the residential scenario from dry sediments. Surface water does not have any future risk based on the human health risk assessment. The results and analysis from site vegetation, animals, and fish samples indicate there is no uptake of contaminants into the environment or food web.

7.2.5 Groundwater

The groundwater summed ILCR are presented on Table 6-5. The groundwater pathway is only applicable for the residential scenario utilizing groundwater in the Alluvial and Local Aquifers. The summed ILCR for the resident recreational scenario utilizing the Alluvial Aquifer is 3.4×10^{-4} and for the Local Aquifer is 7.7×10^{-4}. As previously stated, maintaining existing institutional controls and subsurface restrictions at the site will restrict water well installation and the use of groundwater. In addition, a water supply system is being proposed by the DOE in the immediate vicinity of the Salmon Site, further eliminating this pathway. Groundwater flow and transport modeling results predict that the PCOCs identified in groundwater will naturally attenuate to below regulatory limits within two years. This decay as been observed with groundwater sample analytical results. Through these remedial measures and the natural decay of the contaminants, this pathway and source will be eliminated.

Results from the human health risk assessment indicate that if institutional controls are maintained, there are no significant risks at the Salmon Site.

7.3 Remedial Action Recommendations

This section presents the recommended remedial actions for the Salmon Site.

7.3.1 Operable Unit 1

Operable Unit 1 consists of the surface and subsurface soils in all six source areas and the shallow aquifer in Source Areas 1, 3, 4, and 5. As discussed in Section 4.1.1, a very conservative approach was used for identifying potentially site-related contaminants for the surface and subsurface soils in the six source areas of the Salmon Site.

Soil

The potentially site-related contaminants identified in Operable Unit 1 soil were used to calculate potential risks for a current and future land-use scenarios. The surface and subsurface soils in all the source areas do not pose a risk under a current, recreational scenario, land use. Without institutional controls, the human health risk calculations indicate that the surface and subsurface soils are above the MDEQ target summed ILCR value of 10^{-6} (MDEQ, 1999).

Groundwater

The Alluvial and Local Aquifers at the Salmon Site are currently not used as potable water sources. However, an assumption made for the human health risk assessment was that groundwater would be used by a resident. The primary risks identified in the shallow aquifer are TCE, vinyl chloride, arsenic, and tritium. The likely source of the TCE, vinyl chloride, and tritium is the SGZ Mud Pits. Arsenic was detected in one monitoring well above the MCL and is suspected of being naturally occurring. The human health risk assessment determined that arsenic and tritium are the primary contributors to the total summed ILCR and that TCE and vinyl chloride to not significantly influence the risk calculations.

The groundwater laboratory analysis and fate and transport modeling indicate that the arsenic and tritium are naturally attenuating, and in approximately two years the concentrations will be below the respective MCLs. While maintaining existing institutional controls at the Salmon Site, the residual tritium groundwater contamination detected in the vicinity of the SGZ Mud Pits will not pose a significant human health risk, and will soon be below the MDEQ target value. Arsenic is strongly suspected to be naturally occurring at the Salmon Site. Contaminant fate and transport modeling indicate that the arsenic concentration, detected in one monitoring well, will naturally attenuate to below the MCL in approximately two years.

In addition to the institutional controls and subsurface restrictions at the Salmon Site, the DOE is installing a water supply system for the residents in the immediate proximity of the Salmon Site. Therefore, if there is a future resident at the Salmon Site, it is unlikely that they would use groundwater as their water supply source. Note that the recreational and park ranger scenarios do not have a groundwater source or pathway.

Based on results of the Baseline Ecological Risk Assessment, the RI groundwater flow and transport model, and human health risk assessment, the risk to existing and future land-use scenarios at the Salmon Site are minimal. Sampling and modeling results indicate that the contaminants detected are naturally attenuating since the Salmon Site experiments were conducted. Contaminant plumes in the groundwater are anticipated to be below the respective MCLs within two years. The contaminant plumes are not anticipated to reach the site boundary.

The Baseline Ecological Risk Assessment (DOE/NV, 1995a) indicated through sample results that there is no evidence that the plants and animals at the Salmon Site are being exposed to or adversely impacted by contamination. The remaining sources of contaminated media and material that represent the conclusions of the risk assessment have been determined to be the SGZ Mud Pits and shallow groundwater at SGZ.

The recommended remedial actions for Operable Unit 1 include the following:

- The installation of a water supply system that will provide potable water to the site and residents in the proximity to the site.
- Continued maintenance of institutional controls that prohibits subsurface intrusion within the site boundary.
- Continue to implement the long-term hydrologic monitoring program

The only significant residual contamination remaining at the Salmon Site is in the SGZ Mud Pits, below the water table. The majority of other contamination sources were remediated in 1972. As previously discussed, there is not a significant hydrologic connection between the residual material in the SGZ Mud Pits and the shallow groundwater. The SGZ Mud Pits were excavated and backfilled with clean soil in 1972 and capped with native material. The existing cap serves as an effective natural barrier between the residual material and the surface. This soil barrier supports a vegetative cover over the area and reduces the accidental contact with the contaminated residual material below the groundwater table. Current available technology does not exist to feasiblely treat tritium contamination in groundwater.

7.3.1.1 Water Supply System for Operable Unit 1

The DOE has agreed to provide funding to Lamar County to extend an existing regional drinking water supply system to residents in the vicinity of the Salmon Site as part of restoration activities. This action was implemented to address public concern regarding the potential for contamination to migrate in the shallow groundwater at SGZ from the site and to further enhance the protection of human health. Installation of this potable water system will serve to further reduce the potential for any risk from the site by eliminating the groundwater pathway. All new residential development within the defined boundary will be required to connect to this water system. The proposed drinking water supply system is presented on Figure 7-1.

7.3.1.2 Institutional Controls for Operable Unit 1

As a minimum, existing institutional controls and subsurface restrictions will be maintained at the site and will include:

- Restrictions on subsurface intrusion in the vicinity of SGZ (drilling, installation of groundwater wells for potable and/or non-potable use, and on-site construction in accordance with the land use stipulations).

- All new residential development within the defined boundary will be required to connect to the drinking water supply system.

- Enforcement of the future land use for the site surface area land that mandates the release of this area to the State of Mississippi for use as a wildlife refuge and working demonstration forest. This action was instituted by the Public Law (Section 2851(b) of Part IV of the *National Defense Authorization Act* for Fiscal Year 1997, Public Law 104-201 - Sept. 23, 1996).

- Restriction on intrusion into the SGZ Mud Pits, which are located approximately 100 m from SGZ.

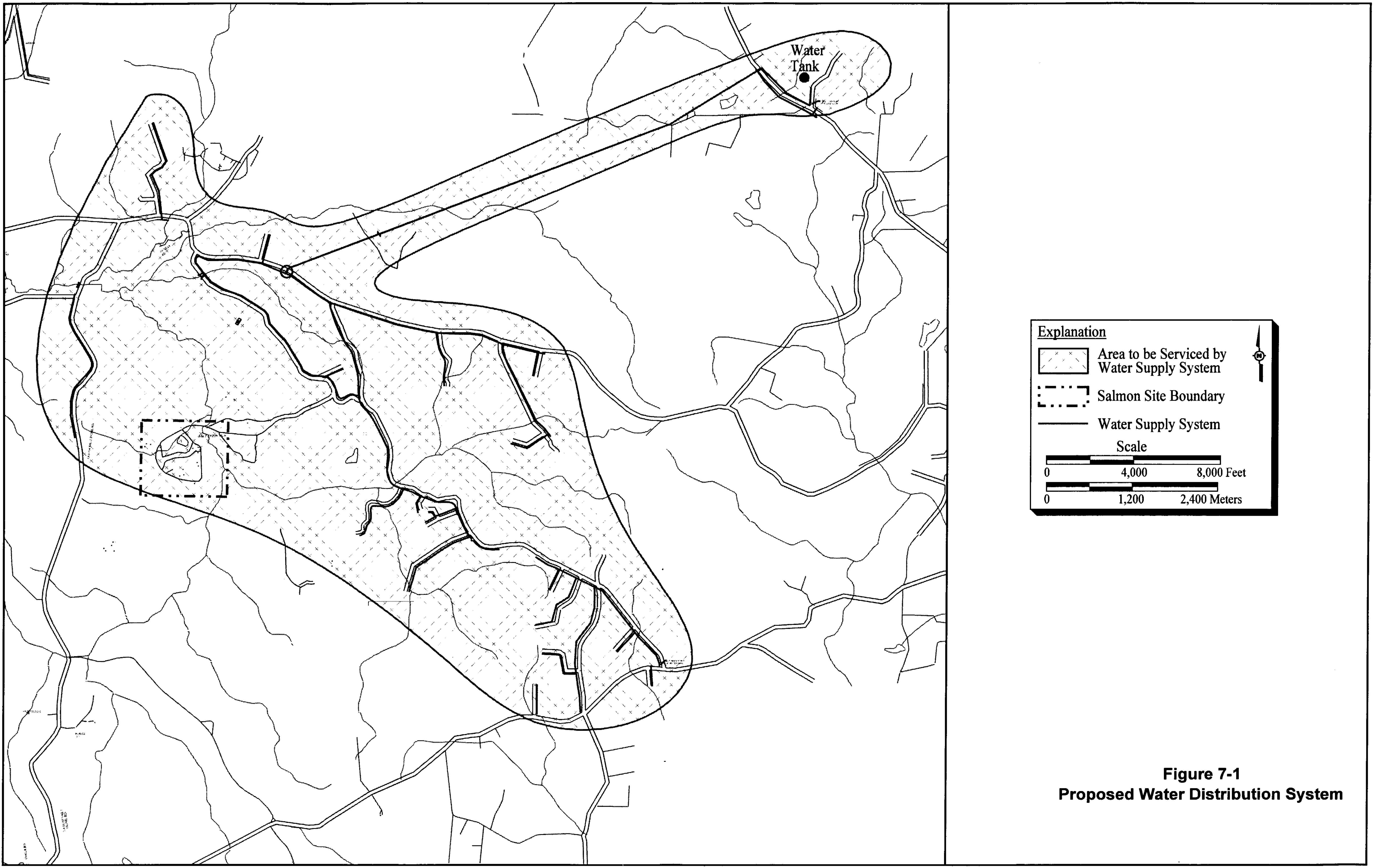

Figure 7-1
Proposed Water Distribution System

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7.3.1.3 Long-Term Hydrologic Monitoring Program for Operable Unit 1

Design and implementation of a long-term monitoring program will be performed, in consultation with the MDEQ. This program will incorporate existing groundwater monitoring wells into a site-wide monitoring network to monitor site conditions. This program will encompass both the shallow and deep groundwater aquifers at the site and provide information on the migration of groundwater contaminants toward the risk-based compliance boundary.

This program will provide information on any changing site conditions. In the event that the land use changes in the future and/or if monitoring information indicates a change in site conditions. The DOE will reassess the risk impacts to human health and the environment based on either the new land uses or changing site conditions and implement actions to ensure protection of human health and the environment.

7.3.2 Operable Units 2 and 3

The Local Aquifer currently is not used as a water source at the site. However, as previously stated the existing institutional controls and subsurface restrictions, including the restricted use of groundwater at the site, will be maintained. Tritium was the only contaminant detected in the Local Aquifer above the MCL. In addition to the observed natural attenuation of tritium at the site, the DOE has proposed the installation of a water supply system for the site and surrounding existing residents. Therefore, as previously stated this pathway would no be applicable and not pose a risk to future residents at or in the vicinity of the site.

Currently, sample results and other field evidence do not indicate that tritium or other man-made radionuclides are migrating from the test cavity into the aquifers that comprise Operable Unit 2 (the Local Aquifer and Aquifers 1, 2a, 2b, and 3). As discussed in Section 5.6.2, even if tritium was to migrate from the test cavity, its activity in each Operable Unit 2 aquifer at the site boundary would be substantially below its MCL.

Current available technology does not exist to economically remediate the test cavity and deep groundwater. The recommended remedial actions for the test cavity and deep groundwater incorporate the following actions which are protective of both human health and the environment. The recommended remedial actions for Operable Units 2 and 3 include the following:

- The installation of a water supply system, which will provide potable water to the site and residents in the proximity to the site.

- Continued maintenance of institutional controls that prohibit subsurface intrusion within the site boundary.

- Implementing an optimally designed monitoring well network to monitor potential leaks from the test cavity

7.3.2.1 Water Supply System for Operable Units 2 and 3

The DOE has agreed to provide funding to Lamar County to extend a drinking water supply system to residents in the vicinity of the Salmon Site as part of restoration activities at the site. This action was implemented to address public concern regarding the potential for contamination to migrate in the shallow groundwater at SGZ and to further enhance the protection of human health. Installation of this system will serve further to reduce the potential for any risk from the site by eliminating the groundwater pathway. All new residential development within the defined boundary will be required to connect to this water system. The proposed drinking water supply system is presented on Figure 7-1.

7.3.2.2 Institutional Controls for Operable Units 2 and 3

Institutional controls will be maintained at the site and will include the following:

- Restrictions on subsurface intrusion in the vicinity of SGZ (drilling, installation of groundwater wells for potable and/or non-potable use, and on-site construction in accordance with the land use stipulations).

- Restrictions on subsurface intrusion into the salt dome due to both the existence of radionuclides in the salt dome and also due to National Security issues concerning the classification of test materials utilized for the experiments.

- All new residential development within the defined boundary will be required to connect to the drinking water supply system.

- Enforcement of the future land use for the site surface area land that mandates the release of this area to the State of Mississippi for use as a wildlife refuge and working demonstration forest. This action was instituted by the Public Law (Section 2851(b) of Part IV of the *National Defense Authorization Act* for Fiscal Year 1997, Public Law 104-201 - Sept. 23, 1996).

7.3.2.3 Long-Term Hydrologic Monitoring Program for Operable Units 2 and 3

Design and implementation of a long-term monitoring program will be performed, in consultation with the MDEQ. This program will incorporate existing groundwater monitoring wells into a site-wide monitoring network to monitor site conditions. This program will encompass both the shallow and deep groundwater aquifers at the site and provide information on the migration of groundwater contaminants toward the risk-based compliance boundary for the site.

This program will provide information on any changing site conditions. In the event that the land use changes in the future and/or if monitoring information indicates a change in site conditions, the DOE will reassess the risk impacts to human health and the environment based on either the new land uses or changing site conditions and implement actions to ensure protection of human health and the environment.

7.4 Conclusions

Through the implementation of the following recommended remedial actions, risks associated with the site will be addressed and will serve to protect both human health and the environment.

- The installation of a water supply system that will provide potable water to the site and residence in the proximity to the site.
- Continued maintenance of surface institutional controls and subsurface restrictions.
- Continue to implement the long-term hydrologic monitoring program

In the event that the land use changes in the future and/or if monitoring information indicates a change in the site conditions, the DOE will reassess the risk impacts to human health and the environment based on either the new land uses or changing site conditions and implement actions to ensure protection of human health and the environment.

8.0 References

AEC, see U.S. Atomic Energy Commission.

American Publish Health Association. 1992. *Standard Methods for the Examination of Water and Wastewater*, 18th Edition. Washington, DC.

APHA, see American Public Health Association.

Armstrong, C.A., H.B. Harris, R.E. Taylor, R.V. Chafin, and T.N. Shows. 1971. *Log of Hydrologic Test Well 1, Tatum Dome Area, Lamar County, Mississippi (Dribble-6),* USGS-474-110. Jackson, MS: U.S. Geological Survey.

BNL, see Brookhaven National Laboratory.

Borg, I.Y., R. Stone, H.B. Levy and L.D. Ramspott. 1976. *Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site, Part 1: Review and Analysis of Existing Information,* UCRL-52078. Livermore, CA: Lawrence Livermore Laboratory.

Brookhaven National Laboratory. 1998. Table of the Nuclides. Brookhaven, NY: Department of Advanced Technology.

CFR, see *Code of Federal Regulations.*

Carsel, R.F. and R.S. Parrish. 1988. "Developing Joint Probability Distributions of Soil Water Retention Characteristics." In *Water Resources Research,* Volume 24, No. 5:755-769.

Chapman, J.B. and S.L. Hokett. 1990. *Evaluation of Groundwater Monitoring at Offsite Nuclear Test Areas.*

Cleary, R.W. and M.J. Ungs. 1994. "PRINCE, Princeton Analytical Models of Flow and Mass Transport," Version 3.0. Ontario, Canada: Waterloo Hydrogeologic, Inc.

Code of Federal Regulations. 1996a. 40 CFR Part 300, "National Oil and Hazardous Substances Pollution Contingency Plan." Washington, DC: U.S. Government Printing Office.

Cosgrove, G.E. 1971. "Reptilian Radiobiology." In *Journal of the American Veterinary Medical Association,* Volume 159, No. 11:1678-1684.

DOE, see U.S. Department of Energy.

DOE/NV, see U.S. Department of Energy, Nevada Operations Office.

EPA, see U.S. Environmental Protection Agency.

ERDA, see U.S. Department of Energy Research and Development Agency.

Faur, G. 1977. Principles of Isotope Geology. Santa Barbara, CA: John Wiley and Sons.

Fetter, C.W. 1993. *Contaminant Hydrogeology.* New York, NY: Macmillan Publishing Co.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater.* Englewood Cliffs, NJ: Prentice-Hall, Inc.

Gardner, M.C. and C.E. Downs. 1971. *Evaluation of the Project Dribble Site, Hattiesburg, Mississippi, for Disposition, Including Identification of Restrictions, Part I,* Report NVO-1229-145, Part I. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office.

Gelhar, L.W., C. Welty, and K.R. Rehfeldt. 1992. "A Critical Review of Data on Field-Scale Dispersion in Aquifers." In *Water Resources Research,* Volume 28, No. 7: 1955-1974.

Geraghty and Miller. 1993. "ModelCAD^{386}." Reston, VA: Geraghty and Miller, Inc.

Guiger and Franz. 1997. Visual, MODFLOW for Windows Version 2.7.2. Ontario, Canada: Waterloo Hydrogeologic, Inc.

Heath, R.C. 1984. *Ground-Water Regions of the United States,* U.S. Geological Survey Water-Supply Paper 2242.

Hem, J.D. 1985. *Study and Interpretation of Chemical Characteristics of Natural Waters,* 3rd Edition, U.S. Geological Survey Water-Supply Paper 2254. Alexandria, VA.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko. 1991. *Handbook of Environmental Degradation Rates.* Chelsea, MI: Lewis Publishers.

IRIS, see U.S. Environmental Protection Agency.

IT, see IT Corporation.

IT Corporation. 1992. *Results of a Preliminary Survey to Threatened and Endangered Species and Floodplains/Wetlands at the Tatum Dome Test Site, Lamar County, Mississippi.* Las Vegas, NV.

Koopman, F.C., A.I. Johnson, C.A. Armstrong, and R.E. Taylor. 1963. *Results of Aquifer Tests at Hydrologic Test Sites 1 and 2, Tatum Dome, Lamar County, Mississippi,* Technical Letter Dribble-32. Denver, CO: U.S. Geological Survey.

Matthess, G. 1982. Properties of Groundwater. New York, NY: John Wiley & Sons.

McDonald, M.G., and A.W. Harbaugh. 1988. “A Modular Three-Dimensional Finite Difference Ground-Water Flow Model.” In *Techniques of Water Resources Investigations*, Book 6, Chapter A1. Washington, DC: U.S. Geological Survey.

MCEQ, see Mississippi Commission of Environmental Quality.

MDEQ, see Mississippi Department of Environmental Quality.

MDRH, see Mississippi Division of Radiological Health.

Mississippi Commission on Environmental Quality. 1999. Final Regulations Governing Brownfields Voluntary Cleanup and Redevelopment in Mississippi. Jackson, MS.

Mississippi Department of Environmental Quality. 1995. State of Mississippi Water Quality Criteria for Intrastate, Interstate and Coastal Waters. Jackson, MS: Office of Pollution Control.

Mississippi Department of Environmental Quality. 1998. Hazardous Waste Management Regulations. Jackson, MS: Office of Pollution Control.

Mississippi Department of Environmental Quality. 1999. Subpart II, Risk Evaluation Procedures for Voluntary Cleanup and Redevelopment of Brownfield Sites. Jackson, MS.

Mississippi Division of Radiological Health. 1996. Regulations for Control of Radiation in Mississippi. Jackson, MS: Bureau of Environmental Health, State Department of Health.

Papadopulous and Associates. 1991. “PATH3D—A Gound-Water Path and Travel-Time Simulator,” Version 3.20. Rockville, MD.

Papadopulous and Associates. 1992. “MT3D—A Three-Dimensional Solute Transport Model,” Version 1.85. Rockville, MD.

Spiers, C.A. and L.A. Gandl. 1980. *A Preliminary Report of the Geohydrology of the Mississippi Salt Dome Basin*, U.S. Geological Survey, Water Resources Investigations Open-File Report 80-595. Jackson, MS.

State of Mississippi. 1996. *Maximum Allowable Concentrations for Groundwater and Soil/Sediment Sample Analysis Conducted at Uncontrolled CERCLA Sites*, revised, June. Jackson, MS: Mississippi Office of Pollution Control.

Stover, C.W., D.W. Harrelson, and W.H. Johnson. 1981. *Monitor Well Construction and Hydrological Testing, Tatum Salt Dome, Lamar County, Mississippi, March-April 1981*, Open File Report 4, Bureau of Geology. Jackson, MI: Mississippi Department of Natural Resources.

TETC, see The Earth Technology Corporation.

The Earth Technology Corporation. 1986. *Regional Ground-Water Flow Near Richton and Cypress Creek Domes, Mississippi, Annual Status Report for Fiscal Year 1984.* Prepared for U.S. Department of Energy.

USGS, see U.S. Geological Survey.

U.S. Atomic Energy Commission. 1972a. *Clean Up Summary Report, Tatum Dome Test Site, Mississippi*, NVO-129. Las Vegas, NV.

U.S. Atomic Energy Commission. 1972b. *Tatum Salt Dome Test Site, Lamar County, Mississippi,* NVO-117. Las Vegas, NV.

U.S. Department of Energy. 1992. *Environmental Measurements Laboratory Procedures Manual,* HASL-300, 27th Edition, Volume 1. New York, NY.

U.S. Department of Energy, Nevada Operations Office. 1978. *Special Study Tatum Dome Test Site Lamar County, Mississippi* Final Report, NVO-200. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1980. *The Tatum Dome Project, Lamar County, Mississippi,* NVO-225. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1992. *Remedial Investigation and Feasibility Study of the Tatum Dome Test Site, Lamar County, Mississippi,* Volume 1, Final Work Plan. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1994a. *Preliminary Data Report of Investigations Conducted at the Salmon Site, Lamar County, Mississippi,* DOE/NV--369. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1994b. *Task Summary for Cone Penetrometer Testing Sounding and Soil and Groundwater Sampling Salmon Site Lamar County, Mississippi,* DOE/NV--381. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1994c. *Trench Sampling Report, Salmon Site, Lamar County, Mississippi,* DOE/NV--373. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1995a. *Baseline Ecological Risk Assessment, Salmon Site, Lamar County, Mississippi,* DOE/NV--394. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1995b. *Geophysical Investigation, Salmon Site, Lamar County, Mississippi,* DOE/NV--391. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1995c. *Work Plan Addendum for the Remedial Investigation and Feasibility Study of the Salmon Site,* DOE/NV--411. Las Vegas, NV.

U.S. Energy Research and Development Administration. 1975. *Long-Term Radiological Surveillance Program, Tatum Dome Test Site, Hattiesburg, Lamar County, Mississippi,* NVO-143. Las Vegas, NV.

U.S. Environmental Protection Agency. 1980. *Prescribed Procedures for Measurement of Radioactivity in Drinking Water*, EPA/600/4-80/032. Washington, DC.

U.S. Environmental Protection Agency. 1984. *Eastern Environmental Radiation Facility Radiochemistry Procedures Manual,* EPA/521/5-84/006. Washington, DC.

U.S. Environmental Protection Agency. 1987. "National Primary Drinking Water Regulations, Synthetic Organic Chemicals Monitoring for Unregulated Contaminants." In *Federal Register,* Volume 52:25690-25734. Washington, DC.

U.S. Environmental Protection Agency. 1988a. "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA," EPA/540/G-89/004 Interim Final. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1988b. *USEPA Contract Laboratory Program Statement of Work for Organics Analysis, Multi-Media, Multi-Concentration.* Washington, DC.

U.S. Environmental Protection Agency. 1989a. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A), EPA/540/1-89/002, Interim Final. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1989b. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish,* EPA/444/4-89/001. Washington, DC.

U.S. Environmental Protection Agency. 1990. *USEPA Contract Laboratory Program Statement of Work for Organics Analysis, Multi-Media, Multi-Concentration.* Washington, DC.

U.S. Environmental Protection Agency. 1991a. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors,* Memorandum, OSWER Directive 9285.6-03. Washington, DC.

U.S. Environmental Protection Agency. 1991b. *Role of Baseline Risk Assessment in Superfund Remedy Selection Decisions,* OSWER Directive 9344.0-3.0. Washington, DC: Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency. 1992. *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,* SW-846, Third Edition. Washington, DC.

U.S. Environmental Protection Agency. 1995. *Health Effects Assessment Summary Tables (HEAST), Annual FY 1993,* OERR 9200.6-303. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1998. “Integrated Risk Information System (IRIS),” on-line database. Washington, DC.

U.S. Geological Survey. 1963. *Geology and Hydrology of the Tatum Salt Dome, Lamar County, Mississippi.* Denver, CO.

U.S. Geological Survey. 1982. "Baxterville, Miss.," Scale 1:24,000, Reston, VA.

Wilson, J.L. and P.J. Miller. 1978. “Two-Dimensional Plume in Uniform Groundwater Flow.” In *Journal of the Hydraulics Division,* Volume 104, No. 4. New York, NY: American Society of Civil Engineers.

Zheng C. and G.D. Bennett. 1995. *Applied Contaminant Transport Modeling, Theory and Practice.* New York, NY: Van Nostrand Reinhold.

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