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ENVIRONMENTAL RESTORATION PROGRAM

Site Investigation Report for Waste Area Grouping 4 at Oak Ridge National Laboratory

Volume 1. Text

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Energy Systems Environmental Restoration Program
ORNL Environmental Restoration Program

Site Investigation Report for Waste Area Grouping 4 at Oak Ridge National Laboratory

Volume 1. Text

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CONTENTS

FIGURES v
TABLES vii
ABBREVIATIONS ix
ACKNOWLEDGEMENTS xi
EXECUTIVE SUMMARY xiii

1. INTRODUCTION 1-1
   1.1 BACKGROUND 1-1
   1.2 OVERVIEW OF THE UNDERLYING ISSUES AND STRATEGY 1-1
      1.2.1 Contribution to Surface Water Risk from Waste Area Grouping 4 1-1
      1.2.2 Historical Strontium Releases from Waste Area Grouping 4 1-5
      1.2.3 Releases of Strontium-90 from Localized Sources in Waste Area Grouping 4 1-7
      1.2.4 Data Management 1-7
   1.3 OBJECTIVES OF THE STUDY 1-10
   1.4 SHARED DATA INITIATIVE 1-10

2. PRESENTATION OF RESULTS 2-1
   2.1 LOCATION OF SOURCES OF STRONTIUM-90 2-1
      2.1.1 Radiological Survey and Soil Sampling 2-1
      2.1.2 Remote Sensing Evaluations 2-13
      2.1.3 Drive Point Installations 2-23
      2.1.4 Topographic Survey 2-27
   2.2 ASSESSING THE RELATIVE IMPORTANCE OF IDENTIFIED SOURCES 2-30
      2.2.1 Seep Collection Systems 2-30
      2.2.2 Surface Water Transport in the WAG 4 Tributary 2-45
      2.2.3 Tracer Studies 2-47
   2.3 DATA FOR EVALUATING OPTIONS FOR INTERIM ACTION 2-53
      2.3.1 Water-Table Elevation Data 2-53
      2.3.2 Chemical Composition of Trench Water 2-56
      2.3.3 Burial Trench Characteristics 2-74
      2.3.4 Data Management and Presentation 2-82

3. SUMMARY OF RESULTS 3-1
   3.1 KEY FINDINGS 3-1
   3.2 CONCEPTUAL MODEL FOR SOURCE RELEASE AND CONTAMINANT FATE 3-5
   3.3 GENERAL CONSIDERATIONS THAT AFFECT REMEDIAL OPTIONS 3-7

4. REFERENCES 4-1

APPENDIX A: RADIOLOGICAL SURVEY DATA FROM CHEMRAD A-1
APPENDIX B: RADIOLOGICAL SURVEY DATA FROM ORNL MEASUREMENT APPLICATIONS AND DEVELOPMENT GROUP B-1
APPENDIX C: WAG 4 SITE INVESTIGATION LOCATION DATA C-1
APPENDIX D: GROUND-PENETRATING RADAR SURVEY RESULTS D-1
APPENDIX E: DRIVE-POINT INSTALLATION LOGS E-1
APPENDIX F: DAILY DRIVE-POINT-INSTALLATION FIELD PLAN AND DAILY NOTES F-1
APPENDIX G: SAMPLING AND ANALYSIS METHODOLOGY FOR THE TRACER STUDY G-1
APPENDIX H: WATER LEVEL DATA COLLECTED AT WAG 4 ..... H-1

FIGURES

1.1 ORNL waste area groupings 1-2
1.2 Locations of WAG 4 remediation sites 1-3
1.3 Drinking water risk at White Oak Dam 1-4
1.4 Relative contaminant contributions to risk at White Oak Dam 1-6
1.5 Comparison of annual Sr-90 mass flow at White Oak Dam and WAG 4 from 1987 to 1994 1-8
1.6 Percentage of total mass flow at tributary points in WAG 4 1-9
1.7 WAG 4 baseline map 1-11
2.1 Gross surface radiation contours (1983 study) 2-2
2.2 Terrestrial radiation contours (1994 study) 2-3
2.3 Soil sampling locations based on terrestrial radiation contours (1994 study) 2-5
2.4.a Sr-90 in soil based on soil sampling and terrestrial radiation 2-10
2.4.b Sr-90 in soil based on soil sampling and terrestrial radiation 2-11
2.4.c Sr-90 in soil based on soil sampling and terrestrial radiation 2-12
2.5 Strategic Environmental Research and Development Project map 2-14
2.6.a Comparison of geomagnetic, thermal, and visual data to infer trench orientation and extent 2-16
2.6.b Comparison of geomagnetic, thermal, and visual data to infer trench orientation and extent 2-17
2.6.c Comparison of geomagnetic, thermal, and visual data to infer trench orientation and extent 2-18
2.7.a Ground penetrating radar survey lines 2-20
2.7.b Ground penetrating radar survey lines 2-21
2.8 Approximate trench locations superimposed on GPR 2-22
2.9 Strategy for location of drive points 2-25
2.10 Typical drive point well construction diagram 2-26
2.11 Drive point locations 2-28
2.12 Locations of seep collection systems 2-32
2.13 Typical weir construction for seep collection systems 2-33
2.14.a Hydrographs for MS-1 and SCS sites 2-34
2.14.b Hydrographs for MS-1 and SCS sites 2-35
2.15 WAG 4 strontium-90 ***C/Q*** (concentration/discharge) relationship 2-39
2.16 WAG 4 MS-1 tributary discharge comparison 2-43
2.17 WAG 4 MS-1 strontium-90 ***C/Q*** relationships 2-44
2.18 Sr-90 concentrations as a function of distance along SWSA 4 tributary 2-46
2.19 Tracer study (central section) 2-48
2.20 Tracer study (west section) 2-49
2.21 Locations of wells at WAG 4 where water level data were collected 2-54
2.22 Water level hydrographs – October 1994 through May 1995 2-55
2.23 Water level contours – April 6, 1995 2-57
2.24 Water level contours – April 20, 1995 2-58
2.25 Water level contours – May 24, 1995 2-59
2.26 Response hydrographs 2-60
2.27 WAG 4 sampling scheme 2-62
2.28 WAG 4 seep characterization 2-73
2.29 Phase II Sr-90 vs stable Sr 2-75
2.30 Phase II Sr-90 vs gross beta 2-76

2.31 Phase II Sr-90 and Cs-137 vs gross beta 2-77
2.32a Trench overburden 2-78
2.32b Trench overburden 2-79
2.32c Trench overburden 2-80
3.1.a Major targets for interim action (west section) 3-2
3.1.b Major targets for interim action (central section) 3-3
3.1.c Major targets for interim action (east section) 3-4
3.2 WAG 4 bathtubbing trench conceptual model 3-6

TABLES

1.1 Strontium releases at WAG 4 and White Oak Dam 1-7
2.1 Radiological results for surface soil samples collected in seep areas at SWSA 4 2-6
2.2 Drive point installation summary 2-29
2.3 Water budget and flow at the SCSs 2-36
2.4 Phase I results for SCSs and emerging seep (SP) samples collected at WAG 4 2-38
2.5 Flow/contaminant concentration relationship coefficients for ^{90}Sr 2-40
2.6 Contribution of ^{90}Sr and volume of water from the SCSs to MS-1 during storm flow 2-41
2.7 Contribution of ^{90}Sr and volume of water from the SCSs to MS-1 during base flow 2-42
2.8 Monthly contribution of ^{90}Sr from the SCSs to MS-1 2-42
2.9 Results of tracer study for SCS 3 2-50
2.10 Results of tracer study for SCS 4 2-51
2.11 Results of tracer study for SCS 6 2-52
2.12 In-line field parameter measurements 2-63
2.13 Phase II anion results from samples taken at WAG 4 2-65
2.14 Phase II inorganic results from samples taken at WAG 4 2-66
2.15 Phase II results for all samples collected at WAG 4 2-70
2.16 Phase I results for all samples collected at WAG 4 2-71
2.17 Estimated overburden calculations for drive points 2-81

ABBREVIATIONS

Bechtel	Bechtel National, Inc.
bgs	below ground surface
CDM Federal	CDM Federal Programs Corporation
CQ	concentration vs discharge
DO	dissolved oxygen
DOC	dissolved organic carbon
DOE	U.S. Department of Energy
Energy Systems	Lockheed Martin Energy Systems, Inc.
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
GM	Geiger-Müeller
GPR	ground-penetrating radar
IC	ion chromatography
ICP	inductively coupled plasma
ID	inside diameter
LLW	low-level waste
MAD	Measurement Applications and Development
OD	outside diameter
OREIS	Oak Ridge Environmental Information System
ORNL	Oak Ridge National Laboratory
PVC	polyvinyl chloride
SCS	seep collection system
SERDP	Strategic Environmental Research and Development Project
SWSA	Solid Waste Storage Area
TDS	total dissolved solids
USRADS	Ultrasonic Ranging and Data System
WAG	waste area grouping

ACKNOWLEDGMENTS

The characterization project summarized in this report represents the efforts of a team of investigators brought together to conduct an expedited project. The project occurred in two discrete stages, both of limited duration. The field season available for conducting the second stage of the work was expected to last only 10 weeks, and the goal was to establish instrumentation, install drive-point wells, collect samples, and gather sufficient data to provide a basis for a decision on an interim action to control ^{90}Sr releases from Waste Area Grouping 4. The first draft of the report was requested about 2 weeks after most of the field operations ended, although some data collection was still in progress. The successful accomplishment of the project objectives is a tribute to the participants and their willingness to work as a team. Because each component of this report was prepared by a subgroup of the team, it was considered important to identify the participants and their areas of responsibilities. They are summarized in the table below.

Task	Organization participants	Authors and contributors
Radiological surveys	Chemrad, Energy Systems MAD Group, CDM Federal	D.D. Huff, C. Provost, T. Phillips
Soil sampling	CDM Federal	T. Phillips
Remote sensing	ESD Geophysics group SERDP	W. Doll, J. Nyquist, R. Kaufman A. King, T. Evers
Drive-point installations	ESD Earth Sciences CDM Federal	N. Farrow, C. Lamb, D. Huff J. LaForest, J. Mitchell
Trench water sampling	ESD Earth Sciences CDM Federal	D. Marsh J. LaForest, J. Mitchell
Civil survey	Energy Systems Engineering Adams Craft Herz Walker, Inc.	S. Laman
Seep collection systems	ESD Earth Sciences	B. Burgoa, W. McCalla, D. Borders, D. Pridmore, R. Kennard, A. Thomas, C. Lamb, N. Farrow, J. Riggs, R. Freeman
Surface water transport	ESD Earth Sciences	D. Borders, D. Hicks, D. Huff, B. Burgoa, K. Ziegler, D. Pridmore
Tracer studies	ESD Earth Sciences	W. Sanford, D. Huff, B. Burgoa, W. McCalla
Groundwater studies	Energy Division – ORNL	R. Ketelle, A. Hunley, M. Yambert
Analytical results	Close Support Laboratory ESD Earth Sciences	J. Burn D. Marsh
Data management	CDM Federal ESD Earth Sciences	C. Inman, J. LaForest, R. Edwards, B. Alsobrooks, L. Wylie D. Huff

Task	Organization participants	Authors and contributors
Risk analysis		T. Purucker
Historical ^{90}Sr releases	ORNL OECD	M. Tardiff

In addition to the field team, several individuals provided management and administrative support needed to conduct field activities. The following table summarizes these contributions.

Task	Contributing organization	Contributors
Program management	ORNL ER ESD Earth Sciences CDM Federal	C. Bednarz D. Herron K. McPherson H. Boston A. Georgeopoulous D. Huff C. Provost
Environmental documentation		B. Copeland E. Mulkey
Engineering support	Energy Systems Engineering	S. Laman

EXECUTIVE SUMMARY

Waste Area Grouping (WAG) 4, one of 17 WAGs within and associated with Oak Ridge National Laboratory (ORNL), is located along Lagoon Road south of the main plant complex. Solid Waste Storage Area (SWSA) 4 is the largest unit at WAG 4, covering approximately 23 acres. In the 1950s, SWSA 4 received a variety of low- and higher-activity-level wastes, including transuranic wastes, all buried in trenches and auger holes. A fire destroyed most of the records of burial operations.

Surface water data indicate that a substantial quantity of ^{90}Sr is being released from the burial trenches in SWSA 4. These trenches contributed 25% of the ^{90}Sr release observed at White Oak Dam for the period 1987–1994 and about 14% of the total ORNL off-site risk via the drinking water pathway. The site investigation reported here was undertaken to locate the sources of ^{90}Sr release, to determine a relative ranking of their importance, and to provide sufficient information to evaluate alternatives for an interim measure to control release and thus reduce the off-site risk. The strategy involved "back-tracking" along the discharge pathway to the western portion of SWSA 4, which contributes about 80% of the ^{90}Sr release. In that area, radiation surveys were conducted to locate discrete discharge points, and suspect trenches upslope of the seeps were examined through use of drive point wells to quantify ^{90}Sr concentrations and pinpoint locations of "hot spots." The investigation also simultaneously measured releases from individual seeps and the tributary draining SWSA 4 so that the relative importance of identified sources could be determined. Tracer studies were undertaken at the most important source areas to establish links to seep areas. Finally, the most contaminated of the trenches and their associated seeps were sampled to provide water chemistry information for evaluating treatability of trench water and to allow assessment of the feasibility of source treatment options such as grouting. Throughout the study, data were synthesized through a geographic information system, allowing spatial display and interpretation. This was an important element in expediting the investigation.

Evaluation of trench water chemistry showed that strontium minerals were undersaturated in all wells where this was investigated. The lack of a relationship between stable strontium and ^{90}Sr, together with increased mass flow during storms, indicates that active leaching from sources is occurring, particularly at higher flows. An excellent correlation between ^{90}Sr concentration and measured gross-beta emitters exists at WAG 4. This relationship allowed use of overnight analyses of gross-beta content for estimating ^{90}Sr source strength, thus allowing decisions to be made in the field to guide drive point installation and avoid unneeded wells.

Of the six individual seep areas identified, measured releases via the surface pathway at two were responsible for more than 50% of the ^{90}Sr releases during the evaluated periods, even though they contributed only about 10% of the flow volume during the same period. Subsurface pathways apparently contributed the remainder of ^{90}Sr released, and ^{90}Sr concentrations in the tributary draining the site suggest the same two areas are most important for this pathway. Upslope from each seep area, one or two apparent source regions were identified. It was possible to isolate four apparent major sources in trenches directly upslope from the two most important contributing seeps. In each case, the ^{90}Sr concentration at the seep was approximately from 35% to 50% of the highest value observed in the upslope trench most likely to be the source. It is believed that control of these few sources is the key to a cost-effective interim action.

1. INTRODUCTION

1.1 BACKGROUND

Waste Area Grouping (WAG) 4 is one of 17 WAGs within and associated with Oak Ridge National Laboratory (ORNL). As shown in Fig. 1.1, WAG 4 is located south of the main facility along Lagoon Road. WAG 4 consists of three separate areas:

- Solid Waste Storage Area (SWSA) 4, a shallow-land-burial ground containing radioactive and potentially hazardous wastes;
- an experimental Pilot Pit Area, which includes a pilot-scale testing pit; and
- sections of two abandoned underground pipelines used for transporting liquid, low-level, radioactive waste.

These areas are identified in Fig. 1.2. SWSA 4 is the largest site at WAG 4, covering approximately 23 acres. In the 1950s, SWSA 4 received a variety of low- and high-activity wastes, including transuranic wastes, all buried in trenches and auger holes.

Recent surface water data, collected during monitoring of the tributary to White Oak Creek as part of WAG 2 investigations as well as during previous studies conducted at WAG 4, indicate that a significant amount of ^{90}Sr is being released from the old burial trenches in SWSA 4. This release represents a significant portion of the ORNL off-site risk (DOE 1993). With recent corrective measures, the proportion of the release has increased in 1995. A detailed discussion of the site history and previous investigations is presented in the *WAG 4 Preliminary Assessment Report*, ORNL/ER-271 (Energy Systems 1994b). In an effort to control the sources of the ^{90}Sr release and to reduce the off-site risk, a site investigation was initiated to pinpoint those trenches that are the most prominent ^{90}Sr sources.

1.2 OVERVIEW OF THE UNDERLYING ISSUES AND STRATEGY

1.2.1 Contribution to Surface Water Risk from Waste Area Grouping 4

WAG 4 is one of numerous sources contributing contamination to the surface waters of the White Oak Creek watershed. White Oak Dam is the last downgradient monitored point before contamination leaves the watershed. Therefore, the Environmental Restoration (ER) Program pays close attention to the calculations of drinking water risk performed at this point, to determine the need for remediation and to establish priorities for remediation within the watershed.

The total risk at White Oak Dam is the sum of the risk from individual contaminants identified in the surface water. The risk for each contaminant is a function of exposure parameters, the dose-response relationship, and the concentration of the contaminant in the surface water. The total risk at White Oak Dam based on monthly concentration data is presented in Fig. 1.3. The risk is

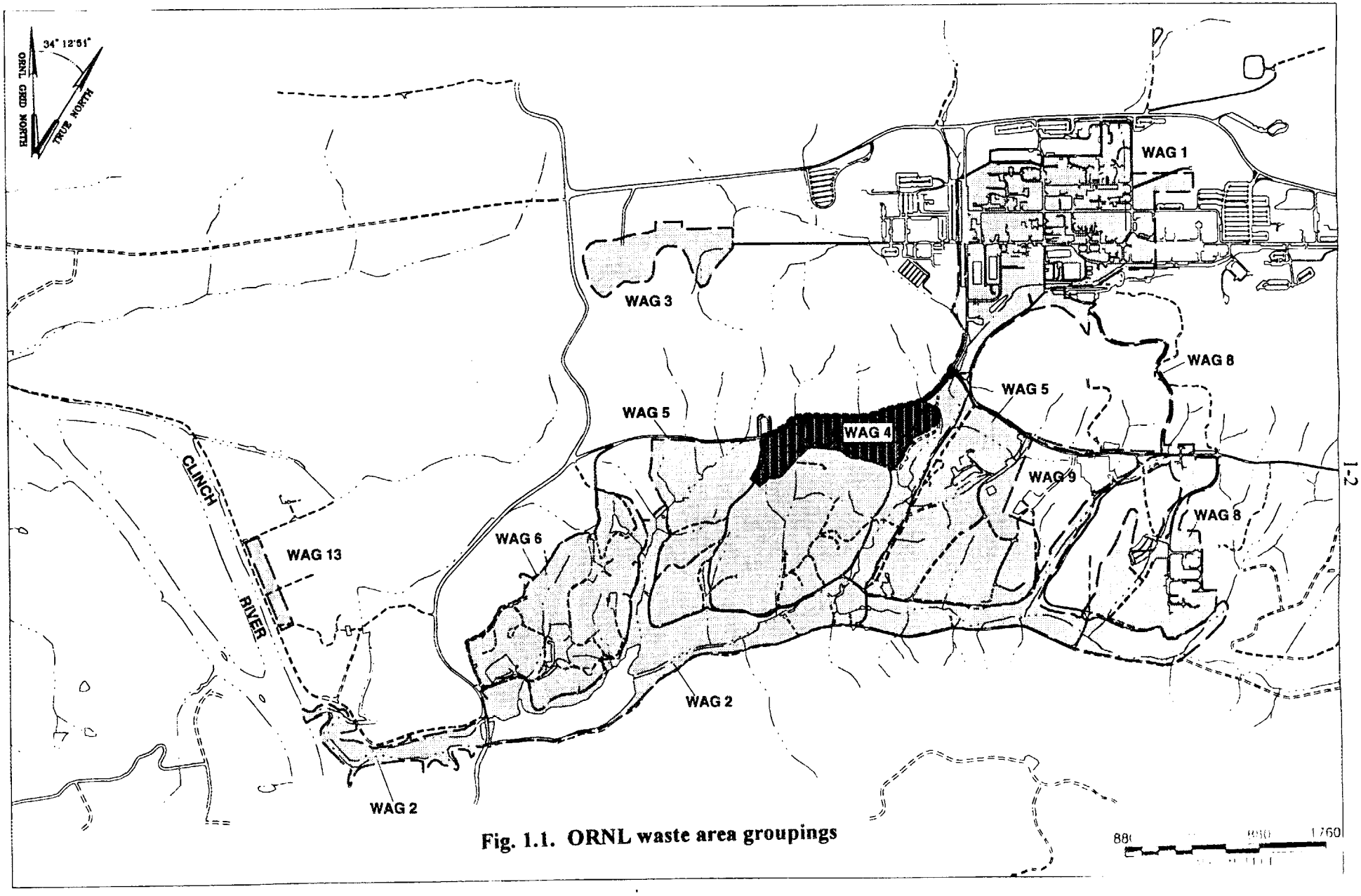

Fig. 1.1. ORNL waste area groupings

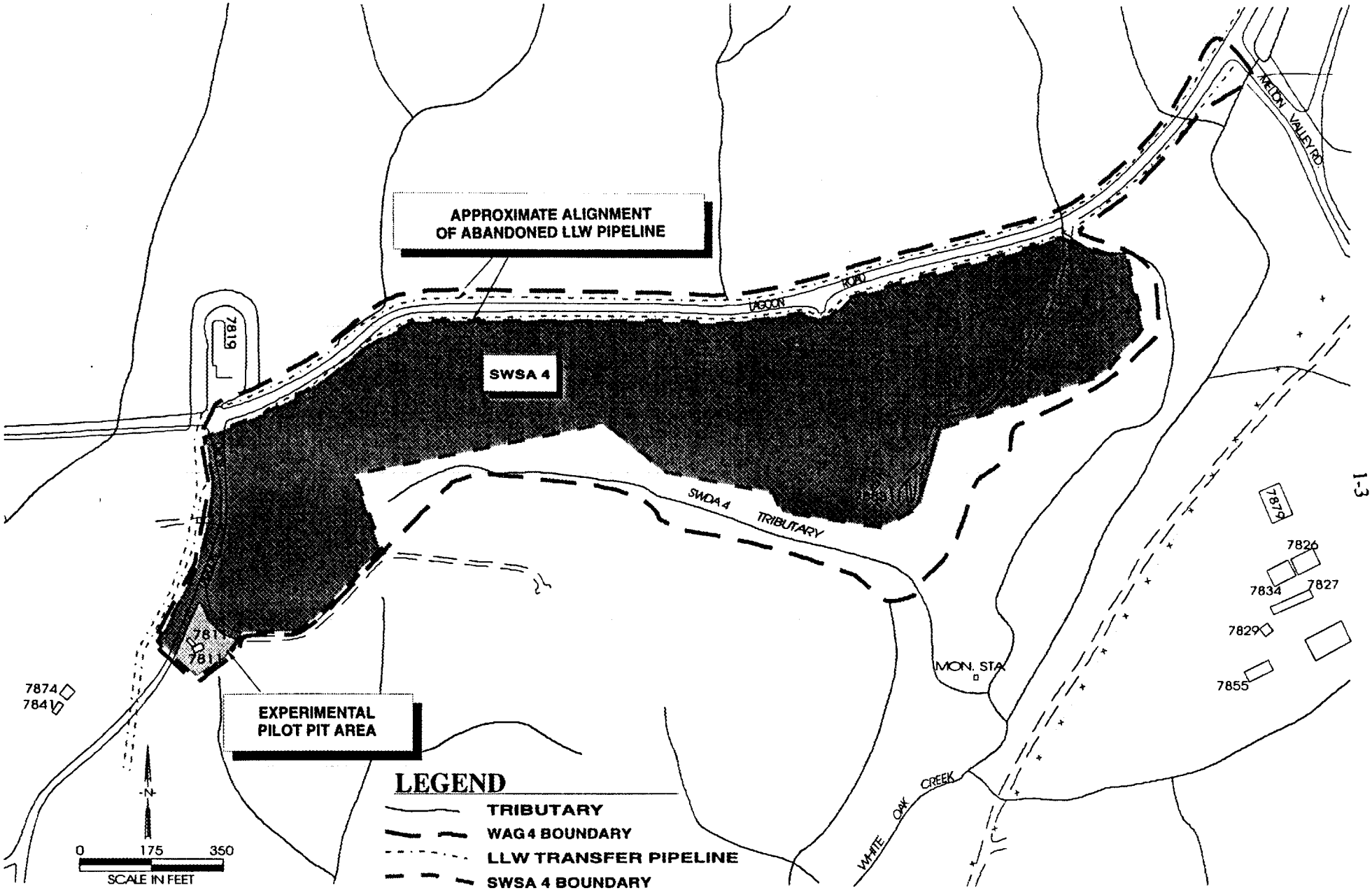

Fig 1.2. Location of WAG 4 remediation sites

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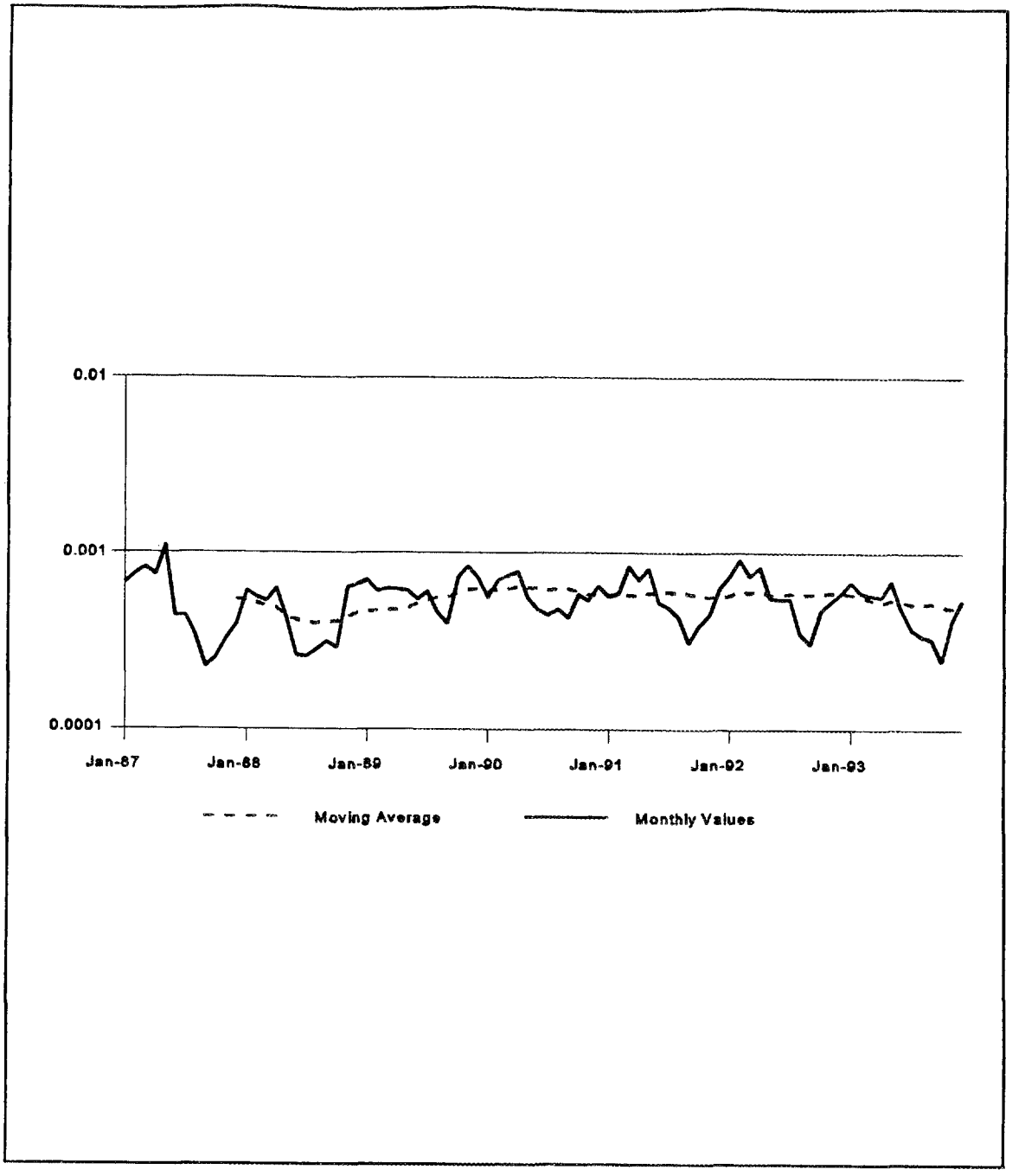

Fig. 1.3. Drinking water risk at White Oak Dam

calculated based on a lifetime exposure for the drinking water pathway (assuming a constant concentration), on U.S. Environmental Protection Agency (EPA) default ingestion parameters (EPA 1989), and on the dose-response relationships for radionuclides (EPA 1993, Eckermann 1993). Other potential pathways may exist (e.g., inhalation, irrigation, swimming), and have been calculated in other sources (DOE 1995a), but the drinking water pathway has been the primary pathway used by the ER Program to determine remediation priorities.

Figure 1.3 shows that the total risk calculated at White Oak Dam during the past 7 years has fluctuated within a range of risk from 1×10^{-4} to 1×10^{-3}. The smooth line represents the risk based on the concentration data for each month, and the dashed line represents the 12-month moving average (that is, the average concentration of that month and the 11 preceding months). These risk results exceed the EPA's target risk range of 1×10^{-6} to 1×10^{4}, and therefore warrant consideration for remedial action. Of specific interest for identifying risk sources is the identification of the primary contaminants that contribute to the calculated risk. Figure 1.4 shows the moving average of the relative contributions of ^{90}Sr, ^{3}H, ^{137}Cs, and the other contaminants contributing to the risks calculated in Fig. 1.3.

Figure 1.4 demonstrates that most of the risk is from the ^{90}Sr concentrations at White Oak Dam, and that the relative contribution of ^{90}Sr at the dam has been increasing (from 50% to more than 60%) until recent corrective steps have been taken. Because of these trends, the ER program has instituted source control activities to mitigate the releases of ^{90}Sr by identifying and remediating the significant ^{90}Sr sources. WAG 4 has contributed 25% of the total ^{90}Sr released at White Oak Dam during the past 8 years (see Sect. 1.2.2 for details), and therefore is a target for a source control action. Source control actions conducted at WAG 4 to mitigate ^{90}Sr releases are expected to reduce the total risk at White Oak Dam by approximately 10%, based on 1994 releases.

1.2.2 Historical Strontium Releases from Waste Area Grouping 4

Monitoring data from 1987 through 1992 were summarized at the beginning of the WAG 4 seeps investigation project to estimate the average contribution of strontium from WAG 4 to the strontium signature at White Oak Dam. These data consist of contaminant concentration data from the Office of Environmental Compliance and Documentation and discharge data from the Environmental Sciences Division at ORNL. The concentration data result from flow-proportional composite samples that are collected each week. The weekly samples are combined into monthly flow-weighted composites and are analyzed in accordance with protocols specified in the ORNL Environmental Monitoring Program. The percent monthly contribution of strontium at White Oak Dam from WAG 4 averaged 22%, based upon those data. During the 6-year period, nearly 28% of the total strontium released at White Oak Dam came from WAG 4. An additional 2 years of monitoring data now are available. All of the data are summarized in Table 1.1.

The data in Table 1.1 show that the annual percent contribution of strontium to White Oak Dam is variable, ranging between 11% and 36%. For the 8-year period 1987 to 1994, WAG 4 contributed 25% of the total strontium released at White Oak Dam. The overall monthly average contribution, including that of the past 2 years, is 19.4%. The variations in contribution to the signature at White Oak Dam result from multiple sources in the watershed contributing contaminants in response to highly localized conditions and processes. The strontium signature at the dam is a synthesis of all of these sources, and typically does not reflect completely the dynamics of any one of the sources.

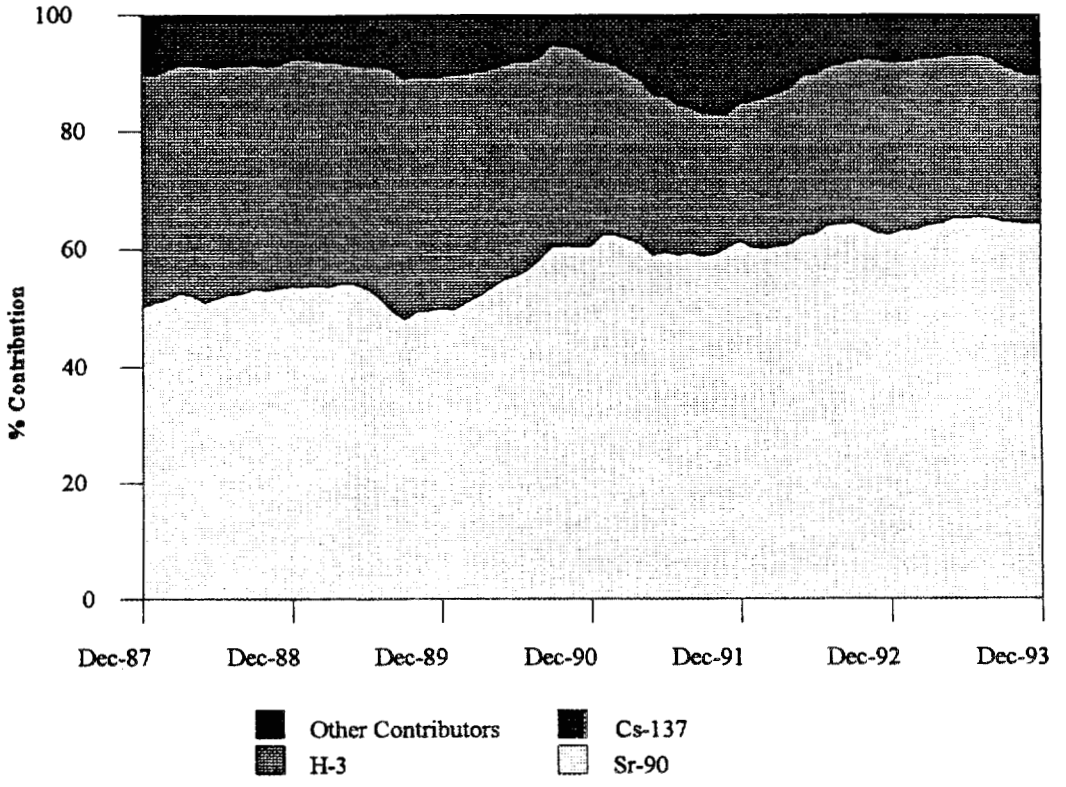

Fig. 1.4. Relative contaminant contributions to risk at White Oak Dam

Table 1.1. Strontium releases at WAG 4 and White Oak Dam

Year	Strontium releases (in total Curies)		Percentage of total ^{90}Sr Curies at White Oak Dam attributed to WAG 4
	WAG 4	White Oak Dam	
1987	0.29	1.33	22%
1988	0.31	1.29	24%
1989	1.01	3.02	33%
1990	1.11	3.1	36%
1991	0.8	3.18	25%
1992	0.37	2.16	17%
1993	0.23	2.14	11%
1994	0.7	3.11	22%
TOTAL	4.82	19.33	25%

Consequently, a contaminant source may be more variable or less variable than indicated at White Oak Dam. The coefficient of variation for strontium at White Oak Dam is 0.76, based upon data from these 8 years. In contrast, the coefficient of variation for strontium at WAG 4 is 1.20. Figure 1.5 shows annual strontium mass flow at WAG 4 and White Oak Dam from 1987 to 1994. The lack of complete correspondence is apparent in this figure.

1.2.3 Releases of Strontium-90 from Localized Sources in Waste Area Grouping 4

Although few results are available and some uncertainty exists concerning flow rates, it appears that roughly 80% of the ^{90}Sr mass transport from the WAG 4 area enters the tributary above MS-1 (a monitoring station at WAG 4). Figure 1.6 displays the estimated percentage of total ^{90}Sr mass flow at different study locations (MS-1, WCTRIB-3, and T-2A) on streams draining the site. Data collected during the 1992 wet-season baseflow sampling event showed a measured flow rate of 0.8 L/second and concentrations of 11.23 nCi/L at MS-1. At T-2A, flow rate was 1.2 L/second (estimated) and the concentration was 8.1 nCi/L. At WCTRIB-3, which drains the eastern side of WAG 4, estimated flow rate was 1.2 L/second and the concentration was 1.6 nCi/L (DOE 1993). The respective ^{90}Sr flux rates were 9.0 nCi/second, 9.7 nCi/second, and 1.9 nCi/second; and the combined total for all of WAG 4, which is assumed to be the sum of sites T-2A and WCTRIB-3, was 11.6 nCi/second. Subsequent data gathered in 1993 and 1994 during the WAG 2 Seep Characterization Task consistently show both lower concentration and lower flow at T-2A than at MS-1. The reduced flow is most likely the result of leakage around or under the flume at T-2A.

As stated previously, although some uncertainties exist for the flow rate data, it is evident that the area above MS-1 is the most significant ^{90}Sr source area in WAG 4.

1.2.4 Data Management

The Data Management Plan (Energy Systems 1995) developed for the WAG 4 project was written in accordance with the *Environmental Measurements Data Management Plan for the Environmental Restoration Program*, ES/ER/TM-88 (Energy Systems 1994a). The relational database was developed to link computerized data to the original hard-copy sources and to document

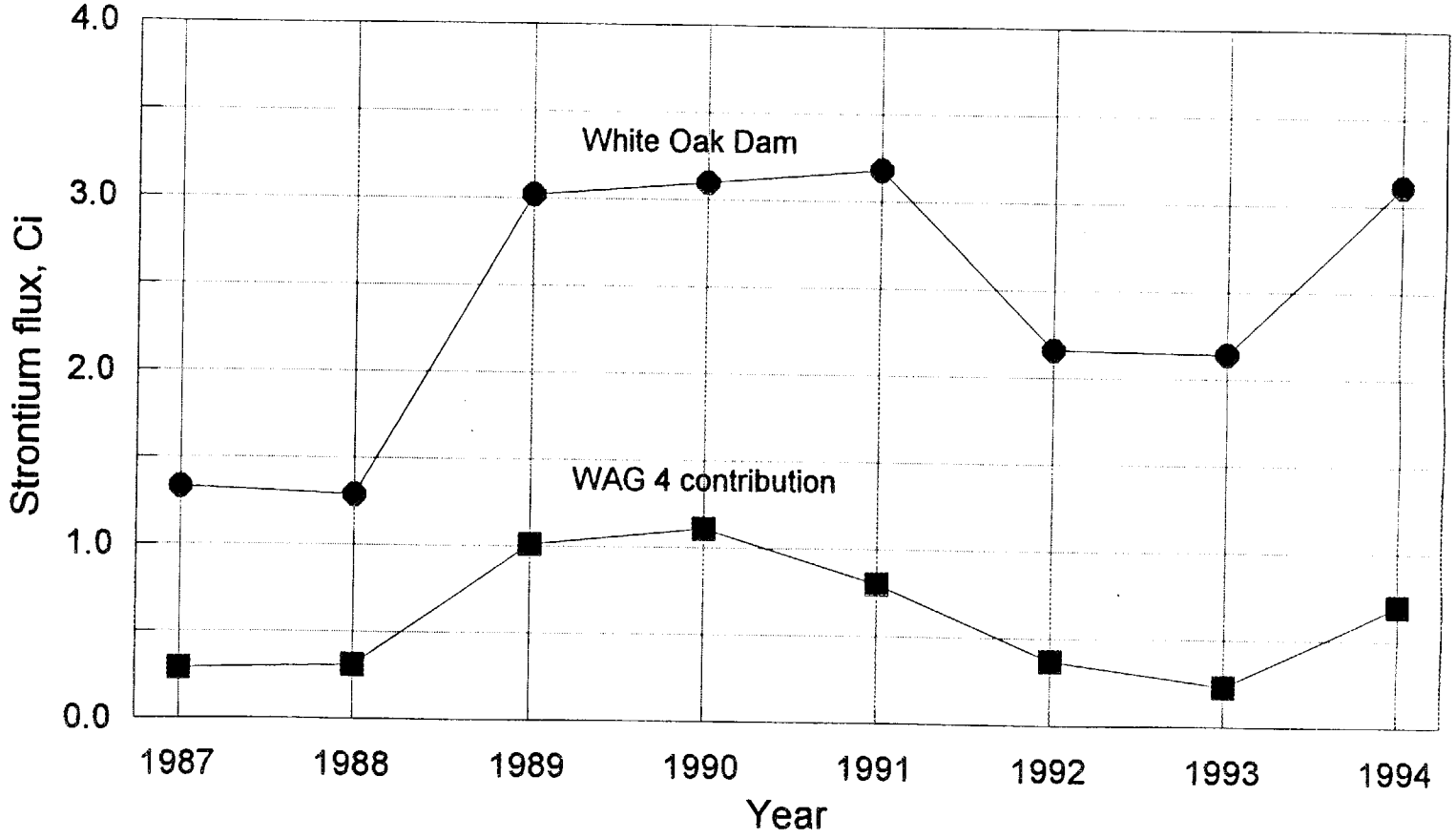

Figure 1.5. Comparison of annual Sr-90 mass flow at White Oak Dam and WAG 4 from 1987 to 1994

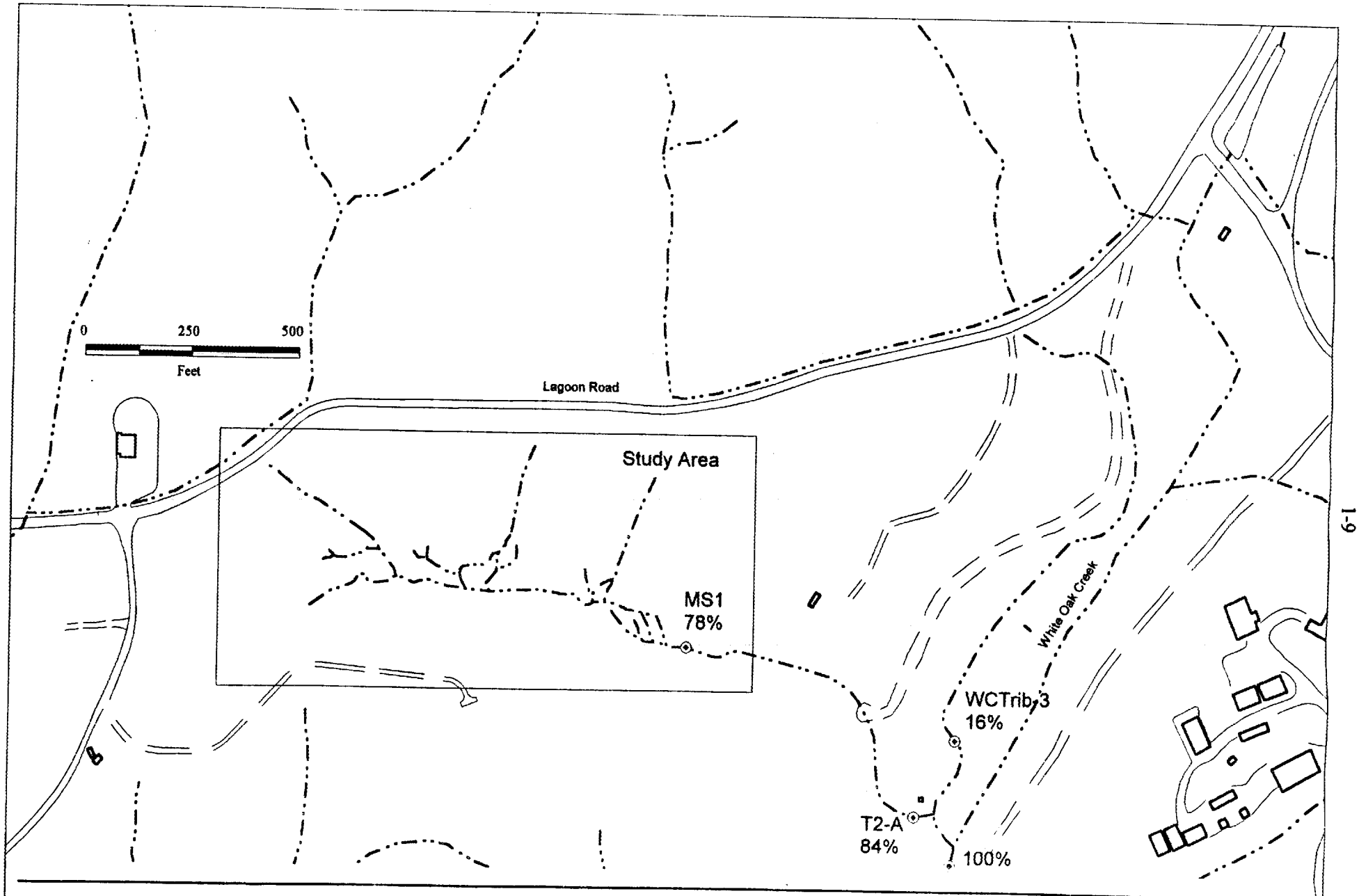

Fig. 1.6. Percentage of total mass flow at tributary points in WAG 4

the flow of data from the hard-copy source to the final data repository. The flow of all data into the project database and its subsequent incorporation into MapInfo (Geographic Information System software) graphics software were essential in allowing the project staff to rapidly process and interpret data.

1.3 OBJECTIVES OF THE STUDY

There were three major objectives for this study:

- to pinpoint sources releasing ^{90}Sr from WAG 4,
- to assess the relative importance of identified ^{90}Sr sources, and
- to provide sufficient data to evaluate potential interim remedial actions and to support selection of remedial alternatives.

This report is organized to address these objectives sequentially. The task of pinpointing the sources involved the use of a radiological survey to identify contaminated seeps that discharge ^{90}Sr to the surface water pathway, remote sensing methods to help locate trenches upslope from the seeps, and installation and sampling of drive point wells to locate high concentrations of ^{90}Sr in trench water (associated with individual sources). To assess the relative importance of sources, seep collection systems were installed and used to measure flow and concentrations released from the seeps. By combining this information with similar data from the MS-1 streamflow-monitoring site, it is possible to estimate the fraction of the total release from the area that comes from each of the contaminated seeps. Tracer studies were conducted to demonstrate movement of water from identified sources to contaminated seeps. Evaluating the concentrations of ^{90}Sr in trench water at discrete sources, as well as evaluating previously measured concentrations in surface water along the tributary draining the area, together provide confirmation of the importance of the identified contributing sources. Finally, evaluation of potential interim actions depends on a knowledge of the physical characteristics of the site, such as depth and location of trenches, amount and nature of added fill material placed on the area after disposal operations ended, and the chemical character of the trench and seep water, which could require treatment. Evaluation also depends on an understanding of the site conceptual model, which describes the mechanisms leading to release of ^{90}Sr from the site.

1.4 SHARED DATA INITIATIVE

To accommodate the accelerated reporting schedule and to supplement the incorporation of project data in the Shared Data Initiative, most of the figures in this report were constructed using MapInfo (Geographic Information System) software. Figure 1.7 displays the baseline MapInfo work space used to display data from the site investigation. In most cases, smaller subsections of this work space were used to display data and reinforce textual descriptions. Figure 1.7 is intended to serve as a reference point for readers of this report.

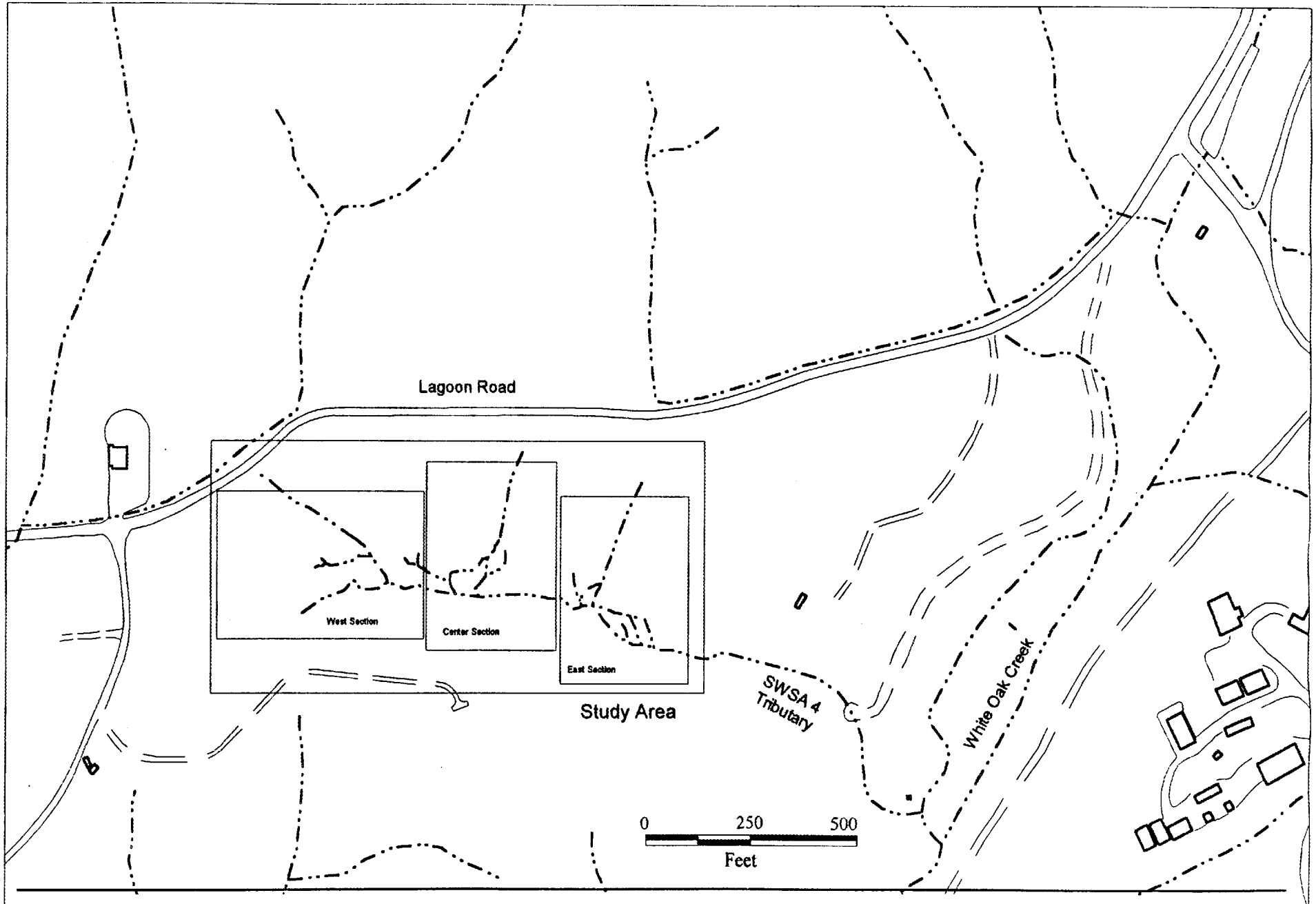

Fig. 1.7. WAG 4 baseline map

WAG 4 Site Investigation

2. PRESENTATION OF RESULTS

2.1 LOCATION OF SOURCES OF STRONTIUM-90

2.1.1 Radiological Survey and Soil Sampling

Overview—Radiological Survey

The WAG 4 radiological survey was instituted to map patterns of radioactively contaminated surface soils and to evaluate whether any additional sources had occurred during the decade since similar studies were conducted by Melroy et al. (1986). Figure 2.1 shows the study area and the results of the earlier radiation survey. In addition, the survey was designed to give an indication of the relative strength of sources contributing to the contaminated seeps. The survey consisted of a walkover of an area of approximately 2 acres along the southern border of WAG 4.

Because ^{90}Sr, the target radionuclide, is a beta emitter, the focus of the radiological survey was beta radiation. The presence of ^{137}Cs, a gamma emitter, is the other source of radiation most likely to be detected during the survey. The primary instrument used to detect beta radiation in the field is a Geiger-Müeller (GM) "pancake" detector. A sodium iodide (NaI) scintillation detector also was used to monitor for the presence of gamma radiation to help distinguish between ^{137}Cs and ^{90}Sr.

Field Data Collection—Radiological Survey

To conduct the radiological survey, where conditions permitted, Ultrasonic Ranging and Data System (USRADS) technology was used with radiation detectors to automatically record readings and locations simultaneously. Using USRADS, beta and gamma radioactivity were measured and recorded electronically, providing in real time the surficial radiological readings measured at the site. The energy-independent dose rate also was measured during this part of the study. The survey was initiated in the bathtubbing trench (a trench which collects water along its length and in extreme cases overflows at the trenches' downgradient end) area because this area had been cleared and was easily traversed; however, conducting a full survey with USRADS equipment in the wooded area proved to be impractical because of thick vegetation. Partial coverage of three of the eastern areas was achieved, and areas of elevated radiation were marked with flags. Data collection in the wooded area using USRADS did not prove to be efficient; therefore, the use of USRADS was discontinued. A detailed description of the elements of the USRADS study is included in Appendix A.

Because thick vegetation impeded physical maneuvering and USRADS instrument performance, the wooded area was surveyed by the ORNL Measurement Applications and Development (MAD) Group using hand-held GM instruments. Flags were placed to mark approximate radiation area contours, and hand-drawn sketches were prepared. Marker locations were referenced to an existing 30-m grid system having a known relationship to the ORNL grid system. Details of the survey are included in Appendix B.

Discussion and Conclusions—Radiological Survey

Results of the radiological surveys were used to map surficial "hot spots" to indicate locations of discharge points from leaking trenches. Figure 2.2 demonstrates the same pattern visible in the

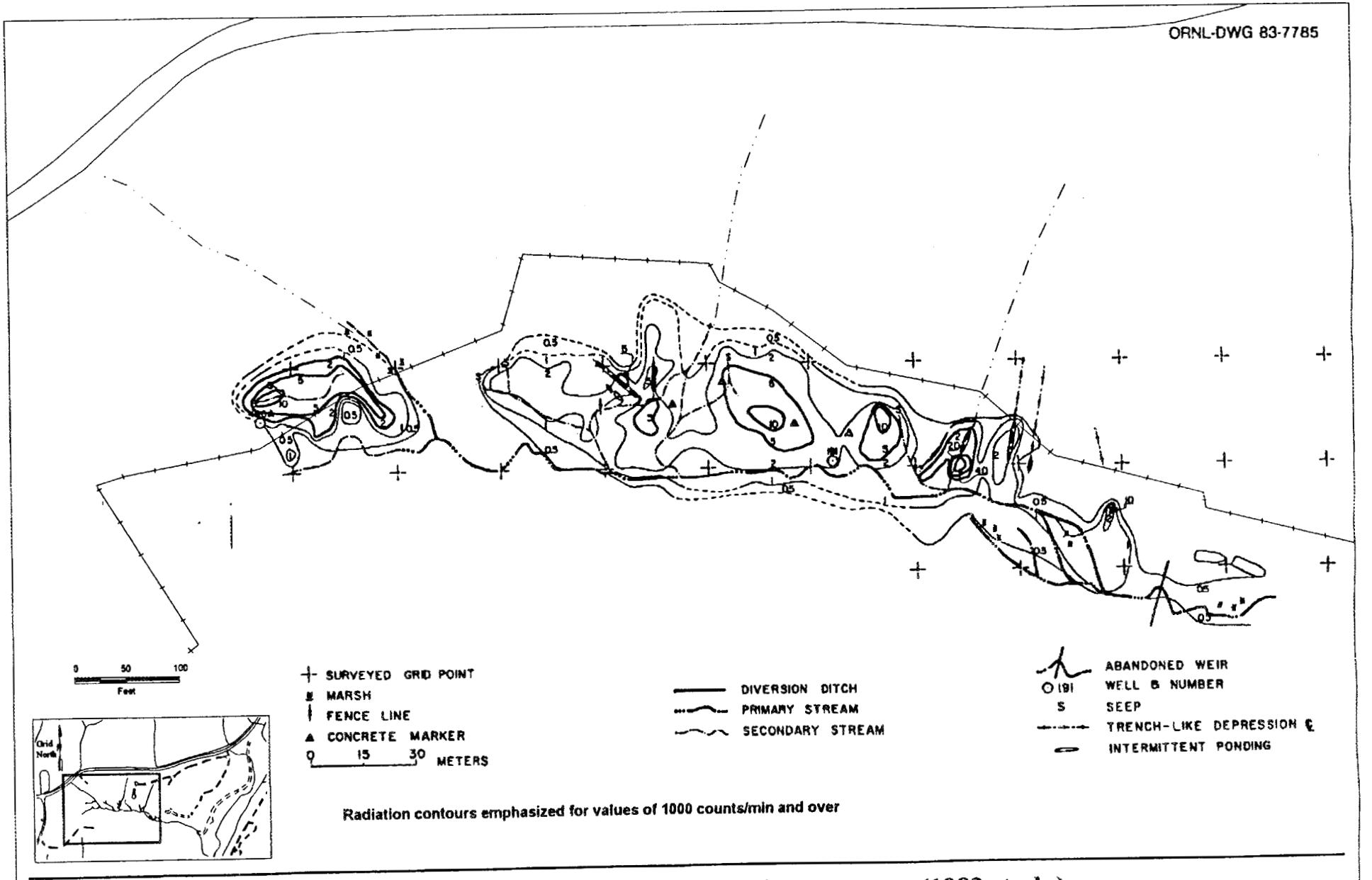

Fig. 2.1. Gross surface radiation contours (1983 study)

WAG 4 Site Investigation

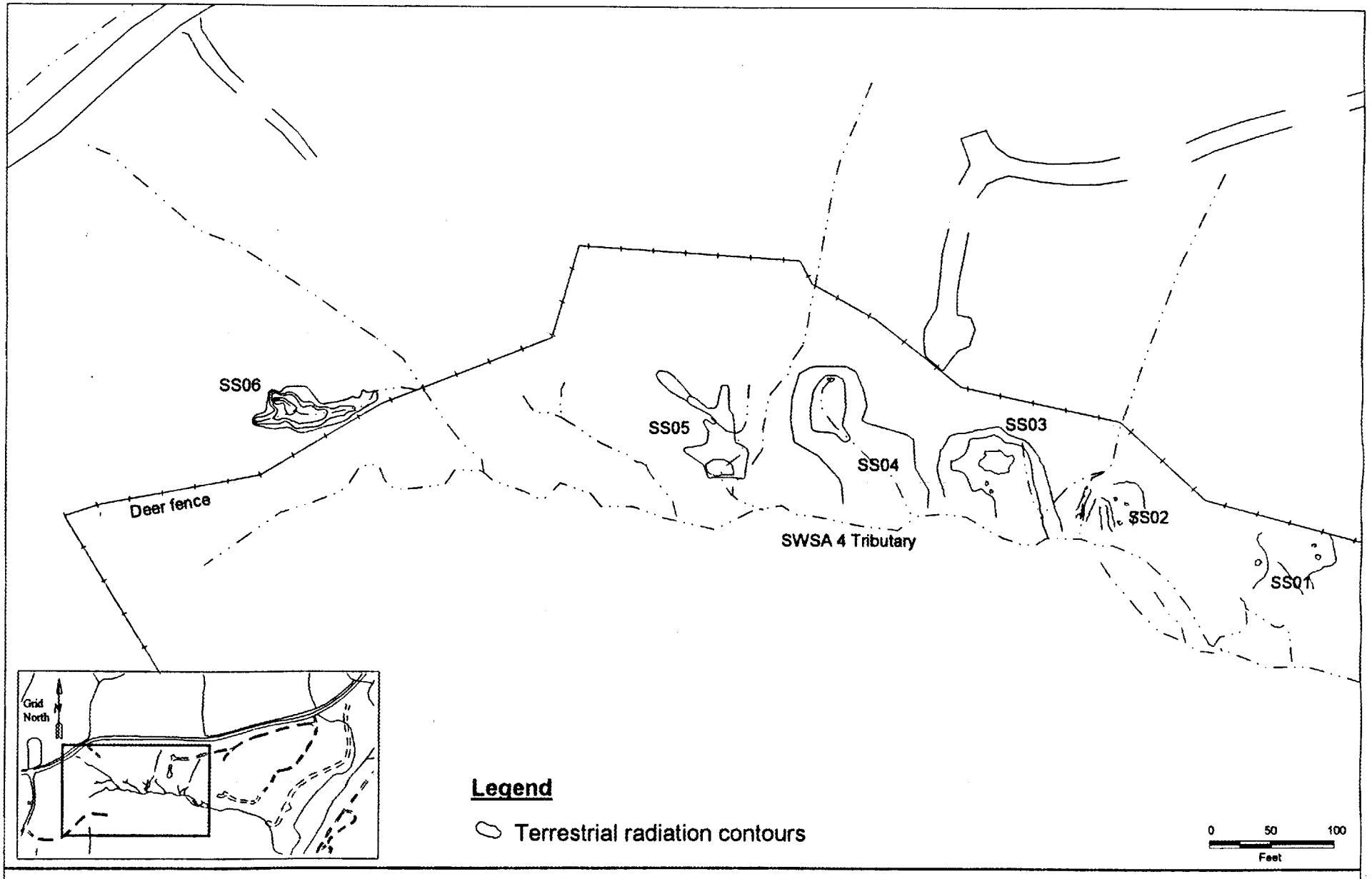

Fig. 2.2. Terrestrial radiation contours (1994 study)

WAG 4 Site Investigation

radiation contours displayed in Fig. 2.1, at least in the locations of major appearance points for surface contamination. In most of the seep areas there exists a region of higher activity in which contaminated seepage emerges from a source, and an apparent dispersion zone that indicates the flow pathway from the seep toward the stream. Although a few differences exist in the way radiation contours are drawn, it is apparent that the primary "hot spots" identified in the early 1980s are the same ones that exist in 1995. Perhaps more important is the observation that no new sources were detected during the later survey. These indications strongly suggest that the sources of contamination in trenches are not changing.

Overview—Soil Sampling

Information obtained from the radiological surveys combined with information from past studies was used to select soil sampling locations for radiological analysis. The soil sampling task was designed to confirm the presence and amount of ^{90}Sr at each of the seep areas. Six areas of concern were identified during the Radiological Survey. Figure 2.3 shows the relationship of soil sample sites to radiation patterns. A blue flag identifying the sample to be collected was placed at each location selected for sampling. A total of seven to ten soil samples were collected from each area. Placement of sampling site locations was based primarily on patterns of beta radiation emissions from contaminated soils.

Summary of Field Phase—Soil Sampling

Soil sampling began on July 6, 1994, and was completed on July 8, 1994. A total of 53 soil samples, 5 of which were duplicate samples, were collected from ground surface to a depth of 3 in. Three rinseate blanks (corresponding to the three sampling spoons used) and two field blanks (collected at project beginning and end) were also collected and submitted along with the soil samples for gross alpha and beta, ^{90}Sr, and gamma spectroscopy analyses.

Samples were collected according to the procedures set forth in the project Work Plan (Energy Systems 1994c). Sampling activities were recorded in the field logbook, on field activity sheets, and chain-of-custody forms. Samples were taken daily to the ORNL Close Support Laboratory for analyses.

Soil sampling locations were surveyed by Adams Craft Herz Walker, Inc., on August 2, 1994. Topographic survey data are included as Appendix C.

Presentation of Results—Soil Sampling

Soil sampling analytical results are listed in Table 2.1. Maps showing the distribution of ^{90}Sr contamination in each of the six areas were developed by combining radiological survey data and soil analytical data and are provided in Fig. 2.4a,b,c.

The automated gamma spectroscopy analysis program, which was used on the measured spectra for soils, identified ^{57}Co, ^{125}I, ^{22}Na, ^{237}Np, and ^{226}Ra scattered among some of the samples. However, these nuclides were present at extremely low levels. Specific evaluation of water collected from source trenches showed none of these nuclides.

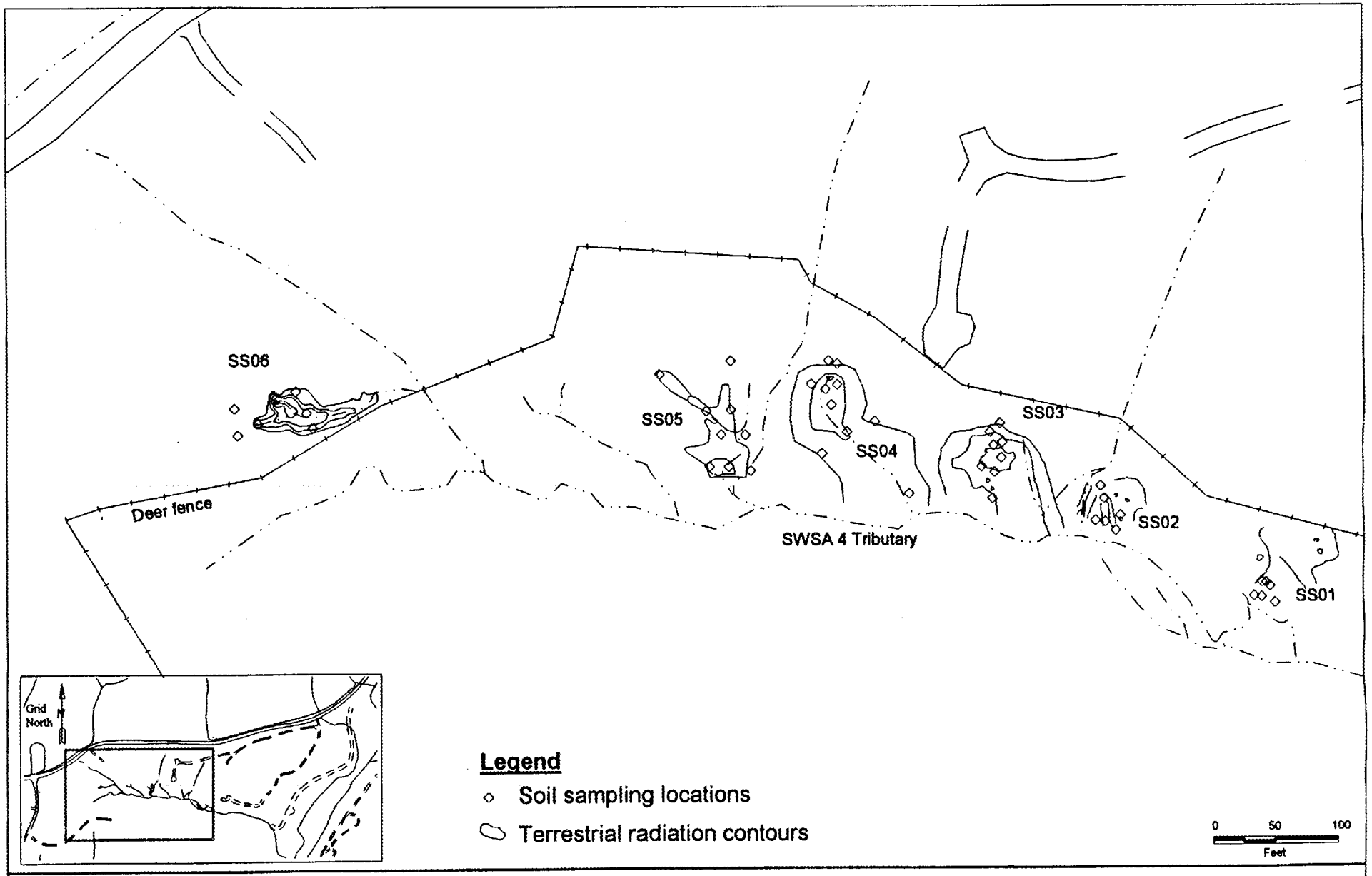

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Fig. 2.3. Soil sampling locations based on terrestrial radiation contours (1994 study)

WAG 4 Site Investigation

Table 2.1. Radiological results for surface soil samples collected in seep areas at SWSA 4

Soil sample identification	Lab identification	Date received	Sample type	Gross beta (pCi/g)	Gross alpha (pCi/g)	Strontium-90 (pCi/g)	Tritium (pCi/g)	Cesium-137 (pCi/g)
SS01001	7069404	07/06/94	FLD	640 ± 55	<12.3	326.6 ± 11.8	8.2 ± 0.52	595 ± 4.76
SS01002	7069405	07/06/94	FLD	800 ± 61	<12.1	219.7 ± 11.5	14 ± 0.65	167 ± 2.40
SS01003	7069406	07/06/94	FLD	5800 ± 160	12 ± 11	526.2 ± 17.1	16 ± 0.69	5240 ± 13.3
SS01004	7069410	07/06/94	FLD	790 ± 60	16 ± 12	474.5 ± 14.7	9.6 ± 0.55	57.7 ± 1.43
SS01005	7069411	07/06/94	FLD	1700 ± 92	<12.9	761.8 ± 17.1	130 ± 1.9	177 ± 2.47
SS01006	7069412	07/06/94	FLD	1900 ± 95	13 ± 12	1459.5 ± 21.0	910 ± 4.9	155 ± 2.33
SS01007	7069413	07/06/94	FLD	207.5 ± 26	17 ± 13	976.5 ± 18.7	980 ± 5.1	157 ± 2.35
SS02008	7069414	07/06/94	FLD	2000 ± 95	18 ± 13	264.7 ± 12.6	7.3 ± 0.49	1390 ± 6.32
SS02009	7079402	07/07/94	FLD	36000 ± 400	110 ± 28	3067.0 ± 35.0	7.6 ± 0.50	37800 ± 49.8
SS02010	7079403	07/07/94	FLD	42000 ± 390	72 ± 21	1422.2 ± 22.8	9.9 ± 0.56	45100 ± 120
SS02011	7079404	07/07/94	FLD	4500 ± 130	<11	1665.8 ± 23.1	14 ± 0.65	141 ± 4.95
SS02012	7079405	07/07/94	FLD	3100 ± 110	15 ± 11	1169.3 ± 23.8	15 ± 0.66	749 ± 5.11
SS02013	7079406	07/07/94	FLD	12000 ± 240	63 ± 22	1574.8 ± 29.9	19 ± 0.75	9300 ± 18.9
SS02014	7079408	07/07/94	FLD	1900 ± 93	23 ± 14	1617.6 ± 30.2	35 ± 1.0	143 ± 2.21
SS03015	7069415	07/06/94	FLD	580 ± 52	16 ± 12	276.3 ± 12.3	7.6 ± 0.50	11.1 ± 0.652
SS03016	7069416	07/06/94	FLD	4800 ± 150	41 ± 19	846.2 ± 21.1	10 ± 0.57	10.7 ± 0.903
SS03017	7069417	07/06/94	FLD	1100 ± 73	<12.9	771.9 ± 15.9	7.1 ± 0.49	16.1 ± 0.824
SS03018	7069418	07/06/94	FLD	6800 ± 180	25 ± 15	2785.7 ± 28.8	9.3 ± 0.54	95.0 ± 2.14
SS03019	7069419	07/06/94	FLD	8900 ± 210	<13.5	3528.9 ± 33.4	7.4 ± 0.50	294 ± 3.25
SS03020	7069420	07/06/94	FLD	11000 ± 230	33 ± 17	2355.9 ± 28.2	6.8 ± 0.48	64.8 ± 1.89
SS03021	7069421	07/06/94	FLD	5600 ± 160	<12.5	2452.3 ± 26.2	8.0 ± 0.51	12.9 ± 0.895
SS03021	7069421	07/06/94	LAB DUP	5200 ± 150	13 ± 12	2672.7 ± 30.0	8.6 ± 0.53	13.6 ± 0.889

Table 2.1 (continued)

Soil sample identification	Lab identification	Date received	Sample type	Gross beta (pCi/g)	Gross alpha (pCi/g)	Strontium-90 (pCi/g)	Tritium (pCi/g)	Cesium-137 (pCi/g)
SS03022	7079409	07/07/94	FLD	17000 ± 240	30 ± 14	7606.3 ± 57.2	17 ± 0.71	56.9 ± 1.67
SS04023	7079416	07/07/94	FLD	4800 ± 150	<13.1	3970.0 ± 47.0	4.3 ± 0.40	12.1 ● 0.826
SS04024	7079417	07/07/94	FLD	25000 ± 350	<12.8	9058.9 ± 55.6	3.0 ± 0.36	7.93 ± 1.15
SS04025	7079418	07/07/94	FLD	31000 ± 370	21.3 ± 14	10057.2 ± 51.8	3.4 ± 0.38	95.0 ± 2.14
SS04026	7079419	07/07/94	FLD	27000 ± 350	26 ± 15	12373.5 ± 60.4	4.6 ± 0.42	166 ± 2.62
SS04027	7079420	07/07/94	FLD	14000 ± 220	35 ± 15	4842.2 ± 44.1	4.8 ± 0.42	148 ± 2.31
SS04028	7079421	07/07/94	FLD	34000 ± 400	26 ± 16	15254.7 ± 68.9	3.8 ± 0.39	1060 ± 6.53
SS04029	7079422	07/07/94	FLD	17000 ± 270	<11.7	7314.2 ± 53.4	4.3 ± 0.41	188 ± 2.68
SS04030	7079423	07/07/94	FLD	29000 ± 330	29 ± 14	12874.2 ± 73.4	4.7 ± 0.42	470 ± 4.40
SS04031	7079424	07/07/94	FLD	5200 ± 160	<13.2	3058.8 ± 31.2	6.8 ± 0.48	202 ± 2.73
SS04032	7079425	07/07/94	FLD	8300 ± 170	17 ± 11	4694.0 ± 41.0	18 ± 0.72	74.2 ± 1.70
SS04032	7079425	07/07/94	LAB DUP	7500 ± 180	<11.9		18 ± 0.73	
SS05033	7079427	07/07/94	FLD	14000 ± 220	46 ± 17	5330.8 ± 42.3	58 ± 1.3	3040 ± 15.6
SS05034	7079428	07/07/94	FLD	28000 ± 380	110 ± 29	12460.0 ± 74.3	5700 ± 12	988 ± 9.99
SS05035	7079429	07/07/94	FLD	12000 ± 250	78 ± 25	5435.0 ± 47.7	1700 ± 6.8	1640 ± 8.46
SS05036	7079430	07/07/94	FLD	13000 ± 320	120 ± 37	4652.0 ± 44.2	1100 ± 5.4	6320 ± 15.1
SS05037	7079431	07/07/94	FLD	4100 ± 140	36 ± 18	2478.6 ± 33.3	310 ± 2.9	145 ± 2.28
SS05038	7079432	07/07/94	FLD	10000 ± 220	120 ± 30	1630.4 ± 29.5	48 ± 1.2	8930 ± 17.2
SS05039	7079433	07/07/94	FLD	6100 ± 170	20 ± 14	2714.4 ± 34.8	60 ± 1.3	1560 ± 7.79
SS05040	7079434	07/07/94	FLD	4300 ± 150	52 ± 21	1307.8 ± 24.1	23 ± 0.83	25.6 ± 1.03
SS05041	7079436	07/07/94	FLD	11000 ± 220	28 ± 15	4222.9 ± 40.2	9500 ± 16	129 ± 2.29

Table 2.1 (continued)

Soil sample identification	Lab identification	Date received	Sample type	Gross beta (pCi/g)	Gross alpha (pCi/g)	Strontium-90 (pCi/g)	Tritium (pCi/g)	Cesium-137 (pCi/g)
SS02042	7079401	07/07/94	FLD DUP of SS02008	1400 ± 75	13 ± 11	209.1 ± 12.1	8.1 ± 0.52	1340 ± 6.70
SS02043	7079407	07/07/94	FLD DUP of SS02013	16000 ± 250	54 ± 19	878.3 ± 20.1	12 ± 0.61	13300 ± 23.3
SS04044	7079426	07/07/94	FLD DUP of SS04032	6500 ± 170	<12.4	3574.4 ± 37.0	20 ± 0.79	7.29 ± 1.73
SS05045	7079435	07/07/94	FLD DUP of SS05040	2900 ± 110	12 ± 11	1509.3 ± 27.1	13 ± 0.66	24.0 ± 0.952
SS06046	7089401	07/08/94	FLD	110 ± 27	15 ± 12	72.9 ± 13.5	2.8 ± 0.41	23.1 ± 0.903
SS06047	7089402	07/08/94	FLD	1700 ± 89	18 ± 13	26.4 ± 9.1	3.9 ± 0.44	217 ± 2.68
SS06048	7089403	07/08/94	FLD	150000 ± 770	280 ± 41	3283.4 ± 36.1	12 ± 0.65	223000 ± 386
SS06049	7089404	07/08/94	FLD	260000 ± 1100	450 ± 57	6180.3 ± 49.8	3.6 ± 0.43	339000 ± 599
SS06050	7089405	07/08/94	FLD	28000 ± 370	63 ± 22	9325.4 ± 57.3	1.0 ± 0.34	7560 ± 16.1
SS06051	7089406	07/08/94	FLD	69000 ± 590	130 ± 31	17297.4 ± 93.1	9.7 ± 0.59	40000 ± 113
SS06052	7089407	07/08/94	FLD	50000 ± 480	130 ± 31	15627.3 ± 95.8	13 ± 0.66	136000 ± 270
SS06053	7089409	07/08/94	FLD	33000 ± 380	57 ± 21	8129.1 ± 55.7	11 ± 0.61	12800 ± 20.2
SS06053	7089409	07/08/94	LAB DUP	28000 ± 330	44 ± 17	8507.5 ± 68.7	12 ± 0.64	12900 ± 20.2
SS06054	7089408	07/08/94	FLD DUP of SS06052	40000 ± 400	120 ± 28	13199.1 ± 88.9	11 ± 0.61	19500 ± 26.3
RBDI001	7069407	07/06/94	RINS BLK for Spoon #1	<0.0360	<0.0130		3.5 ± 0.38	0.102 ± 0.0236
RBDI001	7069408	07/06/94	RINS BLK for Spoon #1	<0.0360	0.023 ± 0.015		5.7 ± 0.45	
RBDI001	7069409	07/06/94	RINS BLK for Spoon #1	<0.0360	<0.0130		5.8 ± 0.45	

Table 2.1 (continued)

Soil sample identification	Lab identification	Date received	Sample type	Gross beta (pCi/g)	Gross alpha (pCi/g)	Strontium-90 (pCi/g)	Tritium (pCi/g)	Cesium-137 (pCi/g)
RBDI002	7079410	07/07/94	RINS BLK for Spoon #2	<0.0360	0.015 ± 0.013		1.3 ± 0.30	
RBDI002	7079411	07/07/94	RINS BLK for Spoon #2	<0.0360	<0.0130		0.72 ± 0.27	
RBDI002	7079412	07/07/94	RINS BLK for Spoon #2	0.059 ± 0.029	<0.0130		0.85 ± 0.28	0.240 ± 0.297
RBDI003	7079413	07/07/94	RINS BLK for Spoon #3	<0.0360	<0.0130		0.54 ± 0.26	
RBDI003	7079414	07/07/94	RINS BLK for Spoon #3	<0.0360	0.0175 ± 0.013		<0.393	
RBDI003	7079415	07/07/94	RINS BLK for Spoon #3	<0.0360	0.0145 ± 0.012		0.46 ± 0.26	
FBDI001	7069401	07/06/94	FLD BLK (project start)	0.055 ± 0.029	<0.013		8.4 ± 0.52	0.52 ± 0.0415
FBDI001	7069402	07/06/94	FLD BLK (project start)	0.078 ± 0.031	0.017 ± 0.013		9.4 ± 0.55	0.134 ± 0.0260
FBDI001	7069403	07/06/94	FLD BLK (project start)	0.048 ± 0.028	<0.013		6.7 ± 0.48	
FBDI002	7089410	07/08/94	FLD BLK (project end)	0.22 ± 0.043	<0.0130		0.56 ± 0.26	0.293 ± 0.0328

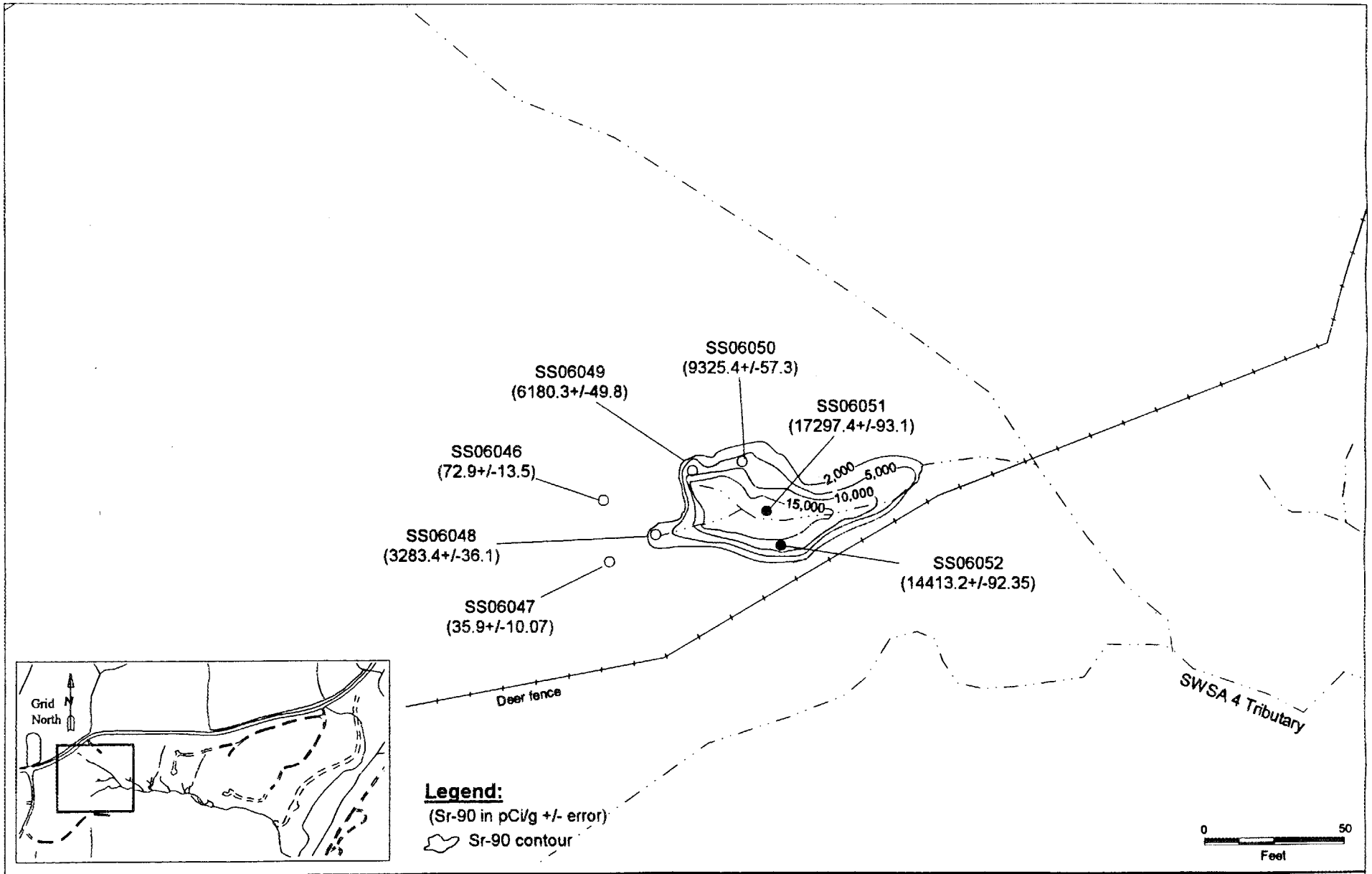

Fig. 2.4.a. Sr-90 in soil based on soil sampling and terrestrial radiation

WAG 4 Site Investigation

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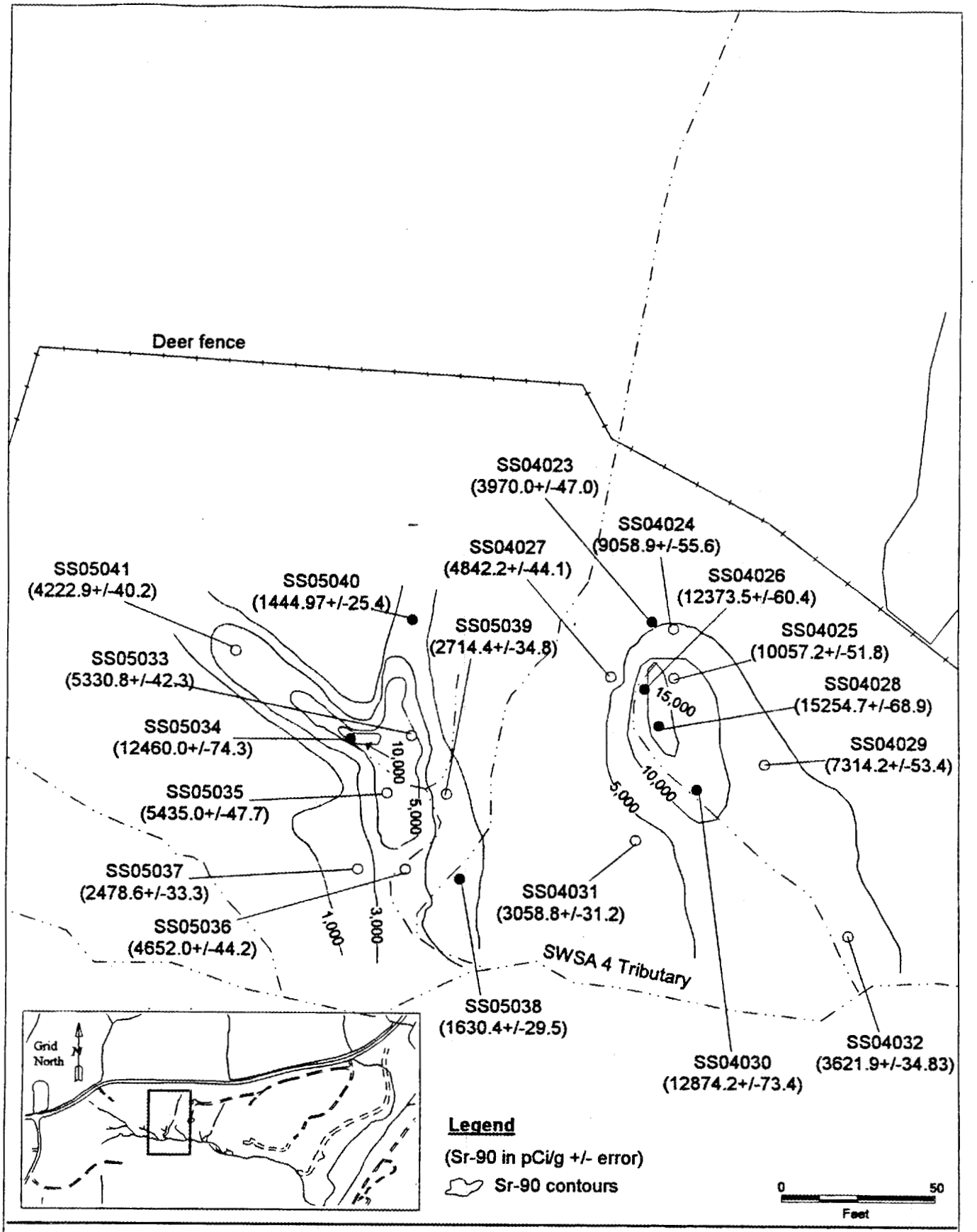

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Fig. 2.4.b. Sr-90 in soil based on soil sampling and terrestrial radiation

WAG 4 Site Investigation

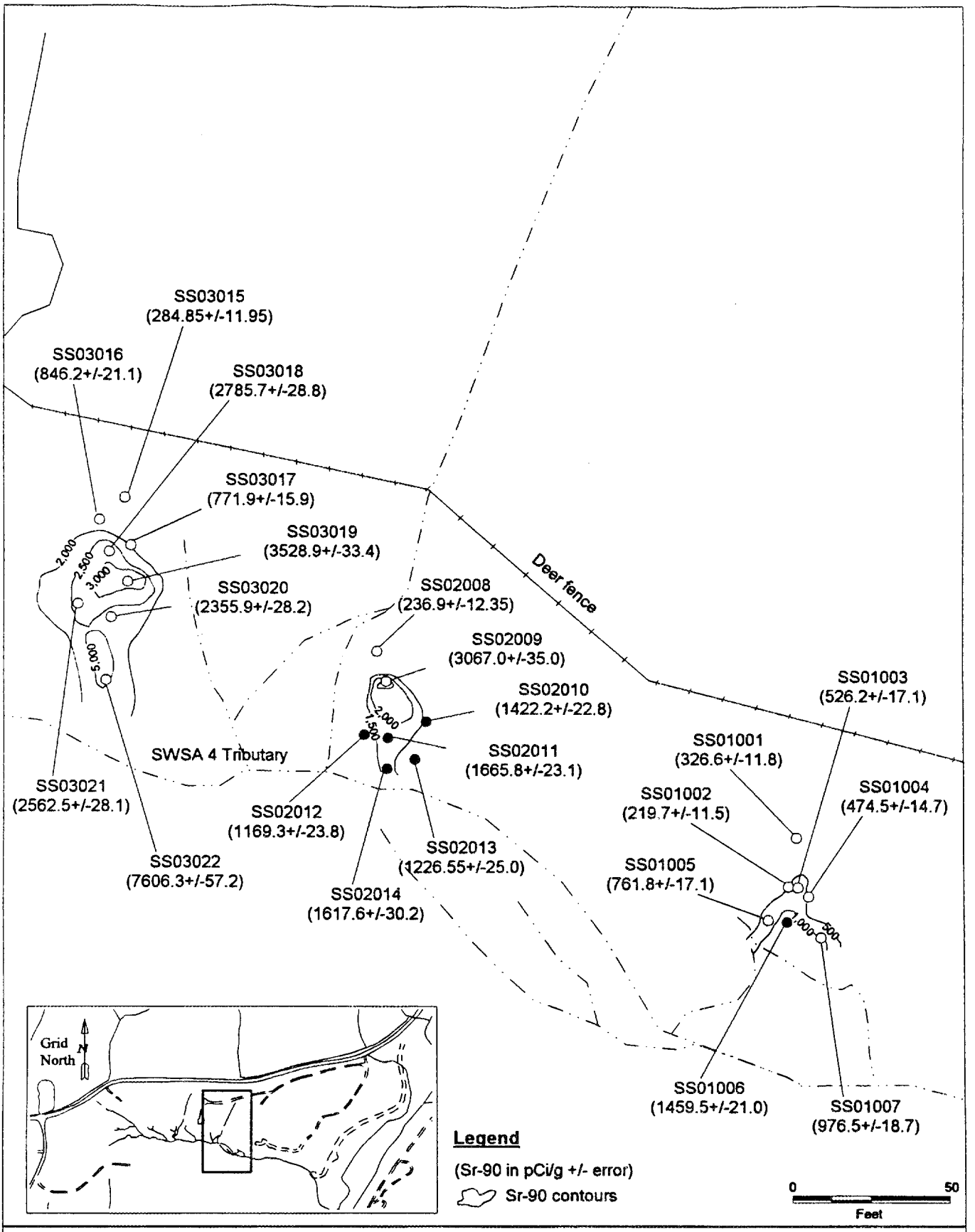

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Fig. 2.4.c. Sr-90 in soil based on soil sampling and terrestrial radiation

WAG 4 Site Investigation

Conclusions—Soil Sampling

Surface soil analytical results confirmed that ^{90}Sr was present at all of the radiation "hot spots" identified during the walkover survey. However, the data suggested that areas 4 and 6 had the strongest sources feeding them, followed by areas 5 and 3. Areas 2 and 1 were of much less apparent significance. Although there were some minor differences between distribution of surface radiation and quantities of ^{90}Sr present, the patterns of ^{90}Sr contamination on surface soils confirmed the conceptual model (refer to Sect. 3.2) and were consistent with earlier work by Melroy et al. (1986). That earlier study also showed that the highest concentrations of ^{90}Sr in soils were at ground surface and generally declined rapidly with increasing depth. Depth profile studies were not repeated in the current study. The results obtained in 1994 were judged acceptable for use in focusing a search on the upslope and upgradient areas to locate the trenches and associated sources feeding the contaminated seeps.

2.1.2 Remote Sensing Evaluations

Overview

Lack of precise knowledge of trench locations at WAG 4 has been a continuing limitation on efforts to link discharge seeps to specific sources in waste trenches. Information about trench size and location also is needed for evaluating practical options for corrective measures on sources in trenches. A few promising remote-sensing options have been undertaken to help improve knowledge of trench features. A magnetometer survey using USRADS technology was conducted in 1993 (Chemrad Tennessee Corporation 1994). Processing of the data offered some promise of identification of trench locations, particularly those trenches containing metal objects. In addition, low-frequency ground-penetrating radar (GPR) offered potential for nonintrusive location of trench boundaries. Finally, a combination of photographic and thermal images of the site were explored to determine if they could help locate trench boundaries.

The Strategic Environmental Research and Development Project Map

As a part of the Strategic Environmental Research and Development Project (SERDP), the Oak Ridge ER Remote Sensing Program collaborated with the WAG 4 Site Investigation team to test the applicability of various remote-sensing technologies to waste site characterization. The project involved both data analysis and data fusion, using both classified and unclassified characterization tools. Many of the results and data products from this work are classified at secret and higher levels. However, some derived products have been individually reviewed by a classification board and made available at the unclassified level. Figure 2.5 represents such a product.

Figure 2.5 represents a compilation of site information collected from 1952 to the present. Visible trench or cap features were derived from photographs, but location accuracy was limited by a lack of identifiable features. Soil patches, associated with subsidence, represent areas that were filled in to prevent collection of water in trenches. This activity was a common maintenance practice, and such soil patches give reliable clues to the locations of subsiding trenches in many photos. Thermal signatures are the most recently obtained information, and are probably most accurately located. Persistent features were identified, and an interpreter drew a line along the center of the feature. The width of the line on the feature is roughly equal to the width of the thermal signature. Although thermal signatures could not be guaranteed always to represent trenches, the

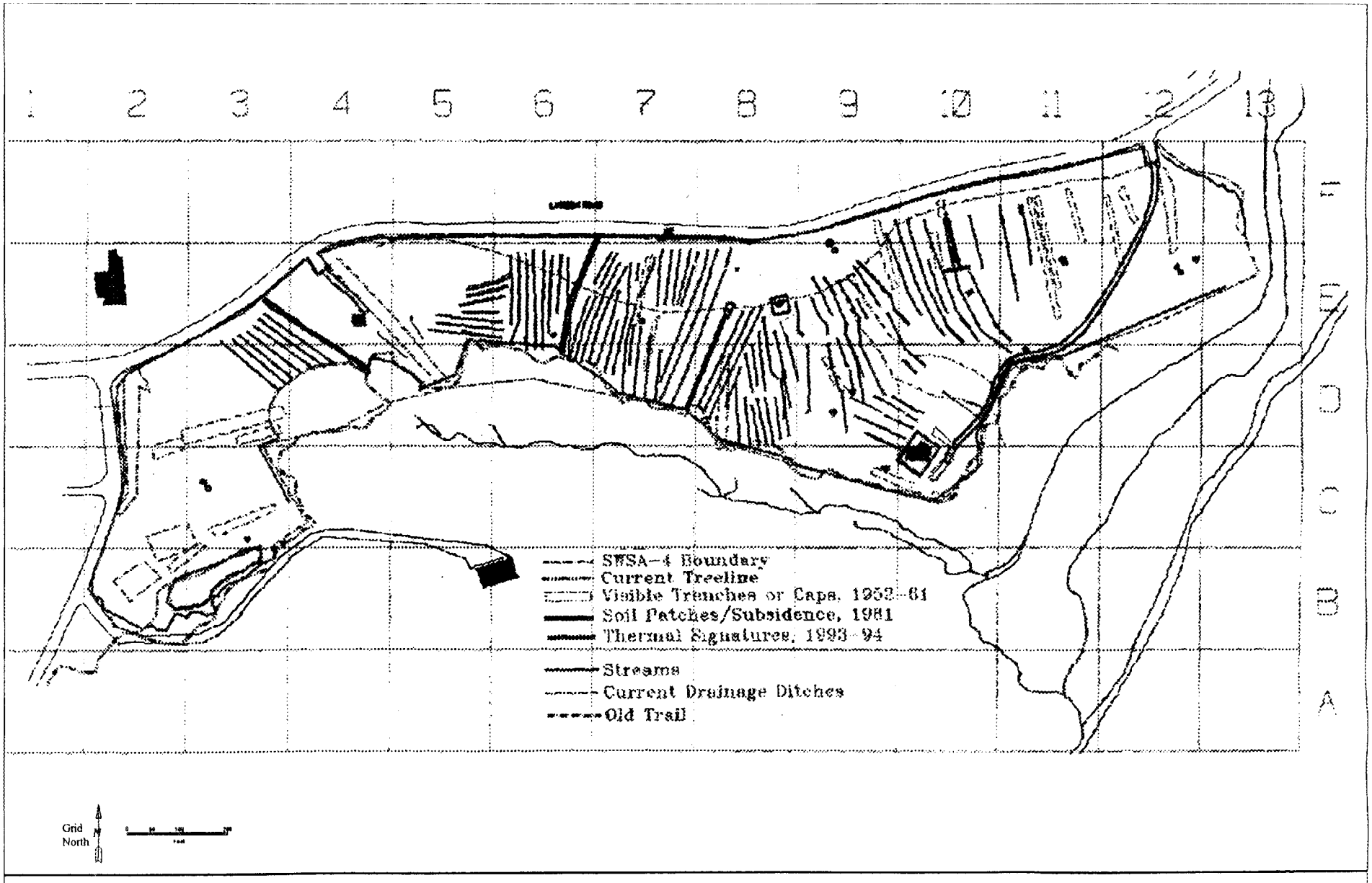


Fig. 2.5. Strategic Environmental Research and Development Project map

WAG 4 Site Investigation

apparent correlation was excellent in the field with trench locations that could be observed. In particular, locations for the original 12 drive-point wells installed in the early part of this investigation corresponded to trench features shown on the SERDP map.

As a result of the excellent correspondence with other available information, the SERDP map was selected as the basis for an expanded investigation to pinpoint locations of sources in individual trenches. The SERDP map information was extracted into a MapInfo (Geographic Information System) format and combined with other site information to produce a base map for much of the drive-point-installation task.

Geomagnetic Walkover Survey

During an earlier characterization of the WAG 4 area, a geomagnetic survey was conducted, using a magnetometer and the USRADS technology for simultaneous recording of instrument readings and precise location (Chemrad Tennessee Corporation 1994). The data from this survey were analyzed to produce a vertical-magnetic-gradient contour map. This map was combined with thermal and visual spectrum information (discussed in the previous section) to produce the image shown in Fig. 2.6a,b,c. In most locations, the magnetic patterns appear to match historical drawing of areas and orientation for trench disposal sites in WAG 4. Although the detail is not sufficient to define boundaries of single trenches, the orientation of the magnetic features provides useful information for the interpretation of trench locations.

Low-Frequency Ground-Penetrating Radar

Overview. Efforts to trace ^{90}Sr contamination from seep areas northward to the source trench(s) were limited because records of trench locations and contents were destroyed by fire. Because knowledge of trench boundaries will be beneficial in developing remedial action plans, it was determined that an evaluation of GPR should be conducted to test this nonintrusive method of locating trench boundaries, and thus address the third project objective. A Field Change Request Form (Form No. W40000002) was completed and approved to implement this task.

Summary of Field Phase. GPR surveys provide high-resolution imaging of the near surface by transmitting a short radar pulse from an antenna placed on the ground surface, and measuring the reflected pulses at a nearby receiving antenna. Three different antennae were tested at WAG 4—25 MHz, 50 MHz, and 100 MHz.

In August 1994, six GPR lines were run across portions of WAG 4. These lines were laid out in two groups: one group near the bathtubbing trenches near the western portion of the site, and one group near drive point 4, near the center of the site. The Sensors and Software PulseEkko IV, using 25-MHz and 50-MHz antennae, was operated on 1-ft spacing to collect data. In general, the 50-MHz antennae seem to have a penetration depth of about 10 ft, and the 25-MHz antennae seem to penetrate about 15 ft. Data were collected along one line (C03) in the central group using 100-MHz antennae, but these had at best a penetration of 6 ft to 7 ft, and were not used after that test.

Each radar line location was selected to cross one or more trenches in a direction approximately perpendicular to its axis. This was determined from magnetic maps and photography available before field operations began. Locations of the endpoints of the GPR lines were surveyed after acquisition to allow direct comparison of the GPR data with other data sets.

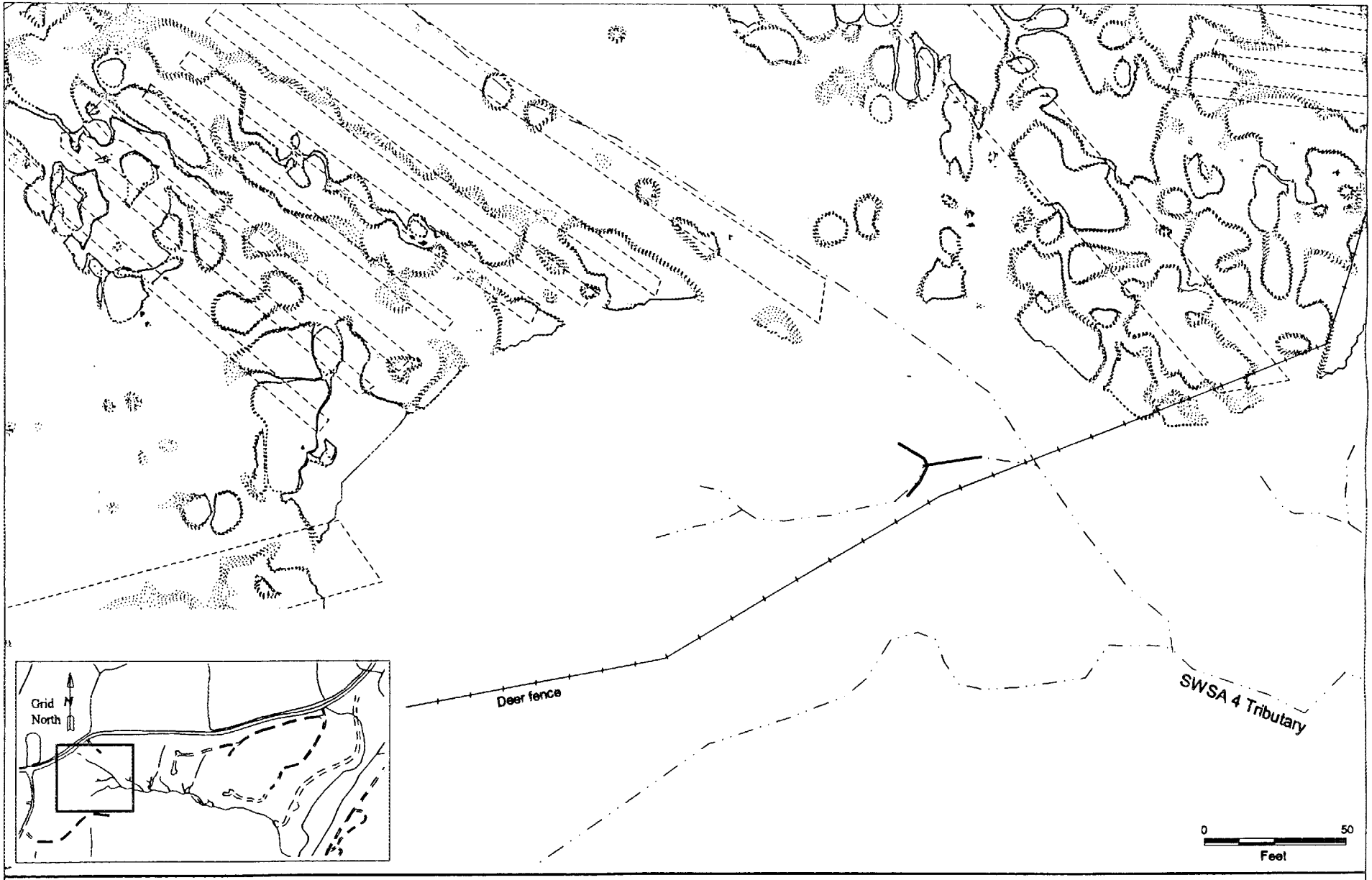


Fig. 2.6.a. Comparison of geomagnetic, thermal and visual data to infer trench orientation and extent

WAG 4 Site Investigation

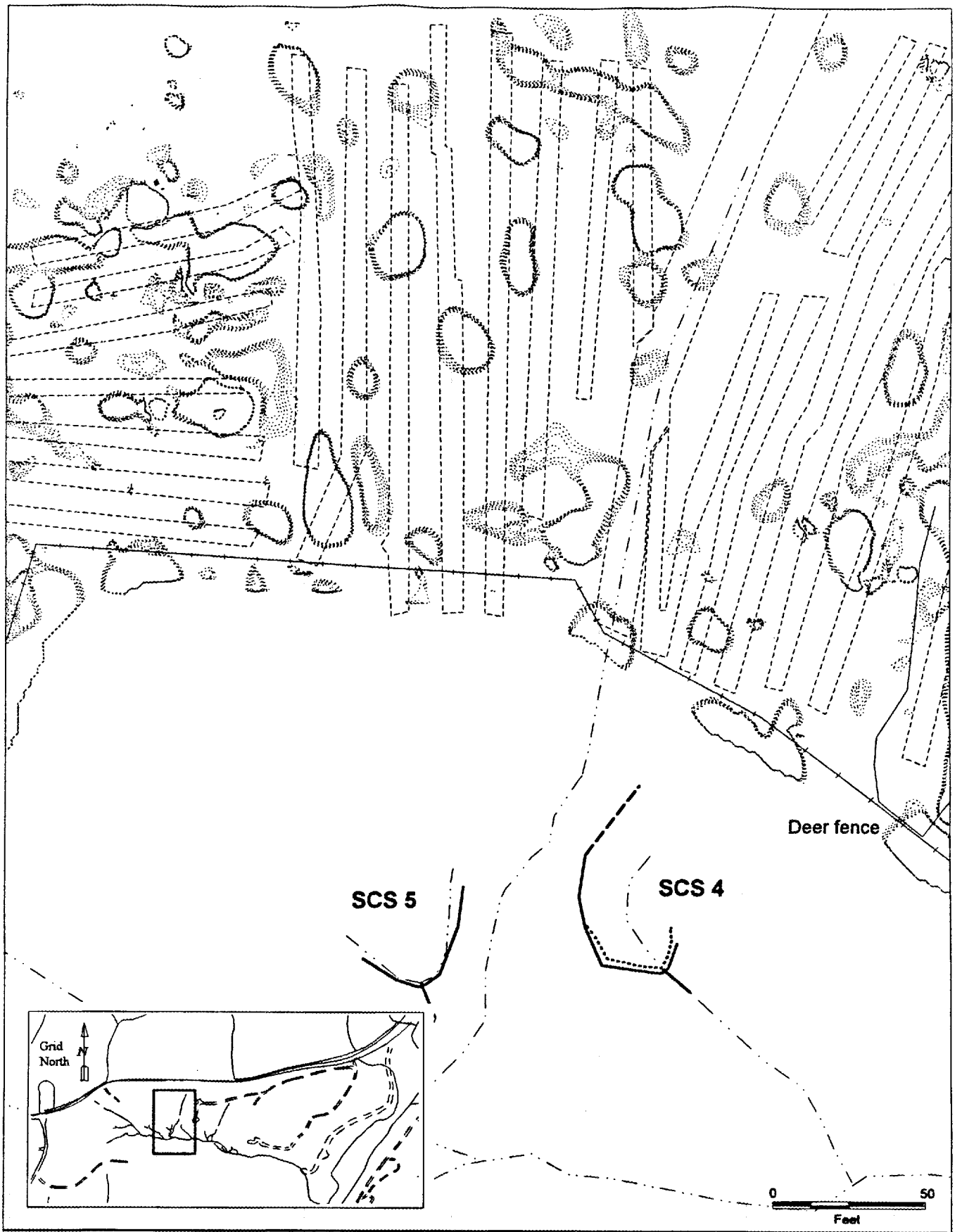


Fig. 2.6.b. Comparison of geomagnetic, thermal and visual data to infer trench orientation and extent

WAG 4 Site Investigation

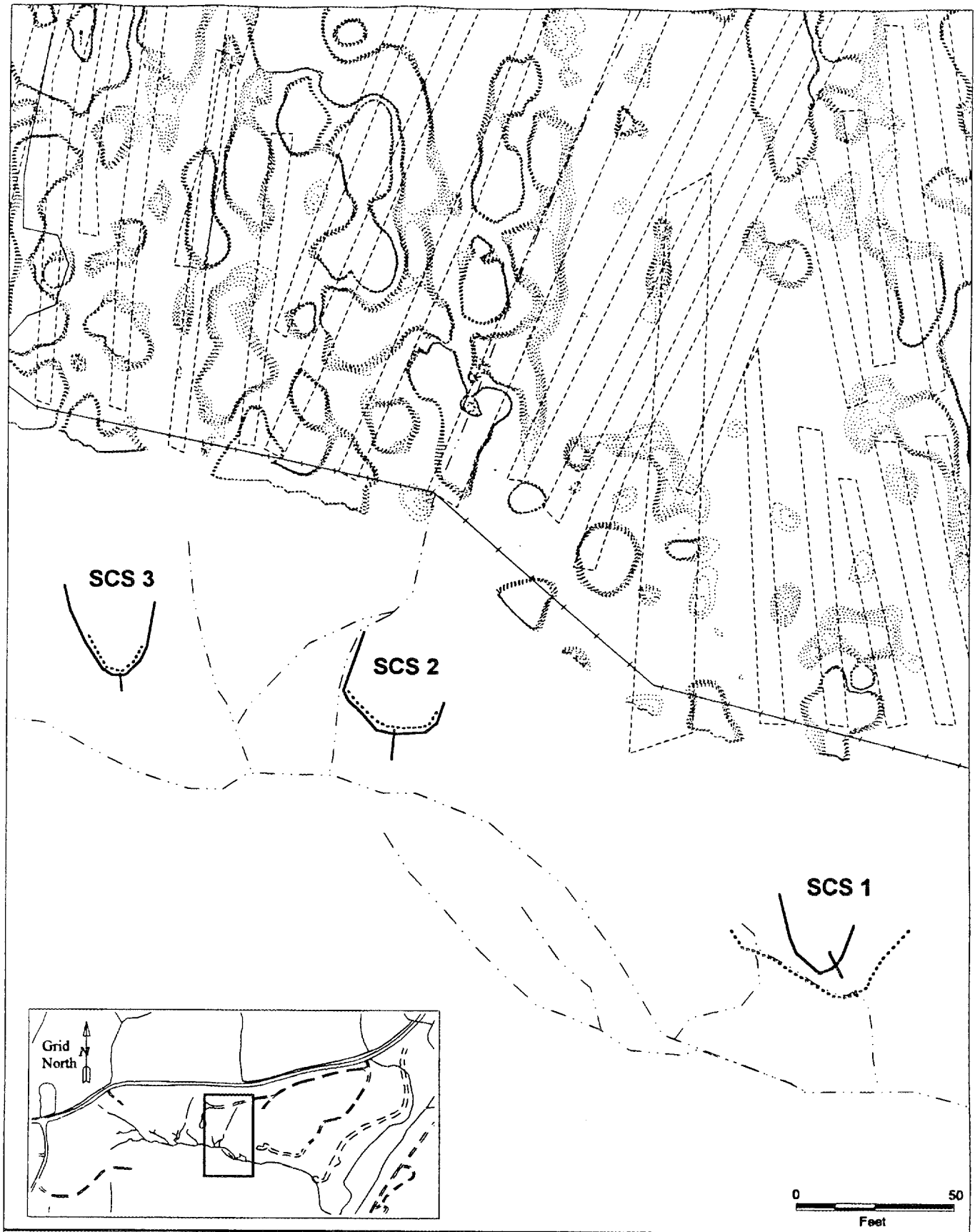


Fig. 2.6.c. Comparison of geomagnetic, thermal and visual data to infer trench orientation and extent

WAG 4 Site Investigation

The GPR method provides cross-sectional images of the subsurface by reflecting radar pulses from natural or man-made objects that have dielectric properties differing from those of overlying or surrounding materials. The cross-sectional images included in Appendix D are likely to include reflections from materials within the trenches and weathered bedrock between and beneath the trenches. There is no simple way to distinguish between the man-made and natural objects; therefore, interpretation of the images relies heavily on previously acquired experience and site information.

Presentation of Results. GPR survey lines for the study areas are shown superimposed on approximate trench locations derived from the SERDP map (Fig. 2.5) in Fig. 2.7a,b. Figure 2.8 is a cross-sectional image developed from a 25-MHz survey showing distance on the horizontal axis and time (depth) on the vertical axis from line C03 (Fig. 2.7b). Traces are plotted at 0.5-ft increments, with CDP 200 being the west end of the line. Because the first trace plotted is at station 203, it is 1.5 ft from the west end of the line. Depth is determined by calculating travel times based on an estimated velocity. In the analysis, a velocity of 0.2 ft/ns is assumed. This is probably accurate to about 20%. Appendix D provides a more complete graphical display and discussion of GPR data for all six GPR lines that were analyzed.

The image shown in Fig. 2.8 was derived by common-midpoint enhancement of data acquired at several antenna separations. These data were acquired only along line C03. Signals occurring at depths of less than 5 or 6 ft in Fig. 2.8 should be discounted, because they do not represent reflected signals. Comparison of the data with drive point data and photographic imagery suggests that GPR is able to detect the bottoms of trenches, and is not responding as much to the material in the trenches as to the trenches themselves.

Conclusions. Several conclusions can be drawn from the GPR data. First, antenna frequencies above 25 MHz do not provide sufficient depth penetration to be useful for defining trenches at WAG 4. Second, data collected for common-midpoint enhancement processing appear more useful than data collected using a single antenna separation method. Finally, the data interpretation is very difficult, if not impossible, without supplementary site-specific information such as approximate trench locations and depths. However, where such information is available, radar data can be valuable for refining trench boundaries, and the method appears promising enough to merit further use for localized studies. It appears that common-midpoint acquisition and processing are needed to image trenches. Data acquisition for the image shown in Fig. 2.8 required about 3 hours in the field and about 3 days of processing afterward. The GPR antennae that were used have a maximum penetration depth of about 15 ft at this site, and therefore will be ineffective where thick fill was deposited over the trenches. Lower-frequency antennae are not a reasonable option, although penetration might be improved slightly by using a more powerful transmitter.

Summary of Remote Sensing Methods Evaluation

Overall, the SERDP map (Fig. 2.5) appears to be the most generally useful remote sensing product available for this study. It appears to provide more detailed information than the vertical-magnetic-gradient map; however, the combined information from both sources is probably more robust than either one in isolation. For example, where the general orientation of features is the same in both data sets, the magnetic data may help in allowing fine-scale interpretation of the SERDP map, especially when used in concert with other information such as drive point construction data or visual observations in the field.

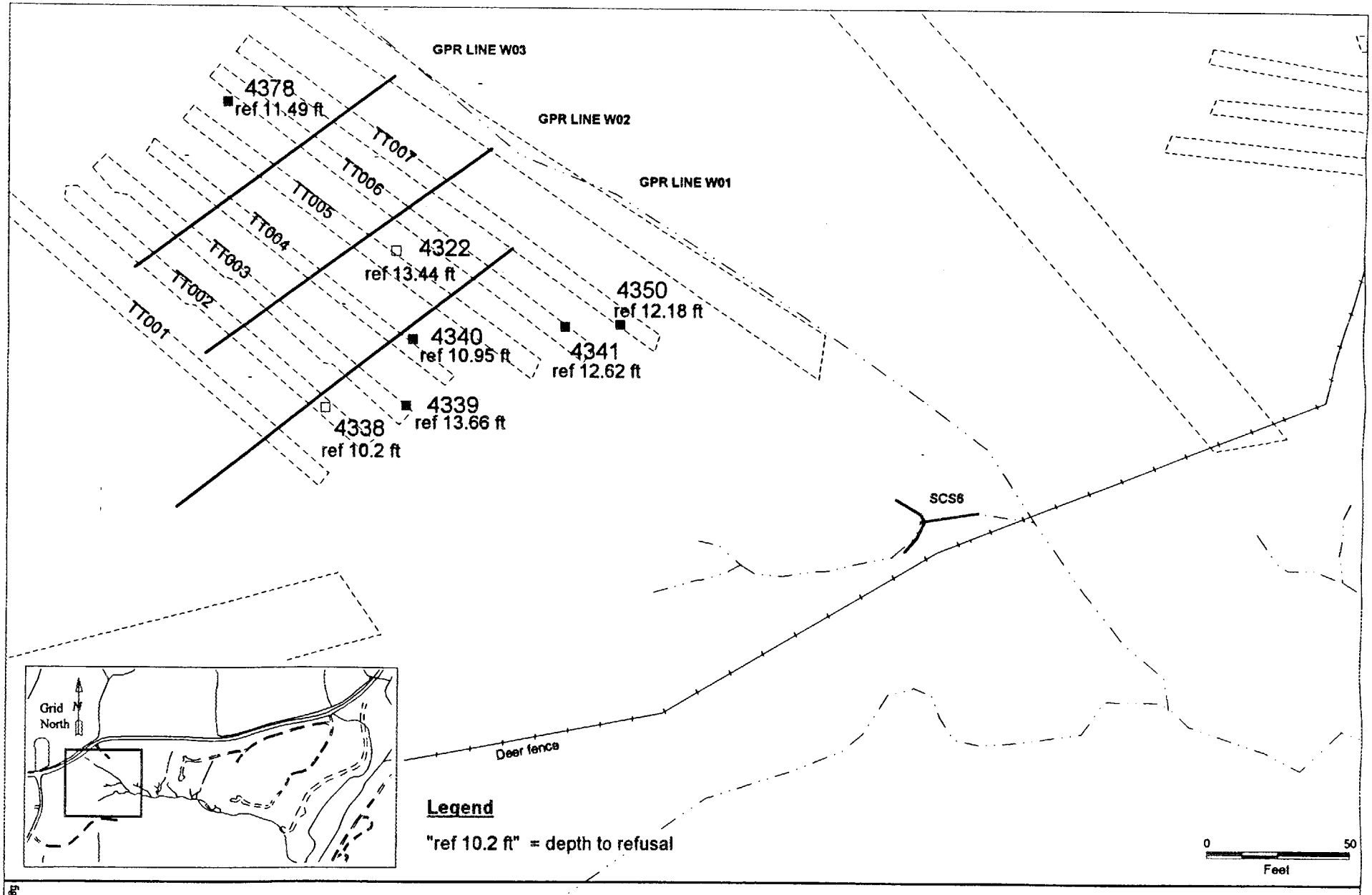


Fig. 2.7.a. Ground penetrating radar survey lines

WAG 4 Site Investigation

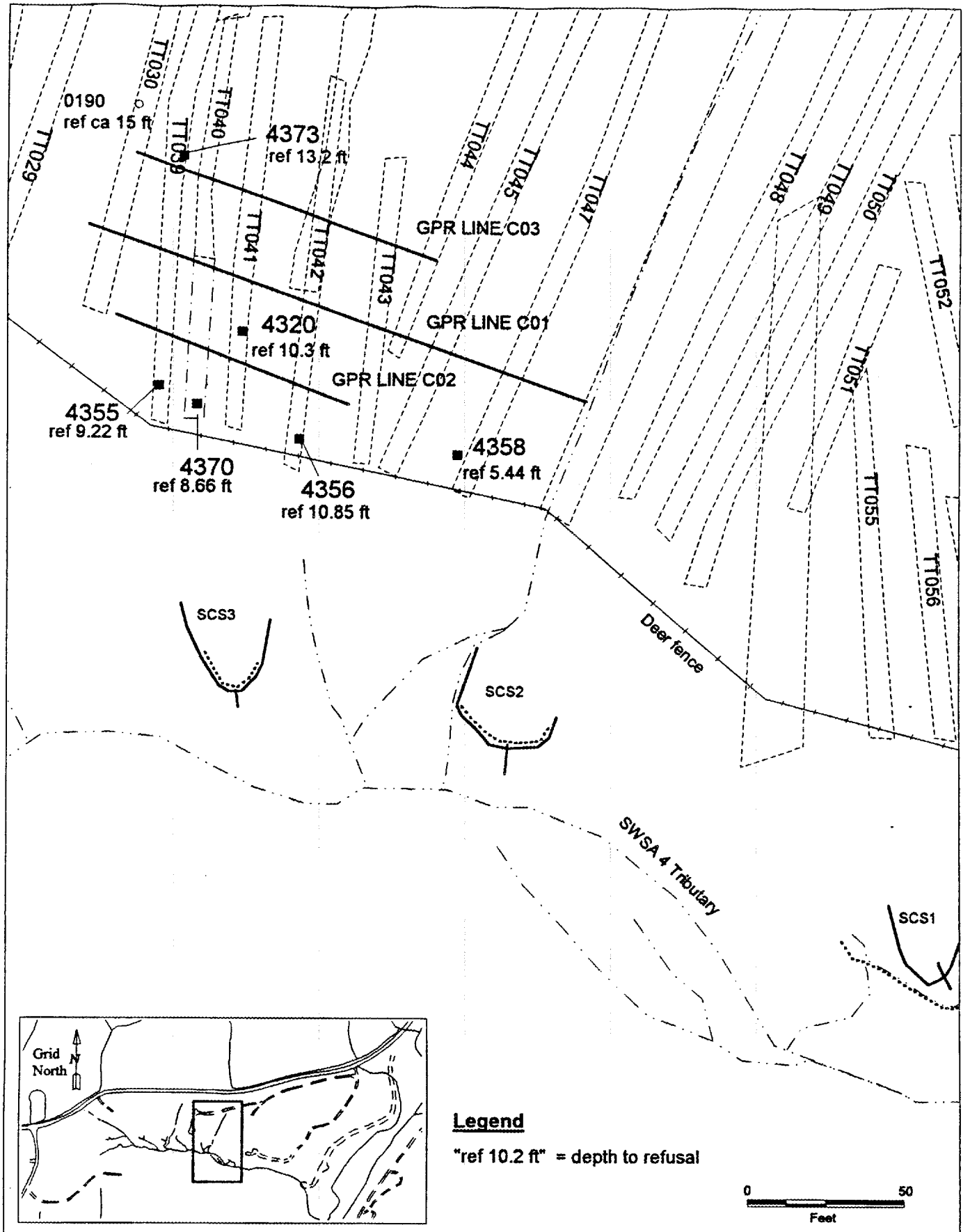
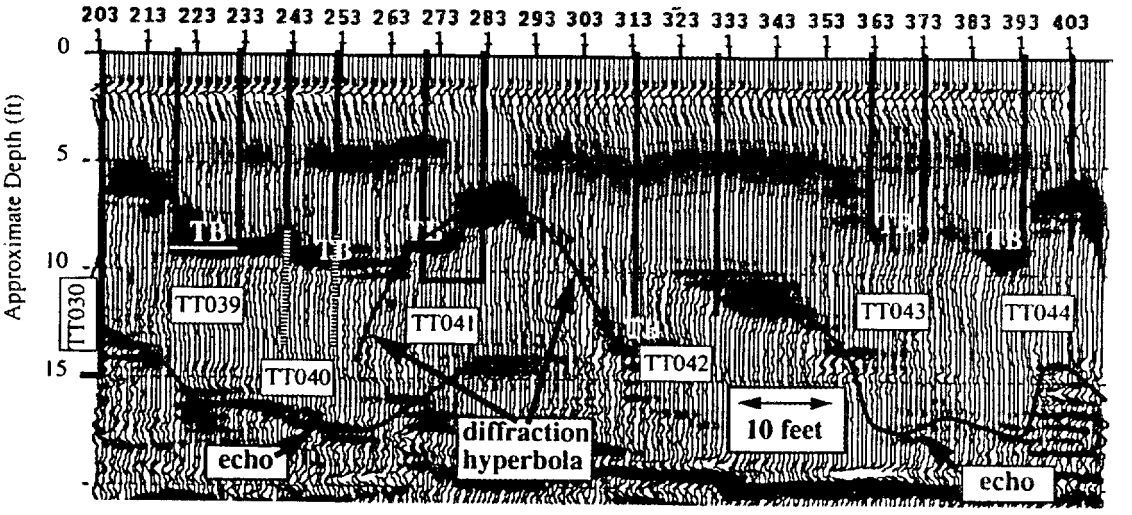
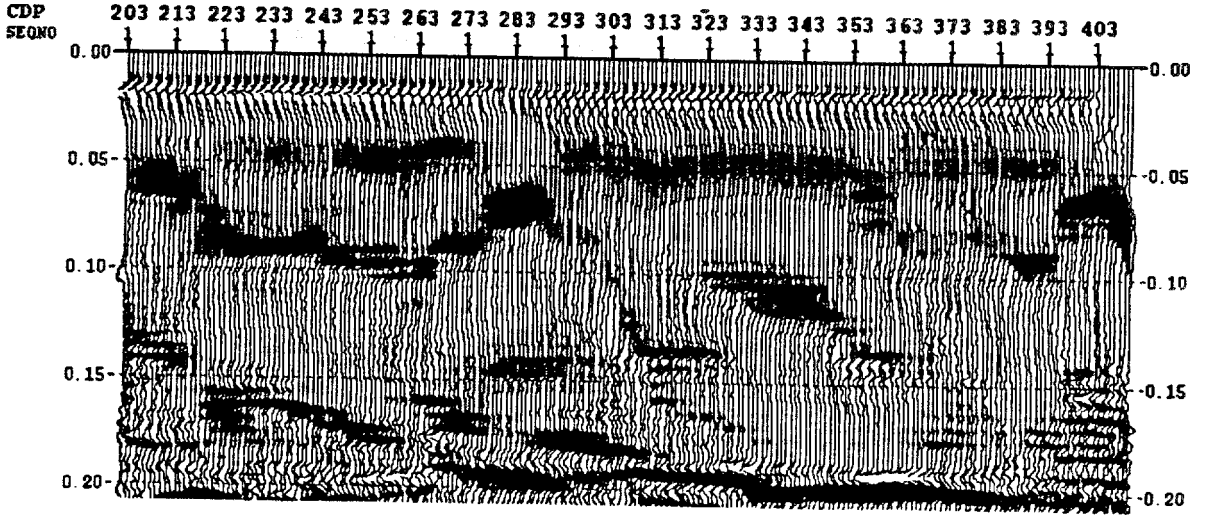


Fig. 2.7.b. Ground penetrating radar survey lines

WAG 4 Site Investigation



Approximate trench locations superimposed on radar data. TB=interpreted trench bottom



Uninterpreted radar section for comparison with above

Fig 2.8. Approximate trench locations superimposed on GPR

The low-frequency GPR analysis discussed in the preceding section shows promising results, when combined with information from the SERDP map and the vertical-magnetic-gradient data. Because it represents a non-intrusive method, it merits consideration as a tool for detailed trench delineation in conjunction with interim actions on specific trenches. The key to successful application is beginning from a known target and extending to new areas. It should be particularly useful in areas where burial trenches do not contain many metal objects.

2.1.3 Drive Point Installations

Overview and Objectives

The primary objective for drive point installation was to penetrate suspect trenches to allow sampling of trench water for determination of ^{90}Sr content. This information was expected to make it possible to trace the pathway to the major sources that feed the seeps identified in the first stages of the investigation. In the first phase of the study, there also was interest in gathering information to allow estimation of the rate and depth of penetration of the drive rod, as a measure of whether a trench had been found, and, if so, the elevation of the bottom of the trench. As the study progressed into the second phase, information collected during drive point installation included a reference point for all elevation data, the full depth of penetration, the elevation interval of the well screen, and some estimate of the depth of fill material placed over the original land surface after disposal operations were completed. The latter estimate depends upon an assumption that trenches were excavated to a depth from 8 ft to 15 ft, and at a typical value of 10 ft, depending on the nature of the natural geologic materials encountered.

In the early stages of the study, little documented information was available to use as a basis for selection of locations for the drive points. As a result, locations for the first 12 drive points were selected based on seep locations, topography, surface evidence of subsidence, and an assumption that vegetation vigor and/or trench subsidence could be extrapolated along a straight line. Thus, selections were made in the field in an attempt to position drive points in features that appeared to be "aimed" directly at the seeps.

For the first 12 drive points, locations were selected, the drive points were installed, and, when all installations were complete, the drive points were sampled. When the comprehensive remote-sensing information became available, some adjustments were made. The strategy was based on an assumption that the downslope edges of the source trenches would have elevated ^{90}Sr concentrations. By adopting a strategy that began with drive points at the downslope ends of the most likely candidates, followed by lateral movement to the next adjacent trench until appreciably lower concentrations were encountered, the most likely contributing trenches were identified. Once located, the strategy involved moving upslope in each source trench to try to pinpoint the source location. Through that process, the sources could be located while minimizing the necessary number of drive points.

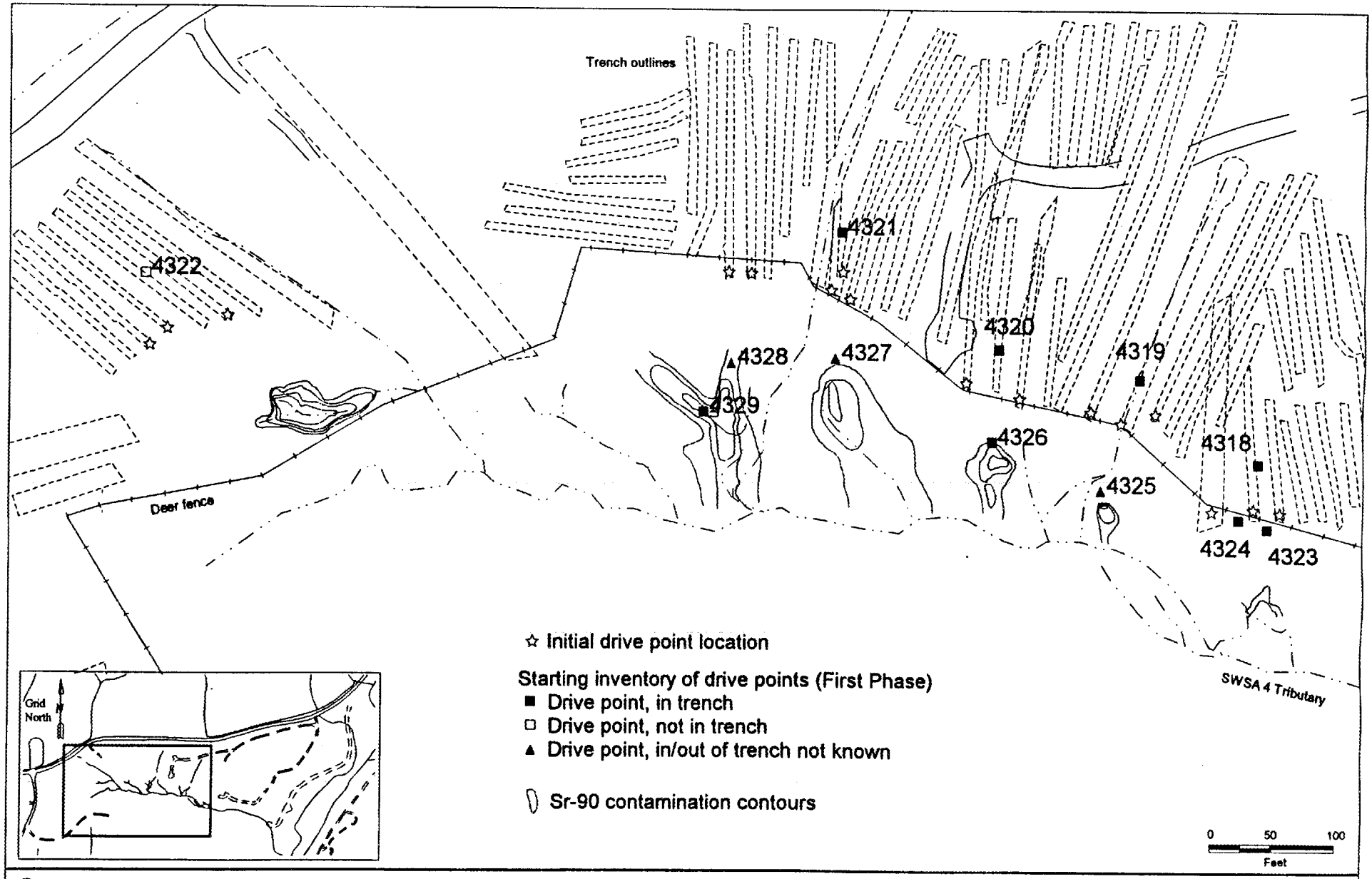
In the second phase of the study, sampling and rapid analysis of the trench-water contents became very important to maintaining an efficient pace of drive point installation. There were two obstacles to overcome. First, health and safety concerns during installation made it impractical to both install and sample a drive point during the same day. Installation in an area generally required most of the day, and access for sampling was denied until all installation work in the area was completed for the day. Because each drive point required more than an hour for installing sampling

tubing and collecting the suite of samples, there simply was not enough time. This problem was overcome by designating 2 days per week as sampling days, and coordinating installation work so that newly installed drive points could be available on sampling days. The second obstacle to overcome is that ^{90}Sr must equilibrate with its daughter product, ^{90}Y to achieve accurate analysis; therefore, analysis always requires more than 2 weeks. The team explored the relative merits of using a gross-beta count or using the Cerenkov method without allowing time for radionuclide equilibration. Both of these analyses could be completed overnight, making results available the next morning for deciding locations of new drive points. In the final analysis, the overnight gross-beta count was the more reliable indicator; therefore, it was used exclusively for selection of new drive point locations.

Drive-Point Installation Method

Selection of Locations. The location selection method for the first phase of the study was explained in the overview. Basically, locations were chosen in the field, using professional judgment and available information. In the second phase of the work, the remote-sensing information on suspected trench locations was combined with the known seep locations, and an initial set of locations were selected to begin implementation of the strategy. Figure 2.9 shows the locations initially selected. To find the locations in the field, surveyors were called in to place wooden stakes on the centerline of suspected trenches, and the final locations were selected by referencing to the appropriate stake. As drive points were installed and sampled and the results analyzed, the gross-beta radioactivity content of the water was noted at the drive point location on a map of the site, and decisions on the proposed locations for new wells were made by the technical team. These locations were given to the installation team for subsequent action. If questions arose, field meetings occurred during which the project technical lead investigator assisted in selection of exact locations.

Drive Point Installation. Drive rods were driven to the bottom of each trench; the rods then were withdrawn approximately 14 in., leaving the steel drive point embedded in the trench bottom and exposing an open zone for the well screen. The polyvinyl chloride (PVC) well screen and casing then were installed through the drive rods to seat the rubber seal and complete the installation. The first 12 drive points were installed from July 18, 1994, through July 29, 1994, using a mobile drive-point-installation rig. During the second phase of the project, which occurred from January 24, 1995, to March 23, 1995, an additional 42 drive points were successfully installed. Five other attempted installations were abandoned because the drive point penetration was refused at depths ranging from 3 to 7 ft, and appeared to be encountering obstructions that would prevent reaching the bottom of a trench. Nine probes using 6-ft lengths of heavy reinforcing rod were driven in areas where obstructions appeared to be blocking successful drive-point installation. Once a probe indicated that near-surface obstructions were not present, a nearby location was selected for a drive point. Because of the possibility of encountering buried drums containing metallic sodium, which could result in an explosion, all drive points were installed using remote-operation controls. A typical drive-point well-construction diagram is provided in Fig. 2.10. Appendix E contains detailed information collected during drive point installations. Appendix F contains a log of daily notes taken during installation operations, and the field plan for installing the drive point wells.



fig_dpst

Fig. 2.9. Strategy for location of drive points

WAG 4 Site Investigation

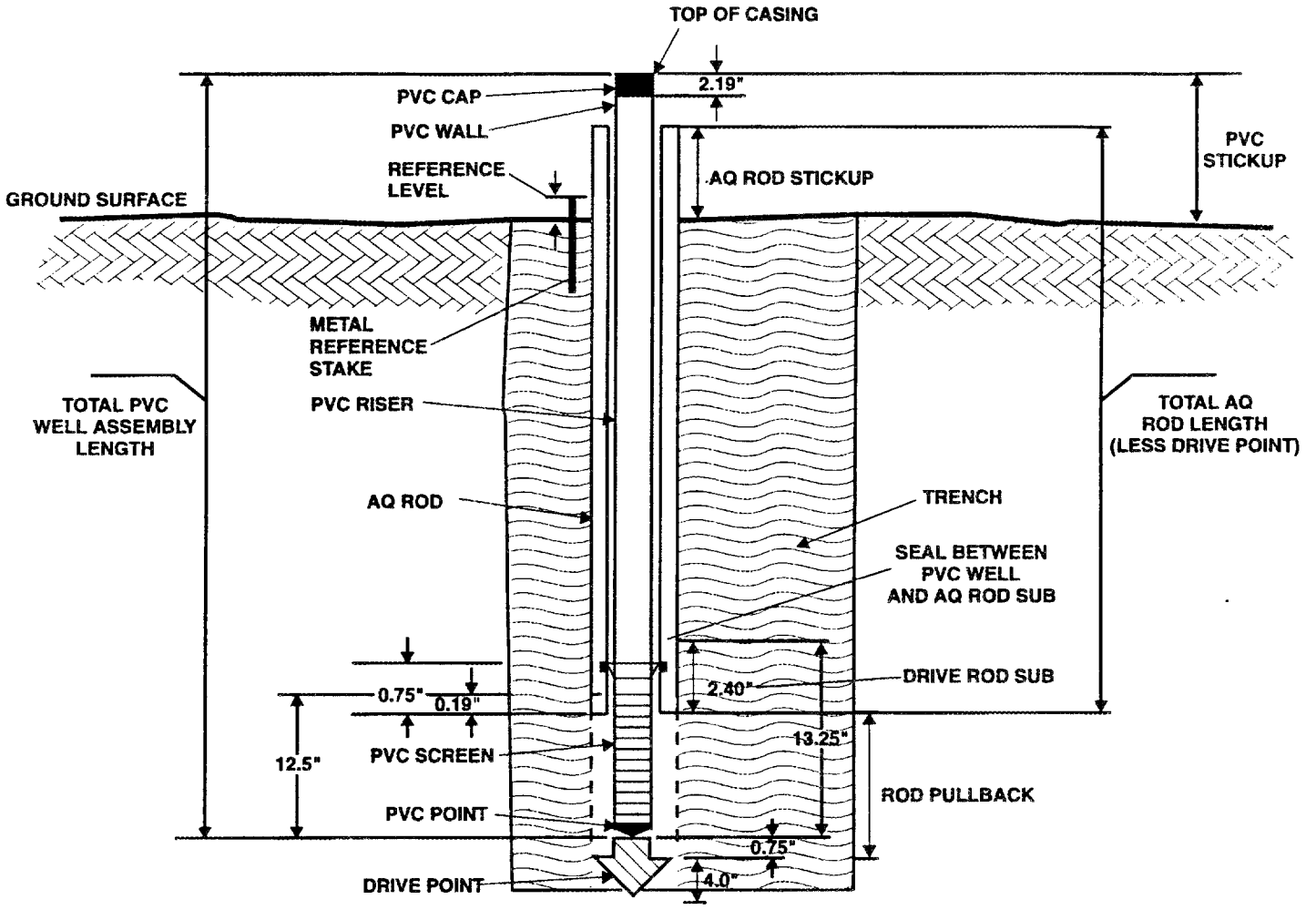


Fig. 2.10. Typical drive point well construction diagram

Initial Sampling of Drive Point Wells

The initial sampling of drive point wells was intended to provide short-term information to indicate general levels of beta-radiation-emitting radionuclides in groundwater to assist in selecting new drive-point locations, as well as to provide more complete analysis for identification of specific sources. In particular, ^{90}Sr content was to be used in the final analysis for identification of specific sources within trenches causing ^{90}Sr release from the site.

Once a drive point well had been completed, a copy of the installation log was provided to the groundwater sampling team. Plastic tubing was cut to the appropriate length and installed in the drive point well to allow sampling by peristaltic pump. In general, a water-level measurement was made to ensure that a sample could be collected, then samples were taken in accordance with the project Work Plan (Energy Systems 1994c). The samples then were submitted to the laboratory for analysis.

The morning after sample submission, gross-beta and "short-count" Cerenkov results for ^{90}Sr were provided to project management and the technical lead investigator, and were used for selecting new drive-point locations. Subsequent results were made available in electronic format, and were incorporated into the project database.

Results Achieved

Throughout the full course of the study, 54 drive-point wells were successfully installed—12 in the first phase and 42 in the second phase. Five drive-point installation attempts were abandoned, and nine sections of metal rod were driven to probe for locations in which obstructions could be avoided for subsequent well installations. The locations of the drive points are shown in Fig. 2.11. Drive points were initially identified with the prefix "DP" followed by a sequential number; ORNL well numbers now have been assigned to each successful installation and are presented in Fig. 2.11. Table 2.2 provides a summary of drive-point installation information. Figure 2.11 also includes the location of four previously existing wells in the bathtubbing trench area (Area 6). These wells (ORNL Well Numbers 2568, 2569, 2578, and 2581) were sampled in August 1994 and analyzed for ^{90}Sr as part of this investigation.

2.1.4 Topographic Survey

The topographic (civil) survey of drive points, seep collection systems (SCSs), emerging seeps, and other site features was conducted to obtain accurate horizontal- and vertical-control information for each of the data collection locations. This information then could be used in data interpretation and presentation as well in corrective action planning. The survey was conducted by Adams Craft Herz Walker, Inc., using a two-man crew. Radial topographic methods were used to conduct the survey. Existing benchmarks located in and near WAG 4 were used whenever necessary. Measurements were taken within a vertical accuracy of 0.01 ft and a horizontal accuracy of 0.1 ft. Survey crews located all points and provided descriptions in accordance with the project Work Plan and with instructions from the on-site field coordinator. Electronic and hard copy deliverables were provided of the site drawing and database.

The survey database was received into the project data management program. After incorporation, survey data were used to construct digital geographic layers indicating the exact

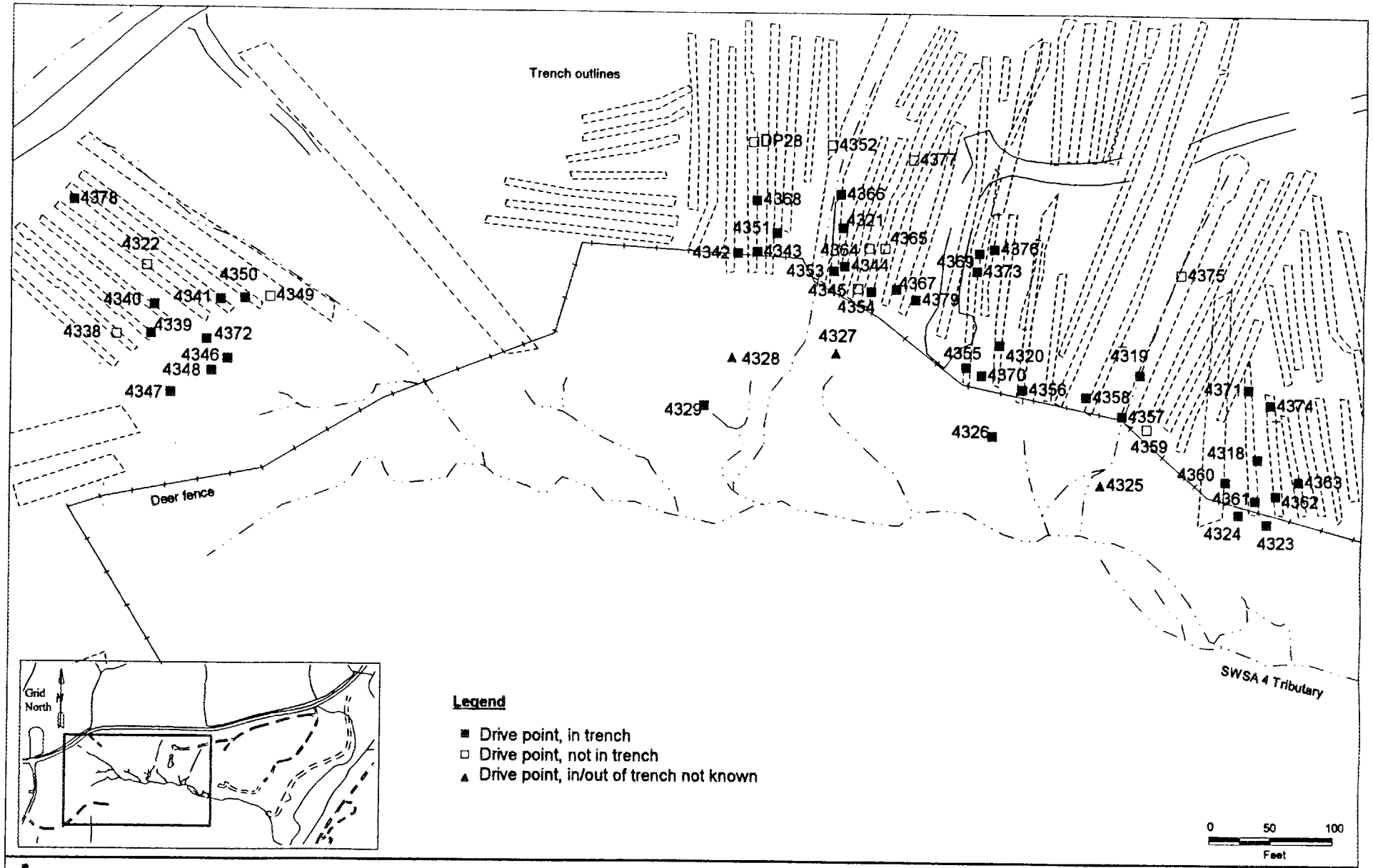


Fig. 2.11. Drive point locations

WAG 4 Site Investigation

Table 2.2. Drive point installation summary

ORNL well number	Drive point ID	ORNL Easting (ft)	ORNL Northing (ft)	Top of casing elevation (ft)	Ground surface elevation (ft)	Top of screen elevation (ft)	Refusal elevation (ft)	Inside trench?
4318	DP01	28,287.48	19,045.18	788.33	785.05	775.12	771.53	Yes
4319	DP02	28,191.95	19,110.99	787.69	785.27	775.48	772.50	Yes
4320	DP03	28,080.25	19,133.92	790.50	788.57	780.29	777.42	Yes
4321	DP04	27,953.75	19,225.00	800.59	797.99	785.38	782.18	Yes
4322	DP05	27,400.69	19,190.90	810.28	806.85	795.07	791.25	No
4323	DP06	28,295.27	18,994.29	787.45	783.42	769.24	764.32	Yes
4324	DP07	28,272.28	19,001.47	785.71	781.52	769.50	764.17	Yes
4325	DP08	28,160.85	19,024.21	783.54	780.47	770.33	767.32	Unknown
4326	DP09	28,074.58	19,062.07	786.89	783.57	775.68	772.05	Yes
4327	DP10	27,949.67	19,126.72	792.44	789.06	781.23	777.62	Unknown
4328	DP11	27,867.15	19,122.73	790.31	787.54	781.10	778.54	Unknown
4329	DP12	27,844.92	19,084.92	788.01	784.68	780.80	776.97	Yes
4338	DP16	27,376.53	19,136.91	814.37	810.80	801.17	800.81	No
4339	DP14	27,404.48	19,137.74	811.99	808.82	795.79	795.43	Yes
4340	DP13	27,406.74	19,160.55	810.60	808.03	798.44	797.29	Yes
4341	DP15	27,459.37	19,165.19	807.99	805.21	792.96	792.76	Yes
4342	DP17	27,870.91	19,204.89	799.77	796.06	784.62	784.63	Yes
4343	DP18	27,886.27	19,206.01	798.70	795.57	783.41	782.92	Yes
4344	DP19	27,955.41	19,195.07	798.41	795.35	785.25	783.27	Yes
4345	DP20	27,966.04	19,177.61	798.54	793.71	787.37	787.04	No
4346	DP21	27,465.25	19,118.31	809.42	805.19	803.24	802.90	Yes
4347	DP22	27,420.12	19,091.83	816.42	810.35	800.21	799.84	Yes
4348	DP23	27,452.48	19,109.00	808.28	806.41	795.10	794.76	Yes
4349	DP29	27,882.43	19,292.19	805.74	800.47	794.56	794.22	No
4350	DP30	27,498.82	19,167.42	806.34	803.74	792.16	791.82	Yes
4351	DP25	27,901.61	19,220.81	799.31	797.01	789.12	788.77	Yes
4352	DP27	27,944.75	19,289.75	805.63	802.62	794.44	794.09	No
4353	DP26	27,947.06	19,191.47	797.72	795.08	786.53	786.18	Yes
4354	DP24	27,976.41	19,175.22	797.38	793.71	784.18	781.82	Yes
4355	DP31	27,478.85	19,165.93	790.03	787.50	778.84	778.49	Yes
4356	DP32	28,053.77	19,116.27	787.35	784.28	774.11	773.70	Yes
4357	DP34	28,177.55	19,078.28	785.84	782.80	774.65	774.30	Yes
4358	DP33	28,098.42	19,098.74	786.64	783.29	778.43	778.05	Yes
4359	DP35	28,197.87	19,068.36	788.54	783.78	777.35	777.00	No

Table 2.2 (continued)

ORNL well number	Drive point ID	ORNL Easting (ft)	ORNL Northing (ft)	Top of casing elevation (ft)	Ground surface elevation (ft)	Top of screen elevation (ft)	Refusal elevation (ft)	Inside trench?
4360	DP36	28,261.26	19,027.49	786.00	782.50	772.02	771.68	Yes
4361	DP37	28,285.46	19,013.08	786.61	783.24	769.41	769.01	Yes
4362	DP38	28,302.13	19,016.43	787.03	784.42	773.84	773.49	Yes
4363	DP39	28,320.66	19,027.75	788.05	786.85	770.86	770.51	Yes
4364	DP46	27,974.69	19,209.38	802.73	796.91	791.57	791.25	No
4365	DP42	27,987.35	19,209.20	800.93	797.18	792.76	792.43	No
4366	DP41	27,951.63	19,251.35	803.21	800.18	786.07	785.78	Yes
4367	DP43	27,996.76	19,177.33	798.55	794.86	787.42	787.12	Yes
4368	DP40	27,885.46	19,246.48	802.43	799.37	787.26	786.93	Yes
4369	DP45	28,063.20	19,205.71	803.46	797.38	792.30	791.98	Yes
4370	DP44	28,065.94	19,110.14	789.71	786.58	778.51	778.15	Yes
4371	DP47	28,278.87	19,100.15	791.96	788.57	774.79	774.45	Yes
4372	DP49	27,448.56	19,133.31	810.39	806.54	794.23	793.90	Yes
4373	DP50	28,061.60	19,191.59	798.69	796.10	783.50	783.15	Yes
4374	DP48	28,296.90	19,087.96	791.14	788.50	773.95	773.60	Yes
4375	DP51	28,224.31	19,189.82	796.15	791.74	785.00	784.68	No
4376	DP52	28,075.25	19,209.11	799.54	797.17	793.36	793.01	Yes
4377	DP53	28,009.66	19,278.67	806.24	803.38	798.06	797.72	No
4378	DP54	27,341.65	19,241.58	811.20	807.95	796.99	796.65	Yes
4379	DP55	28,012.52	19,168.88	796.38	794.29	783.21	782.88	Yes

locations for major points of interest at WAG 4. A detailed listing of the survey data is included in Appendix C.

2.2 ASSESSING THE RELATIVE IMPORTANCE OF IDENTIFIED SOURCES

2.2.1 Seep Collection Systems

In conjunction with drive point installation and sampling, the WAG 4 Site Investigation also included an evaluation of the seeps emerging from the trench and discharging to the WAG 4 tributary, the surface-water exit pathway. The purposes of this evaluation are (1) to estimate the relative contributions of individual seep discharge areas to total releases from WAG 4, (2) to confirm that ^{90}Sr sources in trenches are related to seep flows and ^{90}Sr levels, and (3) to provide critical data for evaluation of interim action options such as hydraulic isolation or collection and treatment of seep discharges.

Location and Construction of Seep Collection Systems

To conduct this evaluation, SCSs were constructed in six locations. as shown in Fig. 2.12. Systems 1 through 5 were constructed by placing sandbags in a semicircular pattern surrounding the seep, installing heavy-gauge plastic sheeting over the sandbags, and inserting a flap into the ground approximately 12 in. deep to force shallow flow to the surface (Fig. 2.13). An 8-in. PVC pipe then was installed at the low point of the structure (the outlet), through an opening fabricated as part of the liner, to allow flow measurement and water-quality sample collection. SCS 6 had been installed previously (consisting of a sandbag berm and 6-in. outflow pipe). Only minor maintenance changes were made to SCS 6 to improve flow and strengthen the outlet structure. When initial observations indicated that the 12-in. plastic cutoff wall was not adequate to collect the flow from the emerging seeps, a secondary subsurface wall of interlocking sheet piling was installed to supplement portions of SCSs 1, 2, 3, and 4, to increase the amount of water intercepted. The wall consisted of interconnected, 3-ft-long, heavy gauge aluminum pilings. The pilings were driven vertically into the soil to a depth of approximately 3 ft, and the piling at the discharge pipe outlet was made flush with the ground surface.

At the downstream end of the outflow pipe, a laboratory-calibrated weir (of a combination V-notch and rectangular construction) was installed at all SCS sites except SCS 1, at which a 45° V-notch weir was installed. Approximately 3 to 5 ft upstream from the weir, a stilling well was installed into the outflow pipe to measure the water level depth (or stage). A staff gauge was placed on the stilling well to allow visual observation of stage, and a pressure transducer was installed in the stilling well. The pressure transducer was connected to a data logger that recorded water stage every 5 minutes. At SCS 1, a staff gauge and pressure transducer were installed approximately 5 ft upstream from the V-notch weir. Stage data were recorded (in feet) at 5-minute intervals for conversion into hourly, daily, and monthly discharges (in liters/second), using a stage-discharge relationship.

Flow Data Collection and Water Quality Analysis

Water depths in the SCS stilling wells were used to calculate the rate of flow passing each weir. The objective was to relate flow at each site to stream flow from the area, which was measured at site MS-1. MS-1 is a WAG 2 monitoring station that receives discharge from SCS 1 through SCS 6 (see Fig. 2.12). Hydrographs are plotted in Fig. 2.14a,b for MS-1 and all the SCS sites. SCSs 1 through 3 were not flowing during February, before installation of the sheet-piling cutoff walls. The SCS hydrographs show a daily cycle in flow. The cycle may be related to a temperature effect on the pressure transducers. In any case, it has a negligible effect on calculated flow volume and mass transport of ^{90}Sr.

Total volume, together with average, maximum, and minimum flows at all the sites, are presented in Table 2.3. The combined percentage of the total MS-1 water volume that was measured at the SCS sites was 13%, 19%, 21%, and 23% for the months of February, March, April, and May, respectively. However, it appears that when the sheet-piling cutoff wall was installed at SCS 1, its placement inadvertently captured flow from the stream channel system that drains the entire site. The original berm and plastic cutoff weir yielded negligible flow before installation of the cutoff piling wall and V-notch weir. Therefore, flow volumes and concentrations at SCS 1 should be discounted, since they contain mostly drainage from the upstream areas, including all the other seep collection systems. Flow from all the SCS sites was sporadic and was strongly influenced by

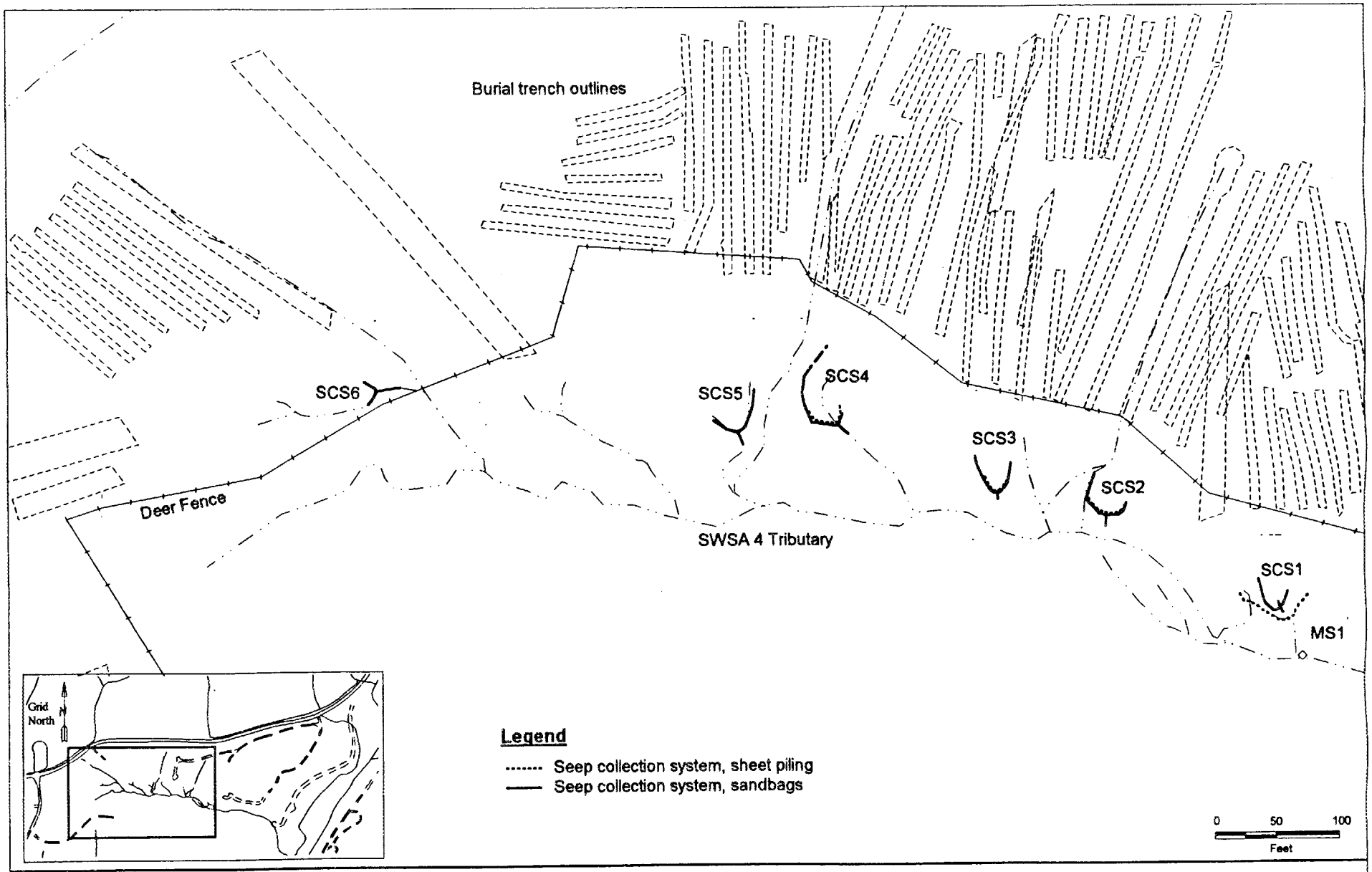


Fig. 2.12. Locations of seep collection systems

WAG 4 Site Investigation

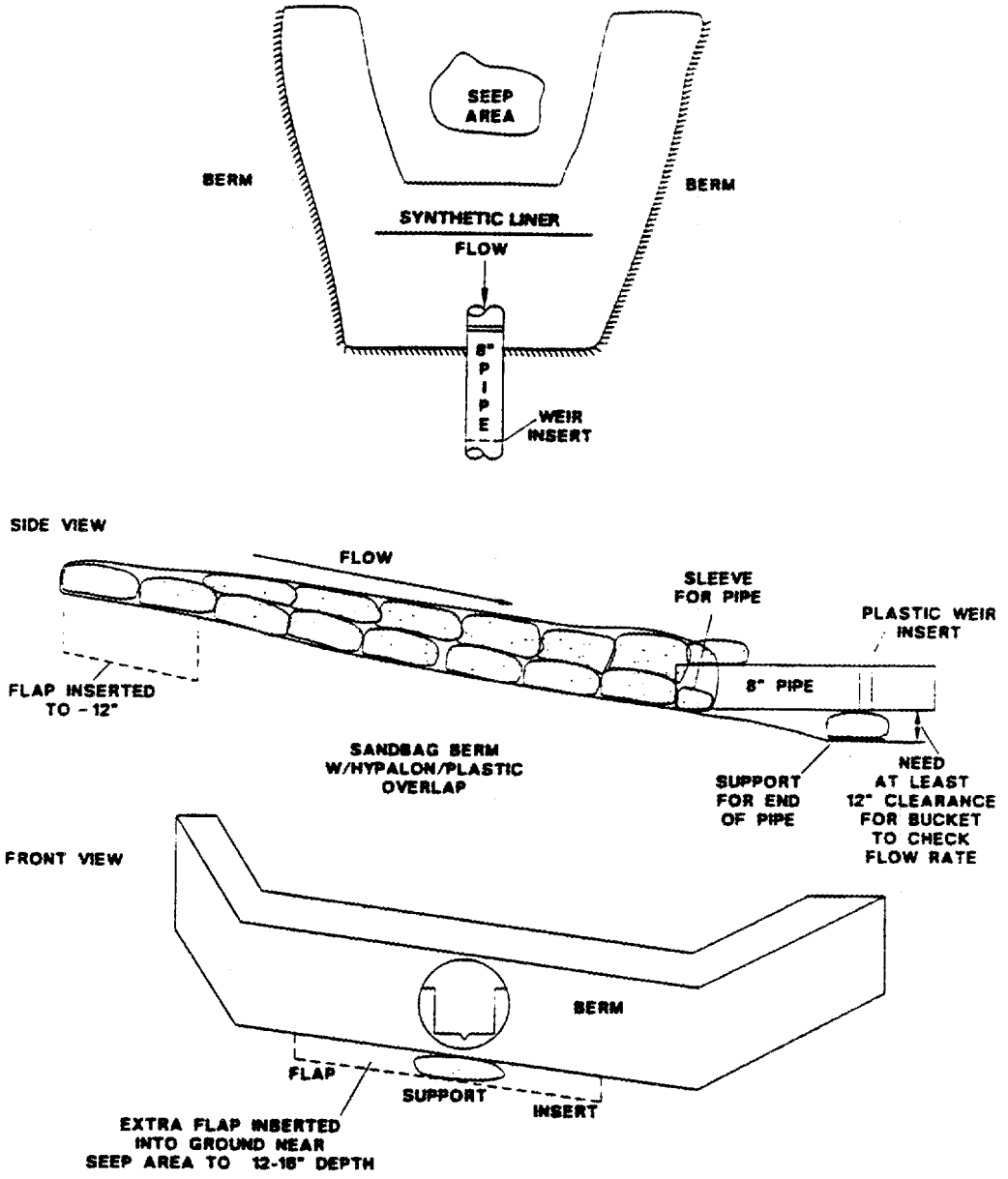


Fig. 2.13. Typical weir construction for seep collection systems

WAG 4 Site Investigation

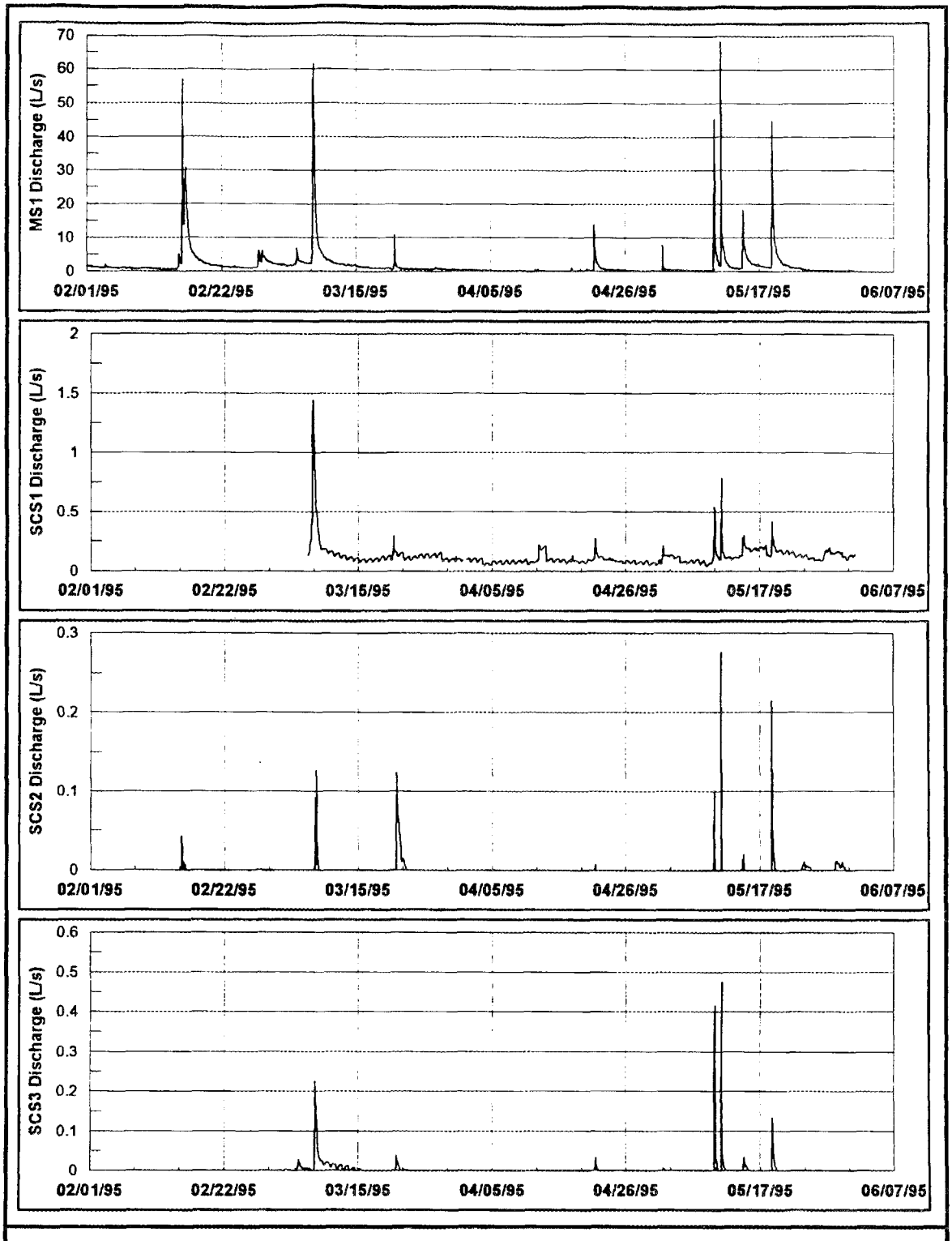


Fig. 2.14.a. Hydrographs for MS-1 and SCS sites
WAG 4 Site Investigation

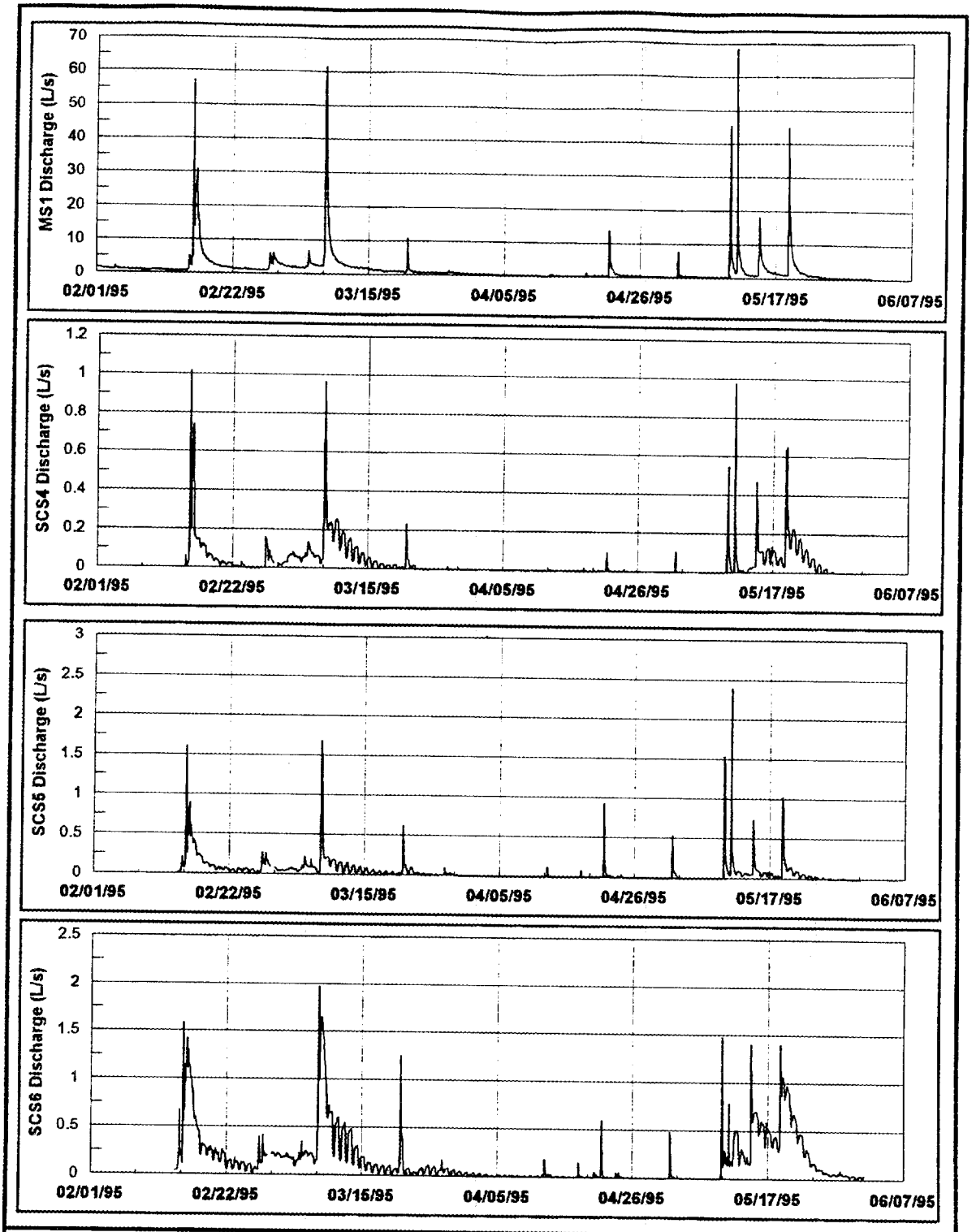


Fig. 2.14.b. Hydrographs for MS-1 and SCS sites
WAG 4 Site Investigation

Table 2.3. Water budget and flow at the SCSs

Site	Total volume (m^3)	Percentage of MS-1	Average flow (L/s)	Maximum flow (L/s)	Minimum flow (L/s)
		February (Precipitation = 9.47 cm)			
MS-1	6014.3	100	2.463	67.449	0.651
SCS 1	nm[a]				
SCS 2	nm				
SCS 3	nm				
SCS 4	78.7	1.64 pm[b]	0.065	1.284	0.000
SCS 5	169.9	3.54 pm	0.140	1.879	0.003
SCS 6	345.0	7.38 pm	0.292	2.238	0.016
		March (Precipitation = 8.43 cm)			
MS-1	6750.5	100	2.520	67.449	0.510
SCS 1	313.4	5.97 pm	0.151	1.510	0.077
SCS 2	6.7	0.10	0.002	0.831	0.000
SCS 3	15.6	0.23	0.005	0.268	0.000
SCS 4	143.0	2.12	0.053	1.235	0.000
SCS 5	176.3	2.61	0.065	1.899	0.000
SCS 6	556.8	8.25	0.207	2.277	0.000
		April (Precipitation = 6.25 cm)			
MS-1	1245.9	100	0.453	15.715	0.113
SCS 1	225.2	18.08	0.086	0.391	0.046
SCS 2	0.0	0.00	0.000	0.076	0.000
SCS 3	0.5	0.04	0.000	0.059	0.000
SCS 4	1.3	0.10	0.000	0.316	0.000
SCS 5	13.5	1.08	0.005	1.173	0.000
SCS 6	24.4	1.96	0.009	1.398	0.000
		May (Precipitation = 15.90 cm)			
MS-1	5626.8		2.1	109.086	0.168
SCS 1	361.0	6.42	0.134	1.238	0.045
SCS 2	5.3	0.09	0.001	0.818	0.000
SCS 3	11.1	0.20	0.004	1.052	0.000
SCS 4	125.6	2.23	0.046	1.631	0.000
SCS 5	157.3	2.80	0.058	3.758	0.000
SCS 6	617.0	10.97	0.230	2.238	0.000

[a] nm = not measured
[b] pm = partial month

antecedent water content in soil and by amount of precipitation. During the wettest months (February, March, and May), most of the flow came from SCS 6. During the driest month (April), most of the flow came through the SCS 1 site.

Water quality samples were collected at MS-1 and SCS sites during base-flow conditions on March 13, 1995, and during storm-flow conditions on February 16, March 8, and April 21, 1995. Samples were collected in accordance with the work plan and were sent to the Close Support Laboratory for filtering and analyses (gross alpha/beta, ^{90}Sr, ^{3}H, and ^{137}Cs). Analytical results are presented in Table 2.4. During the water-quality sample collection, the instantaneous flow rate was measured by noting the time required to collect a known volume of water passing the weir (i.e., by bucket gauging). These data provided a means to calibrate and refine the relationship between stage height measured by the pressure transducers and flow rate from the SCS sites.

Flow/Contaminant Concentration Relationships and Contaminant Fluxes

Instantaneous flow measurements and ^{90}Sr concentrations were used to calculate the relationship of flow (Q) versus contaminant concentration (C) in the equation $C = C_0 Q^{exponent}$. There is useful information in the magnitude of the exponent:

exponent = -1	implies simple dilution of a constant groundwater source by uncontaminated storm runoff
exponent < -1	implies that mass flow decreases with increasing flow; hence, the (groundwater) source strength is diminished
exponent > -1	implies mass flow increases with increasing flow; hence, new sources are contributing.

Results are shown in Fig. 2.15. The best fit for the CQ relationship is presented in Table 2.5. Only one sample was collected at SCS 2, and no CQ relationship was calculated; the ^{90}Sr concentration at this site was assumed to be constant through time. The CQ exponents for MS-1, SCS 1, SCS 4, and SCS 5 ranged between -0.26 and -0.31, and had an R^2 greater than 70%. SCS 3 and SCS 6 showed a very weak CQ relationship because of wide variability in the data (that is, wide variability in Q for very similar C). However, the value of the exponents shows that source contributions increase with increasing flow at the SCS sites; hence, storm flow must be mobilizing new ^{90}Sr material from trenches.

Contaminant mass flow contributions from the SCS sites through MS-1 could not be accurately assessed from instantaneous flow and contaminant-concentration measurements because of rapidly changing flow conditions and the impracticality of simultaneous sampling at all sites. The CQ relationships were used to calculate mass flows for each storm-flow period (of 3- or 4-day duration) and base-flow period (of 1-day duration). The results are presented in Tables 2.6 and 2.7. They indicate that the SCS sites contribute over 60% of the total ^{90}Sr mass flow through MS-1 and less than 16% of the total flow during major storm-flow periods. During the base-flow (recession) period, after the March 8, 1995, storm, the SCS sites contributed 63% of the total mass flow of ^{90}Sr and about 22% of the total flow through MS-1 (discounting SCS 1 contributions). During the April storm, average flow rates were lower than the base flow sampling condition, and showed about 8–9% of the MS-1 mass flow of ^{90}Sr and 4% of the volume of water came from the SCS sites

Table 2.4. Phase I results for SCSs and emerging seep (SP) samples collected at WAG 4

Location	Date collected	Time collected[a]	Gross alpha (pCi/L)	Gross beta (pCi/L)	Sr-90 (pCi/L)	Flow rate (bucket gauging) (L/S)	Cs-137 (pCi/L)	Tritium (pCi/L)
MS1	2/16/95	1156	13.6 ± 3.4	4946.9 ± 37.3	4590 ± 48.4	22.220[b]	27.2 ± 19.5	4147108.1 ± 6400.6
	3/08/95	0720	3.8 ± 2.5	4518.9 ± 35.7	3730 ± 44.2	49.387		3045964 ± 3879
	3/13/95	1009	20.2 ± 4	10333.3 ± 53.9	10200 ± 70.2	1.63	24.7 ± 21.6	6233036 ± 7846.1
	4/21/95	0950	15.1 ± 3.7	8244.1 ± 48.1	6980 ± 58.6	3.904	39.2 ± 18.7	4391297.3 ± 4657.5
SCS1(A)	2/16/95	1220	10.3 ± 3.6	5561 ± 39.6	6210 ± 55.5	0.061	18 ± 16.8	682453.2 ± 2599.8
SCS1(B)	2/16/95	NA[c]	19.5 ± 4.4	9155.5 ± 50.7	8820 ± 65.5	NA[c]		1416927.9 ± 3743.1
SCS1	3/08/95	0726	7.2 ± 3	7247.7 ± 45.1	4850 ± 49.6	1.379		1991405.4 ± 3136.9
	3/13/95	1016	17.8 ± 4	9352.8 ± 51.3	9740 ± 68.6	0.146		3310108.1 ± 5718.5
	4/21/95	0959	19.2 ± 4.2	10639.2 ± 54.7	9690 ± 68.4	0.184	21.4 ± 19.1	5408846.8 ± 5168.7
SCS2	3/08/95	711	1 ± 2.1	3613.2 ± 31.9	3890 ± 45	0.008		4309 ± 174.2
SCS3(A)	2/16/95	1257	35.8 ± 4.7	23717.7 ± 81.6	23100 ± 104	0.002		10800.9 ± 356.7
SCS3(B)	2/16/96	NA	58 ± 5.8	35274.1 ± 99.5	33300 ± 125	NA	33.7 ± 17.6	7720.7 ± 311.2
SCS3	3/08/95	0718	18.6 ± 3.6	22018.7 ± 78.6	21200 ± 99.7	0.21		6796.4 ± 206.5
	3/13/95	1035	88.1 ± 7.2	43598.1 ± 110.6	44700 ± 144	0.005	170 ± 25.2	6549.5 ± 289.3
	4/21/95	0913	62.3 ± 6.5	69711.6 ± 139.8	43200 ± 142	0.004		8124.3 ± 230.9
SCS4	2/16/95	1254	4.9 ± 2.8	47707.4 ± 115.7	42800 ± 141	0.125		0 ± 143.6
	3/08/95	0735	5.2 ± 2.7	40500.4 ± 106.6	37000 ± 131	0.659		1155.9 ± 121.6
	3/13/95	1050	9.5 ± 3.6	85308.5 ± 167.7	75100 ± 186	0.065	37.7 ± 18.7	0 ± 138
	4/21/95	0928	11.1 ± 3.5	71992.5 ± 142.1	49200 ± 151	0.006		2655.9 ± 162.2
SCS5	2/16/95	1241	8.1 ± 2.9	7064.4 ± 44.6	5930 ± 54.4	0.356		2959252.3 ± 5407.3
	3/08/95	0742	0.1 ± 1.9	1533.8 ± 20.9	4140 ± 46.2	1.218		1858693.7 ± 3030.7
	3/13/95	1100	2.8 ± 2.5	8726.8 ± 49.5	8820 ± 65.4	0.071	65 ± 21.5	5109738.7 ± 7104.3
	4/21/95	0936	1.4 ± 2.5	11691.8 ± 57.3	9010 ± 66.1	0.092	43.8 ± 24.4	7717702.7 ± 6173.7
SCS6	2/16/95	1211	159.1 ± 10.2	28173.6 ± 88.9	29100 ± 117	1.351	458 ± 35	20427.9 ± 471.5
	3/08/95	0751	118 ± 8.5	25056.1 ± 83.8	23900 ± 106	1.364	421 ± 34	18696.4 ± 318.4
	3/13/95	1129	116.3 ± 8.6	21988.9 ± 78.5	23900 ± 106	0.156	1040 ± 64.3	20039.6 ± 465.7
	4/21/95	1017	140.3 ± 9.6	27044.5 ± 87.1	19600 ± 96	0.023	95.1 ± 24.2	30029.7 ± 401.8
SP01	1/31/95	NA	15.5 ± 4	33107.4 ± 96.4	41400 ± 139	NA	361 ± 36.9	4618.9 ± 259.7
SP02	2/01/95	NA	5.8 ± 3	9757.3 ± 52.4	11400 ± 74.2	NA	1390 ± 59	4399.1 ± 181.8
SP03	2/09/95	NA	265.6 ± 13.1	13810.6 ± 62.3	13400 ± 79.9	NA	2360 ± 73	23228.8 ± 498.7
SP04	2/24/95	NA	28.6 ± 4.5	11168.4 ± 56	9560 ± 68	NA	18.4 ± 16.5	6496522.5 ± 8010.5

[a] Time given is for bucket gauging measurement. Samples were collected approximately five minutes earlier.
[b] Too much flow present. Stage measurement was used to calculate flow because no bucket gauge was performed.
[c] Not applicable

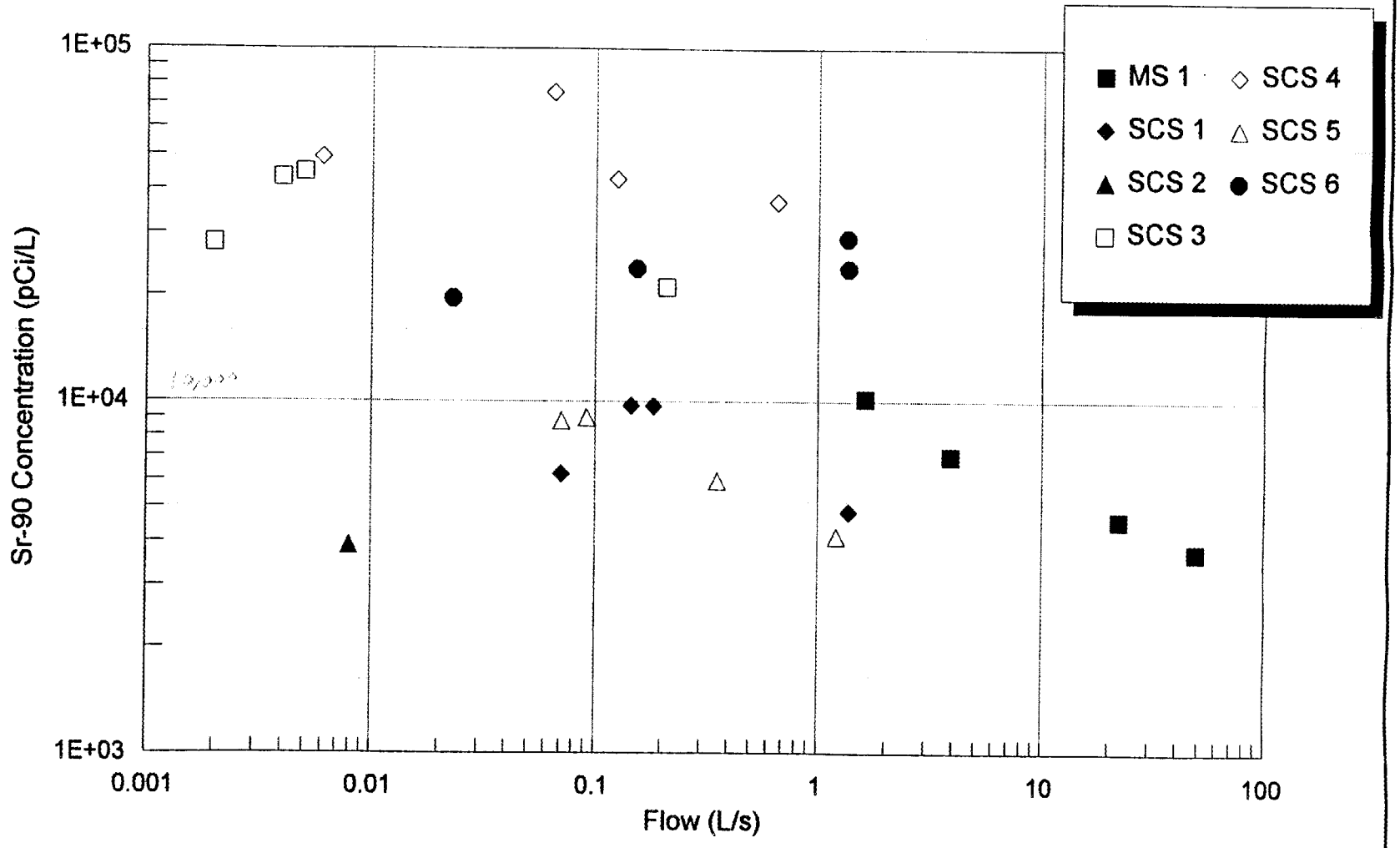


Figure 2.15. WAG 4 strontium-90 C/Q (concentration/discharge) relationship

WAG 4 Site Investigation

Table 2.5. Flow/contaminant concentration relationship coefficients for ^{90}Sr

Site	C_o	Exponent	R^2 (%)
MS-1	11,081	-0.28418	99.48
SCS 1	5,826	-0.15202	31.39
SCS 2	3,890	0.0	Not applicable
SCS 3	18,951	-0.11787	47.54
SCS 4	41,467	-0.06597	17.73
SCS 5	4,421	-0.27894	98.87
SCS 6	26,074	0.06952	71.72

(discounting the SCS 1 values). Table 2.8 shows the monthly contributions of ^{90}Sr from the SCS sites to MS-1. Discounting the SCS 1 values, the measured releases at the SCS sites range from 54.3% in May (wettest) to 8.3% in April (driest). There is an apparent trend toward increasing importance of seeps with increasing storm runoff. Thus, it appears that for smaller events, there is a subsurface pathway that accounts for most of the ^{90}Sr mass flow, but this pathway diminishes rapidly in importance as the magnitude of runoff events increases. It is very unfortunate that the study period in 1995 was characterized by such dry conditions, which limited use of the results to examine larger events, as explained in the next section.

Integrated Flows from Seeps and Other Sources—the MS-1 Baseline

The MS-1 surface water-monitoring station on the WAG 4 tributary serves as the integration point for the area from which most of the ^{90}Sr releases originate. Therefore, it is an important element in this assessment of contaminant releases. However, because the field study was brief, it is also important to view the results in the context of the annual hydrologic cycle.

The WAG 4 Seeps Investigation Project was conducted during the middle to latter portion of the 1995 wet season. Monitoring and sampling at the six seeps and at MS-1 were conducted approximately from February 1 through April 30. Soil moisture typically begins to decrease significantly in April, with the onset of the growing season, and intermittent seeps, springs, and streams begin to dry up. The WAG 4 tributary and the seeps that feed it are intermittent. (Some of the seeps are ephemeral.) The majority of total annual discharge recorded at MS-1 occurs in a few months, during the wet season. Therefore, the majority of contaminants (e.g., ^{90}Sr) are transported from WAG 4 sources to the receiving tributary and ultimately off-site in White Oak Creek during the few wettest months of the year.

During the period from February through April 1994, average discharge at MS-1 was 8.25 L/second. This 3-month period in 1994 accounted for approximately 74% of the total discharge recorded at MS-1 for calendar year 1994. By comparison, average discharge for the period from February through April 1995 was only 1.82 L/second. These measurements are consistent with precipitation rates for the two periods as well: 29.02 in. in 1994 and 9.51 in. in 1995. The 3-month period in 1994 was one of the wettest on record, and the same 3-month period in 1995 was significantly drier than normal. Figure 2.16 provides a comparison between MS-1 discharge data for 1994 and 1995.

Table 2.6. Contribution of ^{90}Sr and volume of water from the SCSs to MS-1 during storm flow

	Storm sampling (Feb.15–18, 1995)				Storm sampling (March 7–10, 1995)				Storm sampling (April 20–22, 1995)			
	Mass flow		Total volume		Mass flow		Total volume		Mass flow		Total volume	
Site	(μCi)	(%)	(m^3)	(%)	(μCi)	(%)	(m^3)	(%)	(μCi)	(%)	(m^3)	(%)
MS-1	14,873		3,168.7		16,935		3,246.5		3,724		432.6	
SCS 1	–		–		793	4.68	121.2	3.73	239	6.42	22.4	5.17
SCS 2	–		–		8	0.05	2.12	0.07	0	0.00	0	–
SCS 3	–		–		280	1.65	10.59	0.33	16	0.43	0.5	0.12
SCS 4	2,796	18.80	61.74	1.95	3,146	18.58	69.43	2.14	56	1.50	1.1	0.26
SCS 5	642	4.32	111.23	3.54	462	2.73	76.08	2.34	76	2.04	10.9	2.53
SCS 6	5,769	38.79	225.17	7.11	6,362	37.57	245.3	7.56	169	4.54	7.3	1.70
Total		61.91		12.57		65.26		16.17		14.93		9.79

95-095/7908-009/0725

Table 2.7. Contribution of ^{90}Sr and volume of water from the SCSs to MS-1 during base flow

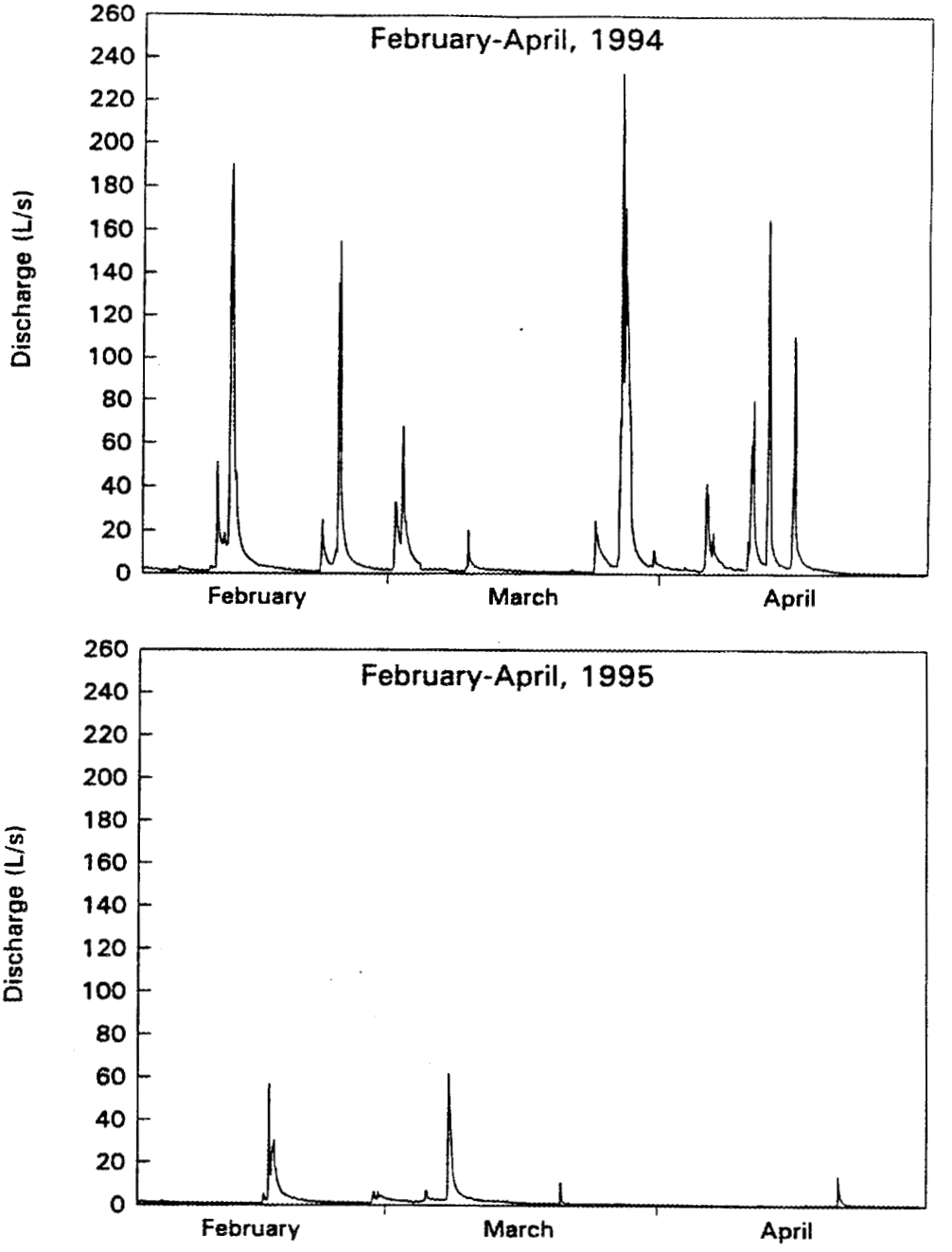
	Base flow sampling (March 13, 1995)			
Site	Flux (μCi)	(%)	Total volume (m^3)	(%)
MS-1	1591		175.7	
SCS 1	77	4.84	9.5	5.41
SCS 2	0	0	0	0
SCS 3	16	1.01	0.5	0.27
SCS 4	302	18.98	6.2	3.51
SCS 5	53	3.33	5.9	3.33
SCS 6	631	39.66	26	14.82
Total		67.82		27.34

Table 2.8. Monthly contribution of ^{90}Sr from the SCSs to MS-1

	February		March		April		May	
Site	Flux (μCi)	(%)	Flux (μCi)	(%)	Flux (μCi)	(%)	Flux (μCi)	(%)
MS-1	45,258		50,364		15,615		41,725	
SCS 1	–	–	2,421	4.8	1890	12.1	2,824	6.8
SCS 2	–	–	26	0.1	0	0.0	20	0.1
SCS 3	–	–	441	0.9	16	0.1	272	0.7
SCS 4	3,662	11.2	6,792	13.5	66	4.2	5,914	14.2
SCS 5	1,172	3.6	1,405	2.8	104	0.7	1,107	2.7
SCS 6	8,773	30.0	13,636	27.1	512	3.3	15,273	36.6
Total		44.8		49.2		20.4		61.1

CQ relationships have been developed for ^{90}Sr transported from WAG 4 through MS-1 for a number of discrete storm events beginning in May 1993. These relationships (Fig. 2.17) exhibit similar characteristics, and collectively represent an annual cycle, which follows the hydrologic cycle, from wet season to dry and vice versa. For each sampling event, concentration decreases with subsequent increases in discharge, but contaminant mass flow continues to increase with discharge. However, a given discharge corresponds to a higher concentration in the wet season than in the dry season.

The ***CQ*** relationship value for the current sampling period falls between those of the wet season (January through March) of 1994 and the dry season (May) of 1993. The current ***CQ*** relationship represents a wet season; therefore, it should produce higher concentrations than the dry season. However, because it represents a significantly drier wet season than in 1994, concentrations would be expected to be smaller than in the 1994 wet season. Presumably, because substantially less precipitation has infiltrated the surface soil layer during this (1995) wet season, and because the



figms1td

Fig. 2.16 WAG 4 MS-1 tributary discharge comparison

WAG 4 Site Investigation

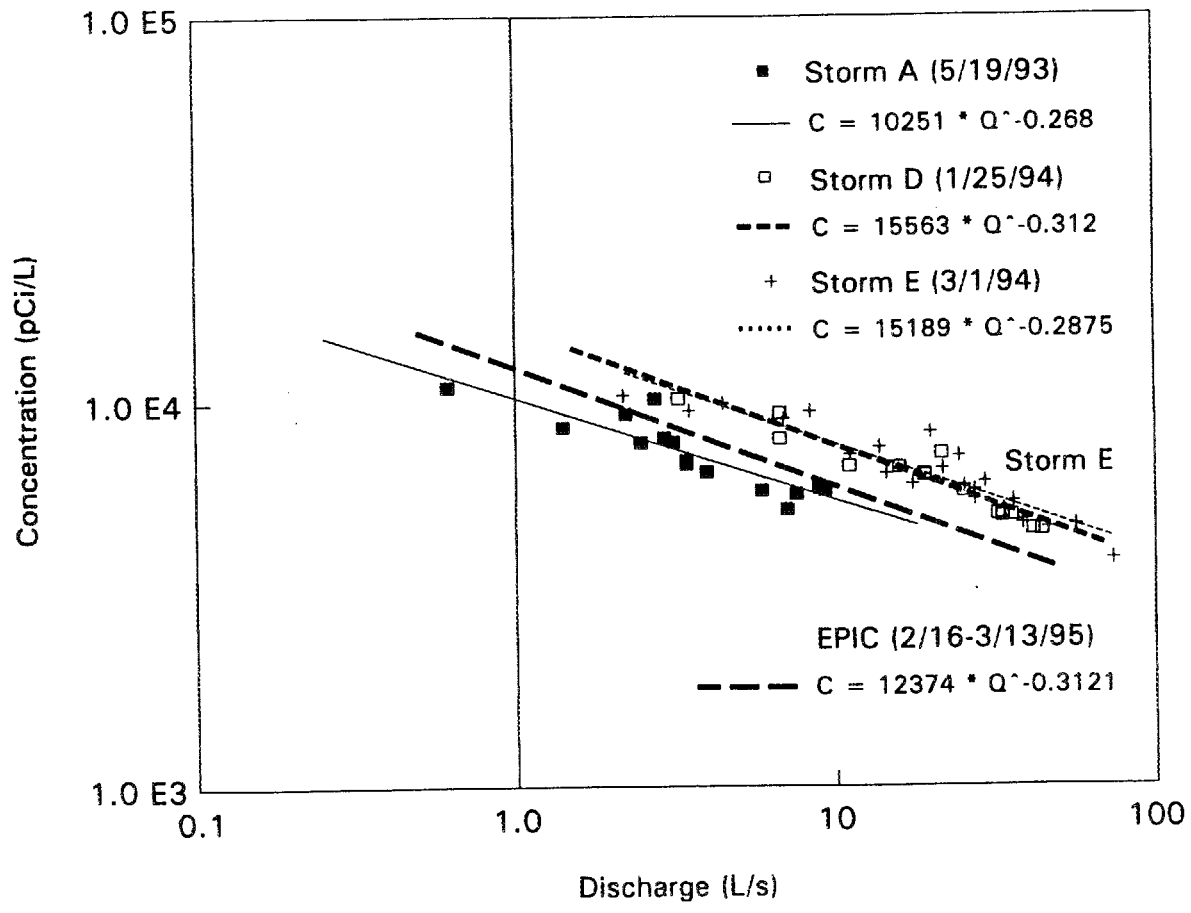


Fig. 2.17. WAG 4 MS-1 strontium-90 C/Q relationships

WAG 4 Site Investigation

water table is depressed in comparison with wetter years, the surface pathway represented by active seeps discharge is diminished, and, thus, total mass transport of ^{90}Sr is reduced.

It is important to note that the decrease in total wet-season ^{90}Sr mass flow between 1994 and 1995 is primarily the result of the substantial difference between the quantities of water available in the hydrologic cycle during the two periods. The ***CQ*** relationship for the 1995 wet season indicates only a minor reduction in concentrations (≈20%) in comparison to the 1994 wet-season relationship. However, estimated ^{90}Sr mass flow (0.110 Ci) for the period from February through April 1995 indicates a reduction of 71% from the estimated release (0.384 Ci) for the same period in 1994. The ***CQ*** relationships permit comparison of dissimilar periods because they largely remove the climatic influence (i.e., dependence on the amount of water in the system). Therefore, the ***CQ*** relationships developed before and measured after remediation will be important to a determination of the effectiveness of remedial measures designed to reduce the ^{90}Sr mass flow from WAG 4.

2.2.2 Surface Water Transport in the WAG 4 Tributary

Supporting evidence exists to help evaluate the relative contribution of individual seeps to the overall ^{90}Sr releases from WAG 4. Figure 2.18 shows ^{90}Sr concentration as a function of distance along the WAG 4 south tributary. The data are referenced to sampling points along the tributary to allow easy association between SCS locations and changes in concentration along the tributary. The data shown here were derived from 1992 wet-season base-flow sampling, concluded as part of the WAG 2 ER Program (DOE 1995).

Figure 2.18 shows that two major input regions exist along the tributary. The first one is in the headwaters area near SCS 6. The highest concentration appears to be associated with the branch of the tributary that receives flow from the SCS 6 surface-flow discharge. It also is apparent that some contaminated seepage enters the westernmost portion of the headwaters. This seepage is probably a combination of surface overflow and subsurface seepage from the SCS 6 area. The second region for major input appears to be that in which discharges from SCS 4 and SCS 3 are located. The figure suggests that SCS 4 is a more important contributor than SCS 3, based on relative rises in concentration in the adjacent stream. Some contribution may occur from SCS 5, but SCS 2 and SCS 1 do not appear to contribute greatly to contaminant transport away from WAG 4.

Unfortunately, flow measurements were not made along the tributary in conjunction with the 1992 surface water sample collections. This is in part because the low flow rates are associated with shallow water that precludes direct velocity measurements. Therefore, it is not possible to make reliable mass-transport estimates for points along the tributary in 1992. Even though mass flow estimates along the tributary cannot be made reliably, the relative importance of the seep areas is consistent with that indicated by 1995 data discussed in Sect. 2.2.1. A very crude attempt was made to assess the distribution of flow along the tributary in late April 1995. Although the data are only semi-quantitative, it appears that flow increases in the tributary occur primarily in the SCS 6 and SCS 4 areas, corresponding to the same regions where concentration of ^{90}Sr shows sharp increases.

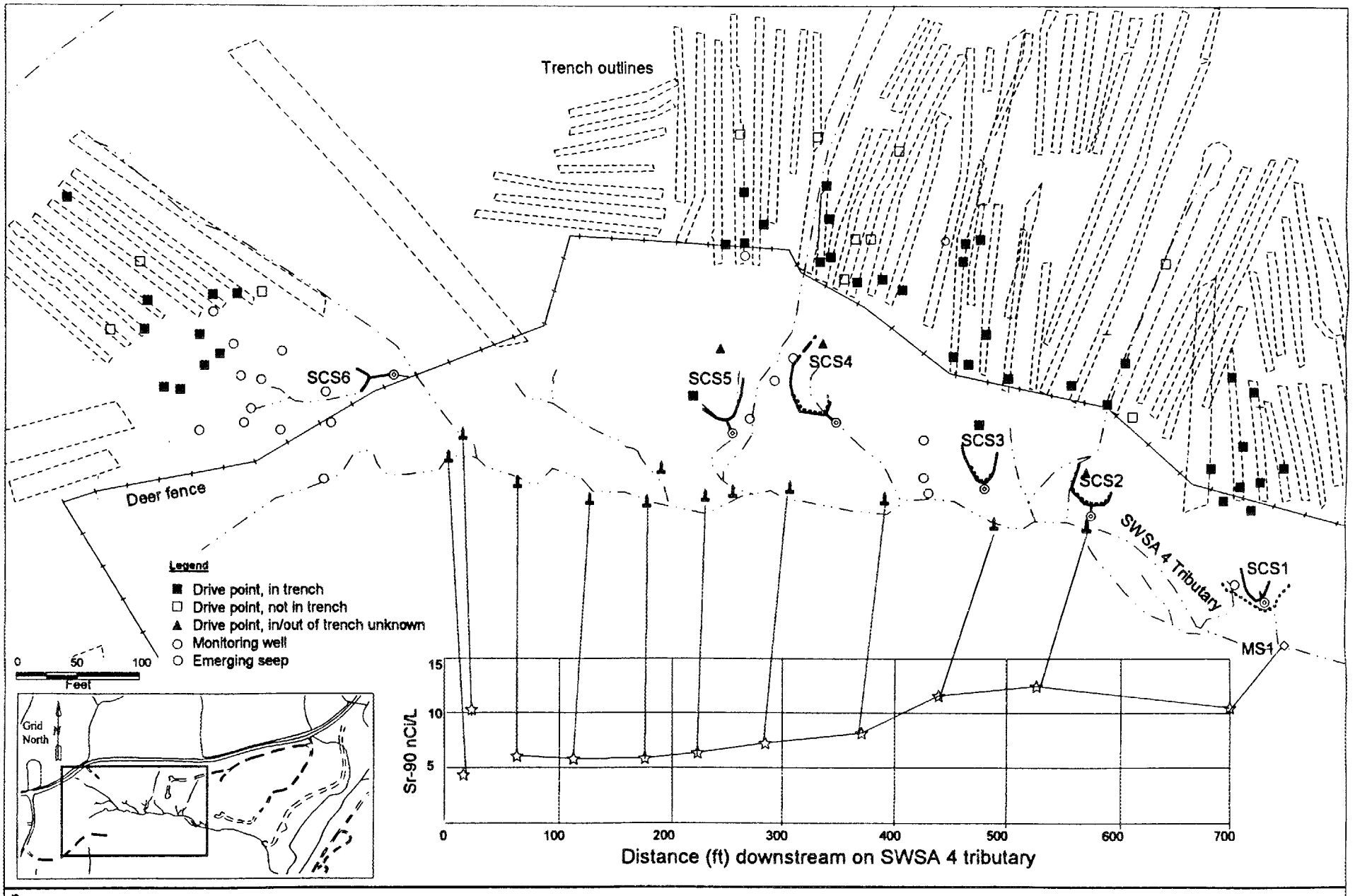


Fig. 2.18. Sr-90 concentrations as a function of distance along SWSA 4 tributary

WAG 4 Site Investigation

2.2.3 Tracer Studies

Objective

The objective of the tracer study was to demonstrate a direct connection between the ^{90}Sr sources identified during the drive point investigations and the discharge points at the contaminated seep areas. Making this connection would confirm the suspected link between specific high concentration regions in trench water and the discharge releases to the surface water system.

Implementation

A decision was made to focus initially on three of the six seep areas to limit the number of samples requiring analysis to a manageable number at any one time. The three most important areas, based on earlier determinations of ^{90}Sr concentrations, were SCS 6, SCS 4, and SCS 3. The plan was to move the test to other areas (SCS 5, SCS 2, and SCS 1) once success was achieved. Three different inert tracers (helium, neon, and argon) were diffused continuously into groundwater at three separate locations in each seep area. The injection locations were based on findings from the drive point investigation indicating that these areas contained the highest levels of ^{90}Sr activity. The injection and sampling wells are shown in Fig. 2.19 for SCS 3 and SCS 4 and in Fig. 2.20 for SCS 6. After the first 2 months of the tracer study, some of the monitoring wells became dry, and the decision was made to sample other locations. These locations also are shown in Figs. 2.19 and 2.20, and are listed in Tables 2.9, 2.10, and 2.11. Wells were monitored around and in the seeps once each week to determine if any tracer migrated to that point. Monitoring depends upon the gas tracer diffusing out of the groundwater into a sample chamber, which is evacuated to a gas chromatograph for analysis. (Sampling and analysis methodology are detailed in Appendix G). The monitoring locations also were selected based on results from the drive point investigation. These wells had lower ^{90}Sr activity levels than the injection wells, but significantly higher levels than the "normal" background for WAG 4. Positive detection of a tracer at a monitoring site indicates a direct connection between the injection point and the monitoring point. Because of time limitations, tracer studies were not conducted for the SCS 5, SCS 2, and SCS 1 areas.

Results

Background Levels. Samples of the dissolved gases contained in the groundwater in the monitoring wells were collected before the beginning of the tracer study (Tables 2.9, 2.10, and 2.11), to establish background levels of helium, neon, and argon. As expected, helium and neon were not present in background levels, but argon did exist before injection. Argon is naturally present in the atmosphere and is produced by the groundwater decay of the naturally occurring isotope ^{40}K. The amount present in the background remains fairly constant with time. In the data presented, a positive argon detection is one that is above the typical background levels for each well.

Sampling Wells. The results of the tracer study to date are presented in Tables 2.9, 2.10, and 2.11 for SCS 3, SCS 4, and SCS 6, respectively. In summary, analysis of water at the argon injection well (2568) in the SCS 6 area showed the presence of both neon and helium, in addition to argon. Evaluation of the argon gas being injected showed no traces of either helium or neon as impurities. Thus, it is apparent that water moved from wells 4322 and 4340 to well 2568 (Fig. 2.20) during the test. At the SCS 4 area, well 4353 showed the presence of helium on May 31, 1995. This showed the expected pattern of movement from well 4321, where helium was infused.

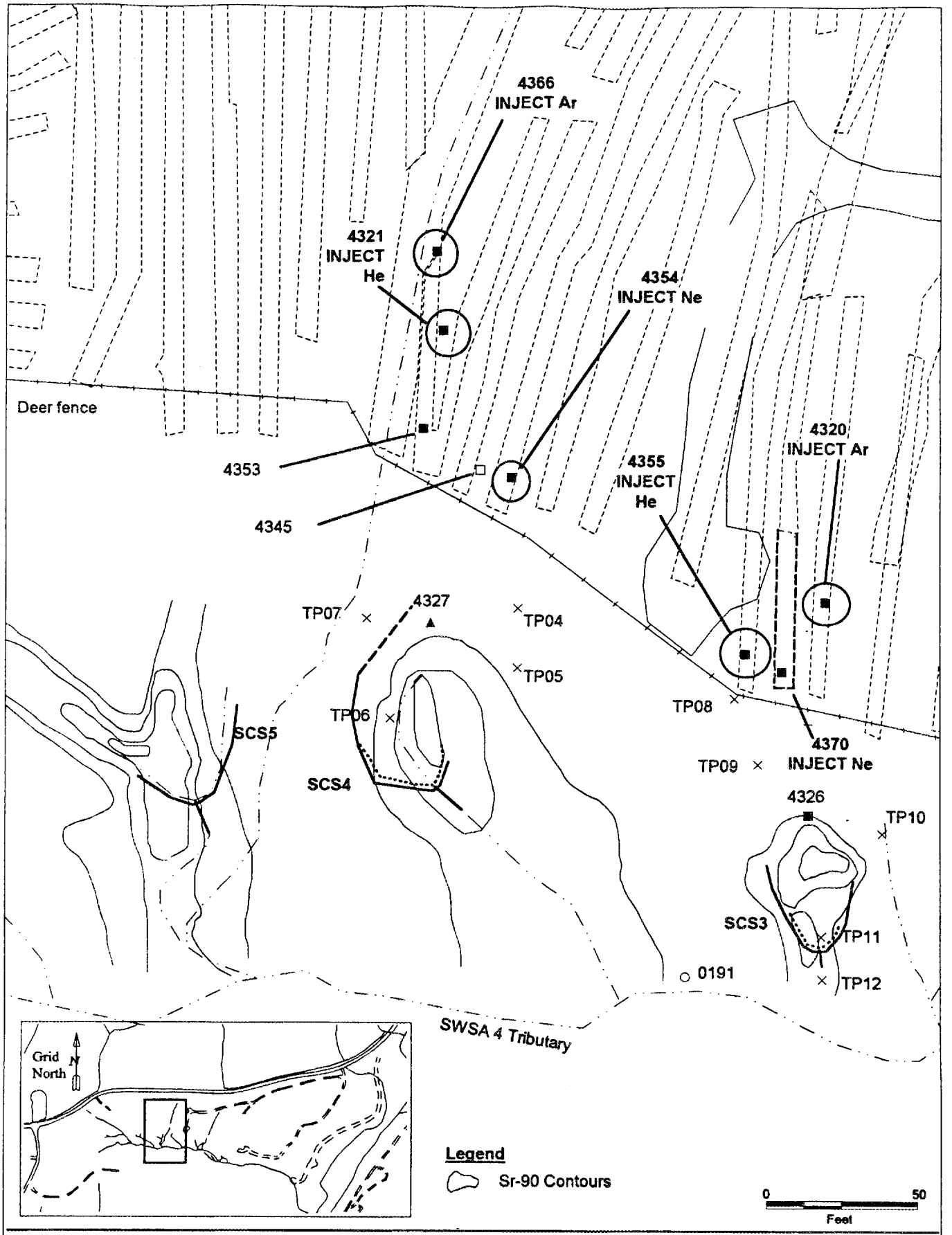


Fig. 2.19. Tracer study (central section)

WAG 4 Site Investigation

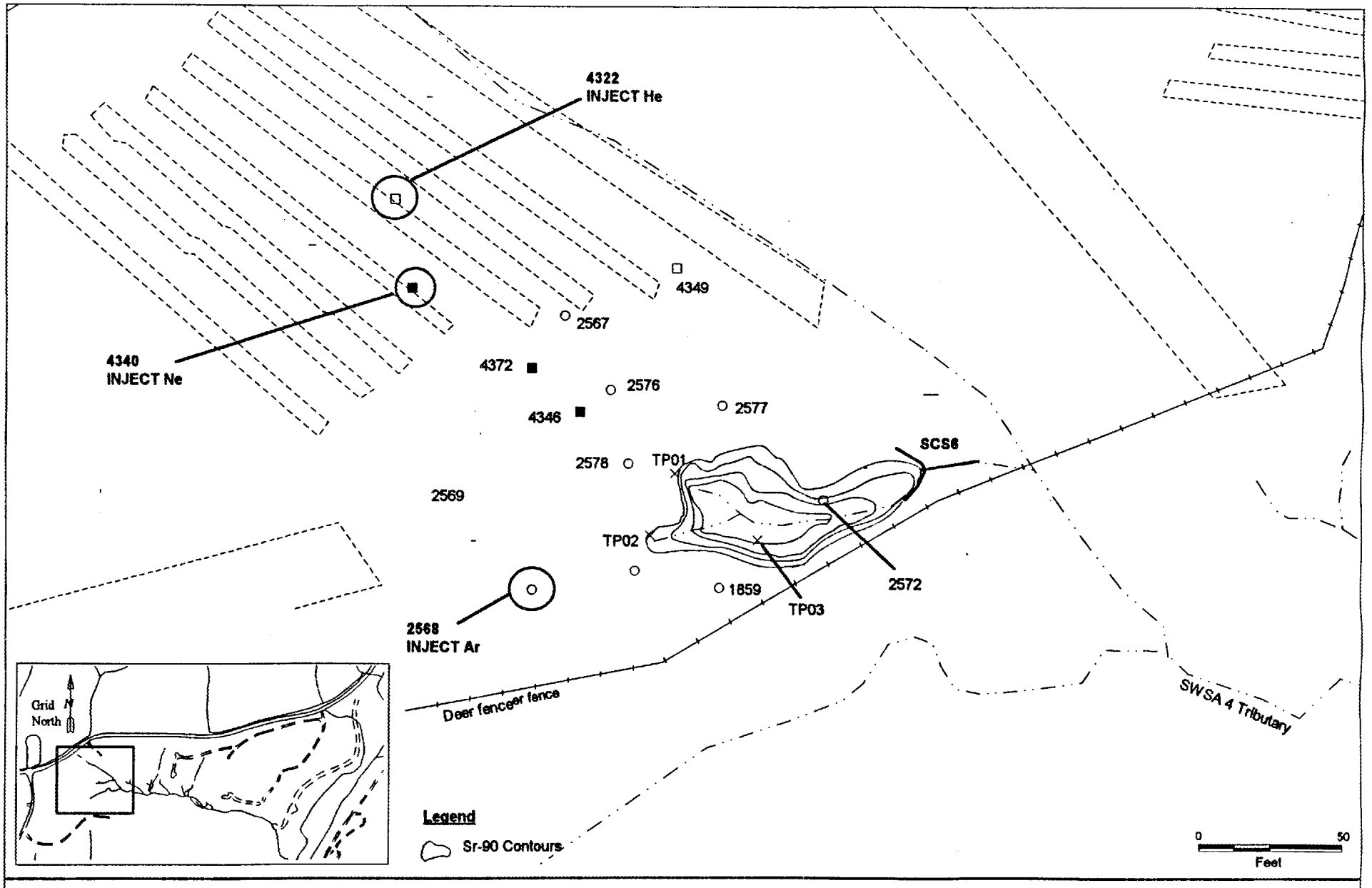


Fig. 2.20. Tracer study (west section)

WAG 4 Site Investigation

Table 2.9. Results of tracer study for SCS 3

ORNL well number	Sample point ID	03/15/95 Background	03/29/95	04/05/95	04/18/95	04/27/95	05/04/95	05/11/95	05/18/95	05/24/95	06/02/95	06/06/95
NA[a]	TP 08	ND[b]	ND	ND	ND	ND	ND	–	–	–	–	–
NA	TP 09	ND	LS[c]	ND	LS	ND	ND	–	–	–	–	–
NA	TP 10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
NA	TP 11	LS	ND	ND	ND	ND	ND	ND	LS	LS	ND	–
NA	TP 12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
4326	4326	ND	LS	ND	ND	ND	ND	ND	ND	ND	ND	–
0191	0191	ND	ND	ND	ND	ND	ND	LS	ND	ND	ND	–
2747	2747	–[d]	–	–	–	–	–	ND	ND	ND	ND	–
2748	2748	–	–	–	–	–	–	ND	ND	ND	ND	–
4355	DP 31	–	–	–	He	–	–	–	–	–	–	He
4320	DP 03	–	–	–	ND	–	–	–	–	–	–	Ar
4370	DP 44	–	–	–	Ne	–	–	–	–	–	–	Ne

[a] NA = not applicable
[b] ND = no gas detected above background levels
[c] LS = lost sample during analysis
[d] – = no sample collected

Table 2.10. Results of tracer study for SCS 4

ORNL well number	Sample point ID	03/16/95 Background	03/30/95	04/05/95	04/20/95	04/26/95	05/03/95	05/10/95	05/17/95	05/23/95	05/31/95	06/06/95
4345	DP 20	ND[a]	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
4353	DP 26	ND	ND	ND	ND	ND	ND	ND	ND	ND	He	–
NA[b]	TP 04	ND	ND	ND	ND	ND	LS[c]	–	–	–	–	–
NA	TP 05	LS	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
NA	TP 06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
NA	TP 07	ND	ND	ND	ND	ND	ND	–[d]	–	–	–	–
4327	4327	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
2749	2749	–	–	–	–	–	–	ND	ND	ND	ND	–
1534	1534	–	–	–	–	–	–	ND	ND	ND	ND	–
4367	DP 43	–	–	–	–	–	–	ND	ND	ND	ND	–
2752	2752	–	–	–	–	–	–	ND	ND	ND	ND	–
4321	4321	–	–	–	He	–	–	–	–	–	–	He
4354	DP24	–	–	–	Ne	–	–	–	–	–	–	Ne

[a] ND = no gas detected above background levels
[b] NA = not applicable
[c] LS = sample lost during analysis
[d] – = no sample collected

Table 2.11. Results of tracer study for SCS 6

ORNL well number	Sample point ID	03/14/95 Background	03/28/95	04/04/95	04/19/95	04/25/95	05/02/95	05/09/95	05/16/95	05/22/95	05/30/95	06/06/95
2569	2569	ND[a]	ND	ND	ND	ND	ND	–[b]	–	–	–	–
2572	2572	ND	ND	ND	ND	ND	ND	ND	ND	LS	ND	–
2567	2567	ND	LS[c]	LS	ND	ND	ND	ND	ND	ND	ND	–
2576	2576	ND	ND	ND	ND	ND	ND	–	–	–	–	–
2577	2577	ND	ND	ND	LS	ND	ND	–	–	–	–	–
2578	2578	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
4346	DP 21	ND	–	–	–	–	–	–	–	–	–	–
4372	DP 49	–	ND	ND	ND	ND	ND	LS	ND	ND	ND	–
NA[d]	TP 01	ND	ND	ND	ND	ND	LS	ND	ND	ND	ND	–
NA	TP 02	ND	ND	ND	ND	LS	ND	ND	ND	ND	ND	–
NA	TP 03	LS	ND	ND	ND	ND	ND	ND	ND	ND	ND	–
0186	0186	–	–	–	–	–	–	ND	ND	ND	ND	–
4347	DP 22	–	–	–	–	–	–	ND	ND	ND	ND	–
1859	1859	–	–	–	–	–	–	ND	ND	ND	ND	–
2571	2571	–	–	–	–	–	–	ND	ND	ND	ND	–
4349	DP 29	–	–	–	–	–	–	ND	ND	ND	ND	–
4322	4322	–	–	–	He	–	–	–	–	–	–	He
4340	DP 13	–	–	–	Ne	–	–	–	–	–	–	Ne
2568	2568	–	–	–	Ar, He	–	–	–	–	–	–	He, Ne, Ar

[a] ND = no gas detected above background levels.
[b] – = no sample collected.
[c] LS = sample lost during analysis
[d] NA = not applicable

Tracer in Injection Wells. It was necessary to collect groundwater samples for radionuclide analysis during the beginning of April. During this time, the injection systems were removed from the nine injection wells and a gas sampler was placed in eight of the nine wells. (Because the argon injection well for SCS 4, well 4366, was used to monitor water levels, no room remained in the well to place a sampler.) The correct tracer gas was found in the groundwater at all injection points except well 4320 in SCS 3—the argon injection well (Tables 2.9, 2.10, and 2.11). These results indicate that the groundwater in the vicinity of the injection wells was being charged with tracer. In addition, helium and neon were found in the groundwater around argon injection well 2568 in SCS 6 (Table 2.11) as discussed above. To confirm the result, it was decided to test the purity of the argon being injected into that well. On May 3, 1995, two aliquots of gas were collected from the vent port of injection well 2568. This gas was analyzed in the laboratory and was found to contain no helium or neon. At the completion of the injection phase of the test, all of the argon injection tanks were tested directly, rather than from the end of the diffusion injection system, and it was confirmed that neither helium or neon were present in any of the tanks.

Conclusions

Overall, the limited detection of tracers in sample wells failed to provide the conclusive evidence of movement from suspected sources to discharge points that was sought, with the possible exception of the SCS 6 area. Because conditions were very dry, it is likely that movement simply was too slow during the time available for the test. The positive result at SCS 4 reinforces this conclusion. It is also possible that the sample zones available from many of the existing drive point wells were not located along predominant flow pathways. Finally, because of potential interaction with the atmosphere along the flow pathway, it is possible that the tracers were degassing before they reached the detection points at some seeps. The fact that the greatest movement (over 140 ft in two months) occurred at SCS 6, which is the strongest overall contributor to ^{90}Sr mass flows, is consistent with other results. The pathway that was identified also shows that some ^{90}Sr detected in groundwater to the southwest of the seeps at SCS 6 originates in the contaminated regions identified near wells 4322 and 4340.

2.3 DATA FOR EVALUATING OPTIONS FOR INTERIM ACTION

2.3.1 Water-Table Elevation Data

Water table measurements were made in 23 wells at WAG 4 on a weekly basis from March 2, 1995, through May 17, 1995, to measure the variations in depth to groundwater beneath and adjacent to waste burial trenches (Fig. 2.21). Appendix H contains a complete listing of all Hydrographs produced. Additionally, electronic data loggers with pressure transducers were installed in 12 wells or drivepoints to record hourly water level variations. The data collected in this effort show the general potentiometric and piezometric gradients which drive groundwater flow within the burial ground and show the hydrologic response to seasonal and short-term precipitation variations.

Typical long-term water level measurements in wells at or near WAG 4 (Fig. 2.22) show that for the first half of water year 1995, the lowest water levels observed in area wells occurred in mid-November and that the highest water levels occurred in mid- to late-March. During mid-May intense thunderstorms caused a secondary maximum water level in wells. The general water table

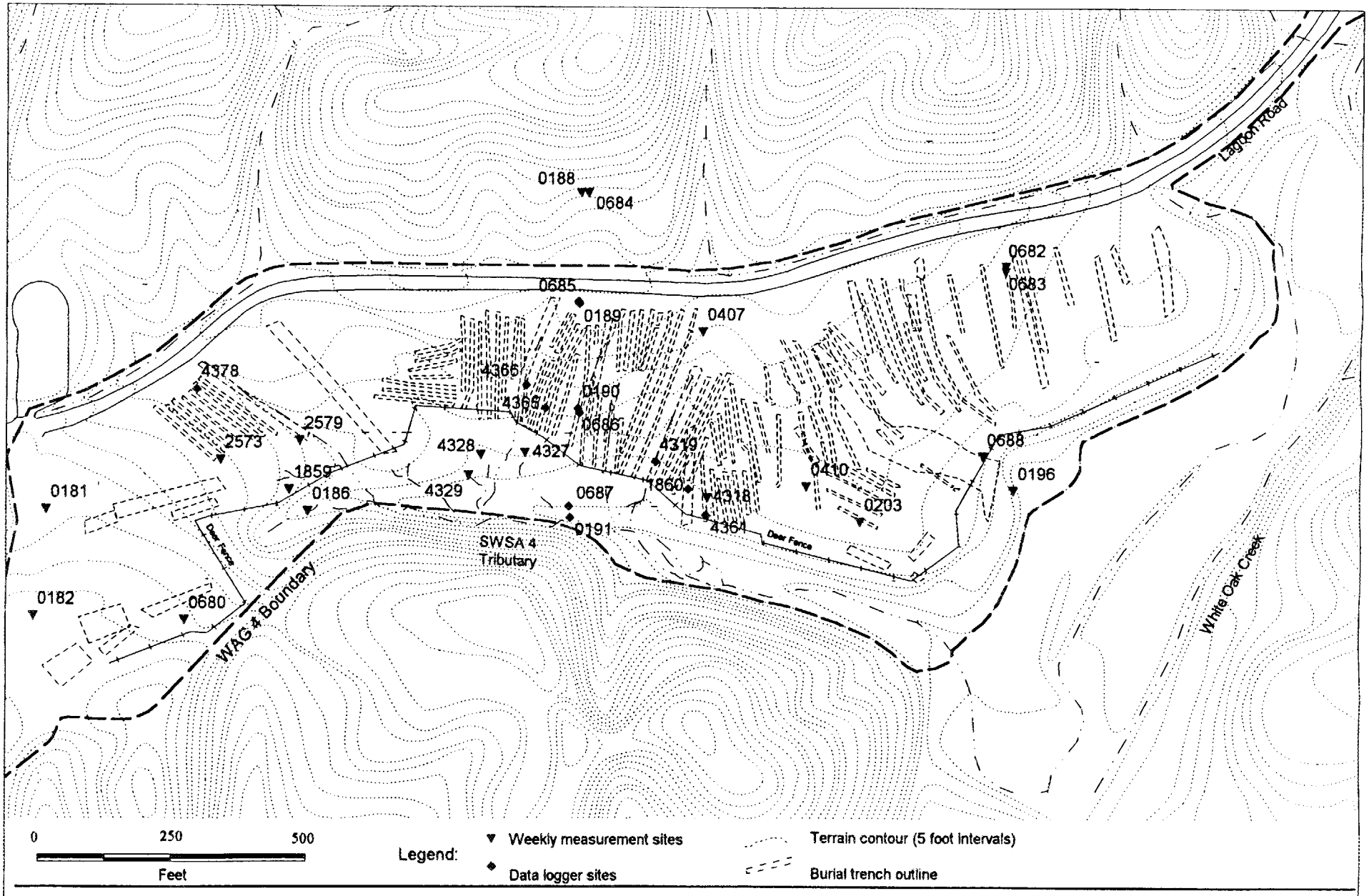
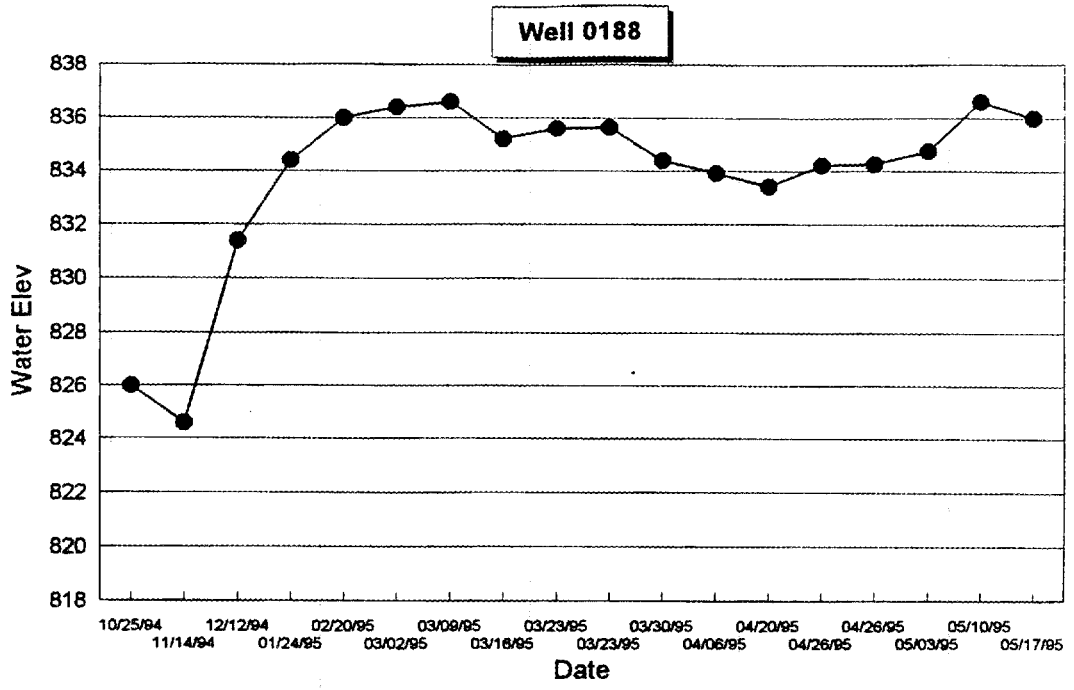


Fig. 2.21. Locations of wells at WAG 4 where water level data were collected.

WAG 4 Site Investigation



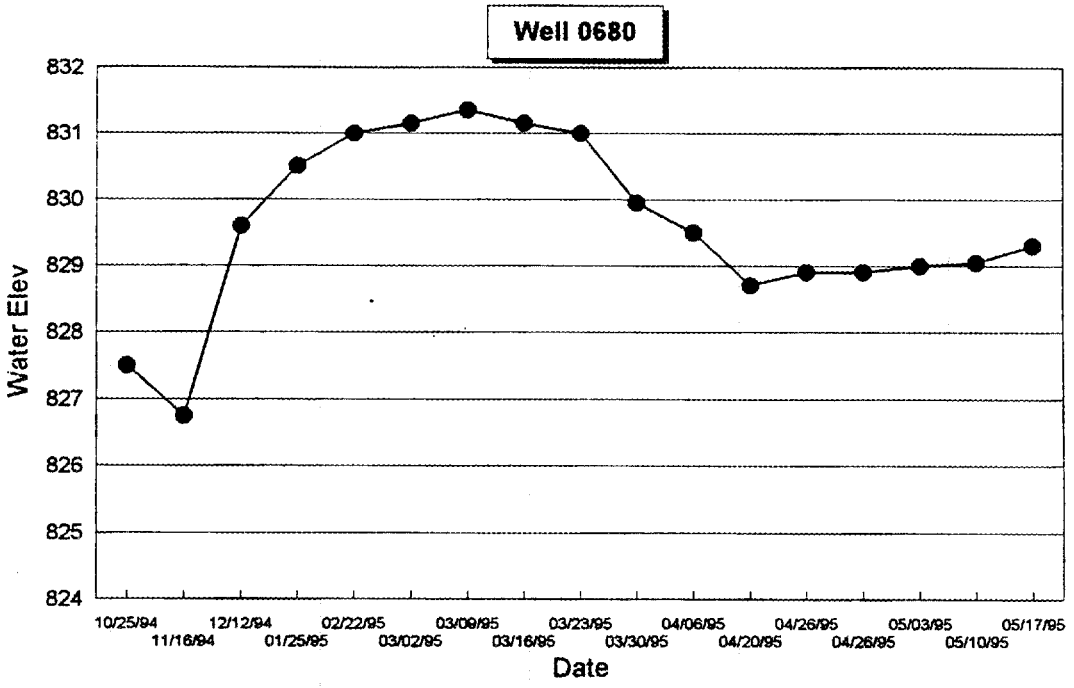


Fig. 2.22. Water level hydrographs - October 1994 through May 1995
WAG 4 Site Investigation

configurations for the WAG 4 area on April 6, April 20, and May 24 are shown in Figs. 2.23, 2.24, and 2.25. The overall site head data, as reflected in the water table map, shows that groundwater flow gradients are generally toward the SWSA 4 tributary and that a recharge head (vertical downward gradient) occurs throughout much of the area except beneath the SWSA 4 tributary and at wells 0682 and 0683 in the northeastern part of the site.

Well and drive point responses to seasonal and short-term rainfall events are variable across the site. The highest water level variability occurs in well 0181 and 0182 on the topographic high area at the west end of WAG 4. The lowest water level variability occurs in wells along the axis of the SWSA 4 Tributary valley and along the east edge of the site at White Oak Creek. Water level variations range from less than 1 ft to nearly 10 ft. These observations are consistent with the overall site conceptual model that recharge occurs on upland areas and groundwater elevations are relatively constant near streams in the local discharge area.

The well hydrographs for the continuously monitored wells show that two general types of hydrologic response to rainfall are observed at SWSA 4 (Fig. 2.26). One characteristic response is that some wells and drive points respond nearly immediately to precipitation of infiltration and water levels reach peak values very soon after rainfall events. This type of water level response is frequently observed in wells in the Oak Ridge area and is indicative of local recharge to the water table in native shales. The other water-level response observed at SWSA 4 was seen in some trench drive points where responses to rainfall during April and early May were subdued, but later in May response curves indicate inflows to trenches that continue long after the precipitation events have ended. The water-level records for these trenches have the appearance of well-recovery curves and are quite different from the typical recharge curves observed in the areas where local, rapid recharge influences the wells. The significance of the delayed response observed in trench drive points in the mid-section of SWSA 4 is thought to reflect the influence of groundwater recharge some distance from the observation sites, either within the WAG 4 area or possibly on the lower slope of Haw Ridge. If so, the results suggest that capping alone would not control groundwater flow through problem trenches.

2.3.2 Chemical Composition of Trench Water

Sampling Methods and Analytical Procedures

Sampling was conducted in accordance with Procedure ER/WAG2-SOP-3207, Rev. 0, "Collection and Processing of Water and Colloidal Samples from Seeps, Streams, and Groundwater." A field change request, W40000007, was issued that permitted use of only those portions of the procedure required by the Work Plan (Energy Systems 1992c).

Before sampling, the depth to water and the depth of the well were measured. The sampling was conducted using a peristaltic pump connected to Tygon #16 tubing cut to reach 1 ft above the well bottom. The pump was powered by a Honda portable electric generator. A low-flow pumping rate of 50 to 60 mL/minute was used to avoid artificially stirring up settled particulate matter that might produce a nonrepresentative sample of the trench water. This also ensured that the trench water itself was being sampled, rather than water drawn in from beyond the trench. Additionally, the water was filtered in the field through a 0.45-micron in-line filter to further ensure removal of large particles that would interfere with the chemical analyses planned for these samples.

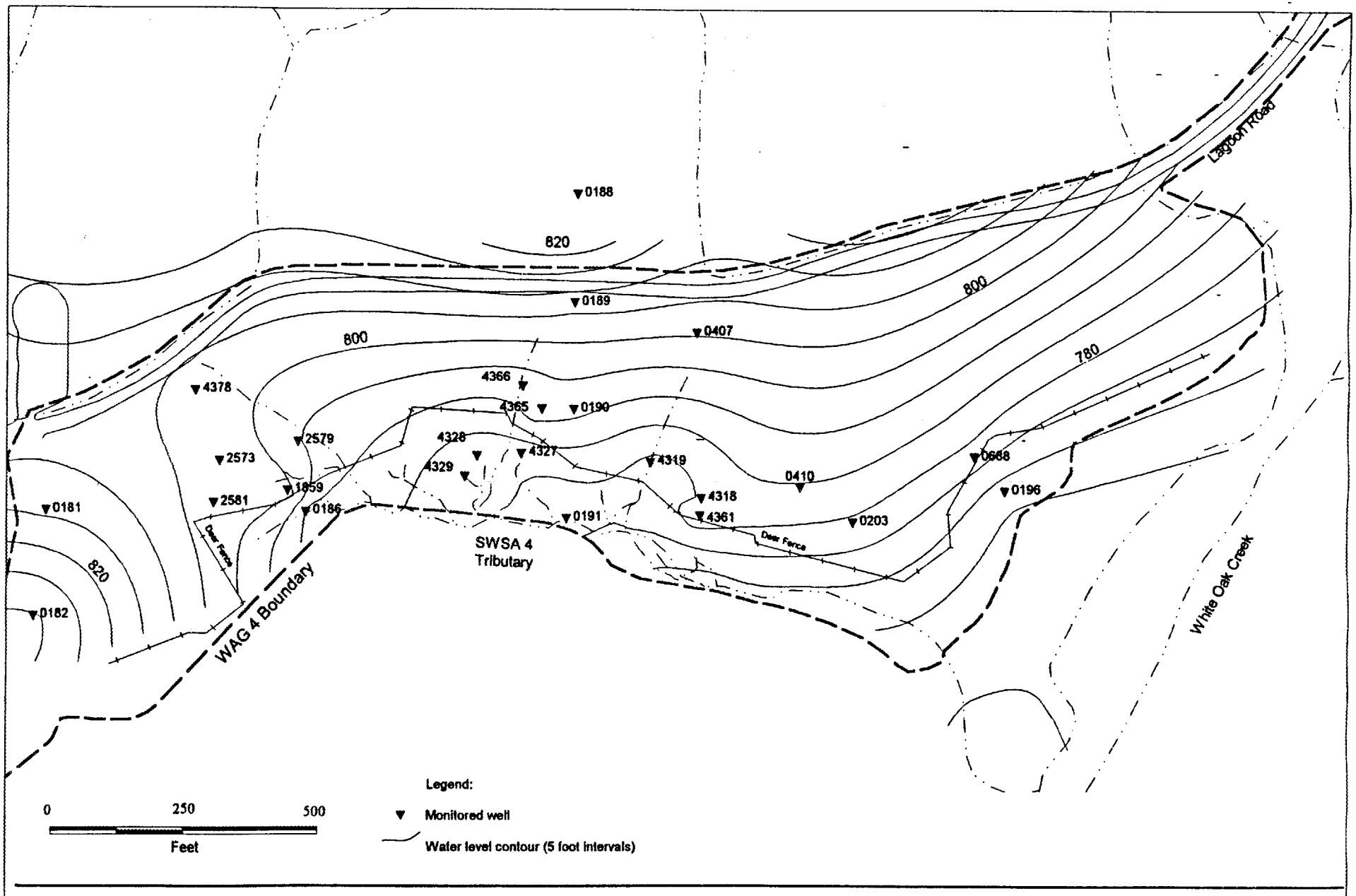


Fig. 2.23. Water level contours - April 6, 1995

WAG 4 Site Investigation

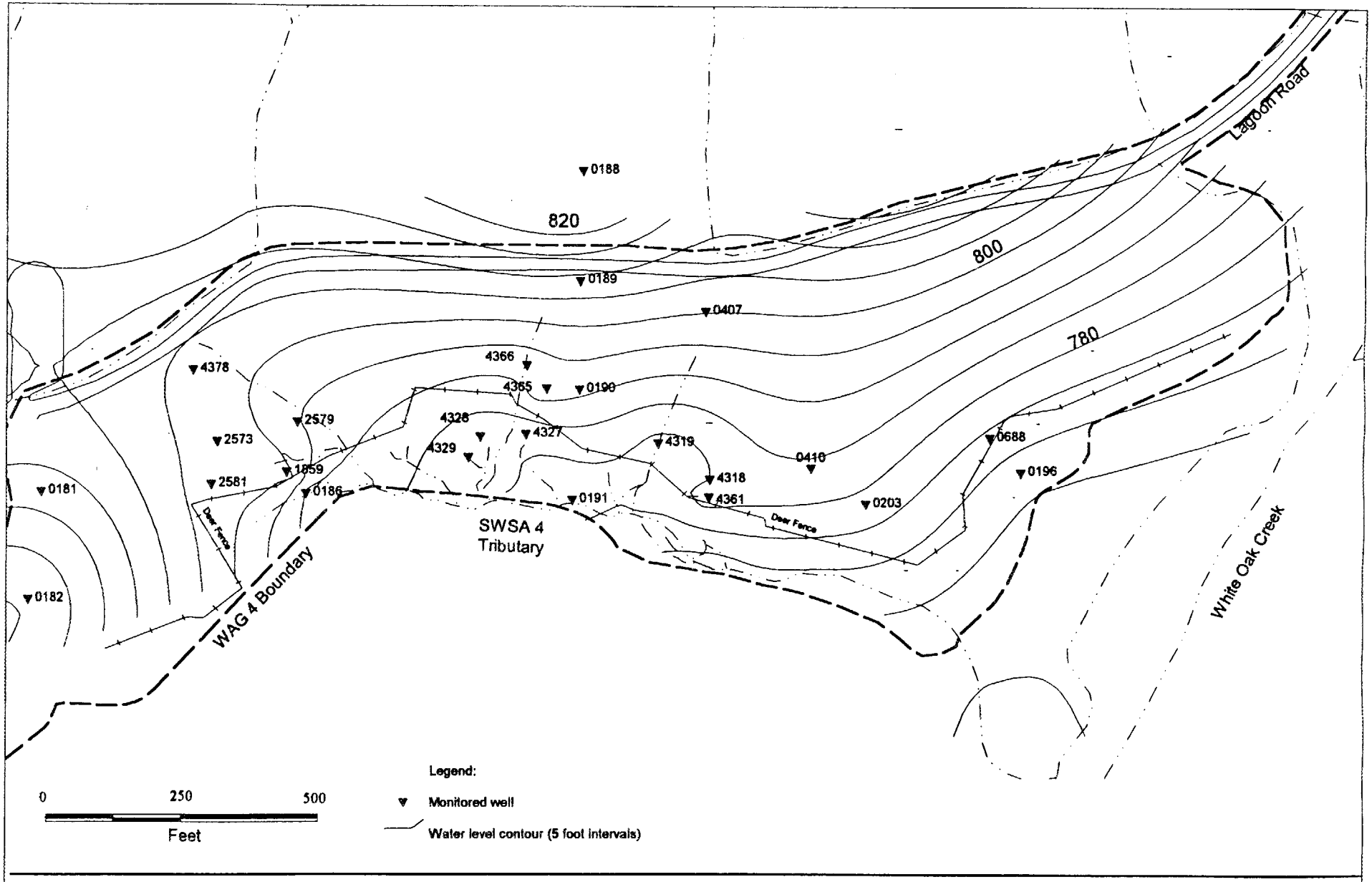


Fig. 2.24. Water level contours - April 20, 1995

WAG 4 Site Investigation

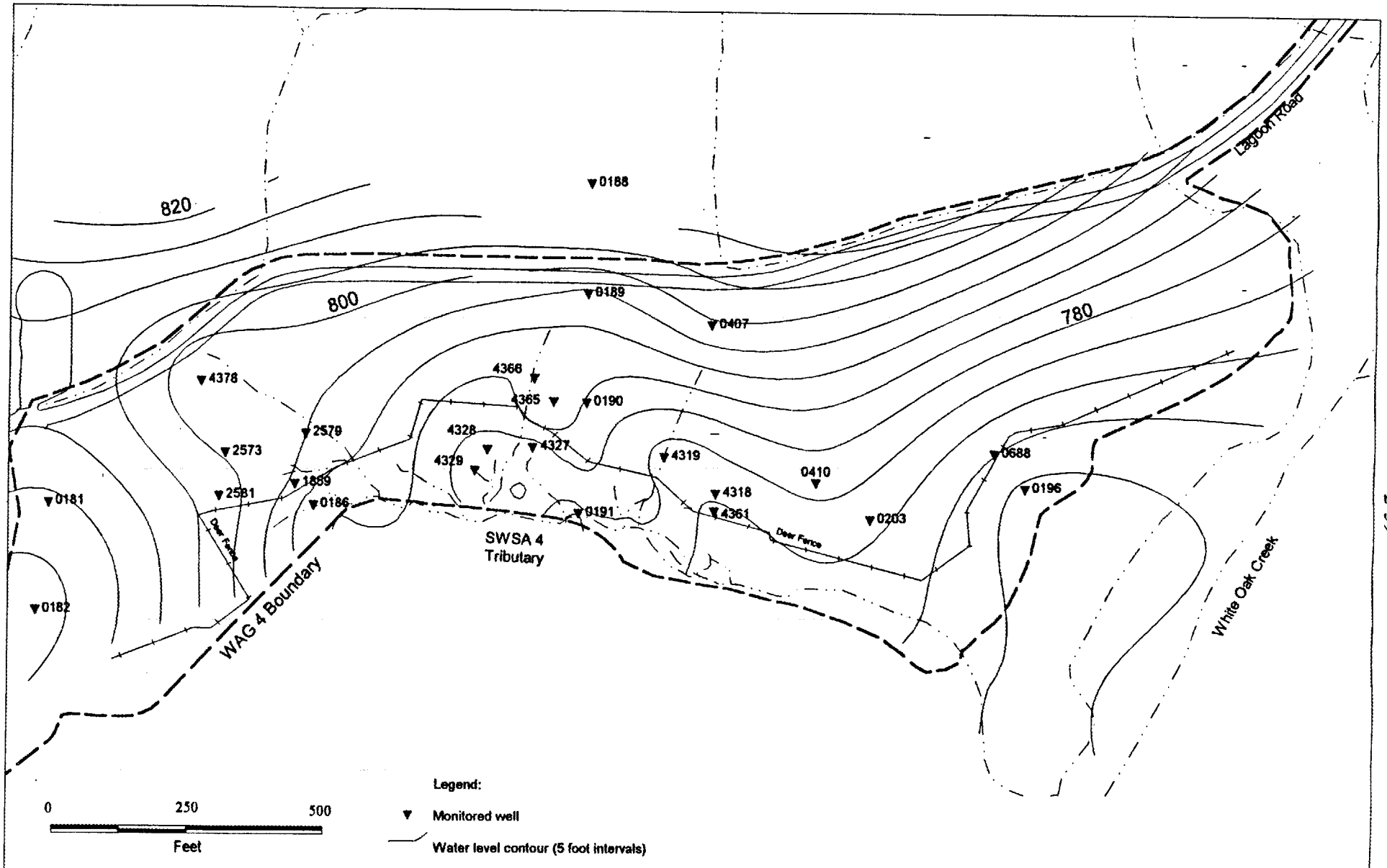


Fig. 2.25. Water level contours - May 24, 1995

WAG 4 Site Investigation

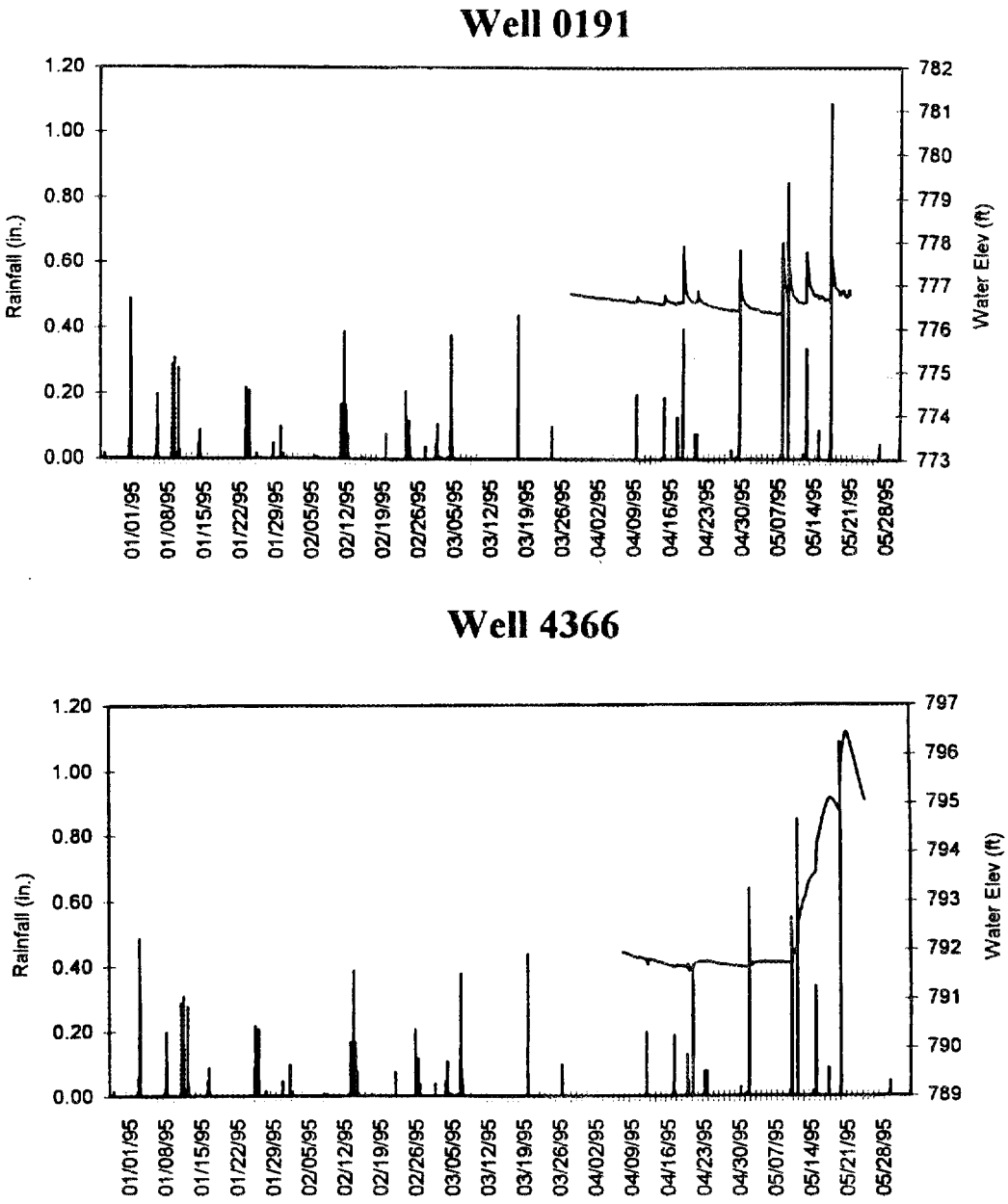


Fig. 2.26. Response hydrographs
WAG 4 Site Investigation

Phase I. The purpose of the Phase I sampling was to determine if activity was present in the newly installed drive points. To do this, samples were collected at the drive points for analyses of ^{90}Sr, gross alpha, gross beta, gamma, and ^{3}H. Samples were analyzed overnight and the results were used to determine whether the drive points were in trenches or needed to be relocated. Altogether, 47 wells (and 8 duplicates) were sampled, and 2 wells were found dry. Phase I sampling began on January 23, 1995, and ended on March 23, 1995.

Phase II. Phase II sampling involved a more in-depth characterization of the trench water. Phase II radiological sampling also served as a confirmation of the Phase I sampling; in this way, any changes in the trench water occurring between the two sampling periods could be noted. Phase II sampling also included field measurements of pH, Eh or oxidation/reduction (redox), dissolved oxygen (DO), conductivity, and temperature. Other laboratory analyses for which samples were collected were inductively coupled plasma (ICP) metals, anions, alkalinity, dissolved organic carbon (DOC), and dissolved solids. For Phase II, 18 wells (and 3 duplicates), 2 seeps, and 1 field blank were sampled. One seep, SCS 5, was dry. Phase II sampling began on March 28, 1995, and ended on April 13, 1995. The Phase I and Phase II sampling schemes are diagrammed in Fig. 2.27.

Physical and Chemical Results

Sample Fractions and Preservation. Four different sample fractions were collected at each drive point. One fraction was collected for radioactivity analyses (except for ^{3}H), one for metals, and one for DOC. Anions, alkalinity, ^{3}H, and dissolved solids were analyzed from one fraction called the water chemistry sample. All sample bottles were high-density polyethylene, except for DOC, which were amber glass. All samples were stored in a cooler at 4°C and were preserved with acid (except for the water chemistry sample) to help prevent iron precipitation and microbiological growth. The radiological fraction was preserved with HCl because HNO_3 interferes with the Cerenkov counting method for the ^{90}Sr analyses. The metals were preserved with HNO_3; DOC was preserved with H_2SO_4. As previously stated, the water chemistry sample was not preserved with acid.

In-line Field Measurements. In-line field measurements were made using a Hydrolab HG20 Multiprobe equipped with a flow-through cell. Trench water was pumped through the cell until most parameters had stabilized. This usually required about 30 minutes, but varied with each well. Eh or redox measurements usually were the slowest to stabilize, because of the slow approach to equilibrium of the platinum electrode used for its measurement. The field data are given in Table 2.12. The temperature of the well points and seeps over the sampling period ranged from 13.15°C to 20.28°C. The pH ranged from a slightly acidic 6.52 to a slightly basic 7.71. The redox conditions ranged from a weakly reducing 51 mV (0.02 mg/L DO) to a moderately oxidizing 432 mV (5.51 mg/L DO). The Eh values are reported relative to the standard hydrogen electrode. The specific conductivity ranged from a low of 0.293 mS/cm to a high of 1.58 mS/cm.

Inorganic Constituents. The inorganic constituents of interest in this study were alkalinity, anions, ICP metals, and total dissolved solids (TDS). Each of these constituents is discussed below.

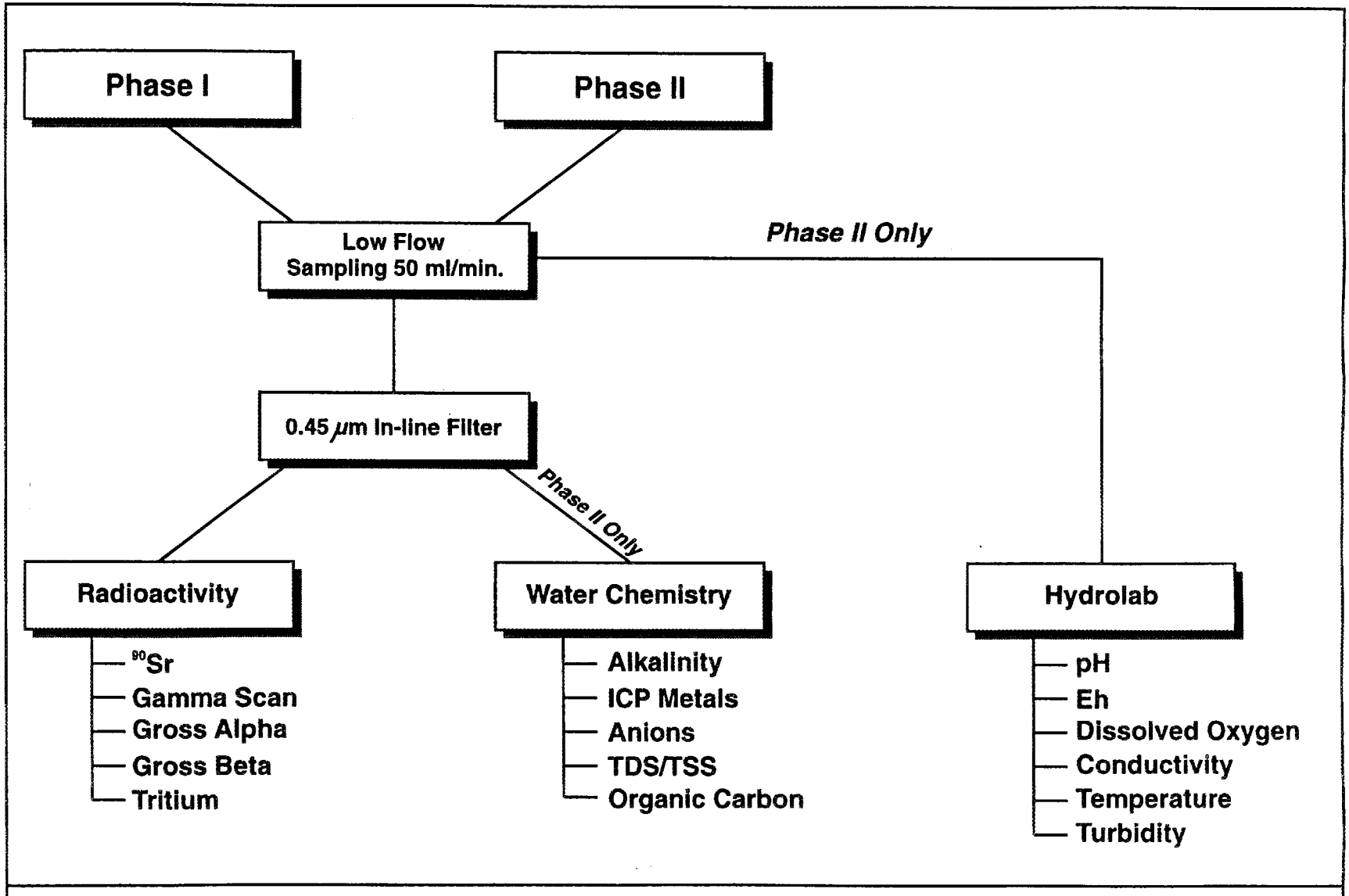


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Fig. 2.27. WAG 4 sampling scheme
WAG 4 Site Investigation

Table 2.12. In-line field parameter measurements

ORNL well number	Project identification	Sampling date	Temperature (°C)	Dissolved oxygen (mg/L)	Specific conductivity (mS/cm)	pH	Eh (mv)
4362	DP38	3/28/95	14.53	0	0.784	7.32	282
4361	DP37	4/03/95	16.13	0	0.857	6.68	174
NA[a]	DP77 (dup)	4/03/95	NMT[b]	NMT	NMT	NMT	NMT
4357	DP34	4/03/95	15.41	0	0.738	6.74	147
4343	DP18	4/04/95	15.71	0.29	0.728	6.81	103
NA	MS1	4/05/95	13.15	5.51	0.51	7.71	432
NA	DP78 (dup)	4/05/95	NMT	NMT	NMT	NMT	NMT
NA	SCS1	4/05/95	14.93	2.98	0.549	7.17	346
4325	DP08	4/05/95	14.43	0.69	0.926	6.76	179
4370	DP44	4/05/95	15.86	0.15	0.674	7.06	161
4355	DP31	4/06/95	15.64	0.01	0.755	6.8	163
4326	DP09	4/06/95	20.28	4.78	0.54	6.88	132
4367	DP43	4/06/95	18.97	3.55	0.316	6.52	197
4354	DP24	4/06/95	15.22	0.01	0.522	6.68	147
4366	DP41	4/10/95	18.84	0.08	0.718	6.79	134
NA	DP79 (dup)	4/10/95	19.28	0.05	0.716	6.77	133
4322	DP05	4/10/95	17.22	0.02	1.58	7.47	51
4372	DP49	4/11/95	14.68	0.02	0.636	6.95	123
2568	WP10	4/11/95	13.44	0.01	0.867	6.84	178
2572	WP14	4/12/95	13.47	0	0.804	7.13	118
4327	DP10	4/13/95	14.27	3.39	0.65	7.16	139
4328	DP11	4/13/95	13.59	0.01	0.512	6.78	167
4329	DP12	4/13/95	17.72	3.84	0.474	7.1	165

[a] Not applicable
[b] No measurement taken

The total alkalinity ranged from 111 to 839 mg/L $CaCO_3$ and was determined by titration of a filtered, unpreserved sample with a standard solution of sulfuric acid to a pH of 4.5. The pH of all the drive points and seeps was around 7.0, so the predominant reaction can be described by the equation below.

$$HCO_3^- + H^+ \rightleftharpoons H_2O + CO_2$$

The alkalinity was assumed to be the result of the bicarbonate, whose concentrations ranged from 135.3 to 1022.9 mg/L HCO_3. Corrections to the alkalinity were made when boron and silica were present. These corrections typically amounted to less than 0.1%. Thus, the titration alkalinity was assumed to be equal to the carbonate alkalinity. The alkalinity data are given in Table 2.13.

Anions were analyzed by ion chromatography (IC) on a filtered, unpreserved sample. The anions analyzed were: chloride, fluoride, sulfate, bromide, nitrate, and phosphate. Phosphate, whose detection limit is 0.2 mg/L, was not found at any site. Nitrate levels were also below detection except at three sites. However, these results are questionable because the samples and duplicates were inconsistent. Bromide levels were found at two sites, with the highest concentration at well 4322 which registered 1.3 mg/L. All sampling sites had chloride ranging from 3.9 mg/L at well 4372 to 34.9 mg/L at well 4357. Fluoride was found at all sites except two (wells 2568 and 2572 in the bathtubbing trench area). Concentrations ranged from 0.3 mg/L at well 4372 to 30.3 mg/L at well 4343 where the fluoride concentration was greater than the chloride concentration. Sulfate also was found at all but six sites. Concentrations of sulfate ranged from 0.4 mg/L at well 4357 to 61.4 mg/L at well 4322 where sulfate was the dominant anion. The detection limit for all anions was 0.2 mg/L. The anion data can be found in Table 2.13.

The metals of interest were analyzed by ICP emission spectrometry. The major cations found were calcium, magnesium, sodium, and potassium. Potassium concentrations exceeded sodium concentrations at wells 4343, 4357, 4354, 4366, and 4328. Minor elements found were iron, manganese, silicon, aluminum, barium, and strontium. The trace elements boron, lithium, nickel, cobalt, and zinc were also found at various sites. Relevant data can be found in Table 2.14.

The TDS were analyzed by evaporating a volume of sample to dryness and weighing the residue. The TDS data ranged from 102 mg/L to 613 mg/L and can be found in Table 2.13.

Organic Constituent. The organic constituent of concern in this study was DOC. DOC analysis was used to obtain an estimate of the amount of organics in the WAG 4 drive points in lieu of the more expensive volatile and semivolatile organic analyses. It is important to know if organics are present at a site because organic complexes of metals and radionuclides play a vital role in their transport properties. Since organic complexes essentially change the chemistry of the metals and radionuclides, knowledge of the presence of these organics is important in developing a remediation strategy. Although a DOC analysis doesn't identify which organics are present, it will reveal at which sites further organic analysis is needed, thus eliminating the need for expensive organic analyses at every well. The DOC at the WAG 4 wells ranged from <0.5 mg/L to 33.7 mg/L. The DOC values can be found in Table 2.13.

Radiochemical Constituents. Radioactivity measurements were done for both Phase I and Phase II sampling. Other than those for ^{90}Sr and gross beta, the results discussed here will be for Phase II only.

Table 2.13. Phase II anion results from samples taken at WAG 4

ORNL well number	Project identification	Date collected	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	Alkalinity (mg $CaCO_3$/L)	Dissolved organic carbon (mg/L)	Total dissolved solids (mg/L)
4322	DP05	4/10/95	1.3	23.7	2	0.2 U	0.2 U	61.4	839	8.17	476
4325	DP08	4/05/95	0.2 U[a]	28.2	1	0.2 U	0.2 U	0.8 J[b]	449	5.32	515
4326	DP09	4/06/95	0.2 U	13	1.1	0.2 U	0.2 U	0.6 J	240[a]	27.7	308
4327	DP10	4/13/95	0.2 U	13.2	0.9 J	0.2 U	0.2 U	1	336	33.4	368
4328	DP11	4/13/95	1	18.9	8.3	0.2 U	0.2 U	0.2 U	201	4.33	102
4329	DP12	4/13/95	0.3 J	33.6	0.3 J	0.2 U	0.2 U	13.4	217	33.7	241
4343	DP18	4/04/95	0.2 U	21.3	30.3	0.2 U	0.2 U	0.2 U	189	5.58	355
4354	DP24	4/06/95	0.2 U	16.7	15.9	0.2 U	0.2 U	1.8	187	2.59	261
4355	DP31	4/06/95	0.2 U	10.1	3.6	0.2 U	0.2 U	9.5	385	4.85	472
4357	DP34	4/03/95	0.2 U	34.9	1.9	0.3 J	0.2 U	0.4 J	311	5.03	446
4361	DP37	4/03/95	0.2 U	14.2	0.9 J	0.2 U	0.2 U	0.2 U	440	4.66	613
4361	DP37 (dup)	4/03/95	0.2 U	13.7	0.9 J	2	0.2 U	0.2 U	422	4.75	505
4362	DP38	3/28/95	0.2 U	12.6	1.8	0.2 U	0.2 U	0.2 U	359	< 0.5	420
4366	DP41	4/10/95	0.2 U	17.4	12.8	3.5	0.2 U	9.5	290	11.65	453
4366	DP41 (dup)	4/10/95	0.2 U	17.1	12.8	0.2 U	0.2 U	10.7	300	3.8	386
4367	DP43	4/06/95	0.2 U	14.8	0.6 J	0.2 U	0.2 U	6	111[a]	4.01	201
4370	DP44	4/05/95	0.2 U	7.3	4.2	0.8 J	0.2 U	18.6	331	3.91	462
4372	DP49	4/11/95	0.2 U	3.9	0.3 J	0.5 J	0.2 U	0.2 U	326	4.77	351
NA[d]	FB01	4/13/95	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	50	2.58	299
NA	MS1	4/05/95	0.2 U	10.3	1.1	0.2 U	0.2 U	12.5	240	1.52	396
NA	MS1 (dup)	4/05/95	0.2 U	9.1	1.1	0.2 U	0.2 U	12.7	276	2.56	386
NA	SCS1	4/05/95	0.2 U	9.5	1	0.2 U	0.2 U	10.5	266	2.41	425
2568	WP10	4/11/95	0.2 U	6.2	0.2 U	1.2	0.2 U	7.9	464	4.22	444
2572	WP14	4/12/95	0.2 U	19	0.2 U	0.2 U	0.2 U	0.2 U	415	4.3	474

[a] Indicates the compound was analyzed for but not detected. The sample quantitation limit has been corrected for dilution and percent moisture.
[b] Indicates an estimated value detected below the sample quantitation limit, but above the instrument detection limit.
[c] Indicates concentration was below the detection limit.
[d] Not applicable

Table 2.14. Phase II inorganic results from samples taken at WAG 4

ORNL well identification	Project identification	Date collected	Ag (mg/L)	Al (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Ca (mg/L)	Cd (mg/L)	Co (mg/L)	Cr (mg/L)
4322	DP05	4/10/95	0.013	< 0.05	0.065	0.39	0.2	< 0.001	40	< 0.005	< 0.004	< 0.004
4325	DP08	4/05/95	< 0.005	< 0.05	0.055	0.94	0.8	< 0.001	130	< 0.005	< 0.004	< 0.004
4326	DP09	4/06/95	< 0.005	< 0.05	0.18	0.12	0.69	< 0.001	53	< 0.005	0.0078	< 0.004
4327	DP10	4/13/95	< 0.005	0.069	0.07	0.21	0.42	< 0.001	80	< 0.005	0.0045	< 0.004
4328	DP11	4/13/95	< 0.005	0.21	0.076	0.098	0.28	< 0.001	56	< 0.005	0.077	< 0.004
4329	DP12	4/13/95	< 0.005	< 0.05	< 0.05	< 0.08	0.092	< 0.001	69	< 0.005	0.0048	< 0.004
4343	DP18	4/04/95	< 0.005	3.6	0.32	< 0.08	0.21	0.0068	49	< 0.005	0.037	< 0.004
4354	DP24	4/06/95	< 0.005	0.48	0.078	< 0.08	0.38	< 0.001	65	< 0.005	< 0.004	< 0.004
4355	DP31	4/06/95	< 0.005	0.055	0.075	0.13	0.26	< 0.001	100	< 0.005	0.099	< 0.004
4357	DP34	4/03/95	< 0.005	< 0.05	0.1	< 0.08	0.9	< 0.001	100	< 0.005	0.0075	< 0.004
4361	DP37	4/03/95	< 0.005	< 0.05	0.11	0.13	0.61	< 0.001	130	< 0.005	0.057	< 0.004
4362	DP38	3/28/95	< 0.005	< 0.05	0.16	< 0.08	0.52	0.0015	110	< 0.005	0.05	< 0.004
4366	DP41	4/10/95	< 0.005	0.12	0.064	0.29	0.27	< 0.001	80	< 0.005	< 0.004	< 0.004
4367	DP43	4/06/95	< 0.005	< 0.05	0.061	< 0.08	0.05	< 0.001	20	< 0.005	0.0059	< 0.004
4370	DP44	4/05/95	< 0.005	< 0.05	< 0.05	< 0.08	0.16	< 0.001	97	< 0.005	0.009	< 0.004
4372	DP49	4/10/95	< 0.005	< 0.05	0.074	< 0.08	0.48	0.0029	100	< 0.005	< 0.004	< 0.004
NA[a]	DP77 (dup)	4/03/95	< 0.005	< 0.05	0.12	0.12	0.61	< 0.001	130	< 0.005	0.057	< 0.004
NA	DP78 (dup)	4/05/95	< 0.005	< 0.05	< 0.05	0.094	0.14	< 0.001	76	< 0.005	< 0.004	< 0.004
NA	DP79 (dup)	4/10/95	< 0.005	0.12	0.085	0.29	0.27	< 0.001	80	< 0.005	< 0.004	< 0.004
NA	FB01	4/13/95	< 0.005	< 0.05	< 0.05	< 0.08	< 0.001	< 0.001	0.012	< 0.005	< 0.004	< 0.004
NA	MS-1	4/05/95	< 0.005	< 0.05	< 0.05	0.099	0.14	< 0.001	75	< 0.005	< 0.004	< 0.004
NA	SCS1	4/05/95	< 0.005	< 0.05	< 0.05	0.1	0.19	< 0.001	85	< 0.005	0.0045	< 0.004
2568	WP10	5/11/95	< 0.005	< 0.05	< 0.05	< 0.08	0.29	< 0.001	140	< 0.005	< 0.004	< 0.004
2572	WP14	4/12/95	< 0.005	< 0.05	< 0.05	< 0.08	0.33	< 0.001	97	< 0.005	< 0.004	< 0.004

Table 2.14 (continued)

ORNL well identification	Project identification	Date collected	Cu (mg/L)	Fe (mg/L)	K (mg/L)	Li (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Ni (mg/L)	P (mg/L)	Pb (mg/L)
4322	DP05	4/10/95	0.015	2.1	7.7	0.024	11	0.37	< 0.04	350	0.17	< 0.3	< 0.05
4325	DP08	4/05/95	< 0.007	13	6.9	0.1	27	1.1	< 0.04	13	0.04	< 0.3	< 0.05
4326	DP09	4/06/95	< 0.007	37	5.5	0.2	16	1.8	< 0.04	10	0.26	< 0.3	< 0.05
4327	DP10	4/13/95	< 0.007	11	6.1	< 0.005	26	7.1	< 0.04	14	0.25	< 0.3	< 0.05
4328	DP11	4/13/95	< 0.007	13	27	0.053	11	0.91	< 0.04	7.6	5.5	< 0.3	< 0.05
4329	DP12	4/13/95	< 0.007	1.5	< 2	< 0.005	11	2.1	< 0.004	25	0.13	< 0.3	< 0.05
4343	DP18	4/04/95	< 0.007	62	37	0.36	11	1.2	< 0.04	9.1	4.6	< 0.3	< 0.05
4354	DP24	4/06/95	< 0.007	14	18	0.061	9.1	1.5	< 0.04	5.5	< 0.01	< 0.3	< 0.05
4355	DP31	4/06/95	< 0.007	11	4	0.021	26	1	< 0.04	11	4.8	< 0.3	< 0.05
4357	DP34	4/03/95	< 0.007	15	12	0.026	16	1.2	< 0.04	6.1	0.31	< 0.3	< 0.05
4361	DP37	4/03/95	< 0.007	17	3.5	0.11	15	1.2	< 0.04	9.4	9.7	< 0.3	< 0.05
4362	DP38	3/28/95	< 0.007	26	2.7	0.54	13	1	< 0.04	14	5.5	< 0.3	< 0.05
4366	DP41	4/10/95	< 0.007	16	37	0.52	19	1.1	< 0.04	11	0.16	< 0.3	< 0.05
4367	DP43	4/06/95	< 0.007	11	5.2	< 0.005	9.4	3.1	< 0.04	5.4	< 0.01	< 0.3	< 0.05
4370	DP44	4/05/95	< 0.007	4.7	2.9	0.5	19	0.34	< 0.04	13	1.1	< 0.3	< 0.05
4372	DP49	4/10/95	< 0.007	14	2.3	0.028	11	1	< 0.04	9.8	0.016	< 0.3	< 0.05
NA	DP77 (dup)	4/03/95	< 0.007	16	3.8	0.11	15	1.2	< 0.04	9.4	10	< 0.3	< 0.05
NA	DP78 (dup)	4/05/95	< 0.007	0.092	6.1	0.021	13	0.34	< 0.04	9.8	0.015	< 0.3	< 0.05
NA	DP79 (dup)	4/10/95	< 0.007	15	36	0.52	19	1.1	< 0.04	11	0.2	< 0.3	< 0.05
NA	FB01	4/13/95	< 0.007	< 0.05	< 2	< 0.005	< 0.02	< 0.001	< 0.04	< 0.05	< 0.01	< 0.3	< 0.05
NA	MS-1	4/05/95	< 0.007	0.1	6.1	0.021	13	0.34	< 0.04	9.8	0.019	< 0.3	< 0.05
NA	SCS1	4/05/95	< 0.007	0.33	5.7	0.024	13	0.65	< 0.04	10	0.02	< 0.3	< 0.05
2568	WP10	5/11/95	< 0.007	4.5	4.3	0.024	16	0.47	< 0.04	31	0.062	< 0.3	< 0.05
2572	WP14	4/12/95	< 0.007	6.3	< 2	0.0075	16	1.8	< 0.04	53	0.024	< 0.3	< 0.05

Table 2.14 (continued)

ORNL well identification	Project identification	Date collected	Sb (mg/L)	Se (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)	Zr (mg/L)
4322	DP05	4/10/95	< 0.05	< 0.05	4.5	< 0.05	0.14	< 0.02	< 0.002	< 0.005	< 0.02
4325	DP08	4/05/95	< 0.05	< 0.05	6.6	< 0.05	0.35	< 0.02	0.0026	0.0078	< 0.02
4326	DP09	4/06/95	< 0.05	< 0.05	5.9	< 0.05	0.16	< 0.02	0.0034	0.045	< 0.02
4327	DP10	4/13/95	< 0.05	< 0.05	5.8	< 0.05	0.27	< 0.02	< 0.002	1	< 0.02
4328	DP11	4/13/95	< 0.05	< 0.05	5	< 0.05	0.13	< 0.02	0.0026	0.0099	< 0.02
4329	DP12	4/13/95	< 0.05	< 0.05	3.8	< 0.05	0.13	< 0.02	< 0.002	0.055	< 0.02
4343	DP18	4/04/95	< 0.05	< 0.05	11	< 0.05	0.098	< 0.02	< 0.002	0.078	< 0.02
4354	DP24	4/06/95	< 0.05	< 0.05	5.2	< 0.05	0.16	< 0.02	< 0.002	0.0051	< 0.02
4355	DP31	4/06/95	< 0.05	< 0.05	6.9	< 0.05	0.2	< 0.02	0.0021	0.013	< 0.02
4357	DP34	4/03/95	< 0.05	< 0.05	5.2	< 0.05	0.21	< 0.02	0.0028	0.0053	< 0.02
4361	DP37	4/03/95	< 0.05	< 0.05	7.1	< 0.05	0.23	< 0.02	< 0.002	0.011	< 0.02
4362	DP38	3/28/95	< 0.05	< 0.05	5.4	< 0.05	0.19	< 0.02	< 0.002	0.048	< 0.02
4366	DP41	4/10/95	< 0.05	< 0.05	8.4	< 0.05	0.31	< 0.02	0.002	< 0.005	< 0.02
4367	DP43	4/06/95	< 0.05	< 0.05	3.8	< 0.05	0.064	< 0.02	< 0.002	0.94	< 0.02
4370	DP44	4/05/95	< 0.05	< 0.05	5.2	< 0.05	0.19	< 0.02	0.0027	0.12	< 0.02
4372	DP49	4/10/95	< 0.05	< 0.05	4.1	< 0.05	0.18	< 0.02	< 0.002	< 0.005	< 0.02
NA	DP77 (dup)	4/03/95	< 0.05	< 0.05	7.1	< 0.05	0.23	< 0.02	0.0027	0.011	< 0.02
NA	DP78 (dup)	4/05/95	< 0.05	< 0.05	2.7	< 0.05	0.17	< 0.02	< 0.002	< 0.005	< 0.02
NA	DP79 (dup)	4/10/95	< 0.05	< 0.05	8.4	< 0.05	0.31	< 0.02	0.0025	< 0.005	< 0.02
NA	FB01	4/13/95	< 0.05	< 0.05	< 0.2	< 0.05	< 0.005	< 0.02	< 0.002	< 0.005	< 0.02
NA	MS-1	4/05/95	< 0.05	< 0.05	2.7	< 0.05	0.17	< 0.02	0.0023	< 0.005	< 0.02
NA	SCS1	4/05/95	< 0.05	< 0.05	3	< 0.05	0.19	< 0.02	< 0.002	< 0.005	< 0.02
2568	WP10	5/11/95	< 0.05	< 0.05	4.9	< 0.05	0.25	< 0.02	< 0.002	2.3	< 0.02
2572	WP14	4/12/95	< 0.05	< 0.05	5.1	< 0.05	0.21	< 0.02	< 0.002	2.8	< 0.02

[a] not applicable

Strontium-90 analyses were done by the Cerenkov method. This approach required that the radiation samples be preserved with HCl because HNO_3 acts as a quenching agent during the scintillation counting. The Phase II results ranged from 194 pCi/L at well 4329 to 173,000 pCi/L at well 4354. The Phase II results are in Table 2.15. The Phase I results had a low of 7.8 ± 15.5 at well 4359 to a high of 184,000 pCi/L at well 4354. These data are presented in Table 2.16. The agreement was fairly good for the wells that were sampled in both phases.

Gross beta analyses were performed by evaporating a known volume of sample on a planchet and then counting using a low background beta counter. The results, except for those from well 4322, were not corrected for self-absorption. The Phase II gross beta results ranged from 448 pCi/L at well 4329 to 326,000 pCi/L at well 4322. The data can be found in Table 2.15. The Phase I gross beta results ranged from 31.5 pCi/L at well 4359 to 292,954.7 pCi/L at well 4354. The agreement was fairly good for the wells that were sampled in both phases. The Phase I data can be found in Table 2.16.

Gross alpha analyses were performed in a manner similar to that used for gross beta, except that the sample was counted on an alpha counter and the results were corrected for self-absorption. The gross alpha results ranged from 1 pCi/L at well 4354 to 2300 pCi/L at well 4322. The data can be found in Table 2.15. It is not known what isotopes are producing this activity. However, well 2568, located in the bathtubbing trench area in what is thought to be an "alpha trench," had a gross alpha of 453.5 pCi/L. This well point has been analyzed before for alpha emitters, and the results showed that the alpha activity was principally due to the uranium isotopes. Further sampling and analyses of the alpha activity at well 4322 are warranted before any remediation begins.

Cesium-137 was determined by gamma spectroscopy. It was the only principal gamma emitter found. Activities ranged from nondetectable to 124,000 pCi/L at well 4322. These data can be found in Table 2.15.

Tritium analyses were done by liquid scintillation counting only. No distillation was performed. The resulting values ranged from nondetectable to 4,170,451 pCi/L at well 4329. The tritium data can be found in Table 2.15.

Results and Discussion

The following discussion deals with Phase II data because only radiation samples were collected for Phase I.

The water chemistry has been well characterized. The charge balances were all under 5% except for well 4326 (6.04%) and well 4343 (10.02%). Six of the wells had charge balances of less than 1%. The ionic strength ranged from 0.007 at well 4354 to 0.02 at well 4322. The hardness of the groundwater (calculated from the data) ranged from 88.5 mg/L $CaCO_3$ at well 4367 to 435.7 mg/L $CaCO_3$ at well 4322. The groundwater in all the wells except well 4322 can be classified as a calcium carbonate water. Well 4322 has a different water chemistry from the other wells and is classified as containing a sodium carbonate water. This difference can readily be seen in the Piper diagram in Fig. 2.28. Most of the wells are supersaturated with respect to calcite and the iron-containing minerals goethite, maghematite, and amorphous $Fe(OH)_3$. To a lesser extent, some wells are supersaturated with respect to quartz, barite, siderite, fluorite, and dolomite. Strontium minerals were undersaturated in all the wells. Therefore, the water chemistry of the trenches would favor

Table 2.15. Phase II results for all samples collected at WAG 4

ORNL well number	Project identification	Date collected	Gross alpha (pCi\L)	Gross beta (pCi\L)	Sr-90 (pCi\L)	Cs-137 (pCi/L)	Tritium (pCi\L)
4322	DP05	4/10/95	2300 ± 60	326000 ± 633	82800 ± 199	124000 ± 475	0 ± 97.8
4325	DP08	4/05/95	1.2 ± 5	162285.3 ± 878	120000 ± 235	38.5 ± 23	0 ± 102.7
4326	DP09	4/06/95	1.1 ± 5.3	67011.3 ± 216.8	39500 ± 135	42.1 ± 54.7	14055.9 ± 282.9
4327	DP10	4/13/95	7.1 ± 6.4	22182 ± 124.8	11300 ± 73.8	553 ± 209	1116.2 ± 125.2
4328	DP11	4/13/95	4.1 ± 2.9	19419.7 ± 73.8	13100 ± 79.1	41.7 ± 23.2	11455.9 ± 258.3
4329	DP12	4/13/95	2.9 ± 4.7	448 ± 16.7	194 ± 18.6	229 ± 179	4170451 ± 4538.6
4343	DP18	4/04/95	11.3 ± 3.6	74994.8 ± 146.8	40500 ± 137	1920 ± 69.9	0 ± 102.7
4354	DP24	4/06/95	1 ± 4.3	217114.7 ± 1014.6	173000 ± 282	[a]	0 ± 103.2
4355	DP31	4/06/95	42.6 ± 5.6	35480.5 ± 99.7	24800 ± 108		34306.3 ± 424.3
4357	DP34	4/03/95	16.6 ± 4.1	31514.8 ± 94	17400 ± 90.8	814 ± 45	1909.9 ± 141.4
4361	DP37	4/03/95	5.8 ± 3.3	57811.5 ± 127.3	37200 ± 131		993.7 ± 124.3
NA[b]	DP37 (dup)	4/03/95	5.4 ± 3.2	52781.2 ± 121.6	38300 ± 133		1327 ± 130.8
4362	DP38	3/28/95	10.7 ± 3.6	40587.5 ± 106.7	26100 ± 111	3200 ± 79.5	16597.3 ± 302.5
4366	DP41	4/10/95	20 ± 4.9	96947.2 ± 190.3	73600 ± 184	40.5 ± 29.6	4193.7 ± 174
NA	DP41 (dup)	4/10/95	34.3 ± 6.1	99240.5 ± 194.8	72800 ± 183	41.6 ± 24.3	4375.7 ± 176.5
4367	DP43	4/06/95	5.1 ± 5.4	57132.2 ± 200.2	32700 ± 124	178 ± 171	0 ± 103.2
4370	DP44	4/05/95	22.9 ± 4.5	70722.1 ± 140.8	44900 ± 144	89.5 ± 24.8	23362.2 ± 354.8
4372	DP49	4/11/95	47.2 ± 8.0	170000 ± 340	125000 ± 240	4670 ± 98.3	0 ± 97.8
NA	FB01	4/13/95	4.2 ± 2.6	40.2 ± 4.3	0.46 ± 15.4		0 ± 100.9
2568	WP10	4/11/95	453.5 ± 17.1	23189.7 ± 80.7	14200 ± 82.9	9740 ± 132	14882.9 ± 288.2
2572	WP14	4/12/95	6.7 ± 3.4	9411.8 ± 51.4	6320 ± 56	68.8 ± 23.9	463442 ± 1515.9
NA	MS1	4/05/95	30.9 ± 4.8	15959.2 ± 66.9	9710 ± 68.5		5860162 ± 5379.7
NA	MS1 (dup)	4/05/95	27.5 ± 4.6	15435.1 ± 65.8	9770 ± 68.7		5842595 ± 5371.6
NA	SCS1	4/05/95	29 ± 4.7	16188.3 ± 67.4	10100 ± 69.7		5850712 ● 5375.4

[a] Blank space indicates value below background
[b] Not applicable

Table 2.16. Phase I results for all samples collected at WAG 4

ORNL well number	Project identification	Date collected	Gross alpha (pCi\L)	Gross beta (pCi\L)	Sr-90 (pCi\L)	Cs-137 (pCi/L)	Tritium (pCi\L)
4318	DP01	1/23/95	4.4 ± 3.1	21304.2 ± 77.3	26200 ± 111	[a]	37935.1 ± 629.6
4320	DP03	1/23/95	434.6 ± 16	9007.2 ± 50.3	9640 ± 68.4	589 ± 49.9	15696.4 ± 420.5
4321	DP04	1/23/95	15.2 ± 4.5	92774.4 ± 182.2	107000 ± 222	158 ± 25.3	7618 ± 311.5
4322	DP05	2/09/95	1471.7 ± 49	179464.6 ± 354.6	90900 ± 209	130000 ± 613	0 ± 139.1
4340	DP13	1/25/95	166 ± 15.1	7440.2 ± 72.5	7650 ± 61.3		5071.2 ± 268.6
4339	DP14	1/26/95	6.5 ± 3.2	1284.5 ± 19.2	1660 ± 31.8	318 ± 34.7	2762.2 ± 172.3
NA[b]	DP14 (dup)	1/26/95	7.8 ± 3.3	1404 ± 20	1600 ± 31.3	176 ± 29.6	2939.6 ± 174.9
4341	DP15	1/26/95	4.6 ± 3	10085.6 ± 53.2	14300 ± 82.6	25.9 ± 23.3	5101.8 ± 203.1
4338	DP16	1/24/95	9.8 ± 3.4	150.5 ± 7	180 ± 18.1		3444.1 ± 234.6
4342	DP17	1/26/95	11.7 ± 3.6	3309.8 ± 30.6	3660 ± 43.9	178 ± 31.8	13762.2 ± 289.8
4343	DP18	2/01/95	3 ± 2.9	23859.7 ± 81.8	25800 ± 110	1420 ± 84.5	2989.2 ± 161.6
4344	DP19	2/01/95	32.2 ± 4.6	9414.5 ± 51.4	12300 ± 76.7	208 ± 28.6	8477.5 ± 230.6
4345	DP20	2/01/95	4 ± 2.4	12564.8 ± 59.4	12000 ± 75.8		596.4 ± 119.5
4346	DP21	2/09/95	10.7 ± 3.4	2455.9 ± 26.4	2960 ± 39.8		5811.7 ± 277
4347	DP22	2/09/95	3.6 ± 5	338.7 ± 17.1	406 ± 20.3		1200 ± 176.6
4348	DP23	2/09/95	96.4 ± 9.4	4021.7 ± 40.7	3320 ± 42.1	2110 ± 77.2	5542.3 ± 272.1
4354	DP24	2/14/95	0.4 ± 5.2	292954.7 ± 615.6	184000 ± 291		0 ± 137.1
4351	DP25	2/14/95	9.8 ± 3.5	4908.4 ± 37.2	4810 ± 49.6	291 ± 34.2	6837.8 ± 293.8
4353	DP26	2/14/95	1.3 ± 2.4	2096.2 ± 24.4	2310 ± 36.2		3265.8 ± 225.9
4352	DP27	3/13/95	4.4 ± 4.3	21319.8 ± 109.4	25200 ± 109		0 ± 138
4349	DP29	2/09/95	8.5 ± 3.3	11874.3 ± 57.7	15000 ± 84.4	75.5 ± 26.8	7458.6 ± 304.9
4350	DP30	2/09/95	2.7 ± 2.7	5045.2 ± 37.7	6850 ± 58.1	35 ± 23.2	8111.7 ± 315.3
4355	DP31	2/14/95	68.7 ± 7.1	23761 ± 81.6	25400 ± 109		36721.6 ± 617.5
4356	DP32	2/14/95	5.7 ± 3.3	443.9 ± 11.5	395 ± 20.7		34831.5 ± 602.2
4358	DP33	2/23/95	9.5 ± 3.4	1032.8 ± 17.2	5460 ± 52.4	27.1 ± 24.3	24870.3 ± 517.9
4357	DP34	2/14/95	13.2 ± 3.9	20709.4 ± 76.2	26300 ± 111	515 ± 37.6	2610.8 ± 211.1
NA	DP34 (dup)	2/14/95	24 ± 4.6	18491.2 ± 72	19500 ± 96	887 ± 46.7	2589.2 ± 210.6
4359	DP35	2/21/95	4.3 ± 3.9	31.5 ± 5.6	7.8 ± 15.5		4777.5 ± 267.6
4360	DP36	2/21/95	2 ± 13.5	4201.6 ± 77.8	160 ± 19.5	5590 ± 112	3397.3 ± 240.8

Table 2.16 (continued)

ORNL well number	Project identification	Date collected	Gross alpha (pCi\L)	Gross beta (pCi\L)	Sr-90 (pCi\L)	Cs-137 (pCi/L)	Tritium (pCi\L)
4361	DP37	2/21/95	12 ± 5.2	34898.4 ± 139.9	48500 ± 150		2647.7 ± 224.9
4362	DP38	2/21/95	49.2 ± 8.5	26566.2 ± 122.1	28100 ± 115	2770 ± 75	18810.8 ± 458.5
4363	DP39	2/21/95	178.8 ± 14.8	1729.4 ± 31.4	1810 ± 32.7		6933.3 ± 304.8
4368	DP40	2/23/95	2 ± 2.9	555.9 ± 12.8	187 ± 18.1	496 ± 37.9	5362.2 ± 275
NA	DP40 (dup)	2/23/95	1 ± 2.8	309.3 ± 9.7	57.5 ± 16.3	165 ± 28.3	5366.7 ± 275.1
4366	DP41	2/21/95	24.7 ± 6.4	50287.8 ± 167.9	70300 ± 180		5772.1 ± 285.4
NA	DP41 (dup)	2/21/95	22.8 ± 15.4	59689.4 ± 448.1	74700 ± 186	32.6 ± 25.2	5659.5 ± 283.4
4365	DP42	2/21/95	1.7 ± 7.4	11768.9 ± 199.1	12500 ± 77.4		964.9 ± 184.3
4367	DP43	3/13/95	-2.9 ± 5	30464 ± 184.9	27200 ± 113		0 ± 138
4370	DP44	3/13/95	11.3 ± 4.7	26899.7 ± 122.8	32800 ± 124		12035.1 ± 371.3
NA	DP44 (dup)	3/13/95	20.4 ± 5.8	29615.4 ± 128.9	34300 ± 126		11918 ± 369.7
4364	DP46	2/21/95	4.7 ± 8.5	2415.9 ± 90.6	2660 ± 38.2		1306.3 ± 193.3
4371	DP47	3/14/95	2.5 ± 4	10028.3 ± 75.1	15400 ± 85.5	23.1 ± 21.2	1130.6 ± 173.8
4374	DP48	3/14/95	15.2 ± 5.5	6378.3 ± 59.9	7400 ± 60.6	3290 ± 78.1	7586.5 ± 306.5
4372	DP49	3/14/95	80 ± 9.8	38690.4 ± 147.3	46200 ± 147	2920 ± 83.3	0 ± 138
NA	DP49 (dup)	3/14/95	69.4 ± 9.3	38943 ± 147.8	46300 ± 147	3030 ± 78.5	0 ± 138
4373	DP50	3/14/95	5.8 ± 4.3	26672.5 ± 122.3	38300 ± 133		35007.2 ± 603.9
4378	DP54	3/21/95	53.2 ± 6	112.4 ± 6.2	14.7 ± 15.7		1306.3 ± 125.8
4379	DP55	3/23/95	454 ± 16	2337.9 ± 25.7	2170 ± 35.2		4045 ± 173
NA	DP55 (dup)	3/23/95	32.3 ± 4.8	1669.3 ± 21.8	2150 ± 35		4457.7 ± 178.7
190	W190	2/23/95	5.7 ± 2.8	961.1 ± 16.6	1120 ± 27.4		7132.4 ± 305.1
NA	W190 (dup)	2/23/95	4.5 ± 2.7	4710.6 ± 36.4	1140 ± 27.6		7734.2 ± 314.7
2576	WP03	1/31/95	1.9 ± 2.8	20846.1 ± 76.5	22900 ± 104	1600 ± 63.8	5381.1 ± 273.8
2577	WP04	1/31/95	20.3 ± 4.4	26280.2 ± 85.9	32800 ± 124		6812.6 ± 298.5
2578	WP05	1/31/95	4 ± 2.9	20121.4 ± 75.1	29500 ± 117	733 ± 44.9	10642.3 ± 356.2
2582	WP09	1/31/95	2.7 ± 2.7	48 ± 4.5	59.5 ± 16.3	104 ± 32	2060.4 ± 205.4

[a] blank space indicates value below background
[b] not applicable

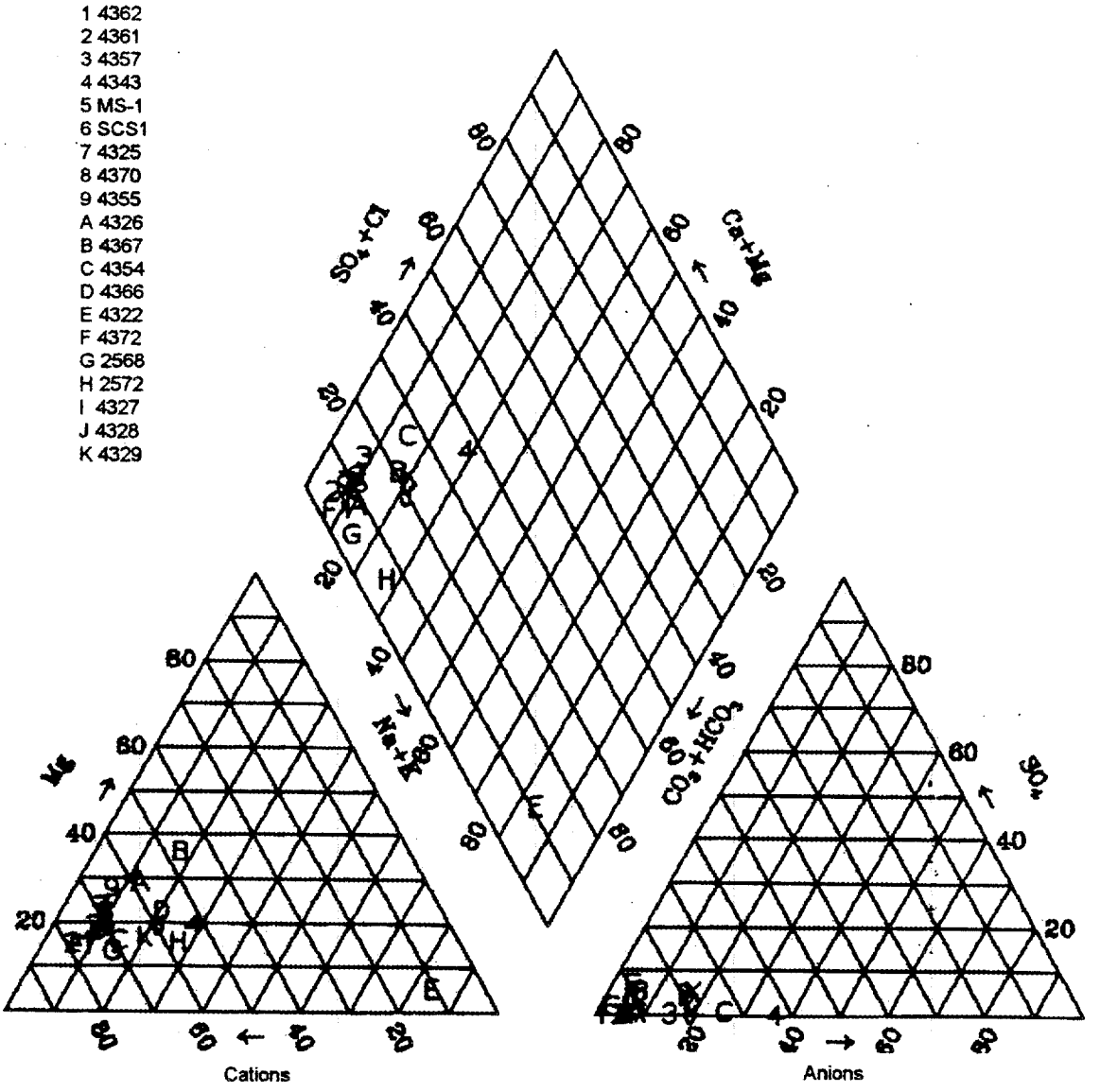

Fig. 2.28. WAG 4 seep characterization

WAG 4 Site Characterization

dissolution of the strontium wastes. A plot of ^{90}Sr versus stable strontium, displayed in Fig. 2.29, shows no clear relationship. This indicates that the ^{90}Sr from the wastes is not homogeneous or has not yet mixed well with the stable strontium. This is significant because it shows that the ^{90}Sr is still being actively leached from sources in the waste trenches, rather than moving from zones of secondary contamination. The ^{90}Sr also did not correlate with any of the chemical parameters measured, whereas the stable strontium did correlate with hardness, alkalinity, and conductivity. The ^{90}Sr did correlate well with gross beta except at well 4322, which has a high concentration of ^{137}Cs (Fig. 2.30). However, if the ^{90}Sr and ^{137}Cs are summed and then plotted versus gross beta, there is a good correlation with all the drive points with an R^2 of 0.92 (Fig. 2.31). If well 4322 is excluded, then the ^{90}Sr versus gross beta R^2 would improve from 0.68 to an R^2 of 0.99. Therefore, gross beta is an useful indicator of ^{90}Sr at WAG 4. However, caution must be used when ^{137}Cs is known to be present. This is important because an overnight gross beta analysis could give a reasonable ^{90}Sr estimate instead of waiting 2 weeks for a ^{90}Sr analysis. The gross beta, therefore, provided information for decisions on placement of new drive points on a daily basis, thus speeding the work and avoiding extra costs.

2.3.3 Burial Trench Characteristics

Although the destruction of waste disposal records in 1957 makes it impossible to ascertain the exact trench configuration or contents, some general information concerning the trenches has been recorded and summarized (Energy Systems 1994b). Trench sizes range from 50 to 400 ft in length, 8 to 30 ft in width, and 8 to 15 ft in depth. As shown in Fig. 2.32a,b,c trench alignments are varied throughout the burial ground.

Table 2.17 displays data collected during drive point installations in 1994 and 1995. The table indicates if the drive points were successfully installed inside or outside of a trench. For drive points installed within the boundary of a trench, the table also indicates if the drive point reached the base of the trench. Because direct observation of the borehole and soil cuttings was not available during the installation of drive points, the determination of whether a drive point was installed within the boundary of a trench and whether the drive point penetrated the base of the trench was a subjective determination. These determinations were based on the collective field experience of the drive point field team. Individual observations such as the total depth reached by the drive point, rate of penetration of the drive point, and drilling characteristics of the strata were all used to determine the position of the drive point with respect to the buried trenches. Drive point construction logs and field notes are presented in Appendix E.

Estimates of overburden above the trenches were calculated by assuming that each trench was originally excavated to a depth of 10 ft below ground surface (bgs) and then covered with overburden. Figures 2.32a,b,c provide a graphical representation of the overburden calculations that are presented in Table 2.17. Overburden estimates in the western section (Fig. 2.32a) are relatively consistent. Values range from 0.51 ft (4347) to 3.39 ft (4339). Overburden estimates in the central section (Fig. 2.32b) are less consistent with values ranging from -2.29 ft (4329) to 5.81 ft (4321). Where negative overburden estimates are obtained, the assumption of a 10-ft trench depth is obviously incorrect. A general trend of lower overburden values is apparent toward the southern portion of the central section (Fig. 2.32b). This is understandable because the surface elevation is lower in these areas and, therefore, trench depth was probably limited by a shallow water table. Overburden estimates in the eastern section (Fig. 2.32c) display the most variability. Those trenches

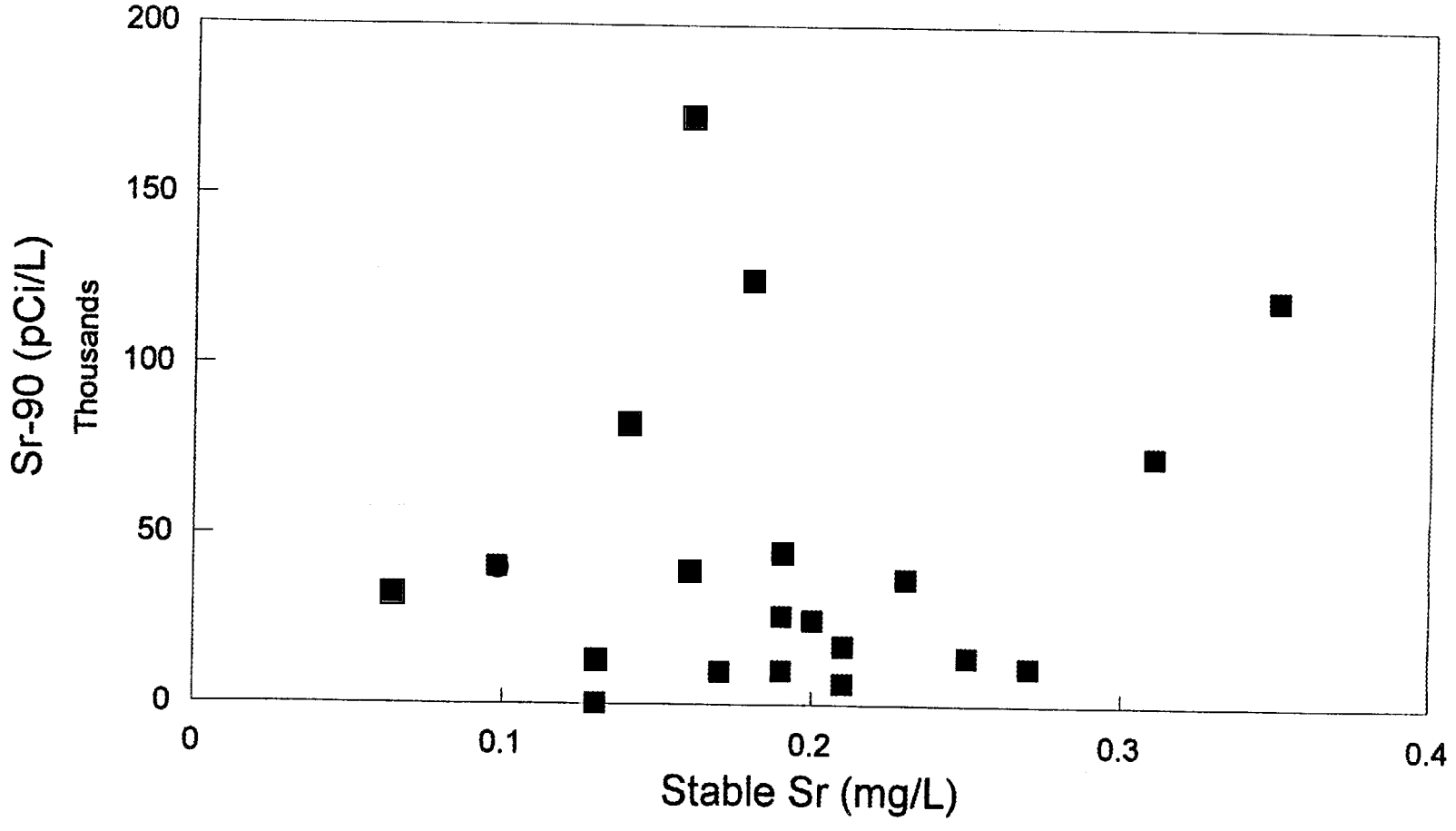

Figure 2.29. Phase II Sr-90 vs stable Sr

WAG 4 Site Investigation

sr-stbsr.wk4

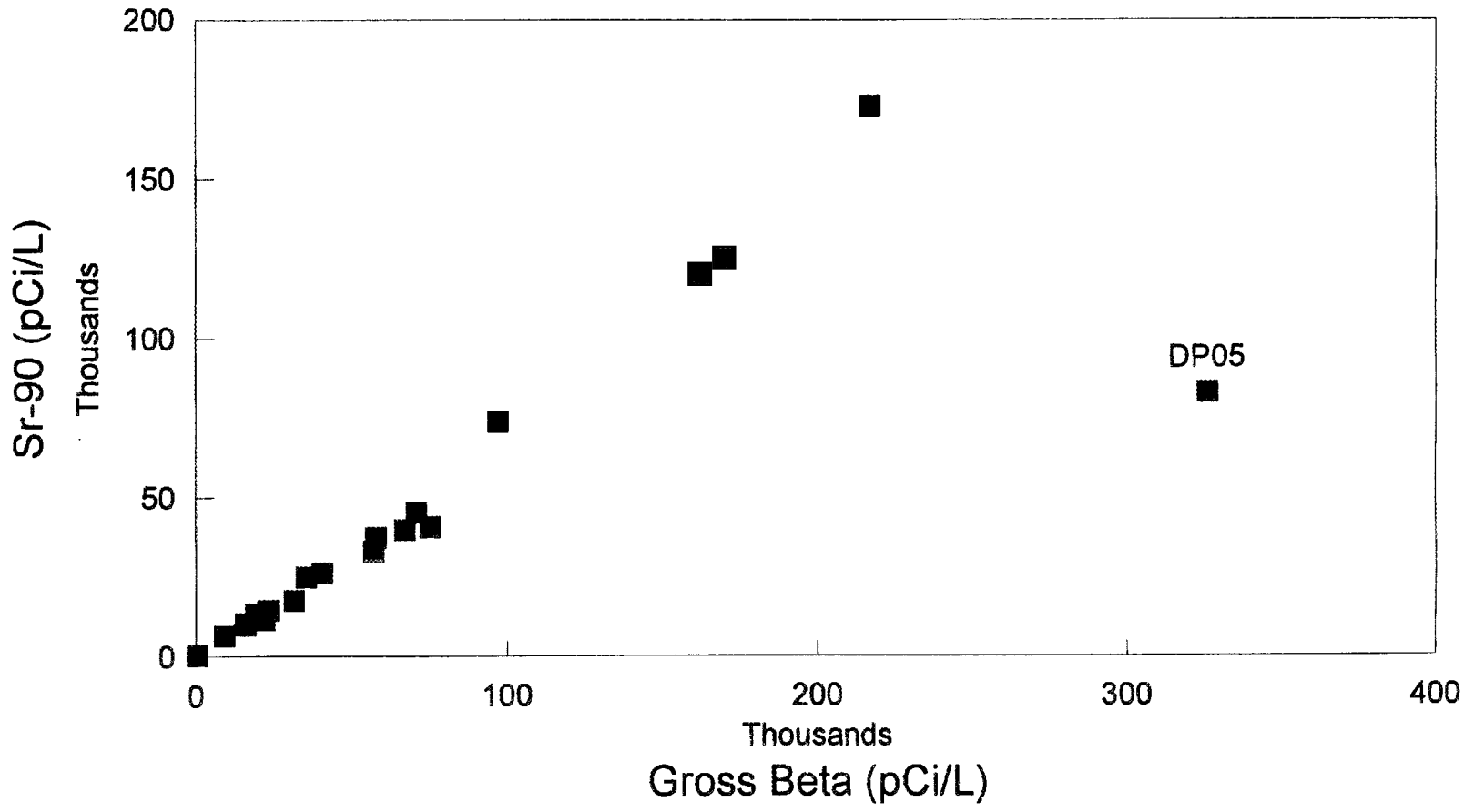

Figure 2.30. Phase II Sr-90 vs gross beta

WAG 4 Site Investigation

sr-beta.wk4

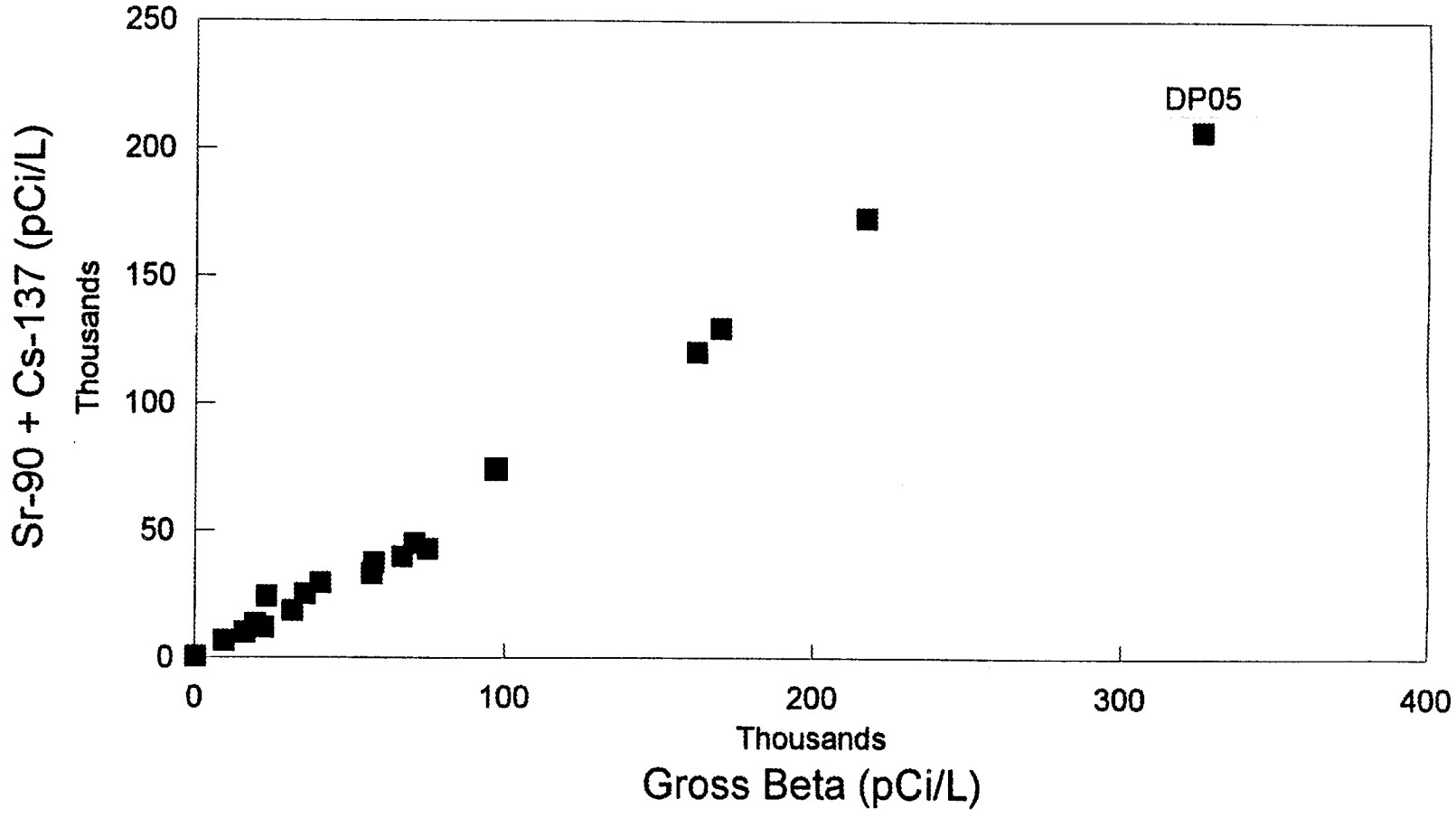

Figure 2.31. Phase II Sr-90 and Cs-137 vs gross beta

WAG 4 Site Investigation

sr-cs-b.wk4

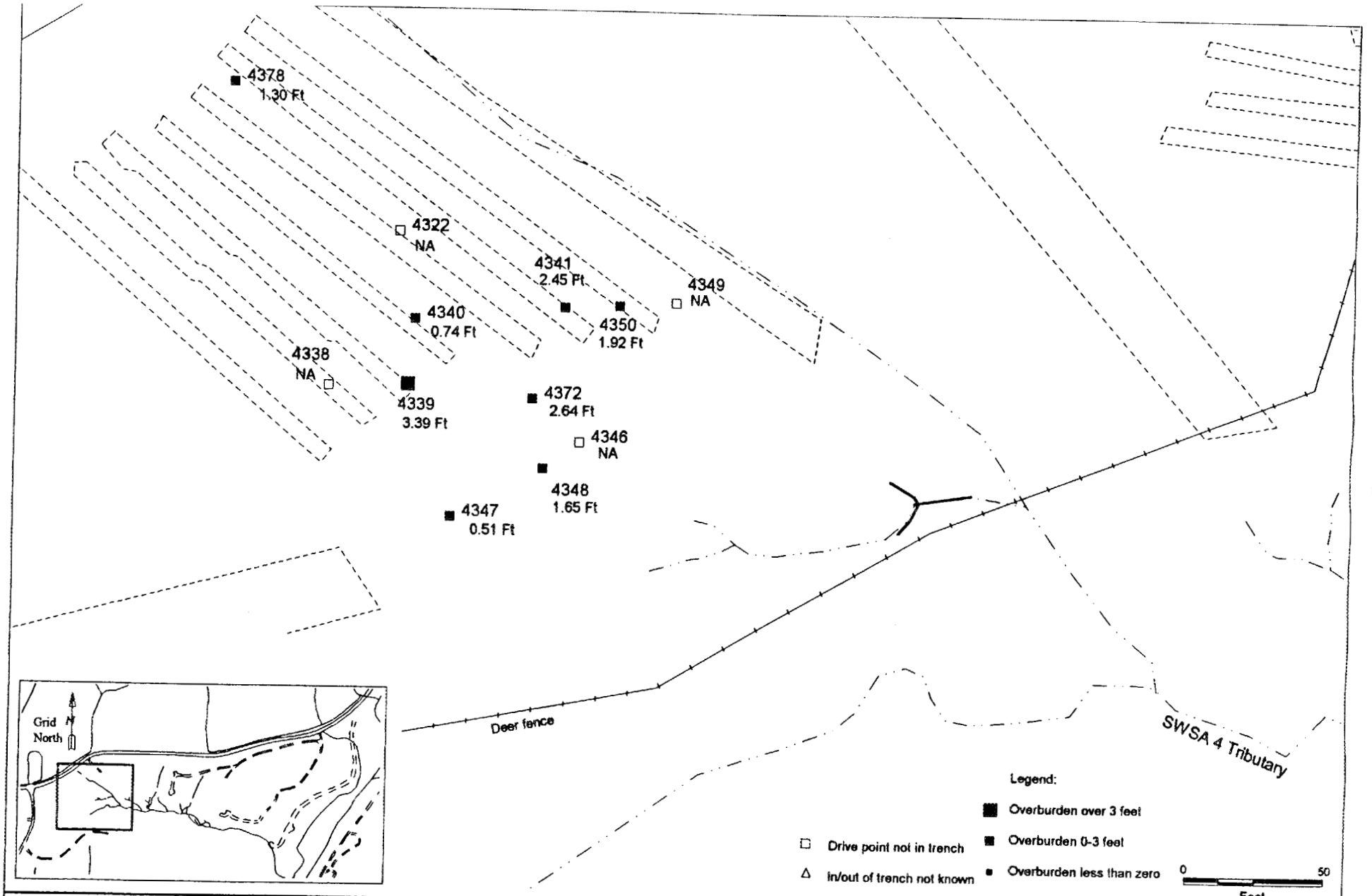

Fig. 2.32a. Trench overburden

WAG 4 Site Investigation

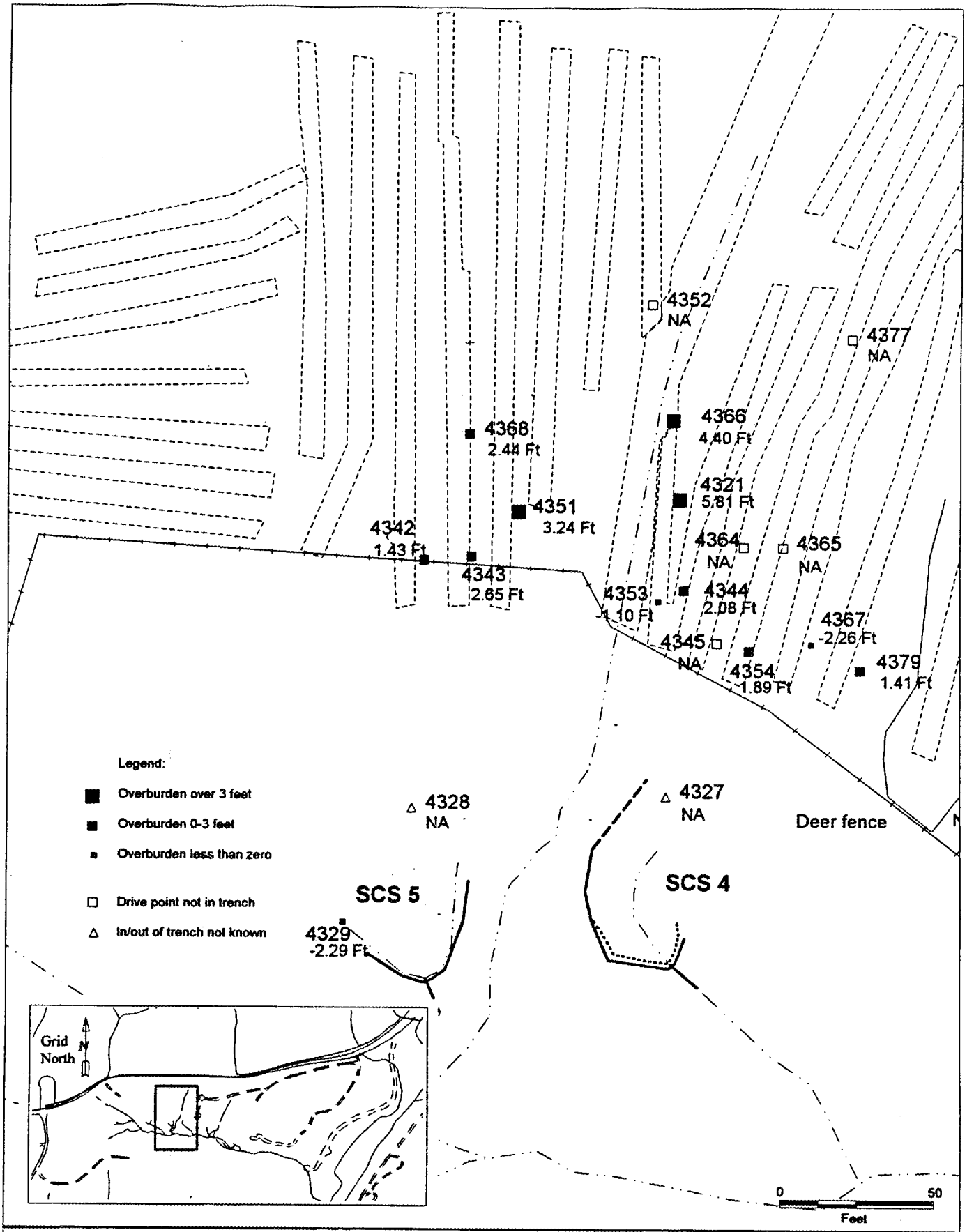

Fig. 2.32b. Trench overburden

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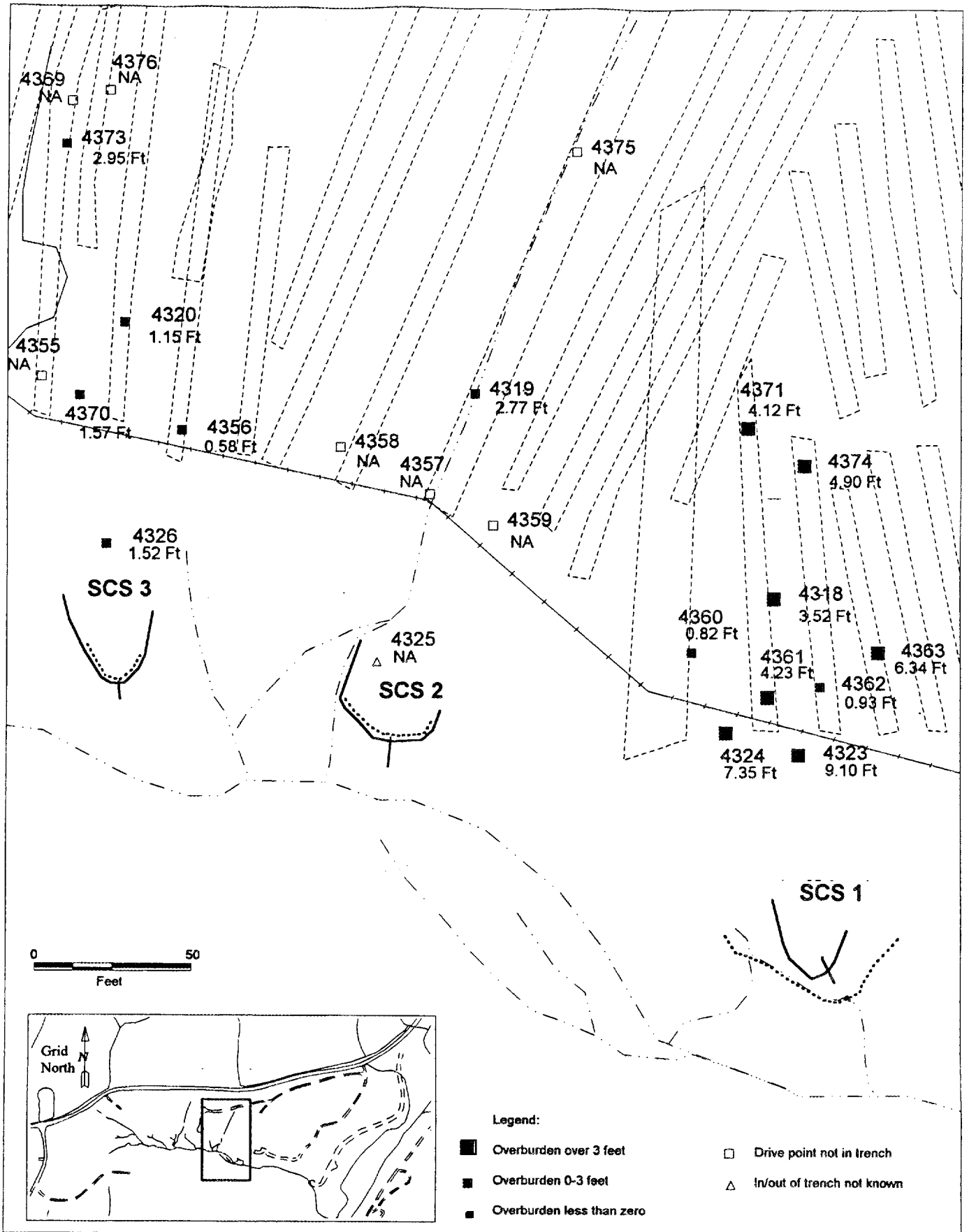

Fig. 2.32.c. Trench overburden

WAG 4 Site Investigation

Table 2.17. Estimated overburden calculations for drive points

ORNL well number	Drive point ID	Ground surface elevation (ft)	Refusal elevation (ft)	Depth to Refusal from bgs (ft)	Estimated amount of overburden (ft)	Inside trench?	Bottom of trench?
4323	DP06	783.42	764.32	19.10	9.10	Yes	Yes
4324	DP07	781.52	764.17	17.35	7.35	Yes	Yes
4363	DP39	786.85	770.51	16.34	6.34	Yes	Yes
4321	DP04	797.99	782.18	15.81	5.81	Yes	Yes
4374	DP48	788.50	773.60	14.90	4.90	Yes	Yes
4366	DP41	800.18	785.78	14.40	4.40	Yes	Yes
4361	DP37	783.24	769.01	14.23	4.23	Yes	Yes
4371	DP47	788.57	774.45	14.12	4.12	Yes	Yes
4318	DP01	785.05	771.53	13.52	3.52	Yes	Yes
4339	DP14	808.82	795.43	13.39	3.39	Yes	Yes
4351	DP25	797.01	783.77	13.24	3.24	Yes	Yes
4373	DP50	796.10	783.15	12.95	2.95	Yes	Yes
4319	DP02	785.27	772.50	12.77	2.77	Yes	Yes
4343	DP18	795.57	782.92	12.65	2.65	Yes	Yes
4372	DP49	806.54	793.90	12.64	2.64	Yes	Yes
4341	DP15	805.21	792.76	12.45	2.45	Yes	Yes
4368	DP40	799.37	786.93	12.44	2.44	Yes	Yes
4344	DP19	795.35	783.27	12.08	2.08	Yes	Yes
4350	DP30	803.74	791.82	11.92	1.92	Yes	Yes
4354	DP24	793.71	781.82	11.89	1.89	Yes	Yes
4348	DP23	806.41	794.76	11.65	1.65	Yes	Yes
4326	DP09	783.57	772.05	11.52	1.52	Yes	Yes
4342	DP17	796.06	784.63	11.43	1.43	Yes	Yes
4379	DP55	794.29	782.88	11.41	1.41	Yes	Yes
4378	DP54	807.95	796.65	11.30	1.30	Yes	Yes
4320	DP03	788.57	777.42	11.15	1.15	Yes	Yes
4362	DP38	784.42	773.49	10.93	0.93	Yes	Yes
4360	DP36	782.50	771.68	10.82	0.82	Yes	Yes
4340	DP13	808.03	797.29	10.74	0.74	Yes	Yes
4356	DP32	784.28	773.70	10.58	0.58	Yes	Yes
4347	DP22	810.35	799.84	10.51	0.51	Yes	Yes
4353	DP26	795.08	786.18	8.90	-1.10	Yes	Yes
4370	DP44	786.58	778.15	8.43	-1.57	Yes	Yes
4367	DP43	794.86	787.12	7.74	-2.26	Yes	Yes
4329	DP12	784.68	776.97	7.71	-2.29	Yes	Yes
4355	DP31	787.50	778.49	9.01	NA	Yes	No
4357	DP34	782.80	774.30	8.50	NA	Yes	No
4369	DP45	797.38	791.98	5.40	NA	Yes	No
4376	DP52	797.17	793.01	4.16	NA	Yes	No
4358	DP33	783.29	779.19	4.10	NA	Yes	No
4346	DP21	805.19	802.90	2.29	NA	Yes	No
4325	DP08	780.47	767.32	13.15	NA	Unknown	Unknown
4327	DP10	789.06	777.62	11.44	NA	Unknown	Unknown
4328	DP11	787.54	778.54	9.00	NA	Unknown	Unknown
4322	DP05	806.85	791.25	15.60	NA	No	No
4338	DP16	810.80	800.81	9.99	NA	No	No
4352	DP27	802.62	794.09	8.53	NA	No	No
4375	DP51	791.74	784.68	7.06	NA	No	No
4359	DP35	783.78	777.00	6.78	NA	No	No
4345	DP20	793.71	787.04	6.67	NA	No	No
4349	DP29	800.47	794.22	6.25	NA	No	No
4364	DP46	796.91	791.25	5.66	NA	No	No
4377	DP53	803.38	797.72	5.66	NA	No	No
4365	DP42	797.18	792.43	4.75	NA	No	No

associated with SCS 3 display similar trends as noted for the central section. Overburden estimates for the trenches associated with SCS 1 vary from 0.82 ft (4360) to 9.10 ft (4323). It is interesting to note that the southward trend of decreasing values does not apply to these trenches. Overburden estimates increase to the south with the thickest overburden occurring next to the deer fence (Fig. 2.32c). The general patterns for each of these areas are consistent with observations made in the field concerning areas where overburden materials are most obvious.

2.3.4 Data Management and Presentation

The Data Management Plan (Energy Systems 1995) was developed and written in accordance with the *Data Management Plan for the Environmental Restoration Program*, ES/ER/TM-88 (Energy Systems 1994a). The WAG 4 database was developed to provide a linkage of computerized data to the original hard copy sources and to allow documentation of the flow of data from the hard copy source to the final repository of the data. The plan was implemented to meet the following objectives:

- to provide environmental measurements data to support project activities or future environmental remediation activities;
- to establish a comprehensive audit trail to ensure data traceability;
- to allow quick and efficient transfer of data to the Oak Ridge Environmental Information System (OREIS) central repository; and
- to develop and document project data management systems.

Specific database requirements were detailed in the Data Management Plan. Data transformation and transfer activities were verified to ensure that data integrity was maintained. To ensure data traceability, all information was loaded into the project database with data source codes. Access controls were instituted to increase data security. Strict control of database content was instituted. Electronic data back-ups were conducted at least once each week to minimize the possibility of data loss and to increase the probability of complete data recovery.

To accommodate the accelerated reporting schedule, the Data Management Plan was structured to use MapInfo (a Geographic Information System tool) to organize results and enhance interpretation through spatial display. Throughout the study, from planning to report writing, interim data was available to project staff in the form of conventional tables, databases, and spatial layers. To facilitate project planning, before fieldwork, all available relevant information was assembled and converted into tables and spatial layers when possible. These initial data were obtained primarily from the ORNL Shared Data Initiative and from previous WAG 4 investigations. During the course of the project, data updates were compiled and made available to investigators in tables and spatial layers. These data were used to direct further project activities.

Because of the widespread use of MapInfo at ORNL (where more than 150 copies are currently in use), study results will be made available to ORNL researchers and operations planners as spatial data layers in the ORNL Shared Data Initiative. This will allow immediate and widespread availability of the project data.

3. SUMMARY OF RESULTS

3.1 KEY FINDINGS

The WAG 4 radiological survey showed that no new sources of ^{90}Sr have emerged in the study area during the past 13 years. This suggests that the major contributors of ^{90}Sr are known. Because 35 to 40 years already have elapsed since disposal operations took place, new ^{90}Sr sources are unlikely to develop in the future. Evaluation of ^{90}Sr mass-transport contributions from individual seeps indicates that the SCS 6 area is the most important contributor to WAG 4 releases, followed by the SCS 4 area. The SCS 5 area is much less important, followed by the SCS 3 area. These results are consistent with concentration profiles along the tributary draining WAG 4, and with the ^{90}Sr concentrations in water in the trenches that appear to be the sources for the seeps.

Examination of ^{90}Sr concentrations in the apparent source trenches for the SCS 6, SCS 4 and SCS 5 areas suggests that portions of four or five trenches are responsible for a very high fraction of the total ^{90}Sr released from WAG 4. Figures 3.1a–c show the areas that were pinpointed during the study as major targets for interim action. The data in these figures include both thermal signatures and vertical-magnetic-gradient contours as indicators of trench location and orientation, as well as locations of drive points (solid symbols indicate that drive points were believed to have penetrated trenches) and results of ^{90}Sr concentration measured in water samples collected from drive point wells. The general orientation of vertical-magnetic-gradient contours matches quite well with thermal signature alignment, with the exception of the area upslope from SCS 2. In this region, it appears the thermal signatures may be associated with grass-mowing patterns, and the true trench orientation is nearly grid-north-south. The interpretation is supported by historical drawings of general trench orientation and by the fact that well 4375 was not in a trench, as would be expected from thermal signature orientation. In the western area near SCS 6, it is also important to note that the thermal signatures and vertical-magnetic-gradient data end along a line defined by the edge of a high radiological contamination zone. The thermal signatures end because the area inside the zone has differing vegetation and much higher moisture content, which obscures the pattern. The magnetic data end along the line because the area near the seeps was not surveyed. The information from both drive point penetration and visual clues, such as subsidence features, indicate that trenches extend to points very near the seep area, as indicated by the target zones shown as shaded features. Similarly, very few trenches in the central and eastern part of the study area appear to extend beyond the deer fence line, toward the tributary. However, this is probably because of the abrupt vegetation change. Visual inspection suggests that most trenches extend to a point near the surface contamination zones near the seeps, well beyond the fence line. In each area above an identified seep, a portion of at least one trench has been shown as a potential target for remediation. The decision as to which targets will be selected for remedial actions will depend on a cost-benefit analysis.

Simple calculations of radioactive decay indicate that about 60% of the ^{90}Sr originally placed in waste trenches has decayed to a stable nuclide. Further, data from 1973 (adjusted for radioactive decay) for a seep discharging in the SCS 4 area show concentrations in the same range as those measured in 1995. Thus, control of the long-term sources identified here appears to be the key to controlling releases, by both surface and subsurface pathways, from the portion of WAG 4 addressed in this study.

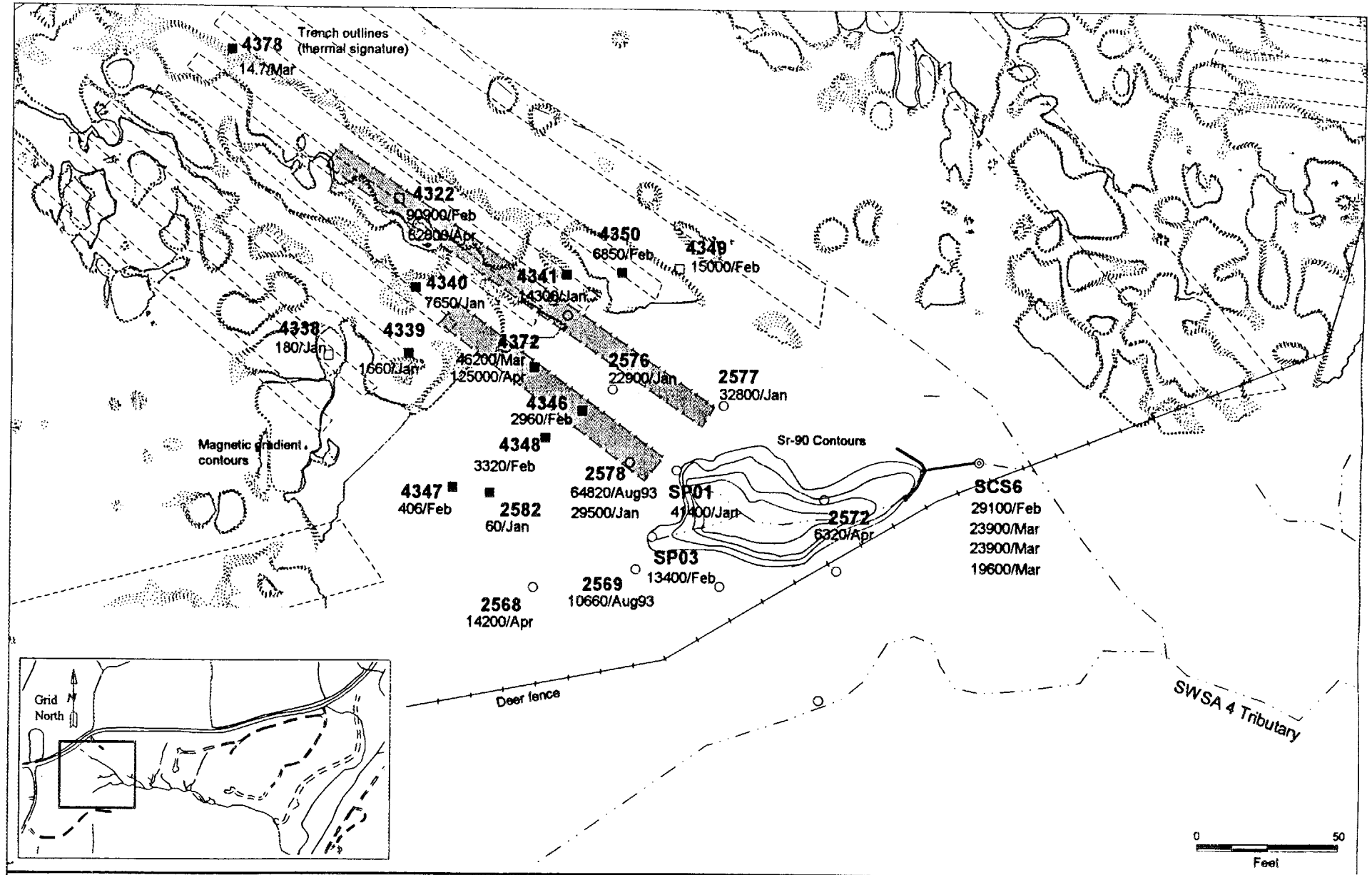

Fig. 3.1.a. Major targets for interim action (west section)

WAG 4 Site Investigation

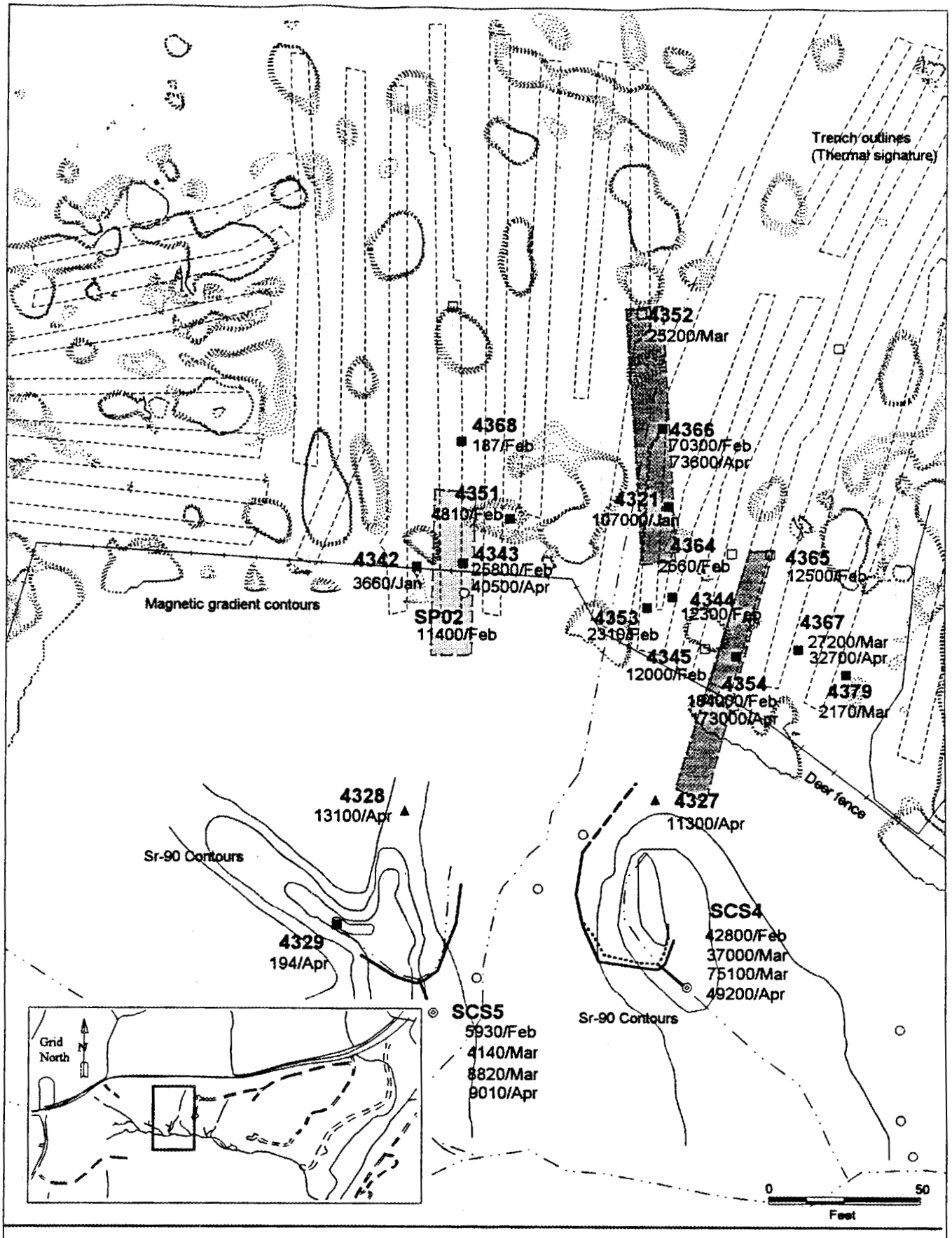

Fig. 3.1.b. Major targets for interim action (central section)

WAG 4 Site Investigation

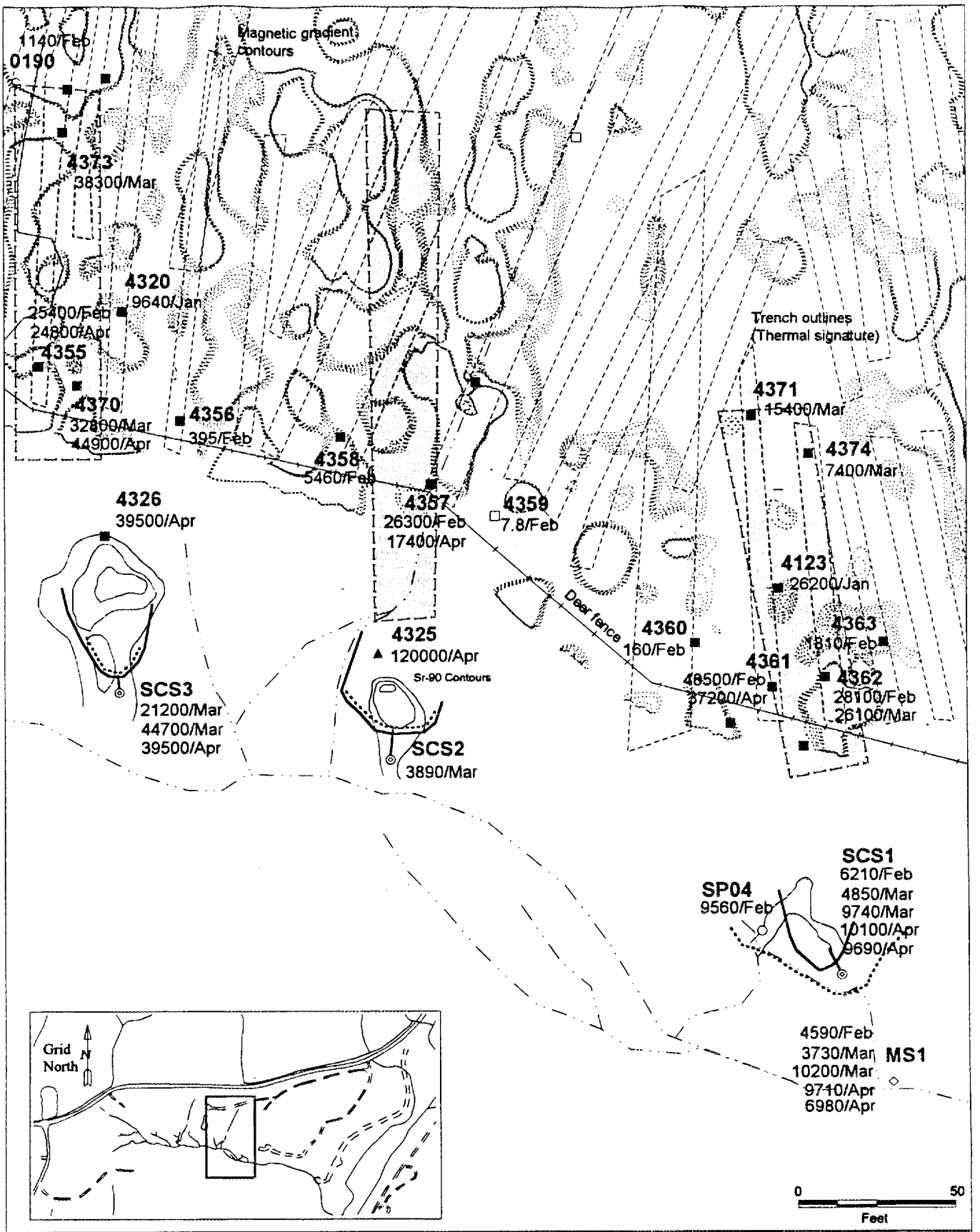

Fig. 3.1.c. Major targets for interim action (east section)

WAG 4 Site Investigation

Determining precise locations of source-trench boundaries remains a challenge. Because the areas in question now have been dramatically reduced in size, it is feasible to consider conducting additional low-frequency GPR surveys using an advanced processing (CDP) method. Although adequate results are not guaranteed, a modest investment of time and effort may provide sufficient information without resorting to intrusive excavation methods.

3.2 CONCEPTUAL MODEL FOR SOURCE RELEASE AND CONTAMINANT FATE

The conceptual model for source release and contaminant fate at WAG 4 is summarized in Fig. 3.2, which depicts a cross section through a typical "bathtubbing" disposal trench. The term "bathtubbing trench" refers to a situation where the trench collects water along its length, the water flows to the downslope end, and in extreme cases overflows out of the trench, in a manner similar to a sloping bathtub. It is not known how many bathtubbing trenches exist at WAG 4 because the exact number and location of trenches was destroyed in a fire that consumed the records. It is safe to say that wherever long trenches exist that are oriented along the steepest downslope gradient, and that terminate in topographically low areas, the potential for a bathtubbing condition is present. Three conditions must exist to create a release problem from such a trench. First, the trench must contain enough ^{90}Sr in a form that will contaminate water present in it. Second, water must be present in the trench. Third, a permeable pathway must allow water to move through the trench to be discharged either at the surface where it can move directly into a stream, or through a subsurface pathway "short" enough to allow a contaminant plume to break through to a surface-water discharge point.

The most important elements of the conceptual model include the proximity of the downslope ends of the trenches to the stream draining the area, and the fact that the trenches extend upslope a substantial distance, allowing collection of water by lateral inflow. The large void volume and related high permeability in the trenches allow many of the trenches to act as collection drains for the lower portions of the disposal site. The presence of construction debris, placed across the site after disposal operations ended, probably enhances infiltration of rainfall. However, where the debris appears to be quite thick, especially at the downslope ends of trenches, it may be a barrier for flow and thus for contaminant release.

The relative importance of flow pathways in the conceptual model is a key to understanding and controlling processes for off-site release. Two distinct sources of water exist for the trenches: transient near-surface flows associated primarily with storm events, and the stable saturated-zone groundwater-flow pathway, of which an important component originates from the full catchment area, including the area upslope from Lagoon Road. Some insights into the relative importance of pathways are available from the comparison of mass flows of ^{90}Sr at seeps and in the tributary draining the site. As storm magnitude increases, it appears that the contributions from overflowing trenches, as measured at the seep areas, also increases. For the month of March, roughly half the mass flow appears to have followed this mechanism. The other major pathway appears to be along a subsurface route, and dominates transport in drier periods. For the full study period in 1995, nearly 65% of the total mass flow appears to have followed this route. At present, it is not possible to differentiate the portions of the subsurface flow that originate from direct infiltration of rainfall at the site and the portion that comes from deeper groundwater that originates in the catchment to the north of the site. Hydrograph analysis suggests that about 70% of the ^{90}Sr mass flow during the year is associated with storms, where local infiltration would be the dominant factor. Thus, a rough

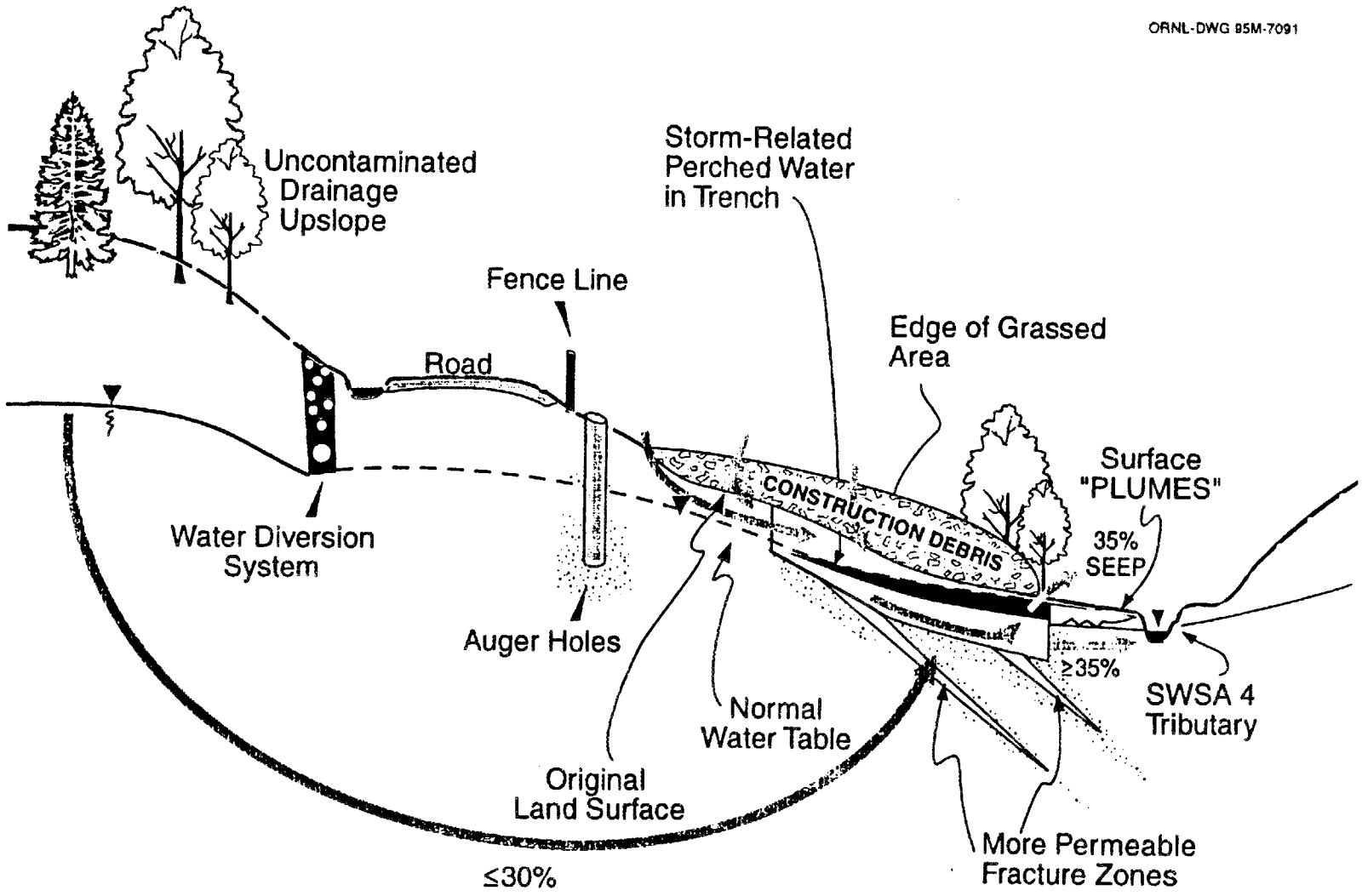

Fig. 3.2. WAG 4 bathtubbing trench conceptual model

WAG 4 Site Investigation

estimate of relative importance of pathways shown in Fig. 3.2. would be about 35% via overflowing water that emerges at seeps, up to 30% from deep groundwater, and the remainder via shallow subsurface flow.

3.3 GENERAL CONSIDERATIONS THAT AFFECT REMEDIAL OPTIONS

The options for controlling contaminant releases at the WAG 4 ^{90}Sr source trenches can be categorized into the following four approaches.

- Prevent water from entering source trenches.
- If water enters, keep source materials from leaching into the water.
- Prevent contaminated water from exiting the trench to a surface-water release point.
- Remove contaminants from water after it leaves the source trench.

The following discussion examines each of the approaches in the context of the WAG 4 hydrologic setting.

Preventing water from entering source trenches at WAG 4 would be very difficult. A surface cap, if it were large enough, could prevent direct surface infiltration, and probably could control most of the lateral storm flow that surges through source trenches at present. However, a component of deeper groundwater flow originates on the ridge north of the SWSA 4 area, and discharges into the low-lying area containing the tributary and lower ends of trenches. Capping would not be effective in controlling this flow. Control of the flow by an interceptor or extraction wells poses the risk of drawing contaminants out of the disposal site by reversing flow gradients.

Preventing materials from leaching into the water that does enter a trench could be accomplished by removing the sources, or perhaps by encapsulating the sources in a barrier material that excludes water and chemically immobilizes the waste. Removal is complicated by the need for precise locations of source packages, and perhaps by the intermingling of the target wastes with other hazardous or classified wastes. Removal, however, is technically possible. Encapsulation, perhaps with a phosphate-based cement or by freezing, appears practical for portions of trenches, and could have the combined effect of both reducing or eliminating water movement near the source, as well as chemically or physically immobilizing ^{90}Sr and any uranium that may be present.

Preventing contaminated water from leaving a source trench would depend in part on capping to control the volume moving through the trench, and on creating a barrier to slow the flow to minimal rates. It is noteworthy that detectable releases do not appear to occur at portions of the WAG 4 site on which fill material covers trenches to depths approaching 20 ft. One way to achieve control of flow from a source trench would be to construct barrier walls around the portion of the trench containing the source to be isolated, and to supplement the walls with an impermeable cap.

Removal of contaminants from water exiting source trenches has been demonstrated at other ORNL sites. Capping to control wide variations in flow rates and to reduce the total volume to be treated would be cost-effective, and should be a part of such an approach. Drawbacks to this strategy include an ongoing maintenance requirement, and the need to transport the treated flow beyond the

contamination area so that it does not become recontaminated. At WAG 4, this could require the water to be piped a distance of about 900 ft.

One special concern that affects any remedial option at WAG 4 is the location of a contaminated deposit of sediments in the floodplain between WAG 4 and White Oak Creek. Any capping must be evaluated to ensure that it does not produce peak flows that would erode these deposits. Another factor to consider is the construction debris over portions of WAG 4. Among the areas defined by this study as targets for interim action, only the SCS 6 area has apparent materials of a thickness that could be problematic. Probing during drive point installations showed materials between 3 and 5 ft thick over what appeared to be a concrete cap placed over wastes during disposal operations.

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