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Remedial Investigation Report on Bear Creek Valley Operable Unit 2 (Rust Spoil Area, Spoil Area 1, and SY-200 Yard) at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee

Volume 1. Main Text

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Y/ER-182/V1&D2

Energy Systems Environmental Restoration Program
Y-12 Environmental Restoration Program

Remedial Investigation Report on Bear Creek Valley Operable Unit 2 (Rust Spoil Area, Spoil Area 1, and SY-200 Yard) at the Oak Ridge Y-12 Plant Oak Ridge, Tennessee

Volume 1. Main Text

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PREFACE

This Remedial Investigation Report on Bear Creek Valley Operable Unit (OU) 2 at the Oak Ridge Y-12 Plant (DOE/OR/01-1273/V1&D2) was prepared in accordance with requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for reporting the results of a site characterization for public review. This work was performed under Work Breakdown Structure 1.4.12.1.1.02.42.10. This document provides the Environmental Restoration Program with information about the results of the 1993 investigation performed at OU 2. It includes information on risk assessments that have evaluated impacts to human health and the environment. Information provided in this document forms the basis for the development of the Feasibility Study Report, DOE/OR/02-1279&D1.

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CONTENTS

FIGURES xi

TABLES xv

ACRONYMS xix

EXECUTIVE SUMMARY xxiii

1. INTRODUCTION 1-1
   1.1 REGULATORY INITIATIVES 1-1
      1.1.1 FFA 1-3
      1.1.2 Other Regulatory Initiatives 1-5
   1.2 THE ORR ER PROGRAM 1-5
      1.2.1 Approach to Remediation on the ORR 1-9
      1.2.2 Roles and Responsibilities of M&O and Prime Contractors at ORR 1-12
   1.3 FACILITY-SPECIFIC ER PROGRAM 1-14
      1.3.1 BCV RIs 1-14
   1.4 INTENT AND SCOPE OF THE RI 1-22
   1.5 SPECIAL PROBLEMS 1-23
   1.6 OBJECTIVES 1-23
      1.6.1 RI Report 1-23
      1.6.2 Human Health BRA 1-24
      1.6.3 BERA 1-24
   1.7 SCHEDULE 1-25

2. CHARACTERIZATION OF ENVIRONMENTAL SETTING 2-1
   2.1 GEOGRAPHY 2-1
   2.2 DEMOGRAPHY 2-1
      2.2.1 Population Information 2-1
      2.2.2 Land Use 2-4
   2.3 CLIMATE 2-7
   2.4 TOPOGRAPHY, GEOLOGY, AND SOILS 2-10
      2.4.1 Topography and General Geology 2-10
      2.4.2 General Soil Characteristics 2-17
   2.5 GROUNDWATER 2-20
      2.5.1 Bear Creek Hydrologic Regime 2-20
      2.5.2 Flow Direction and Rate 2-27
      2.5.3 Aquifer Characteristics 2-31
      2.5.4 Recharge/Discharge Relationships 2-32
   2.6 SURFACE WATER AND SEDIMENTS 2-33
      2.6.1 Surface Water Network 2-33
      2.6.2 Bear Creek Surface Water Hydrology 2-33
      2.6.3 Bear Creek Hydrograph 2-35
      2.6.4 Effects of the Solution Cavity System 2-40

2.6.5 Stormflow System 2-40
2.6.6 Thermal Characteristics 2-41
2.6.7 General Sediment Description 2-41
2.7 ECOLOGY 2-42
2.7.1 Flora 2-42
2.7.2 Terrestrial Fauna 2-45
2.7.3 Aquatic Fauna 2-50

3. SITE HISTORY AND CURRENT CONDITIONS 3-1
3.1 SITE DESCRIPTION 3-2
3.1.1 Geographic Information 3-2
3.1.2 Background Information 3-2
3.1.3 Operational Information and Releases 3-2
3.2 SUMMARY OF EXISTING DATA 3-15
3.2.1 Surface Water Data 3-46
3.2.2 Sediment Data 3-55
3.2.3 Groundwater Data 3-61
3.2.4 Soil Chemical Data 3-93
3.2.5 Contaminant Fate and Transport 3-158
3.2.6 Biomonitoring Data 3-195
3.2.7 Air Data 3-196
3.2.8 Radiation Survey Data 3-198
3.3 DATA QUALITY REPORT 3-199
3.3.1 Purpose 3-199
3.3.2 QA Program 3-203
3.3.3 Assessment of Laboratory Contribution to Data Quality 3-204
3.3.4 Assessment of Field Activities Contribution to Data Quality 3-210
3.3.5 Overall Evaluation of Data Usability 3-213
3.3.6 Report Summary 3-214

4. IDENTIFICATION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS 4-1
4.1 DISCUSSION OF TERMS 4-2
4.2 SITE BACKGROUND 4-3
4.3 CHEMICAL-SPECIFIC ARARs 4-4
4.3.1 Soils 4-4
4.3.2 TBC Guidance 4-5
4.4 RADIATION PROTECTION STANDARDS 4-5
4.4.1 EPA Regulations 4-5
4.4.2 DOE Orders 4-6
4.4.3 TBC Guidance 4-6
4.5 LOCATION-SPECIFIC ARARs 4-6
4.5.1 Wilderness Areas, Wildlife Refuges, Wildlife Resources, and Scenic Rivers 4-7
4.5.2 Wetlands and Floodplains 4-7
4.5.3 Historic Sites and Archaeological Findings 4-7
4.5.4 Rare, Threatened, or Endangered Species 4-11

4.6 ACTION-SPECIFIC ARARs 4-11

5. BASELINE HUMAN HEALTH RISK ASSESSMENT REPORT 5-1
5.1 INTRODUCTION 5-1
5.2 IDENTIFICATION OF CONTAMINANTS OF POTENTIAL CONCERN 5-3
5.2.1 General BCV OU 2 Data Collection Considerations 5-3
5.2.2 General BCV OU 2 Data Evaluation Considerations 5-3
5.2.3 BCV OU 2 Data Evaluation/Preparation 5-4
5.2.4 Summary of Contaminants of Potential Concern for BCV OU 2 Soils 5-9
5.2.5 Groundwater Data Evaluation 5-13
5.3 EXPOSURE ASSESSMENT 5-16
5.3.1 Characterization of Exposure Setting 5-18
5.3.2 Identification of Exposure Pathways 5-19
5.3.3 Quantification of Exposure 5-20
5.3.4 Identification of Uncertainties 5-26
5.3.5 Summary of Exposure Assessment 5-26
5.4 TOXICITY ASSESSMENT 5-26
5.4.1 Toxicity Information and EPA Guidance for Noncarcinogens 5-26
5.4.2 Toxicity Information and EPA Guidance for Carcinogens 5-27
5.4.3 Estimation of Toxicity Values for Dermal Exposure 5-27
5.4.4 Chemicals Without EPA Toxicity Values 5-28
5.4.5 Methodology and Uncertainties Related to Toxicity Information .. 5-28
5.4.6 Summary of Toxicity Information/Profiles for BCV OU 2 COPCs . 5-29
5.5 RISK CHARACTERIZATION 5-48
5.5.1 General Considerations for Evaluating Risks to Human Health .. 5-48
5.5.2 Current Land Use Conditions—Industrial Worker Scenario 5-50
5.5.3 Future Land Use Conditions–Residential Scenario 5-50
5.5.4 Risk Characterization Summary 5-64
5.5.5 Uncertainty Analysis and Assumptions 5-74
5.6 SUMMARY AND CONCLUSIONS 5-80
5.6.1 Contaminants of Potential Concern 5-80
5.6.2 Exposure Assessment 5-81
5.6.3 Toxicity Assessment 5-82
5.6.4 Risk Characterization 5-82

6. ASSESSMENT OF BASELINE ECOLOGICAL RISK 6-1
6.1 IDENTIFICATION OF ECOLOGICAL HAZARD SOURCES 6-3
6.1.1 Ecological Assessment Endpoints 6-4
6.1.2 Environmental Description 6-5
6.1.3 Sources of Contamination 6-12
6.2 EXPOSURE CHARACTERIZATION 6-19
6.2.1 Characterization of the Exposure Environment 6-19
6.2.2 Description of Exposure Routes 6-20
6.2.3 Quantification of Exposure 6-22
6.3 EFFECTS ASSESSMENT 6-23
6.3.1 Conventional Toxicity Data 6-24

6.3.2 Media Toxicity Data 6-26
6.3.3 Biological Survey Data 6-26
6.4 RISK CHARACTERIZATION 6-26
6.4.1 Risk Integration for Current Conditions 6-27
6.4.2 Risk Integration for Future Conditions 6-35
6.4.3 Uncertainties 6-35
6.4.4 Comparison to Human Health Risks 6-40
6.4.5 Summary of Ecological Risk Characterization 6-40
6.5 SUMMARY AND CONCLUSIONS 6-40
6.5.1 Habitats and Wildlife 6-41
6.5.2 Chemicals of Ecological Concern 6-41
6.5.3 Risk Characterization 6-41
6.5.4 Conclusions 6-42

7. REMEDIATION GOAL OPTIONS FOR BCV OU 2 7-1
7.1 INTRODUCTION 7-1
7.2 DERIVATION OF RGOS 7-3
7.3 DERIVATION OF ECOLOGICALLY BASED REMEDIAL GOAL OPTIONS 7-7
7.3.1 Introduction 7-7
7.3.2 Sediment 7-8
7.3.3 Soil 7-8
7.4 COMPARISON OF RGOs FOR HUMAN HEALTH AND ECOLOGICAL PROTECTION 7-10
7.4.1 Introduction 7-10
7.4.2 Air 7-10
7.4.3 Surface Water 7-10
7.4.4 Groundwater 7-11
7.4.5 Sediment 7-11
7.4.6 Soil 7-11
7.5 SUMMARY AND CONCLUSIONS 7-13

8. CONCLUSIONS 8-1
8.1 CURRENT CONDITIONS (NATURE AND EXTENT OF CONTAMINATION) 8-1
8.1.1 Soils 8-1
8.1.2 Groundwater 8-2
8.1.3 Surface Water and Sediment 8-3
8.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS 8-3
8.3 BASELINE RISK ASSESSMENT 8-4
8.4 BASELINE ECOLOGICAL RISK ASSESSMENT 8-4
8.5 OBJECTIVES OF REMEDIATION GOAL 8-5
8.6 RECOMMENDATIONS FOR APPROACH TO FEASIBILITY STUDY 8-6

9. REFERENCES 9-1

Note: Appendixes A through E can be found in Volume 2 of this document

APPENDIX A: CURRENT AND HISTORICAL SOIL BORING AND GROUNDWATER MONITORING WELL INFORMATION, WELL CONSTRUCTION LOGS, AND FIELD CHANGE ORDERS A-1

APPENDIX B: ANALYTICAL DATA B-1

APPENDIX C: HUMAN HEALTH RISK ASSESSMENT DATA C-1

APPENDIX D: ECOLOGICAL RISK ASSESSMENT DATA D-1

APPENDIX E: DATA QUALITY E-1

FIGURES

1.1	The relationships among the integrator and source OUs in the same hydrological system	1-16
1.2	The staged RI process for a source OU	1-17
1.3	Relationships between sites, OUs, and source and integrator OUs in BCV	1-21
1.4	Schedule of BCV OU 2 activities	1-26
2.1	Location of Oak Ridge	2-2
2.2	Location of BCV OU 2 in relation to other OUs in BCV	2-3
2.3	The ORR and surrounding communities	2-6
2.4	Annual precipitation record for the Oak Ridge area	2-8
2.5	1993 wind rose for 10-m level at the west end of the Y-12 Plant	2-9
2.6	Bedrock geology for DOE ORR	2-11
2.7	Bedrock geology in BCV	2-13
2.8	Geologic cross-section based on seismic line on Tennessee 95	2-16
2.9	Generalized soils map for Upper BCV	2-18
2.10	A schematic showing conceptual groundwater flow in the ORR	2-25
2.11	Location of groundwater monitoring wells for the active flow system in Upper BCV	2-28
2.12	Groundwater elevations in the unconsolidated aquifer in BCV	2-29
2.13	Generalized cross-section of BCV showing inferred groundwater flow paths	2-30
2.14	Bear Creek watershed	2-34
2.15	Location of previously sampled surface monitoring sites near Bear Creek	2-36
2.16	Mean daily stream flow in Bear Creek at USGS gauging station 03538270 at BCK 4.55, March 1985–December 1987	2-39
2.17	Particle size distribution of sediment samples collected in Bear Creek for chemical analysis	2-43
2.18	Location of existing biological monitoring sites	2-44
2.19	General vegetation cover types on the ORR	2-46
2.20	General wildlife habitats on the ORR	2-49
3.1	BCV OU 2	3-3
3.2	Aerial photograph showing BCV OU 2 sites, circa 1983	3-4
3.3	BCV OU 2 sites, 1987	3-5
3.4	BCV OU 2 sites, 1988	3-6
3.5	SA-1, early operations circa 1980	3-8
3.6	Current aerial photograph showing SA-1 with established vegetative cover, the newly completed ESF building across Old Bear Creek Road from the SY-200 Yard, and the RSA in the distance	3-10
3.7	Location of concrete pilings at the SY-200 Yard	3-12
3.8	Areal extent of fill areas	3-14

3.9	Late 1993 aerial photograph showing equipment storage at the RSA	3-17
3.10	Site conceptual model for transport of contaminants within BCV	3-18
3.11	BCV OU 2 historical surface water data	3-47
3.12	SA-1 RI surface water/sediment sampling locations	3-48
3.13	SY-200 Yard RI surface water/sediment sampling locations	3-53
3.14	RSA RI surface water/sediment sampling locations	3-54
3.15	Contour map of groundwater levels in wells in upper BCV Hydrologic Regime	3-64
3.16	Cross section east to west along strike showing nitrate concentrations in the Maynardville Limestone and overlying residuum in upper BCV Hydrologic Regime	3-66
3.17	Concentrations of nitrate in groundwater at SA-1	3-81
3.18	Concentrations of nitrate in groundwater at RSA	3-82
3.19	Concentrations of nitrate in groundwater at RSA and SA-1 between 1988 and 1993	3-83
3.20	Concentrations of nitrate in groundwater at GW-122 and -317 between 1988 and 1993	3-84
3.21	Concentrations of VOCs in groundwater in the upper BCV Hydrologic Regime	3-85
3.22	Concentration vs time plots for VOCs and nitrate in wells at SA-1	3-87
3.23	Concentrations of gross alpha in groundwater at SA-1	3-89
3.24	Concentrations of gross alpha in groundwater at the SY-200 Yard	3-90
3.25	Concentrations of gross alpha in groundwater at RSA	3-91
3.26	Piper diagram showing representative groundwater compositions from the upper BCV Hydrologic Regime	3-92
3.27	SA-1 1990 soil boring locations at BCV OU 2	3-97
3.28	Y-12 Plant BCV OU 2 SA-1	3-99
3.29	SA-1 profile locations	3-100
3.30	SA-1 profile M-M′ soil lithology	3-101
3.31	SA-1 profile M-M′ beryllium (ppm)	3-107
3.32	SA-1 profile M-M′ benzo(a)pyrene (ppb)	3-108
3.33	SA-1 profile M-M′ radium (pCi/g)	3-110
3.34	SA-1 profile M-M′ total uranium (pCi/g)	3-111
3.35	Previous soil sampling locations in the vicinity of the SY-200 Yard	3-112
3.36	The SY-200 Yard boring locations	3-114
3.37	The SY-200 Yard profile locations	3-120
3.38	The SY-200 Yard site profile F-F′ soil lithology	3-121
3.39	Areas above 1.007 ppb for all depths of beryllium	3-127
3.40	The SY-200 Yard profile H-H′ for beryllium concentrations	3-128
3.41	The SY-200 Yard profile H-H′ lead concentrations (ppm)	3-129
3.42	Areas above 82 ppm all depths for mercury	3-130
3.43	Boreholes adjacent to filled ESF foundation	3-132
3.44	Boreholes within filled ESF foundation	3-133
3.45	Combined PCBs (aroclor 1254 and 1260 at all depths)	3-135
3.46	Areas above 88 ppb for benzo(a)pyrene at all depths	3-137
3.47	1990 soil boring locations	3-139
3.48	RSA existing soil borings	3-141
3.49	RSA profile locations	3-142

3.50	RSA profile A-A′ soil lithology	3-143
3.51	RSA profile A-A′ beryllium (ppm)	3-144
3.52	RSA profile A-A′ total aroclor	3-153
3.53	RSA profile A-A′ trichloroethene (ppb)	3-156
3.54	Locations of geotechnical samples taken from the SY-200 Yard	3-157
3.55	Conceptual model of RSA expected site conditions	3-168
3.56	Surface water flow paths	3-173
3.57	Ambient air monitoring stations at the Y-12 Plant	3-197
3.58	Terrestrial gamma exposure rate contour map for the Y-12 Plant and EFPC sites	3-200
3.59	Man-made gross count rate contour map for the Y-12 Plant and EFPC sites	3-201
3.60	Net gamma spectrum for ROI 25	3-202
5.1	BCV OU 2 conceptual site model for human health risk assessment	5-21
5.2	High concentration zone for mercury in the SY-200 Yard: human health risk/HQ evaluation	5-78
5.3	High concentration zone for aroclor-1254 in the SY-200 Yard: human health risk/HQ evaluation	5-79
6.1	SA-1 habitats	6-7
6.2	SY-200 Yard habitats	6-8
6.3	RSA habitats	6-10
6.4	Conceptual site model of exposures from BCV OU 2 surface soils	6-21
7.1	CERCLA process for developing final remediation levels	7-4
7.2	Comparison of soil RGOs and maximum concentrations for metals at BCV OU 2	7-12

TABLES

1.1	Other federal regulations affecting the ORR ER Program	1-6
1.2	DOE orders governing environmental restoration activities on the ORR	1-7
1.3	Federal and state agreements and orders affecting BCV	1-8
1.4	Nine criteria by which alternatives are evaluated	1-11
1.5	Y-12 Plant OUs	1-20
2.1	Land use data for the East Tennessee Development District	2-4
2.2	Urban land use data for the city of Oak Ridge, Tennessee	2-4
2.3	Stratigraphy of the Y-12 Plant area	2-12
2.4	Summary statistics for Knox Group (which includes Copper Ridge) Horizon C inorganics on the ORR	2-21
2.5	Summary statistics for Knox Group (which includes Copper Ridge) Horizon C radionuclides on the ORR	2-22
2.6	Soil chemical properties	2-23
2.7	Soil physical and engineering properties of the predominant soil groups in the Y-12 Plant area	2-24
2.8	Mean, standard deviation (SD), and range of stream flows in Bear Creek and selected tributaries, 1985–1987	2-37
2.9	Threatened and endangered plant and animal species on the ORR (Tennessee-specific)	2-47
3.1	Chronological listing of major activities at SA-1	3-7
3.2	Chronological listing of major activities at the SY-200 Yard	3-11
3.3	Summary of 1986 inventory at the SY-200 Yard	3-13
3.4	Chronological listing of major activities at the RSA	3-16
3.5	Summary analysis by medium	3-21
3.6	Analytical methods, parameters, and quantitation limit goals for water and soil/sediment samples	3-24
3.7	Data objectives for BCV OU 2 RI	3-31
3.8	Cross reference of EPA QAMS 005/80 with BCV OU 2 RI work plan sections	3-32
3.9	Environmental technical support RI technical procedures	3-33
3.10	BCV OU 2 COPCs for SA-1	3-36
3.11	BCV OU 2 COPCs for the SY-200 Yard	3-39
3.12	BCV OU 2 COPCs for the RSA	3-42
3.13	Chemicals detected above ARARs and PRGs	3-50
3.14	Summary of radionuclides for surface water	3-52
3.15	Summary of BCV OU 2 sediment data collected in 1993 that exceed reference data from the ORR background soil characterization study	3-57
3.16	Summary of radionuclide concentrations for BCV OU 2 sediment samples collected in 1993	3-59
3.17	Frequency of sampling and the type of analysis performed for the wells in BCV OU 2	3-62

3.18	List of COPCs for groundwater at SA-1 showing relevant benchmark values	3-69
3.19	List of COPCs for groundwater at the SY-200 Yard showing relevant benchmark values	3-72
3.20	List of COPCs for groundwater at RSA showing relevant benchmark values	3-75
3.21	Analytical parameters for SA-1	3-98
3.22	Soil data summary for BCV OU 2 sites at SA-1, comparison to PRGs and soil background data	3-102
3.23	Analytical parameters for the SY-200 Yard and RSA	3-115
3.24	Soil data summary for BCV OU 2 sites at the SY-200 Yard, comparison to PRGs and soil background data	3-122
3.25	Soil data summary for BCV OU 2 sites at RSA, comparison to PRGs and soil background data	3-145
3.26	Adsorption coefficients (K_d) and retardation factors (R_d) for the BCV OU 2 inorganic COPCs	3-161
3.27	Radioactive half lives, decay rates, K_ds, and R_ds for BCV OU 2 radionuclide COPCs	3-162
3.28	Solubility in water, biodegradation/decay rates, Henry's Law constant, and air diffusion coefficients for the BCV OU 2 organic COPCs	3-163
3.29	Adsorption coefficients and retardation factors for the BCV OU 2 organic COPCs	3-169
3.30	List of constituents for the three sites remaining for SESOIL modeling based on screening runs using ODAST	3-175
3.31	Input data accepted by SESOIL	3-179
3.32	Summary of COPCs that are projected to reach the aquifer in 100 years from SA-1	3-183
3.33	Summary of COPCs that are projected to reach the aquifer in 100 years from the SY-200 Yard	3-184
3.34	Summary of COPCs that are projected to reach the aquifer in 100 years from the RSA	3-185
3.35	Contaminant loading to surface water from RSA	3-188
3.36	Contaminant loading to surface water from SA-1	3-190
3.37	Contaminant loading to surface water from the SY-200 Yard	3-191
3.38	Variables used in the surface water runoff model	3-192
4.1	Potential location-specific ARARs for BCV OU 2	4-8
5.1	COPCs for BCV OU 2 soils that will be evaluated quantitatively	5-10
5.2	COPCs for BCV OU 2 soils that will be evaluated qualitatively	5-12
5.3	COPCs for BCV OU 2 groundwater that will be evaluated quantitatively	5-15
5.4	COPCs for BCV OU 2 groundwater that will be evaluated qualitatively	5-17
5.5	Carcinogenic risks for BCV OU 2 soil COPCs—industrial scenario	5-51
5.6	Hazard quotients for noncarcinogenic BCV OU 2 soil COPCs—industrial scenario	5-53

5.7	Carcinogenic risks for BCV OU 2 soil COPCs—residential scenario	5-56
5.8	Carcinogenic risks for BCV OU 2 COPCs—residential homegrown garden scenario	5-59
5.9	Hazard quotients for noncarcinogenic BCV OU 2 soil COPCs—residential scenario	5-62
5.10	Hazard quotients for noncarcinogenic BCV OU 2 COPCs—residential homegrown garden scenario	5-65
5.11	Summary of significant risks and hazard quotients from BCV OU 2 COCs—industrial worker scenario	5-69
5.12a	Summary of significant risks and hazard quotients from BCV OU 2 COCs—residential scenario	5-69
5.12b	Summary of significant risks and hazard quotients from BCV OU 2 COCs—residential ingestion of homegrown vegetables/fruits scenario	5-70
5.13	Cumulative risk and HI summary for BCV OU 2 soil COPCs—industrial worker scenario	5-72
5.14	Cumulative risk and HI summary for BCV OU 2 COPCs—residential scenario	5-72
6.1	Evaluation of COPCs for ecological risk assessment	6-5
6.2	Screening of soil COPCs against background concentrations	6-14
6.3	Inorganic ecological COPCs in soils for BCV OU 2	6-17
6.4	Screening of analytes detected in RSA sediments	6-18
6.5	Inorganic ecological COPCs by site at BCV OU 2	6-20
6.6	Toxicity values in calculation of EQs	6-28
6.7	Site-based EQs for COPCs in soils (0 to 10 ft) at BCV OU 2 (current exposure)	6-30
6.8	Dietary exposure quotients for herbivores	6-32
6.9	Site-based EQs for COPCs in soils (0 to 10 ft) at BCV OU 2 (future exposure)	6-36
7.1	Residential and industrial RGOs for BCV OU 2 soil COCs	7-5
7.2	Soil RGO values for protection of the environment	7-10
7.3	Comparison of RGO values for protection of human health and the environment	7-11

ACRONYMS

ADL	Arthur D. Little, Inc.
ADNCR	analytical data nonconformance report
AEC	Atomic Energy Commission
AET	apparent effects threshold
AMS	Aerial Measuring System
ARAR	applicable or relevant and appropriate requirement
ATDL	Atmospheric Turbulence and Diffusion Laboratory
AWQC	ambient water quality criterion
BCHR	Bear Creek Hydrologic Regime
BCK	Bear Creek Kilometer
BCV	Bear Creek Valley
BERA	baseline ecological risk assessment
BG	burial ground
BMAP	Biological Monitoring and Abatement Program
BRA	Baseline Risk Assessment
BSCP	Background Soil Characterization Project
CAA	Clean Air Act
CAVEAT	Computer Assisted Validation and Evaluation Assessment Tool
CCS	contract compliance screening
CD	comparison dose
CDI	chronic daily intake
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CLP	contract laboratory program
CMS	corrective measures study
COC	contaminant of concern
COPCs	contaminants of potential concern
COR	Contracting Officer's Representative
CV	concentration value
CWA	Clean Water Act
DCG	derived concentration guide
DNA	deoxyribonucleic acid
DOE	U.S. Department of Energy
DOE-ORO	U.S. Department of Energy Oak Ridge Operations
DQO	data quality objective
EA	environmental assessment
EF	exposure factor
EFPC	East Fork Poplar Creek
EG&G/EM	EG&G Energy Measurements, Inc.
EIS	environmental impact assessment
EP	extraction procedure
EPA	U.S. Environmental Protection Agency
EQ	ecological quotient
ER	Environmental Restoration

ER-L	Low Effects Range
ERA	ecological risk assessment
ESF	Environmental Support Facility
ETS	Environmental Technical Support
FDA	U.S. Food and Drug Administration
FFA	Federal Facilities Agreement
FFCA	Federal Facility Compliance Agreement
FR	*Federal Register*
FS	feasibility study
GWQAR	Groundwater Quality Assessment Report
HCDA	Hazardous Chemicals Disposal Area
HI	hazard index
HPD	Health Physics Department
HQ	hazard quotient
HSWA	Hazardous and Solid Waste Amendments
ICP	inductively coupled plasma
IT	International Technology Corporation
IQ	intelligence quotient
LCS	laboratory control sample
LET	linear energy transform
LOAEL	lowest observed adverse effect level
M&O	management and operating
MEPAS	Multimedia Environmental Pollutant Assessment System
MCL	maximum contaminant level
MMGC	man-made gross count
MOU	memorandum of understanding
MS/GC	matrix spike/gas chromatography
MSL	mean sea level
MUSLE	Modified Universal Soil Loss Equation
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NCR	nonconformance report
NCRP	National Council on Radiation Protection
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NESHAP	National Emission Standards for Hazardous Air Pollutants
NFI	no further investigation
NHP	New Hope Pond
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effect level
NPDES	National Pollution Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NRDA	Natural Resource Damage Assessment
NSPS	new source performance standard
NT	North Tributary
ORAU	Oak Ridge Associated Universities
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORNL	Oak Ridge National Laboratory

ORP	Oil Retention Ponds
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PARCC	precision, accuracy, representativeness, completeness, and comparability
PA/SI	preliminary assessment/site investigation
PCB	polychlorinated biphenyl
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
PRG	preliminary remediation goal
QA	quality assurance
QAPjP	quality assurance project plan
QAPP	quality assurance program plan
QC	quality control
RAGs	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfCs	reference concentrations
RfDs	reference doses
RFI	RCRA Facility Investigation
RAO	remedial action objective
RGO	remedial goal option
RI	remedial investigation
RME	Reasonable Maximum Exposure
ROD	record of decision
ROI	Region of Interest
RSA	Rust Spoil Area
SA-1	Spoil Area-1
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SEG	Scientific Ecology Group
SEN	Secretary of Energy Notice
SF	slope factor
SESOIL	Seasonal Soil
SI	site investigation
SL 1	Sanitary Landfill 1
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TAL	target analyte list
TBC	to be considered
TCB	trichlorobenzene
TCE	trichloroethene
TCL	target compound list
TDEC	Tennessee Department of Environment and Conservation
TDLo	threshold dose, low
TIC	tentatively identified compound
TSC	Technical Support Contractor

TSCA	Toxic Substance Control Act
TSD	treatment, storage, and disposal
TSP	total suspended particulate
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
UCB	upper 95% confidence bound
UCL	upper 95% confidence limit
UNC	United Nuclear Corporation
USC	*United States Code*
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
VOA	volatile organic analysis
VOC	volatile organic compound
WAG	waste area grouping
WOM	White Oak Mountain
XQ	exposure quotient

EXECUTIVE SUMMARY

The enactment of the Resource Conservation and Recovery Act (RCRA) in 1976 and the Hazardous and Solid Waste Amendments (HSWA) to RCRA in 1984 created management requirements for hazardous waste facilities. The facilities within the Oak Ridge Reservation (ORR) were in the process of meeting the RCRA requirements when the ORR was placed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) on November 21, 1989. Under RCRA, the actions typically follow the RCRA Facility Assessment/RCRA Facility Investigation (RFI)/Corrective Measures Study (CMS)/Corrective Measures Implementation process. Under CERCLA, the actions follow the preliminary assessment/site investigation/Remedial Investigation (RI)/Feasibility Study (FS)/Remedial Design/Remedial Action process. This document incorporates requirements under both RCRA and CERCLA in the form of an RI report for the characterization of Bear Creek Valley (BCV) Operable Unit (OU) 2.

BCV OU 2 is located within the U.S. Department of Energy (DOE) ORR in Anderson County, Tennessee. The unit is located in BCV, near the headwaters of Bear Creek immediately west of the Oak Ridge Y-12 Plant's main facilities. BCV OU 2 comprises two former construction spoil areas—the Rust Spoil Area (RSA) and Spoil Area 1 (SA-1)—and a former equipment storage yard, the SY-200 Yard.

The RSA was used as a disposal area for solid waste (spoil material) generated as a result of various renovation, maintenance, and construction operations at the Y-12 Plant. Although no detailed records are available, the bulk of spoil material disposed of at RSA consisted of soil, masonry materials, and metal. Discussions with Y-12 Plant personnel indicated the possibility that small quantities of solvent-contaminated material and material containing asbestos, mercury, and uranium may have been disposed of in the RSA. However, existing administrative and other established in-plant controls prevented the disposal of significant amounts of chemicals, wastes, or contaminated material at the RSA. Previous investigations at the site indicated that contaminants of potential concern (COPCs) at RSA included arsenic, beryllium, lead, mercury, selenium, tetrachloroethene, thorium, and uranium. The site is currently covered with a 2-ft layer of clay soil with some grassy vegetative cover and used as an above-ground equipment/supply storage area.

SA-1 was used for the disposal of what was considered to be nonhazardous, nonradioactively contaminated construction debris from various renovation, maintenance, and construction operations at the Y-12 Plant. The bulk of the solid waste known to have been disposed of included asphalt, brick, concrete, roofing materials, brush, metal, rock, and tile. However, the results of soil and groundwater studies in the area confirmed the presence of heavy metals and radiological contamination. Previous investigations at the site indicated that COPCs included arsenic, barium, beryllium, chromium, fluoranthene, lead, mercury, phenanthrene, pyrene, radium, and uranium. The area is currently covered with a layer of clay soil with a grass cover.

The SY-200 Yard was operated as a "hold for future use" equipment and supply storage area. The yard was an outside graveled area used to store nonradioactively contaminated equipment, electrical transformers, piping, tanks, mercury flasks, and miscellaneous items. All

items stored at the site were removed by September 1986. The site has been extensively reworked since 1986 during construction activities for an Environmental Support Facility (ESF) building. Soil sampling conducted during construction activities indicated the presence of contaminated fill material at the site. Based on data obtained through previous soil sampling activities, COPCs included barium, chromium, lead, mercury, polychlorinated biphenyls (PCBs), and uranium. The ESF was later constructed just south of Old Bear Creek Road from the SY-200 Yard, which is currently vacant.

A site conceptual model was developed for the project to identify the migration pathways, transport mechanisms, potential receptors, and potential exposure pathways for the identified contaminant types in the media considered for SA-1, the SY-200 Yard, and RSA. The conceptual model was developed through a review of the site histories to determine the types of contaminants present and the affected media or transport mechanisms. Once this task was completed, then types of migration pathways such as spills, leaks, runoff, and infiltration/percolation were applied. The site conceptual model was then used along with the objectives defined for the project as a guide for developing an effective sampling and analysis plan for the RI.

In the process of developing the site conceptual model, objectives for the project were identified. The objectives of this RI are to verify and define the nature and extent of contamination in the media of concern (i.e., soil), to provide the information needed for the human health and ecological risk assessments (Chaps. 5 and 6), and to provide a basis for the development of remedial alternatives presented in the FS Report. The specific objectives for the project included the following:

- determining the source of volatile organic compounds (VOCs) identified from historical investigations at SA-1,
- defining the nature of soil contamination at the SY-200 Yard,
- defining the extent (vertical and horizontal) of soil contamination at the SY-200 Yard,
- verifying the nature and extent of soil contamination at RSA,
- defining the interaction (transfer mechanism) between soil contamination and shallow groundwater, and
- defining the relative contribution of BCV OU 2 contaminants to BCV shallow groundwater and surface water contamination.

Reviews of the BCV OU 2 site histories identified the following potentially affected media for transport of contaminants: soil, sediment, surface water, and shallow groundwater. The contaminants associated with the sites include metals and PCBs at the SY-200 Yard, metals and radiological contaminants at RSA, and metals and volatile organic compounds at SA-1. Migration pathways including precipitation, runoff, percolation/infiltration, volatilization, and resuspension were then applied to the affected media, and a sampling plan was developed. The sampling plan outlined the evaluation of the migration pathways and transport mechanisms through sample collection and analysis and provided data to the Baseline Risk Assessment (BRA) and Baseline Ecological Risk Assessment (BERA) so the site conceptual model could be evaluated further by assessing potential receptors and exposure pathways.

To ensure that the results of the analysis defined in the sampling and analysis plan provided the data necessary for evaluation of risk and remedial alternatives, data objectives were identified for the project, and requirements of the quality assurance (QA) program were determined. The data objectives included identification of decision types, identification of data uses and needs, and design of a data collection program. Implementation of the project under the QA program included development of a Field and Laboratory Quality Assurance Project Plan (QAPjP). The Field QAPjP defined the procedures that were developed for use in the site preparation and sampling collection activities, and the Laboratory QAPjP defined the procedures that were followed in the custody, analysis, and handling of data.

The sampling and analysis plan was implemented by conducting the field activities for the RI from September 1993 to December 1993. The field activities included the following: (1) collecting subsurface soil samples from 5 borings at the RSA and 59 borings at the SY-200 Yard; (2) collecting 3 geotechnical subsurface soil samples from the SY-200 Yard; (3) installing and sampling 3 unconsolidated (shallow) groundwater monitoring wells at the SY-200 Yard and 2 at SA-1; (4) collecting surface water samples from 3 locations at SA-1, 2 locations at the SY-200 Yard, and 3 at RSA; (5) collecting sediment samples from 4 locations at SA-1, 2 locations at the SY-200 Yard, and 3 locations at RSA; and (6) collecting a seep sample from SA-1 (Sect. 3.2).

The analytes selected for analyses for each medium were chosen based on historical data results and the data objectives that were identified. The analytes selected for soil analysis included both a limited and a full suite. The limited suite included metals, PCBs, isotopic uranium, and gross alpha and beta while the full suite included volatile and semivolatile organic compounds, metals and cyanide, asbestos, isotopic uranium, and gross alpha and beta. At the SY-200 Yard, soil samples in 23 of the borings were analyzed using the limited suite, and soil in the remaining 36 borings was analyzed using the full suite. Also in the SY-200 Yard, geotechnical analysis of grain size and permeability was conducted on three subsurface soil samples. At RSA all soil samples were analyzed for the full suite of analytes; however, asbestos was excluded. All sediment samples were also analyzed for the full suite; however, asbestos was excluded, and organic petroleum hydrocarbons were added. All groundwater, surface water, and seep samples were analyzed for metals (filtered and unfiltered), pesticides/PCBs, volatiles, semivolatiles, filtered and unfiltered gross alpha and beta and isotopic uranium, and miscellaneous characteristics such as alkalinity, anions, total dissolved solids, total suspended solids, and turbidity.

After the data had been collected and analyzed, the results were evaluated for each medium by comparing the data to several different criteria. A comprehensive list of COPCs from historical and current data was developed by medium (soil, sediment, and groundwater) for each site by comparing the 95% upper confidence bound (UCB) of the background median to the UCB of the site median. The Copper Ridge Horizon C was chosen for the soil and sediment background comparisons, and groundwater monitoring well GW-317 was chosen for groundwater reference comparisons. Any sample analyte with a UCB concentration greater than the UCB background concentration for that analyte was determined to be a COPC for that particular site. This list of COPCs by medium is presented in Sect. 3.2 and was provided to the BRA and BERA (soil and groundwater) teams as the initial basis for the risk assessments presented in Chaps. 5 and 6. Data for surface water were compared to Safe Drinking Water Act Maximum Contaminant Levels (MCLs) and groundwater preliminary

remediation goals (PRGs) to determine a list of COPCs for surface water. Surface water and the majority of the sediment data were not evaluated in the risk assessments for the BCV OU 2 RI, since these media will be examined in detail in the valley-wide risk assessments to be performed as part of the Bear Creek Integrator Unit (OU 4).

In order to provide a more focused discussion of the data in Chap. 3, the COPCs were further refined by comparison against known benchmark values such as MCLs and soil and groundwater PRGs. This narrowed the discussion of the nature and extent of contamination to the COPCs that were regularly detected in a medium at or above one or more benchmark values.

The RSA was evaluated by using data collected during the RI field activities and during previous investigations. The SY-200 Yard was evaluated using only the RI-derived data, and SA-1 was evaluated using both RI-derived and historical data (soil and groundwater only). Data evaluation included developing a COPC list and comparing the values to the set of criteria discussed previously.

The analytical soil data evaluation identified 57 soil COPCs at SA-1, 65 soil COPCs at the SY-200 Yard, and 88 soil COPCs at RSA. The entire COPC list for each site was incorporated in the BRA and BERA evaluation to produce a Contaminants of Concern (COC) list. However, only 15 analytes at SA-1, 7 at the SY-200 Yard, and 25 at RSA warranted further discussion in the nature and extent section based on comparison criteria. This focused list included metals, volatiles, semivolatiles, PCBs, and radionuclides.

Evaluation of the soil COPC list indicates that beryllium, total radium, combined aroclor-1254 and -1260, benzo(a)pyrene [polyaromatic hydrocarbon (PAH) representative], and mercury were the only analytes above PRGs.

Although beryllium is above the PRG of 0.15 ppm at all three sites, the higher concentrations were associated with the native soil encountered at the bottom of the boreholes. This suggests that the values detected should be considered as background and not as contamination.

Total radium was only detected above the PRG at SA-1. However, the highest value was only slightly above background concentrations and is considered representative of background concentrations.

The combined PCB concentrations of aroclor-1254 and -1260 were above the PRG of 0.083 ppm in the SY-200 Yard and RSA only in isolated areas of elevated concentrations. However, it should be noted that the U.S. Environmental Protection Agency (EPA) guidance on PRGs is 1 ppm for residential land use and 10 to 25 ppm for industrial land use. The extent of PCB concentrations above the 1 ppm action limit is reduced from that established for the above PRG, and, if the industrial action limit of 10 is applied, then elevated concentrations are sporadic at all sites.

Several PAHs were detected above PRGs. However, benzo(a)pyrene was selected as a representative of this group. Although benzo(a)pyrene was detected above PRGs, the

detection limits were greater than the calculated PRGs. The fact that the PRG is lower than the analytical quantitation limit goal should be taken into account when reviewing the data.

Mercury was only detected at the SY-200 Yard at levels above the PRG of 82 ppm. However, mercury was detected in isolated areas of elevated concentrations in the eastern and western section of the site. Also, visible mercury was noted in isolated areas during sampling activities.

The groundwater historical and current data evaluation, which included the evaluation of a seep sample, identified 37 groundwater COPCs at SA-1, 33 groundwater COPCs at the SY-200 Yard, and 40 groundwater COPCs at RSA. The entire COPC list for each site was incorporated in the BRA and BERA for evaluation and assessment to produce a COC list. There were 14 analytes at SA-1, 11 analytes at the SY-200 Yard, and 18 analytes at RSA that warranted further discussion in the nature and extent section based on comparison criteria. This focused list included metals, semivolatiles, volatiles, radionuclides, and anions.

Evaluation of the focused groundwater COPC list indicates that the metal, radionuclide, and anion constituents detected in the groundwater can be associated with the S-3 plume or with the problems associated with sampling turbid water. Evaluation of the volatile organic compound analytes suggests that there are two and possibly three distinct contaminant plumes found within the BCV OU 2: the S-3 plume containing predominantly PCE, acetone, and chloroform, with minor concentrations of TCE and methylene chloride; a predominantly TCE plume originating from the vicinity of the RSA site; and a plume that appears to be derived from the Fire Training Area, which is located in the upper East Fork Poplar Creek (EFPC) Hydrologic Regime.

The analytical surface water data evaluation identified four surface water COPCs at SA-1, three COPCs at the SY-200 Yard, and six COPCs at RSA. These COPCs included metals and anions. Because surface water data were not being evaluated in the risk assessments, the COPC list was not considered for further evaluation for the BCV OU 2 RI.

The analytical sediment data evaluation identified 10 sediment COPCs for SA-1, 3 sediment COPCs for the SY-200 Yard, and 12 COPCs for the RSA. These COPCs included metals and radionuclides. Two of the samples collected (SS-7 and -8) at the RSA were evaluated in the BERA because they were considered to be located in a perennial aquatic ecological environment. The remainder of the sediment data was not considered for further risk evaluation for the BCV OU 2 RI.

Human health risks associated with BCV OU 2 were evaluated in accordance with the EPA document *Risk Assessment Guidance for Superfund: Volume 1—Human Health Evaluation Manual (Part B), Development of Risk-based Preliminary Remediation Goals*, 9285.7-01B, Office of Emergency and Remedial Response, Washington, DC. The COPC list was reduced for the BRA by several screening methods: limiting the evaluation of soil to depths of only ~12 ft; using the maximum concentration when duplicate sample data were available; performing a human health toxicity screening; and eliminating essential nutrients from consideration, all of which reduced the total number of analytes evaluated in the BRA.

Two exposure scenarios—an industrial worker scenario and a residential scenario—were evaluated in the BRA. Due to the location and current land use of BCV OU 2, the industrial worker was evaluated as the most reasonable and most likely receptor of the BCV OU 2 media in the future. This receptor represents a lower-bound estimate of risk and is not likely to overestimate risks at BCV OU 2 under future industrial land use conditions. An upper-bound risk to human receptors was evaluated using residential parameters to calculate potential risks that are conservative and unlikely to underestimate exposure to future receptors of BCV OU 2 media. Four primary exposure pathways were evaluated (i.e., evaluated in terms of chronic daily intake, risk, and hazard quotient (HQ) for both the residential and industrial worker land uses): incidental ingestion of soil, inhalation of dust and volatile organic compounds, dermal contact with soil, and external exposure to radionuclides in the soil. Ingestion of homegrown vegetables/fruits was also evaluated for the residential scenario.

Ten COCs were identified. Radium-226 (inhalation and external exposure pathways) in the SA-1 area was identified as showing the highest carcinogenic risk (i.e., individual risks $\geq$1.0E-04) and is, therefore, a COC in the SA-1 area. Mercury was identified as having an HQ slightly higher than one (1.0) for the ingestion pathway and is, therefore, a COC in the east end of the SY-200 Yard area. Arsenic, cadmium, manganese, and mercury (ingestion of homegrown vegetables) show the highest HQs [i.e., individual Hazard Indexes (HIs) $\geq$1.0] and are, therefore, COCs for BCV OU 2. Cesium-137, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of homegrown vegetables in the RSA area), and ^{234}U and ^{238}U (ingestion of homegrown vegetables in the SY-200 Yard and SA-1 areas) were identified as showing the highest carcinogenic risks (i.e., individual risks $\geq$1.0E-04) and are, therefore, COCs in these areas.

For the BCV OU 2 COC (^{226}Ra) that was identified as showing the highest carcinogenic risk (i.e., risk $\geq$1.0E-04), risks from the external exposure pathway (for ^{226}Ra) and the inhalation pathway (^{226}Ra/^{222}Rn) contributed the most to the total cumulative carcinogenic risk for the SA-1 area. Cesium-137, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of homegrown vegetables is the RSA area) and ^{234}U and ^{238}U (ingestion of homegrown vegetables in the SY-200 Yard and SA-1 areas) were identified as showing the highest carcinogenic risk (i.e., risks $\geq$1.0E-04) and contributed the most to the total cumulative carcinogenic risk for these areas. For the BCV OU 2 COCs that were identified as having the highest noncarcinogenic/toxic effects, arsenic, cadmium, manganese, and mercury (ingestion of homegrown vegetables/fruits) contributed the most to the total cumulative HIs.

EPA guidelines for contaminated sites consider three regions of carcinogenic risk [risk <1.0E-06, no concern; risk between 1.0E-06 and 1.0E-04, range of concern (or target risk range); and risk $\geq$1.0E-04, unacceptable] and two areas of concern in terms of noncarcinogenic/systemic effects (HI <1.0, no concern, and HI >1.0, concern). A cumulative risk $\geq$1.0E-04 was found for the SA-1 area (the four primary pathways were included in this total); cumulative risks between 1.0E-05 and 1.0E-04 were found for the RSA and the SY-200 Yard areas. When the vegetable ingestion pathway was considered, cumulative risks >1.0E-04 were found for all three areas. Cumulative HIs $\geq$1.0 were not found for the three areas (with the exception of the mercury high concentration zone in the SY-200 Yard area). However, when the vegetable ingestion pathway was considered, cumulative HIs >1.0 were found for all three areas.

Ecological risks at BCV OU 2 were evaluated in accordance with EPA's *Framework for Ecological Risk Assessment.* This framework comprises four interrelated activities: hazard identification or problem formulation, exposure assessment, effects assessment, and risk characterization. Problem formulation (Sect. 6.1) included a description of the components (and especially the indicator organisms of the ecosystem) likely to be at risk and the potential ecological effects, along with a selection of assessment and measurement endpoints as a basis for a conceptual model of stressors, components, and effects. A conceptual model was developed that included soils and sediments as the exposure media of concern. The COPC list for soils and sediments identified in the RI was further reduced for the BERA by the following methods: limiting evaluation to the top 10 ft of soil, examining the frequency of occurrence data, and comparing results to published toxicity benchmark values as described below. Exposure characterization (Sect. 6.2) described ecological stressors at BCV OU 2, especially locations of areas disturbed by waste disposal and the nature and extent of exposure to ecologically significant contaminants. Effects characterization (Sect. 6.3) provided summaries of toxicological data relevant to indicator biota and contaminants at the site. This information was integrated to perform the risk characterization (Sect. 6.4). Because the approved work plan had not called for ecological sampling, there were no data on biota body burdens or media toxicity. As a result, the BERA was done by screening data on physical media against benchmark values for toxicity.

Habitats at BCV OU 2 include an unvegetated industrial site at the SY-200 Yard, grass-covered and graveled areas at SA-1 and RSA, and some old-field and early successional forest bordering the fill areas at the SY-200 Yard and RSA. These habitats do not provide significant habitat values to threatened or endangered species separate from the surrounding habitats on the ORR. No evidence was found for the presence of threatened or endangered species in BCV OU 2. Therefore, Assessment Endpoint 1, "no harm to any state- or federally designated threatened or endangered species and their critical habitats in BCV OU 2," appears to be met at BCV OU 2.

Evidence of use of BCV OU 2 areas by wildlife was observed during site surveillances. In a surveillance in mid-April 1994 there was an abundant growth of grass on both SA-1 and RSA fill areas, and there was no visible evidence of phytotoxicity in the peripheral areas at the SY-200 Yard and RSA. Therefore, Measurement Endpoint 2a, "no visible evidence of phytotoxicity," appears to be met at BCV OU 2.

Chemicals of ecological concern were selected by a series of screens in which contaminant concentrations were compared to background and toxicity benchmark values for grasses, forbs, trees, small mammals, and sediment-dwelling biota.

Risk characterization was performed by calculating ecological quotients (EQs), which reflect direct exposure of plants to soil contaminants, and exposure quotients (XQs), which reflect soil ingestion rates for small mammals. EQs were calculated as the ratios of soil contaminant concentrations to a benchmark value for toxicity, whereas XQs were calculated as the ratio of soil contaminant concentration times an exposure factor for soil ingestion to the toxicity benchmark. Current risks attributable to soil were calculated for grasses and small mammals, which were assumed to be exposed to the upper 95%-confidence limit (UCL) concentrations of soil contaminants. Future risks were assumed to be the same for grasses and small mammals, but, because ecological succession should result in the appearance of grasses

and forbs, XQs for forbs and trees were calculated for future risks. Potential risks attributable to sediment were evaluated by comparing sediment concentrations with benchmarks such as NOAA biological effects levels.

Contaminants with EQs or XQs >1 were mercury for plants at the SY-200 Yard and manganese for small mammals at SA-1. Potential sediment COCs (for which toxicity data were not available) were cobalt, magnesium, and tetrachloroethylene at RSA.

There was no evidence of harm to threatened or endangered species at BCV OU 2 (Assessment Endpoint 1). Similarly, there was no visible evidence of phytotoxicity in BCV OU 2 soils (Measurement Endpoint 2a), but soil mercury concentrations in the rooting zone (upper 3 m) exceeded published toxicity endpoints (Measurement Endpoint 2b) for grasses (and possibly forbs and trees) at the SY-200 Yard. Therefore, Assessment Endpoint 2, "no adverse effects on vegetation," appears to be met at SA-1 and RSA but may not be met at the SY-200 Yard. Soil manganese concentrations were in excess of published chronic toxicity levels for estimated intakes by small mammals (Measurement Endpoint 3) at SA-1. Therefore, Assessment Endpoint 3, "no more than 20% reduction of populations of small mammals residing and ingesting soil at the site," appears to be met at the SY-200 Yard and RSA but may not be met at SA-1. Sediment biota may be exposed to toxic levels of cobalt, magnesium, and tetrachloroethylene at RSA. Therefore, Assessment Endpoint 4, "no more than 20% reduction in populations of biota exposed to sediments derived exclusively from BCV OU 2," appears to be met at SA-1 and the SY-200 Yard but may not be met at RSA.

Once the human health and ecological COCs were identified (Chaps. 5 and 6), the PRGs identified early in the RI scoping phase were modified (Chap. 7) as remedial goal options (RGOs), which involved back-calculating corresponding concentrations in the environmental media under consideration using site-specific values and exposure pathways. Human health soil RGOs were calculated for both an on-site industrial scenario and residential scenario, including cumulative contributions from the incidental ingestion of soil, inhalation of dust and volatile organic compounds, dermal contact, and external exposure pathways. The ingestion of vegetables and fruits was not included as a pathway for the determination of RGOs. The residential and industrial RGOs were calculated for a total of eight COCs, including beryllium, mercury, aroclor-1254, aroclor-1260, benzo(a)pyrene, dibenzo(a,h)anthracene, ^{226}Ra, and ^{238}U. RGOs are shown for a target risk of 1.0E-06 and a target HI of 1.0. RGOs for human health are based on single chemicals and do not yet take into consideration combined exposure and potential antagonistic or synergistic effects among contaminants.

Ecologically based RGOs are chosen to protect the environment from contaminants in the physical media. Two primary pathways were identified: plant uptake and wildlife ingestion of soils and sediment. The ecological RGOs presented in Sect. 7.3 are based on physical media sampling and published information about the toxicity of COCs. RGOs were calculated for mercury, manganese, barium, chromium, and aroclor-1260. As is the case with RGOs for human health, ecological RGOs are based on single chemicals at this time.

RGOs for human health and for ecological protection are based on different exposure pathways, exposure concentrations, and receptor populations. As a result, RGOs are likely to be different for each environmental medium considered. Incidental ingestion of soil provides risks to both humans and ecological receptors at BCV OU 2. Exposure of plants to

soil contaminants is continuous, and ingestion of soil by small mammals living on the source units is assumed to involve a larger fraction of body weight than for humans. Therefore, ecologically based soil RGOs for inorganics are lower than the corresponding RGOs for soil ingestion by humans. In contrast, RGOs to protect humans from carcinogens are much lower than the corresponding RGOs for animals.

The FS will consider the RGOs calculated for the COCs identified at each site in the analysis of remedial alternatives.

Modeling of the fate of contaminants at BCV OU 2 leads to the following recommendations for the FS approach to each of the sites at BCV OU 2:

- Contaminant fate and transport modeling for the next 100 years predict that soil contamination at SA-1 and the SY-200 Yard will not impact groundwater or surface water to an extent that MCLs in groundwater will be exceeded. Groundwater contamination at the SA-1 site is probably the result of plume migrating from neighboring sites: the S-3 Site and the Fire Training Area. This means that remedial alternatives for these sites can be addressed independently of the remedial alternatives suggested for the groundwater and surface water integrator OU in BCV.
- Similar modeling at RSA suggests that soil contamination at this site may be providing contamination, or will impact groundwater in the future, such that the MCL for TCE is currently exceeded and may be exceeded in the future. Remedial alternatives for the soil medium at RSA need to address the potential for contaminants (particularly TCE) to migrate to groundwater. To optimize future valley-wide groundwater protection in BCV, remedial alternatives for RSA should be prioritized regarding their impact on the groundwater in BCV compared with the other source units in BCV. This prioritization will be carried out by the BCV integrator OU RI.

1. INTRODUCTION

1.1 REGULATORY INITIATIVES

The Oak Ridge Reservation (ORR) is comprised of three major installations: the Oak Ridge National Laboratory (ORNL), the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site [formerly referred to as the Oak Ridge Gaseous Diffusion Plant (ORGDP)]. These installations were constructed in the early to mid-1940s by the Atomic Energy Commission [predecessor of the U.S. Department of Energy (DOE)] as research, development, and process facilities in support of the Manhattan Project. These installations, along with Environmental Restoration (ER) at the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky, and the Portsmouth Gaseous Diffusion Plant (PORTS) in Piketon, Ohio, are currently administered by the DOE Oak Ridge Operations (DOE-ORO) office in Oak Ridge, Tennessee.

During the construction and operation of these research, development, and process facilities, the associated fabrication, maintenance, and decontamination processes resulted in the generation of various hazardous and radioactive waste by-products. Hazardous waste treatment, storage, and disposal (TSD) facilities were created at each of the DOE-ORO installations to handle such by-products. Some of these facilities continue to receive hazardous wastes, while others have been decommissioned. All DOE-ORO TSD facilities are currently subject to the requirements of several laws:

- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also referred to as Superfund)**–enacted in 1980 to establish a program to identify sites [operable units (OUs)] from which environmental releases of hazardous substances might occur or have occurred. At such sites, Superfund promotes the evaluation of damage to natural resources, ensures cleanup by the responsible party or the government, and creates a claims procedure for parties involved in site cleanup and natural resource reclamation. Sites identified by CERCLA are evaluated and then placed on the National Priorities List (NPL), if appropriate. The ORR was listed on the NPL in November 1989.
- **Resource Conservation and Recovery Act (RCRA)**–created in 1976 as a hazardous waste management system that mandates permitting currently operating TSD facilities. Under RCRA, these TSD facilities are referred to as solid waste management units (SWMUs). RCRA defines an SWMU as any discernible waste management unit at a RCRA facility from which hazardous waste or hazardous constituents might migrate, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at a facility at which hazardous waste or hazardous constituents have been routinely and systematically released.
- **Hazardous and Solid Waste Amendments (HSWA)**–created as amendments to RCRA (1984) that provide the U.S. Environmental Protection Agency (EPA) with the authority to enforce corrective actions by broadening the scope of the RCRA Corrective Action Program. In addition to evaluating and correcting releases to the uppermost aquifer from

regulated RCRA units, HSWA promotes the cleanup of continuing releases to any media resulting from waste management units and practices at RCRA facilities. Among the most significant provisions of the HSWA are the following:

- — **Section 3004(u): Corrective Action for Continuing Releases.** Section 3004(u) states that for permits issued after November 8, 1984, corrective action is required for releases of hazardous waste or constituents from any SWMU at any TSD facility seeking a permit for permanent operation, regardless of when waste was placed in the unit. Thus, corrective actions apply to releases presently occurring as well as past releases.
- — **Section 3004(v): Corrective Action Beyond the Facility Boundary.** Section 3004(v) authorized EPA to require that corrective action be taken by the facility owner or operator for releases that have migrated beyond the facility boundary (off site). Such action should be taken where necessary to protect human health and the environment unless the owner/operator demonstrates to the satisfaction of the administrator that permission to undertake such action was denied.

- **Superfund Amendments and Reauthorization Act (SARA)**-created in 1986 as a 5-year extension of the Superfund/CERCLA program to clean up hazardous releases at uncontrolled or abandoned hazardous waste sites.
- **National Environmental Policy Act (NEPA)**-enacted in 1969 to direct federal agencies to consider the impacts of their actions (e.g., construction, remediation) on the environment as a part of all decision-making processes.

On November 21, 1989, EPA placed the DOE's ORR and its environs on the NPL [Vol. 54 *Federal Register* (*FR*) No. 233.48187]. On January 1, 1992, a Federal Facilities Agreement (FFA) among DOE-ORO, EPA Region IV, and the Tennessee Department of Environment and Conservation (TDEC), formerly the Tennessee Department of Health and Environment, was implemented. This FFA establishes the procedural framework and schedule by which DOE-ORO will develop, coordinate, implement, and monitor environmental restoration activities on the ORR in accordance with applicable federal and state environmental regulations.

The DOE-ORO ER Program for the ORR addresses the remediation of areas both within and outside the ORR boundaries, including ORNL, the former ORGDP (K-25 Site), Oak Ridge Associated Universities (ORAU), the Y-12 Plant, Bear Creek, East Fork Poplar Creek (EFPC), and the Clinch River. This program of remediation is summarized in the ORR Site Management Plan for the ER Program (DOE/OR-1001). The subject of this report is the Bear Creek Valley (BCV) OU 2, which consists of Spoil Area-1 (SA-1), the SY-200 Yard, and the Rust Spoil Area (RSA). These areas are south of Bear Creek near its headwaters just west of the Y-12 Plant.

Because BCV OU 2 is part of the ORR, it is included on the NPL, and its remediation must follow the specific procedures mandated by CERCLA as amended by SARA. Because contamination at the BCV OU 2 site is the result of TSD activities that continued until the mid-1980s at the Y-12 Plant, its remediation must conform with the procedures of RCRA as amended by HSWA Section 3004(u). Actions taken to remediate these sites may affect the environment, and the potential environmental impact of those actions must be publicly addressed in accordance with NEPA. As specified in the FFA for the ORR, the remedial

investigation (RI) of BCV OU 2, conducted in 1993, integrated the requirements of CERCLA and RCRA as well as those of other applicable federal and Tennessee state regulations. The feasibility study (FS), conducted in early 1994, incorporated the procedures of NEPA by including an Environmental Assessment (EA).

1.1.1 FFA

The FFA between DOE, EPA Region IV, and TDEC for the environmental restoration of the ORR primarily addresses those activities necessary to meet the requirements of RCRA/HSWA, CERCLA/SARA, and NEPA, and establishes an agreed upon schedule for the attainment of those activities. Generally, CERCLA/SARA and RCRA/HSWA provide the principal legal stimuli for undertaking environmental restoration on the ORR and at BCV OU 2. NEPA defines the process by which environmental restoration decisions about ORR sites are made and implemented. This section further explains these three primary regulatory initiatives and their integration under the FFA.

1.1.1.1 RCRA

The primary objective of RCRA is to treat, store, and dispose of hazardous wastes in such a way as to protect human health and the environment. The secondary objective is to conserve valuable material and energy resources by encouraging recycling and treatment of wastes, providing guidelines for solid waste management, and promoting beneficial solid waste management, resource recovery, and resource conservation systems. To fulfill these objectives, RCRA requires that owners and operators of waste management facilities obtain operating or postclosure care permits for certain waste management activities.

RCRA regulates facilities that are currently operating or that have been closed since November 19, 1980, the effective date of RCRA; disposal sites that were closed or abandoned before that date are regulated under CERCLA. RCRA emphasizes a health-based standard for the selection of corrective actions. It does not give response time schedules or cleanup goals, except in permits issued to allow continuing operation of a facility. The RCRA corrective action process involves the completion of a RCRA Facility Investigation (RFI) and a corrective measures study (CMS).

EPA has authorized the state of Tennessee to administer the RCRA program in lieu of the federal program, except for those RCRA provisions imposed by HSWA. Thus, the BCV OU 2 site is regulated by both EPA and TDEC. Region IV of EPA administers the federal RCRA program, including the HSWA provisions, and TDEC administers the Tennessee Hazardous Waste Management Act. TDEC also has RCRA authorization to regulate mixed hazardous and radioactive wastes.

1.1.1.2 CERCLA

CERCLA, originally enacted on December 11, 1980, authorizes the federal government to clean up releases of hazardous substances—primarily at closed or abandoned sites—by conducting site investigations (SIs), performing testing and monitoring activities, and implementing cleanup actions. These activities are conducted under the terms of the National Oil and Hazardous Substances Pollution Contingency Plan [40 *Code of Federal Regulations* (*CFR*) 300], otherwise referred to as the NCP, as mandated by Section 105 of CERCLA. The NCP details the cleanup procedures, including those for both immediate removal and long-

term remedial action, and assigns regulatory authority to federal and state governments. CERCLA imposes strict liability on parties responsible or potentially responsible for hazardous waste sites and establishes funding (the "Superfund") that enables the federal government either to order the responsible parties to clean up the spill or to seek reimbursement from the responsible parties after the government has completed cleanup.

CERCLA focuses primarily on the cleanup of inactive disposal sites. Since May 1989, however, it has also given the federal government the authority to respond to current uncontrolled releases of hazardous and radioactive substances from all onshore and offshore facilities as well as from vessels, including over-the-road transportation vehicles.

SARA was enacted October 17, 1986. As amended by SARA, CERCLA authorizes EPA to maintain an NPL of sites requiring remedial action. Some of the most important sections of SARA discuss stricter cleanup standards, accelerated cleanup schedules, the Community Right-to-Know program, and the Leaking Underground Tank program. CERCLA/SARA emphasizes permanent on-site solutions rather than temporary treatment or transport-and-disposal alternatives, and it requires cleanups to be cost-effective and site-specific. The CERCLA/SARA remedial action process requires the completion of an RI and an FS for all NPL sites.

BCV falls under CERCLA because the entire ORR and its environs are listed on EPA's NPL. BCV remediation planning was initially begun under RCRA corrective action authority; however, placement of the ORR on the NPL does not relieve DOE-ORO from the obligation to implement RCRA Section 3004(u) corrective action requirements on the ORR. The CERCLA provisions for corrective actions on the ORR overlap, to some degree, the provisions of RCRA, thus creating the need for coordination of DOE-ORO's efforts to respond to both sets of requirements. The FFA among DOE-ORO, EPA Region IV, and TDEC establishes the procedural framework and schedule for cleaning up the ORR in compliance with CERCLA/SARA, RCRA/HSWA, and the Tennessee Hazardous Waste Management Act. Specifically, the FFA establishes procedures for integrating the requirements of CERCLA and RCRA by performing integrated RI-RFIs and FS-CMSs and identifies ORR OUs, one of which is BCV OU 2. The FFA also recognizes DOE's responsibilities under NEPA and the impact that the NEPA process may have on meeting the established schedules.

1.1.1.3 NEPA

The purpose of NEPA [42 *United States Code* (*USC*) 4321-4347] is to establish a national policy to protect the environment and to promote a better understanding of the ecological systems and natural resources important to the nation by promoting efforts that will prevent or eliminate damage to the environment and the health and welfare of humankind. NEPA and the Council on Environmental Quality regulations implementing NEPA [40 *CFR* 1500-1508] require that federal agencies consider and publicly address environmental concerns before making decisions on proposed action. These concerns are fully examined and presented in categorical exclusions, EAs, or environmental impact statements (EISs), which are made available to the public and circulated to interested parties. The NEPA process assesses the environmental impacts of the proposed action and the project's alternatives, obtains public input through public scoping and issuance of the EA or EIS, and selects an appropriate alternative, notice of which is prepared and released to the public.

At ORR sites, the NEPA process is integrated with the CERCLA/SARA and RCRA/HSWA processes, as required by the FFA and by DOE Order 5400.4, culminating in issuance of an integrated FS-CMS-EA and, subsequently, an integrated CERCLA record of decision (ROD) and NEPA decision document. In addition to analyzing the site-specific remedial actions in accordance with CERCLA and RCRA, socioeconomic and cumulative environmental impacts of remedial alternatives are analyzed in accordance with NEPA.

1.1.2 Other Regulatory Initiatives

In addition to the three primary regulatory initiatives imposed by the FFA as discussed in the previous sections, the DOE-ORO ER Program for the ORR must satisfy the requirements of several other federal and state regulations. Section 121(d)(2)(A) of CERCLA incorporates into law the CERCLA Compliance Policy, which specifies that Superfund remedial actions meet any federal standards, requirements, criteria, or limitations determined to be legally applicable or relevant and appropriate requirements (ARARs). Also included is the provision that state ARARs must be considered if they are more stringent than federal requirements. Federal statutes specifically cited in CERCLA include the Toxic Substances Control Act (TSCA), the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), and the Clean Water Act (CWA). These regulations are summarized in Table 1.1. The CAA, CWA, and SDWA, by establishing permissible pollution limits, primarily determine the degree of the response required to protect human health and the environment.

DOE-ORO ER Program activities conducted on the ORR must comply not only with the requirements of federal and state regulatory agencies but also with the guidelines established by DOE orders governing environmental restoration and hazardous and radioactive waste management on DOE sites. The primary DOE orders guiding the environmental restoration process on the ORR are highlighted in Table 1.2.

ER Program activities on the ORR are also guided by several interagency agreements between DOE, EPA, and the state of Tennessee, as well as by several state orders. The primary regulators involved in these agreements and orders are the state of Tennessee, which administers the state RCRA program and regulates mixed waste; TDEC, which administers the Tennessee Hazardous Waste Management Act and the Tennessee Water Quality Control Act, and their implementing regulations; and EPA Region IV, which administers a federal RCRA program focusing on HSWA provisions. Table 1.3 briefly discusses those site-specific agreements and orders that pertain to the BCV, either directly or indirectly through requirements and schedules imposed on the Y-12 Plant or the ORR as a whole.

1.2 THE ORR ER PROGRAM

The primary goals of the ORR ER Program are to (1) reduce the risks to public health and the environment resulting from inactive disposal sites and (2) achieve regulatory compliance. Because the regulations have been designed to protect health and the environment, by achieving the second goal, the first will be simultaneously achieved. Sect. 1.2.1 describes DOE-ORO's approach to remediation of the ORR to achieve these goals, and Sect. 1.2.2 presents the roles and responsibilities of the management and operating (M&O) contractor and other prime contractors responsible for implementing the ORR ER Program.

Table 1.1. Other federal regulations affecting the ORR ER Program

Toxic Substances Control Act

TSCA of 1976, which is administered by EPA, regulates existing chemicals that pose an unacceptable risk to human health or the environment. One chemical of concern at several ORR sites, including the Y-12 Plant and BCV, is polychlorinated biphenyls (PCBs). TSCA regulates the use and disposal of materials containing more than 50 parts per million of PCBs. PCB-related projects may also be regulated by CERCLA and RCRA.

Clean Air Act

CAA authorizes EPA to establish national standards for air quality that must be met by the states through compliance with EPA-approved State Implementation Plans. To ensure that national air quality standards are met and maintained, CAA requires that permits be obtained for specific air emissions. The new CAA, passed by Congress on November 15, 1990, contains sections that will revise the permitting program for operating sources and will impose regulations on 189 chemicals that are designated air toxins.

The TDEC Division of Air Pollution Control has the primary responsibility for ensuring compliance with the CAA within the state of Tennessee and for protecting and maintaining Tennessee ambient air quality standards pursuant to the Tennessee Air Quality Control Act. TDEC's Division of Air Quality administers the air permits program. CAA requirements may become ARARs for CERCLA cleanups.

DOE-ORO has received approval of its compliance plan for meeting monitoring requirements of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclides, which are regulated under CAA.

Clean Water Act

CWA of 1977 sets standards for and regulates discharges into surface waters. Facilities that discharge wastewater directly into surface waters must obtain a National Pollution Discharge Elimination System (NPDES) permit. CWA regulations address technology-based effluent limitations, water-quality-based effluent limitations, new source performance standards (NSPSs), control strategies for toxic pollutants, and thermal discharges.

Water pollution resulting from activities on the ORR is controlled through the Tennessee Water Quality Control Act and implementing regulations, and the NPDES permit program for the ORR is administered by TDEC's Division of Water Quality Control. Water quality criteria established under CWA may become ARARs for CERCLA cleanups.

Safe Drinking Water Act

SDWA sets regulatory standards for levels of organic chemicals and other pollutants in drinking water and establishes programs to prevent contamination of groundwater sources. SDWA requires owners and operators to comply with all federal, state, and local requirements, to obtain applicable permits, and to satisfactorily complete required sample analyses and site inspections of public/industrial waste supplies and sources of drinking water. SDWA Primary Drinking Water Standards are frequently used to establish groundwater protection standards pursuant to RCRA and CERCLA.

Table 1.2. DOE orders governing environmental restoration activities on the ORR

DOE Order	Title	Purpose
5400.1	General Environmental Protection Program (11/9/88)	Establishes the environmental protection program for DOE operations.
5400.2A	Environmental Compliance Issue Coordination (1/31/89)	Establishes the process within DOE for resolving conflicting environmental compliance issues.
5400.3	Hazardous and Radioactive Mixed Waste Management (2/22/89)	Establishes DOE hazardous and radioactive mixed waste policies and requirements. The order clarifies DOE's interpretation of the definition of "by-product material" (10 *CFR* 962) as it relates to RCRA regulation of mixed waste and establishes the lines of authority at DOE Headquarters for RCRA implementation.
5400.4	CERCLA Requirements/NEPA Integration	Establishes DOE policy for integrating the NEPA (Sect. 7d) and CERCLA processes for DOE environmental restoration projects under Executive Order 12580.
5400.5	Radiation Protection of the Public and Environment	Establishes guidelines for controlling radioactivity in liquid wastewater effluents and other discharges. It also establishes criteria for residual levels of radioactivity in soils or on equipment that are being released back into the public domain.
5480.1B	Environment, Safety, and Health Program for DOE Operations (9/23/86)	Outlines (1) environmental protection safety and (2) health protection policies and responsibilities.
5820.2A	Radioactive Waste Management (9/26/88)	Establishes policies, guidelines, and minimum requirements for managing radioactive and mixed wastes. This order requires that DOE low-level waste be managed in such a way as to protect public health and safety and to preserve the environment. It calls for performance assessment of all radioactive waste management systems at DOE sites and facilities, including those for waste reduction, segregation, minimization, and characterization; development and implementation of waste acceptance criteria; waste treatment, storage, shipment, and disposal; and disposal site selection, design, operation, and closure/postclosure compliance. Chapter V of DOE Order 5820.2A sets forth requirements for decommissioning radioactively contaminated facilities.

Table 1.3. Federal and state agreements and orders affecting BCV

Memorandum of Understanding (MOU) between DOE, EPA, and TDEC for the Y-12 Plant (5/26/83)

On April 8, 1983, DOE, EPA, and TDEC met to discuss the preliminary measures that must be taken by DOE at the Y-12 Plant to achieve full compliance with all federal and state pollution laws. This MOU, signed by DOE, EPA Region IV, and TDEC on May 26, 1983, outlines the actions that DOE-ORO must take to achieve full compliance with all federal and state pollution laws. These actions include cleaning up (1) discharges to the upper EFPC; (2) pollutants discharged from New Hope Pond (NHP), the New Hope sludge disposal area, S-3 Ponds, burial ground oil pond, isolation area, disposal pits, and oil land farm; and (3) contamination of EFPC and Bear Creek. The MOU also calls for a groundwater study of the Y-12 Plant site and development of a master monitoring plan for the plant.

Federal Facility Compliance Agreement (FFCA)/EPA Region IV, DOE (Y-12 Plant) (3/9/85)

This FFCA between DOE-ORO and EPA Region IV outlines actions that must be taken at the Y-12 Plant to achieve compliance with the CWA and its implementing regulations. It establishes a compliance schedule and reporting requirements for the correction of deficiencies in wastewater treatment at the plant and contains plans for eliminating Category III discharges at the plant.

Agreement-in-Principle between DOE and state of Tennessee (5/91)

DOE-ORO agreed to provide grants to the state of Tennessee for independent oversight by TDEC of ORR ERP activities, including review of FFA-required documents (RI, FS, remedial design, and ROD reports). The state will also conduct independent on-site and off-site monitoring and sampling.

TDEC Order/Division of Water Quality Control, No. 83-228 (9/15/83)

This order, focusing on conditions at Bear Creek, requires DOE to stop disposing of or discharging all materials, except for treatment materials, into the Y-12 Plant S-3 Ponds. DOE-ORO is required to submit to TDEC a plan and schedule for rehabilitating Bear Creek; a report characterizing wastewater discharged from the burial ground oil pond; an NPDES permit application for the discharge; a report inventorying waste deposited in the burial ground oil pond watershed; and a written proposal and schedule for remedial action for the Bear Creek watershed area.

TDEC Order for Correction/Division of Solid Waste Management, No. 84-374-11 (12/6/84)

On December 6, 1984, TDEC issued an order for correction requiring DOE-ORO to submit RCRA Part A permit applications and closure and postclosure plans for the S-3 Ponds, NHP, Bear Creek Burial Grounds, and the oil land farm.

TDEC Order for Correction/Division of Solid Waste Management, No. 84-374, 84-212IAG (12/6/84)

This TDEC order of correction requires DOE-ORO to comply with the interim status standards of Tennessee hazardous waste regulations for all mixed waste facilities until hazardous waste permits are issued by TDEC. It also requires DOE-ORO to comply with the conditions of hazardous waste permits issued by TDEC and to submit to TDEC a schedule for submission of all RCRA Part B permit applications for mixed waste facilities.

1.2.1 Approach to Remediation on the ORR

DOE-ORO, EPA Region IV, and TDEC all recognized the need to coordinate ORR assessment and remediation activities to comply with CERCLA, RCRA, and NEPA and agreed to develop a strategy to facilitate this coordination. In May 1991, DOE, EPA, and TDEC grouped the sites being assessed and remediated under RCRA into CERCLA OUs, and on January 1, 1992, the ORR FFA went into effect. The general purposes of the FFA are to:

- establish a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the ORR in accordance with CERCLA, RCRA, NEPA, appropriate guidance and policy, and Tennessee state law;
- coordinate response actions under CERCLA with RFIs and CMSs now being conducted under RCRA with applicable state laws;
- minimize the duplication of investigative and analytical work and documentation and ensure the quality of data management; and
- expedite response actions.

The FFA provides a CERCLA framework for all future assessments and most remedial action activities planned for the ORR.

The CERCLA cleanup process involves a series of investigation, assessment, public involvement, and decision-making steps leading to publication of a ROD, which documents the preferred choice for a remedial, or cleanup, action. These steps are performed under three major phases: (1) a preliminary assessment/site investigation (PA/SI) to identify releases needing further investigation; (2) an RI to characterize the nature, extent, and rate of contaminant release; (3) an FS to evaluate remedial alternatives; and (4) a proposed plan to propose a remedy. Completion of the proposed plan sets the stage for preparation and signing of a ROD, followed by implementation of the remedial action selected in the ROD.

Not all sites on the ORR must enter the CERCLA process at the PA/SI stage. In some cases, knowledge of past releases may indicate that a site is contaminated without the need for SI sampling. Also, assessments previously performed at some sites can often be substituted for the PA/SI, allowing the investigation to start at the RI stage. In other cases, previous assessments may have shown certain sites to be uncontaminated or to present no threat to human health or to the environment. In such cases, the sites are designated as requiring no further investigation.

The primary steps included in an RI are to:

- collect data to characterize, or describe, site conditions;
- determine the nature and extent of contamination at the site; and
- assess risks to human health and the environment.

Before an RI can begin, a detailed RI work plan, including sampling and analysis, waste management, community relations, health and safety, and quality assurance (QA) plans, must be prepared and submitted to EPA Region IV and to TDEC for approval. After the work

plan is approved, the RI is implemented according to plan, and the results of the investigative steps are published in an RI report, which is also submitted for regulatory approval.

RCRA calls for similar investigative activities to be conducted during an RFI. In some cases, RFI work plans had been prepared for ORR sites designated as RCRA sites before the ORR was placed on the NPL. Because all ORR sites are now categorized as CERCLA sites, requiring that an RI be conducted instead of an RFI, these RFI work plans were modified and submitted to regulatory authorities as RI, or integrated RI/RFI, work plans. All ORR sites designated as both RCRA and CERCLA sites will be investigated in such a way as to meet the requirements of both regulations, and integrated RI/RFI reports will be prepared. For the purposes of this report, the integrated RI/RFI will be referred to as an RI.

After the RI is underway, work begins on the FS. The data collected during the RI are used to determine the extent of contamination and establish a baseline from which potential alternatives are developed for cleaning up the site being investigated. The FS involves a screening and evaluation of potential remedial technologies and an assembly of comprehensive cleanup alternatives followed by a detailed analysis of these alternatives to select the preferred remedial action for the site. Typical alternatives might include treatment of the waste in place, removal and permanent disposal of the contaminated media, removal and treatment of the contaminated media, or a combination of alternatives. The detailed analysis evaluates each comprehensive site-wide alternative independently against the first seven of the nine criteria presented in Table 1.4. Finally, the alternatives are analyzed in a comparative manner, again using the seven CERCLA criteria.

The purpose of the FS is to provide decision-makers with sufficient information to adequately compare the alternatives, to select a remedy for the site, and to demonstrate compliance with CERCLA remedy selection requirements. Again, the objectives of the RCRA-required CMS are very similar to those of the CERCLA-required FS. NEPA, however, requires that adequate information on the environmental impacts, including cumulative impacts, of the alternatives be available to aid decision-making. In addition, the NEPA "no action" alternative is always considered as the baseline from which the effectiveness and feasibility of all other alternatives are judged.

The detailed analysis of several recommended alternatives is documented in the FS report. DOE-ORO uses this report to select a preferred alternative and to develop a proposed plan for site cleanup, which is then submitted to EPA Region IV and TDEC for review and approval. At the proposed plan stage, the final two modifying criteria presented in Table 1.4 are addressed. The proposed plan and all supporting data and documents used to select the preferred alternative and to develop the proposed plan are entered into an Administrative Record for the site. The Administrative Record will be maintained in DOE-ORO's Information Resource Center at 105 Broadway in Oak Ridge, where it will be available to the public.

After EPA and TDEC review and comment on the proposed plan, DOE-ORO responds to the comments and then makes the report available for public comment. Notices announcing the availability of the proposed plan and specifying when and to whom comments should be made are placed in the legal section of *The Oak Ridger* and other local newspapers. The notice either announces the date, time, and location of a public meeting to discuss planned activities at the site or gives instructions on how members of the public may request a meeting.

Table 1.4. Nine criteria by which alternatives are evaluated

The criteria, specified by law, are divided into (1) threshold, (2) balancing, and (3) modifying criteria. The modifying criteria are addressed at the proposed plan stage.

Threshold criteria

These criteria must be met. The selected alternative must:

- provide overall protection of human health and the environment and
- bring the site into compliance with any other regulations that may apply.

Balancing criteria

These criteria are considered in determining which alternative best achieves or comes closest to achieving the threshold criteria. The balancing criteria evaluate the alternatives in terms of:

- long-term effectiveness and permanence;
- the degree to which a treatment reduces the toxicity, mobility, or volume of contamination;
- short-term effectiveness;
- implementability; and
- cost. (Cost cannot be the sole determining factor in a remedial decision.)

Modifying criteria

These criteria allow for the influence of:

- state acceptance of the proposed alternative and
- community acceptance.

After the close of the comment period, DOE prepares a draft ROD and submits it to EPA Region IV. EPA, considering the input from TDEC and the public, makes the final remedial action decision, after which a legally binding ROD is signed by EPA Region IV, TDEC, and DOE. All comments that were received on the proposed plan are documented in a responsiveness summary, which becomes part of the ROD. A remedial design report is then filed with the regulators, detailing construction and work plans. The remedial action must begin no later than 15 months after the ROD is signed.

This integrated CERCLA-RCRA-NEPA process for achieving environmental compliance at contaminated and potentially contaminated ORR sites is a complex procedure requiring consensus on a wide variety of scientific and technical uncertainties among many diverse and competing interests. The objective of the process is to respond to all regulatory requirements in a way that minimizes duplication of effort and expedites response actions while helping decision-makers select the best remediation alternative for safeguarding human health and the environment at a particular site.

The schedule objective of the ORR ER Program is to complete cleanup and compliance as soon as feasible, but no later than the year 2019. Characterization has begun at all facilities, but not at all suspected release sites. Some sites will be remediated in the near

future using existing technologies while others will require scale-up of existing bench-scale technology before cleanup is feasible. Still others will require major development efforts before cleanup can be initiated. The schedule for each potential remediation site must be evaluated individually and the aggregate of all schedules balanced against available technology and resources.

1.2.2 Roles and Responsibilities of M&O and Prime Contractors at ORR

The director of DOE-ORO's ER Division, who reports to the assistant manager for Environmental Restoration and Waste Management, has overall responsibility and authority for planning and executing the ORR ER Program. Working with the DOE-ORO ER Division to accomplish ER Program objectives on the ORR are four prime contractors. The roles and responsibilities of these contractors are described in the following subsections.

1.2.2.1 M&O contractor

As the M&O contractor for all DOE-owned facilities on the ORR, Martin Marietta Energy Systems, Inc. (Energy Systems) is assigned the role of integrating contractor for ER Program activities at these facilities and for the Clinch River and BCV actions. As the integrating contractor, Energy Systems leads the team of contractors in developing all upper-level planning documents, including schedules and budget packages, related to short- and long-term ER Program activities on the ORR. It conducts meetings, collects information, and assembles packages of information about ER Program activities for use by DOE-ORO, including monthly reports of cost and schedule status. Energy Systems also ensures that technical consistency is achieved among all ER Program participants in such areas as risk assessment and waste management.

In its dual role of the facility M&O contractor and integrating contractor, Energy Systems:

- evaluates other DOE prime contractor, subcontractor, and prospective subcontractor environmental restoration programs, procedures, systems, processes, and policies regarding health and safety, housekeeping, environmental requirements, radiation protection, security, QA, and related operations;
- provides coordination with plant operations for all field work, including RIs and remedial actions;
- evaluates the designs, strategies, and sequencing of work recommended by the remedial design architect-engineer in accordance with existing project management procedures established by DOE's assistant manager for construction and engineering; and
- participates in and operates the Levels I and II Change/Configuration Control Board meetings chaired by DOE-ORO and processes and maintains all change requests and approvals for ER Program projects on the ORR.

The M&O Contractor has subcontracted SAIC (and others) to assist with technical support for both project and program management activities such as work plan development, development and implementation of RIs, preparation of integrated decision documents and the studies and assessments necessary to provide them, program-level planning, information

management, QA/QC, and technical support for regulatory compliance and waste management special studies, and other phases of the program.

To fulfill its role as integrating contractor for the ORR ER Program, Energy Systems created a centralized ER Division, which in turn established a dedicated ER Program office for each major facility and off-site area under its authority and control. Site ER Program managers are responsible for planning and implementing ER Program activities at their respective sites.

1.2.2.2 RCRA-CERCLA-NEPA TSC

The role of the TSC for the ORR ER Program, Jacobs Engineering, is to provide technical support in the following areas through task orders issued by DOE-ORO:

- development of FSs;
- preparation of integrated decision documents and the studies and assessments necessary to produce them (i.e., CMS-FS-EA, proposed plan, and ROD);
- technical support for program management activities such as community relations, maintenance of the Administrative Record, public meetings, program-level planning, information management, QA/QC, or work plan development; and
- technical support for regulatory compliance and waste management, special studies, or remedial design or remedial action phases of the program.

In addition, although facility RIs will generally be conducted by the M&O contractor or ETS contractor, DOE-OR may direct the TSC to conduct RIs.

The performance of tasks in the activity areas identified above requires effective interface of the TSC with all other ER Program participants, including DOE-ORO and the M&O contractor, the remedial design contractor, and the construction management contractor. The specific requirements for interface vary with the nature of the activities being performed.

1.2.2.3 Remedial design contractor

ENSERCH Environmental Corporation, the remedial design contractor for the ORR ER Program, provides support as required during the FSs conducted by the TSC. After the presentation of several recommended alternatives in the FS and the selection of an alternative by DOE-ORO, the remedial design contractor begins the design of the selected alternative sufficient for inclusion in the draft ROD and draft remedial design work plan. The remedial design contractor revises the design after the public comment period and supports the preparation of the proposed ROD and remedial action work plan for submittal to the regulators. After the ROD is signed, the remedial design contractor completes the remedial design work plan and the design details sufficient for issue for bidding and award by the DOE-ORO construction management contractor and provides home office support services as needed as well as field services. The remedial design contractor ensures that the final design complies with both the ROD and the remedial action work plan.

1.2.2.4 Construction management contractor

All remedial actions on the ORR are performed by fixed-price or, if necessary, cost-plus-fixed-fee subcontractors. MK-Ferguson of Oak Ridge Company, the construction management contractor for the ORR ER Program, manages these subcontracts.

1.3 FACILITY-SPECIFIC ER PROGRAM

The Y-12 Plant was built in 1943 as part of the Manhattan Project to separate uranium isotopes using the electromagnetic process. When the process was discontinued after World War II, the Y-12 Plant's role was changed to manufacturing and developmental engineering. Since that time, the plant has been responsible for producing nuclear weapon components and subassemblies, developing and fabricating test hardware for the weapon design laboratories, and providing fabrication support to other Energy Systems plants and to federal agencies. The Y-12 Plant has recently discontinued the production of nuclear weapon components and is currently engaged in technology development and weapons disassembly.

Past operations have resulted in extensive on-site and off-site contamination. Contaminants at the 324 ha (800-acre) Y-12 Plant site include hazardous materials, low-level radioactive material (primarily uranium), and mixed wastes resulting primarily from the weapons production process. Sites requiring environmental restoration include waste disposal sites (spoil areas), equipment storage yards, waste storage tanks, spill sites, and contaminated inactive facilities, all resulting from past operations.

The Y-12 Plant ER Program for cleaning up these on-site and off-site areas of contamination is well documented and described in several publications, such as the *Oak Ridge Reservation Site Management Plan for the Environmental Restoration Program* (DOE/OR-1001), the *Environmental Restoration and Waste Management Site-Specific Plan for the Oak Ridge Reservation* (DOE/OR-968 September 1991), and the *Y-12 Plant Long Range Environmental and Waste Management Plan* (Y/TS-83 Rev 7 May 1991). These and other ORR documents are available at the Information Resource Center at 105 Broadway in Oak Ridge, Tennessee. Many are updated and reissued annually. The following sections focus primarily on activities that affect BCV.

1.3.1 BCV RIs

The previously existing RFI work plans for BCV OUs 2 and 4, upper EFPC OUs 1 and 2, and EFPC were revised and submitted to EPA and TDEC for approval in December 1991. Several of these RFI work plans (e.g., EFPC) were implemented, and draft RFI reports were issued. These reports have been subsequently evaluated for CERCLA adequacy. As discussed in Sect. 1.2.1, the RFI work plans were modified and submitted to regulatory authorities as RI or RI/RFI work plans. A resulting integrated RI report will be issued. The paragraphs below focus briefly on the status of the CERCLA process at the BCV OUs.

Because the hydrogeologic regime of the ORR is complex, and because numerous sources contribute to groundwater contamination within a geographical area, more timely and technically sound investigations can be achieved by separating the sources of contamination from the groundwater and surface water for investigation and remediation. To permit effective evaluation of the cumulative impact of releases from multiple sources of

contamination on the ORR, studies of the groundwater and surface water were separated from studies of the sources by establishing waste area groupings (WAGs) as source OUs and the hydrogeologic regimes that are common to more than one source OU as integrator OUs. This approach will result in more immediate attention (removal action/interim action and RODs) for the source OUs while investigation continues into remediation alternatives for the integrator OUs (Energy Systems 1992). A ROD will be achieved for both source and integrator OUs (Fig. 1.1).

Data acquisition for each OU in an integrator unit will be carried out in the following three stages, as shown in Fig. 1.2, rather than as a single event.

- Stage 1–Assemble sufficient data to support making intermediate decisions. Some questions that would need to be answered are the following: Can the site be designated as "Site Evaluation Accomplished"? Should a focused effort be implemented to support a finding of "no further investigation required"? Is a removal action required or appropriate? Is a focused FS relevant to the site? Should the waste unit proceed to Stage 2 of the CERCLA process?
- Stage 2–Assemble sufficient data to select an acceptable source remediation and obtain a source unit ROD.
- Stage 3–Compile valley-wide information including postremediation source unit monitoring to obtain a ROD for the entire hydrologic regime.

The premise of the staged approach is that the remediation of a CERCLA OU is a complex process, starting with the identification of those sources that warrant investigation on the ORR and continuing through the proposed plan for implementing a remedial action. To implement the entire process on all potential sources at the Y-12 Plant would be impossible. Therefore, the staged approach is designed to provide mechanisms for withdrawing a site from the process as soon as information is available that suggests it is not necessary for the site to proceed through the entire RI/FS process.

Each stage supports a different level of decision-making and, therefore, would require different types and amounts of data. However, a goal of the RI is to ensure that sampling operations required for the initial stage are not repeated at later stages. Stage 1 requires review, evaluation, and validation of existing data. Additional Stage 1 data may be required as was the case with BCV OU 2. Data requirements for Stage 2, which is the complete RI, must be sufficient to develop a ROD. It is anticipated that the third stage of the process will rely on postremediation performance monitoring data collected at the source.

One of the primary goals of the Y-12 Plant strategy is to integrate source OUs and integrator OUs. The primary responsibilities of the source OU are as follows:

- To identify the nature and extent of the source.
- To identify and quantify (with models provided by the integrator unit) potential releases and transport mechanisms from the source to the integrator OU, including leaching, transport through the unsaturated zone to the groundwater, movement through the stormflow system to the groundwater, surface water/sediment, and runoff to surface water/sediment.
- To identify and quantify (if possible and necessary) potential releases to the air.

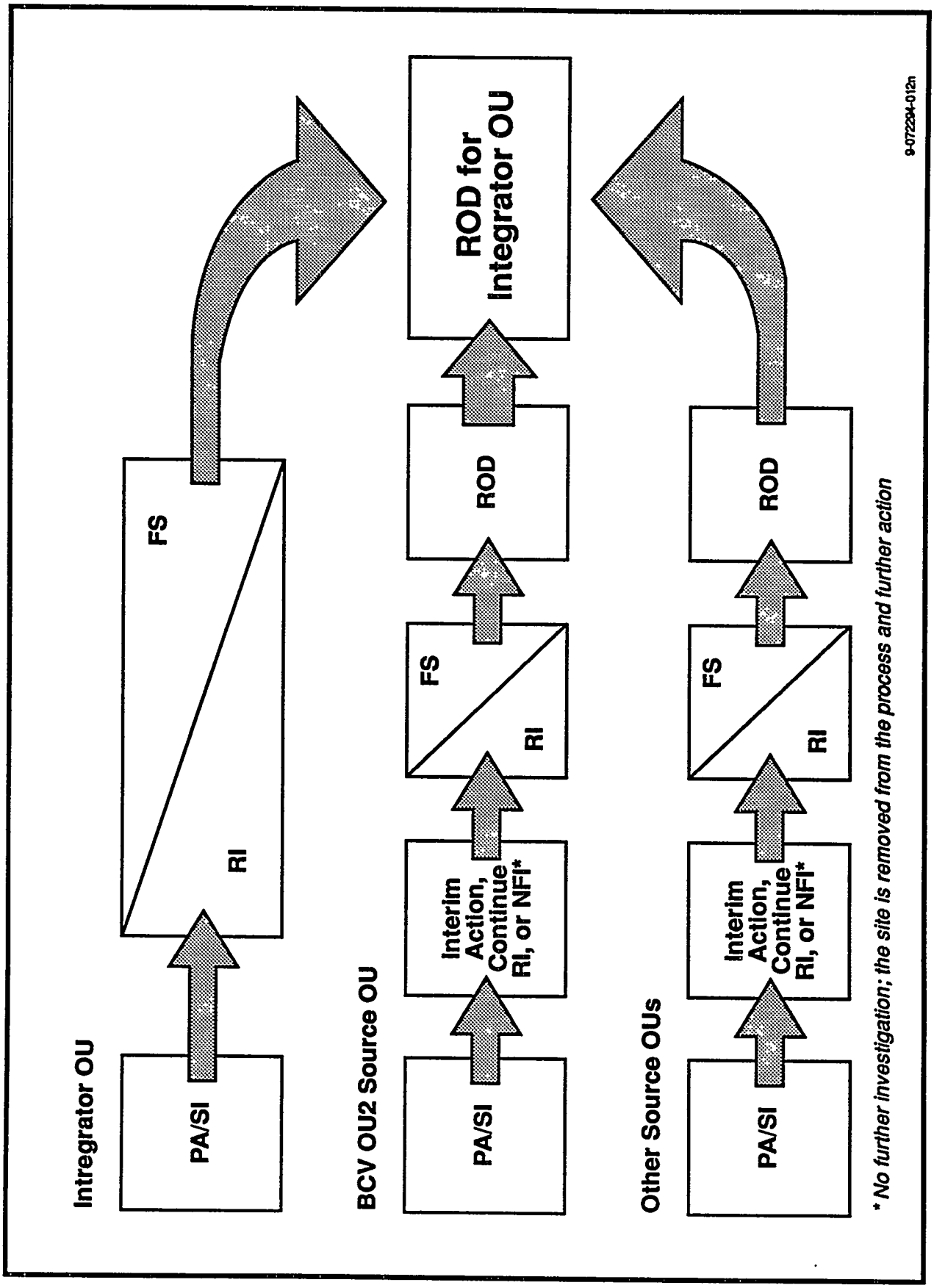


Fig. 1.1. The relationships among the integrator and source OUs in the same hydrological system.

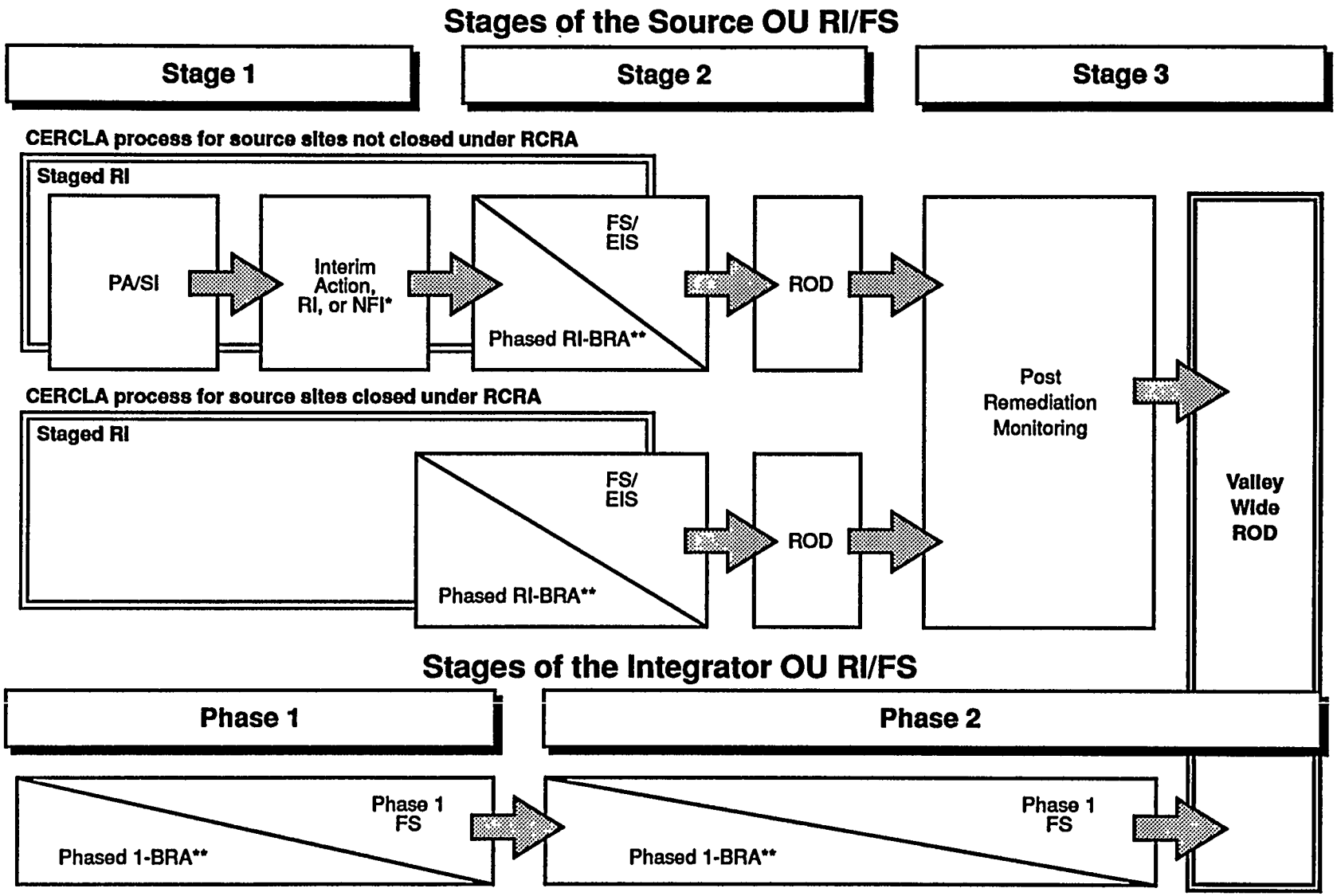


Fig. 1.2. The staged RI process for a source OU.

- To collect and provide to the integrator OU information (e.g., runoff and stormflow data) showing the connection and possible integration points between a specific source and the integrator OU.
- To identify and quantify current and future potential on-site risks to humans associated with the source.
- To identify terrestrial ecological effects associated with the source. To gain an understanding of potential risks to species with a small habitat range that are generally low in the food chain and can be connected easily to a specific source (e.g., earthworms).
- To identify potential wetlands within the source OU boundaries and effects on wetlands species.
- To use risk or ARAR-based groundwater remedial goal options (RGOs), developed by methods consistent with those to be used in the integrator OU, to identify whether current or potential future releases could pose a risk to future on-site receptors and current and future off-site receptors. These RGOs will be compared with detected or modeled concentrations to help determine whether releases from the source need to be remediated.
- To use human and ecological-based soil/sediment RGOs developed by methods consistent with those to be used in the integrator OU to discern whether current or potential future releases from the source need to be addressed by remediation.

The primary responsibilities of the integrator OU are as follows:

- To identify contamination currently in the environmental media that should be addressed immediately.
- To gain an understanding of the primary flow mechanisms within and between the Nolichucky and Maynardville groundwater formations.
- To gain an understanding of the interaction between the Nolichucky and Bear Creek and upper EFPC.
- To gain an understanding of the interaction between groundwater/surface water and the Clinch River.
- To identify points in the environmental media (surface water and groundwater) where high levels of contamination are entering the media (integrator points) to help prioritize the cleanup of the source units.
- To gain an understanding of and provide the tools for quantifying (if possible) contaminant transport through the groundwater system (e.g., identify sorption properties and site-specific water-to-soil distribution coefficients for primary chemicals of concern).
- To develop and provide to the source OUs conceptual and (if possible) quantitative models that should be used to describe unsaturated zone flow, stormflow zone flow, and surface water runoff to ensure that source OUs are using consistent techniques for estimating chemical migration to the integrator.
- To provide source OUs groundwater RGOs that can be used to make remediation decisions about the source. These RGOs should be based on risk and/or ARARs and may account for potential risks to both a future on-site receptor and a downgradient off-site receptor. RGOs for the off-site receptor should eventually account for

dilution/attenuation that occurs as hazardous substances move through the groundwater. Estimated and measured concentrations of hazardous substances being released from the source unit to the groundwater will be compared to these RGOs to determine if remediation of the source is necessary.

- To provide source OUs surface water RGOs that can be used to make remediation decisions about the source. These RGOs should be based on risk and/or ARARs and should account for potential risks to ecological and human receptors. Estimated or measured concentrations of hazardous substances being released from the source to the integrator will be compared to these RGOs to help determine if remediation of the source is necessary.
- To gain an understanding of the off-site risks associated with hazardous substances currently detected in groundwater, surface water, and sediments.
- To gain an understanding of potential future risk associated with continued off-site migration of hazardous substances currently detected in groundwater and sediments (e.g., to learn how this contamination may act as a source for future risk even if source control measures are implemented on source OUs).
- To gain an understanding of potential risks to aquatic species and food chain impacts associated with contamination in surface water and sediments.
- To gain an understanding of the potential risks to terrestrial species that have a large habitat range and that are higher in the food chain (e.g., deer and predator species).

Five integrator OUs have been identified for the ORR: Bethel Valley, Melton Valley, the K-25 Site area, BCV OU 4, and upper EFPC OU 1. ORNL WAGs have not yet been broken into OUs. There have been 14 source OUs identified at the K-25 Site and 8 source OUs identified at the Y-12 Plant. In addition, three combined source and integrator OUs have been identified: Chestnut Ridge at the Y-12 Plant, lower EFPC, and ORNL WAGs 11 and 13 with the ORAU site at Freels Bend.

The Y-12 Plant source OUs have been grouped not only by their proximity but also by common physical and hydrogeologic parameters (Table 1.5). Extensive study of the relationship between groundwater movement and contaminant transport at the Y-12 Plant indicates that groundwater can be subdivided into two distinct hydrogeologic regimes: upper EFPC and BCV. This subdivision is based on topography, surface water drainage, and groundwater flow patterns. It provides a basis for unifying monitoring efforts at the Y-12 Plant and for tailoring monitoring efforts to the hydrogeologic characterization of each regime. The strategy used to delineate the boundaries of each regime is included in *Comprehensive Groundwater Monitoring Plan for the DOE Y-12 Plant, Oak Ridge, Tennessee* (Geraghty and Miller 1990).

BCV OU 2 is one of two source OUs within BCV (Fig. 1.3; refer also to Fig. 2.2 in Chap. 2). The integrator OU for BCV is BCV OU 4, which consists of surface water and groundwater from Bear Creek and its tributaries, as well as floodplain soils and sediments. The boundaries of BCV OU 4 are from the crest of Chestnut Ridge to the crest of Pine

Table 1.5. Y-12 Plant OUs

OU	Type	Sites of concern
Upper EFPC OU 1	Integrator	Groundwater, surface water, and sediment within the Y-12 Plant
Upper EFPC OU 2	Source	Abandoned Nitric Acid Pipeline
Upper EFPC OU 3	Source	S-2 Site, Building 81-10, Salvage Yard (Tank Site 2063, -4, Drum Deheader, Oil Storage Tanks, Oil/Solvent Drum Storage Area, and Scrap Metal Storage Area)
BCV OU 1	Source	S-3 Ponds; SL 1; HCDA[a]/Boneyard/Burnyard; Oil Landfarm; Burial Grounds [includes BG-A (North and South), -B, -C (East and West), -D, -E, and -J; ORPs[b] 1 and 2; the Walk-in Pits; and the Uranium Vaults]
BCV OU 2	Source	RSA, SA-1, SY-200 Yard
BCV OU 4	Integrator	Bear Creek Groundwater and Surface Flow Regime and Floodplain Sediments
Chestnut Ridge OU 1	Source	Chestnut Ridge Security Pits Hazardous Waste Disposal Units
Chestnut Ridge OU 2	Source	Filled Coal Ash Pond, Upper McCoy Branch
Chestnut Ridge OU 3	Source	United Nuclear Corporation (UNC) Disposal Site
Chestnut Ridge OU 4	Source	Rogers Quarry and Lower McCoy Branch
Lower EFPC OU	Integrator/Source	Lower EFPC Floodplain and Creek

[a]Hazardous Chemicals Disposal Area
[b]Oil Retention Ponds

Ridge and from the surface water divide near the S-3 Site to the groundwater divide west of State Highway 95 between Bear Creek and Grassy Creek. Source OUs in BCV are as follows:

- BCV OU 1, which comprises the S-3 Site; the Oil Landfarm; the Boneyard/Burnyard, including the Hazardous Chemicals Disposal Area (HCDA); Sanitary Landfill I (SL 1); and the Bear Creek Burial Grounds [(BG)-A North, BG-A South, BG-B, BG-C East, BG-C West, BG-D, BG-E, and BG-J)], including Oil Retention Ponds (ORPs) 1 and 2, the Walk-in Pits, and the Uranium Vaults.
- BCV OU 2, which includes SA-1, the SY-200 Yard, and RSA.

The BCV OU 2 RI was carried out under the OU strategy described above for Bear Creek Valley. The intent of this strategy was to give more immediate attention (removal action and/or RODs) for the source OUs while an investigation continues into the integrator

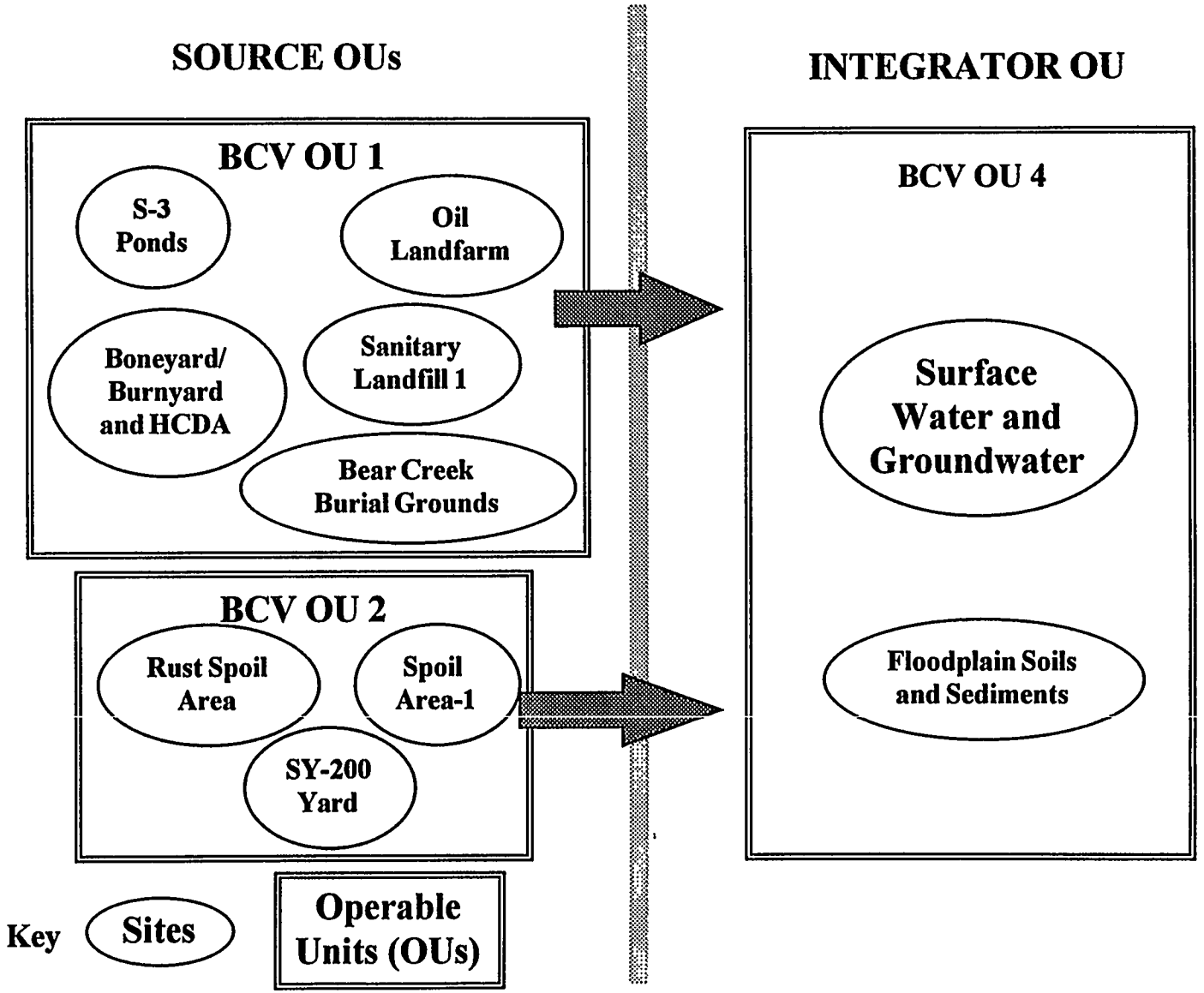


Fig. 1.3. Relationships between sites, OUs, and source and integrator OUs in BCV.

OUs. The unforeseen shortfalls of this approach were a regulatory-perceived lack (or delay) of action on groundwater contamination in BCV and poor site-wide integration that would gain optimal cost-effectiveness of remedial actions.

In response to the shortfalls in the existing strategy, and based on the need to develop a risk-based approach to prioritizing remedial actions in the valley, the strategy in BCV was revised during the summer of 1994. Under this new strategy, BCV will be evaluated in a single integrated study. The waste sites, floodplains, and aquifers will be addressed in a single set of RI/FS documents that will include evaluation of waste sources, soil, surface water, groundwater, and ecological media. The RI/FS for BCV will lead to a decision point at which a Proposed Plan will be prepared. After the proposed plan has been reviewed by the public, the agreed upon decisions will be recorded in a ROD. Since the RI/FS has already been completed for BCV OU 2, the process will continue to a ROD for this OU that will be separate from the BCV valley-wide Rod; however, the ROD for OU 2 will be consistent with the overall BCV strategy.

1.4 INTENT AND SCOPE OF THE RI

BCV OU 2 is the focus of this RI report. The intent of the RI was to assemble all data necessary to select remediation alternatives for the sites in BCV OU 2 that reduce the risk to human health and the environment to acceptable levels based on agreements with the regulators. Because BCV OU 2 is a source OU associated with an integrator OU, there are certain constraints on the media to be addressed for remediation by the RI/FS and on the scheduling of the RI/FS process. Groundwater and surface water associated with BCV OU 2 were not addressed as media to be remediated in the BCV OU 2 RI/FS process; risks to off-source and off-site receptors via groundwater and surface water pathways will be addressed in the BCV OU 4 (integrator OU) baseline risk assessment (BRA). Floodplain soils and sediments will be addressed by the RI for BCV OU 4 and are not included in the RI for BCV OU 2 unless they are within the BCV OU 2 site boundaries.

During the development of the RI work plan, the site conceptual models were described, and lists of likely removal actions/interim actions and likely remedial alternatives were tentatively identified. Likely removal actions/interim actions that were considered are as follows:

- removal or overpacking of drums or other containers;
- excavation of highly contaminated soils, especially those that are radioactive;
- drainage controls (i.e., capture and treatment) of contaminated shallow groundwater;
- drainage controls (i.e., capture and treatment) of contaminated seeps;
- installation of an airborne dust monitoring station; and
- fences, warning signs, or other security measures.

Likely remedial alternatives were proposed as follows:

- no action,
- source containment, and
- removal/treatment.

The site conceptual models have been updated based on data obtained during the BCV OU 2 RI field activities and are presented in Sect. 3.2. Based on the updated site conceptual models, the data presented in this RI will be used to further define these remedial alternatives and likely removal actions in the FS.

The schedule of RI/FS activities in BCV OU 2 will follow the staged approach outlined in the facility OU strategy for the Y-12 Plant outlined in Sect. 1.4. The goal is to develop a ROD for all of the OUs in BCV, including the integrator OU. This report covers field activities carried out to complete Stages 1 and 2. Stage 3 will be completed when the valley-wide risk assessment is carried out.

1.5 SPECIAL PROBLEMS

Several points should be noted here regarding the SY-200 Yard. Although there was existing historical soil boring data at this site, only current data are being considered for the RI. Since the historical data were collected at the site, there has been considerable reworking of the fill material as part of the construction activities for the Environmental Support Facility (ESF) building, which was later completed at a different location across Old Bear Creek Road from the SY-200 Yard. Because the area has been disturbed, the sources of the historical data cannot be accurately located. Therefore, the historical data have been omitted from the data evaluations. There has been no further reworking of the fill material at the site since the current RI data were collected.

During soil sampling activities at the SY-200 Yard, mercury was visible in several locations. The analysis for samples collected at these soil borings does not always indicate elevated levels of mercury, as would be expected. This has been explained as the "nugget effect," which means that due to the spherical nature of mercury and the methods of collecting, compositing, and splitting soil samples for laboratory analysis, the particular aliquot of sample actually analyzed may or may not contain a "piece" of the mercury observed. There is no way to devise a cost- effective sampling and analysis plan that will identify the total distribution of mercury throughout a site. The hope was that enough data would be collected to identify "hot spots" to perform a risk analysis and evaluate alternatives for remediation.

1.6 OBJECTIVES

1.6.1 RI Report

The objective for the BCV OU 2 RI report is to provide information on the physical characterization of the environment and the characterization of the nature and extent of contaminants within the environment for input into the human health risk assessment, baseline ecological risk assessment (BERA), and the FS. Combined with the FS, these report

segments will provide the documentation and technical support for the decisions put forth in the ROD and subsequent remedial actions.

As part of the site characterization process, the RI must confirm or revise the site conceptual model, which (1) specifies contaminant types, concentrations, and distributions and (2) establishes exposure pathways and susceptible population. To accomplish this, the BCV OU 2 RI report seeks to:

- supply an understanding of the physical nature of the site as a basis for identifying areas of concern;
- determine the affected media and establish the boundaries of contamination within the OU and its environs;
- determine the nature of the contaminants and understand their distribution, form, and possible associations with other nearby source areas (e.g., S-3 Ponds);
- characterize primary contaminant transport into and out of the system and define contaminant migration within the system; and
- provide a comparison of groundwater and soil contaminant levels against a background reference site (see Sects. 3.2.3 and 3.2.4).

1.6.2 Human Health BRA

The human health BRA incorporates the results of the RI and determines whether there is an imminent and substantial endangerment to human health based on current and future exposures and whether the need for site remediation exists. Specific end results of the BRA are to:

- identify contaminants of concern (COCs) from the list of chemicals of potential concern (COPCs);
- select ARARs; and
- derive RGOs for COCs and establish cleanup criteria.

To accomplish the above, the risk assessment must complete its evaluation of four fundamental components: data evaluation, exposure assessment, toxicity assessment, and risk characterization. The data evaluation assesses all the available data on COPCs present in the environment within the BCV system; the exposure assessment identifies the receptors at risk of exposure, determines the exposure pathways of importance, and quantifies uptake for all COPCs by pathway to establish ARARs; the toxicity assessment selects toxicological measures for use in evaluating the significance of exposure to identify RGOs; and the risk characterization integrates the exposure and toxicity assessments to identify areas needing cleanup.

1.6.3 BERA

The BERA determines if and where adverse ecological effects to various animal and plant populations occur as a result of exposure to one or more stressors and if and where site remediation may be needed.

The BERA process consists of several steps, including the following:

- problem formulation (determining what populations and habitats are present in the floodplain ecosystem);
- analysis, which includes exposure characterization (determining the relevant exposures to the various indicator populations) and characterization of ecological effects (determining whether contaminants or other site-related stressors are toxic to these indicator biota or deleterious to their habitats at the concentrations to which various populations and habitats are exposed); and
- risk characterization (determining impacts of exposure and toxicity to indicator populations).

In this process, exposure and especially ecological effects data are collected from a variety of sources and integrated into a final assessment of current and potential risks to the environment. Specific objectives of the sampling and analysis of indicator populations and associated habitats and media are to:

- measure concentrations of COPCs in BCV OU 2 site sediments and soils to which biota are exposed;
- model potential exposures of on-site biota to COPCs;
- determine the presence in BCV OU 2 of species designated as threatened and endangered or in need of management, or of essential habitat for those species;
- display these findings using data from Chap. 3 on contaminant distribution and maps of habitats; and
- develop RGOs for ecological COCs.

When these objectives are met, the BERA will provide the organized data to help select remediation alternatives.

1.7 SCHEDULE

The schedule for the RI report incorporates the document requirements of CERCLA and the procedural requirements of NEPA. Time spans are governed by the commitments in the FFA by DOE for submittals and by EPA-TDEC for document review times. Submittals of the draft documents are proposed annually by DOE and negotiated with EPA and TDEC and set as FFA milestones. Per the FFA, a time of 120 calendar days is allowed for regulatory review by EPA and TDEC. DOE has committed to providing responses to regulatory comments within 60 calendar days. DOE's time is extended if there is conflict between EPA's and TDEC's comments. The schedule of the major documents, both draft and final versions, is shown in Fig. 1.4.

Concurrent with the development of the RI report, an integrated FS is being prepared to screen and identify remedial actions capable of meeting the cleanup criteria and ensuring that environmental impacts are acceptable. The draft FS is scheduled to be submitted to EPA and TDEC in November 1994. Concurrent with submittal to the regulators, the draft FS will be available for public review and interested governmental agencies and thus will comply with

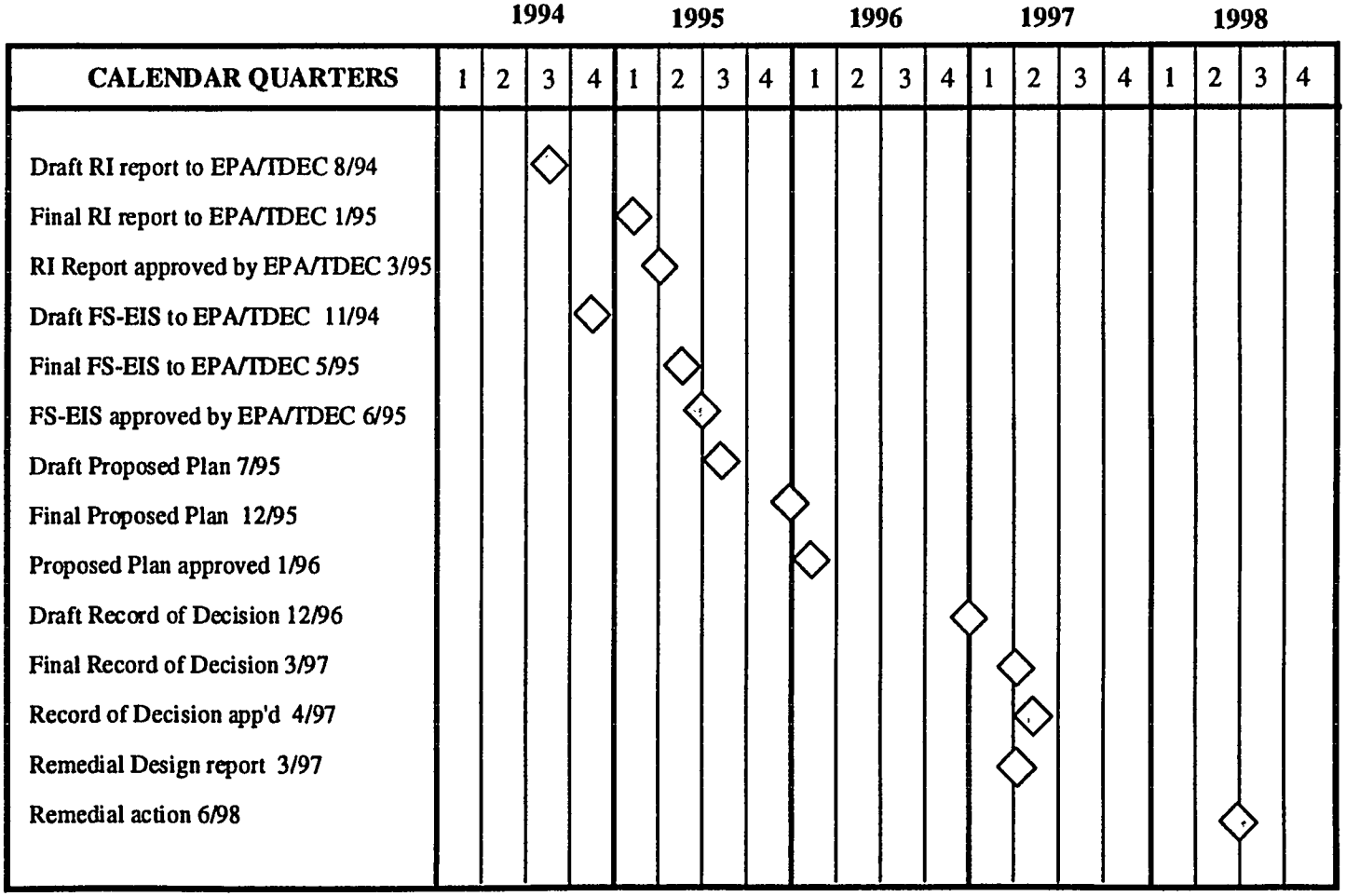


Fig. 1.4. Schedule of BCV OU 2 activities.

the NEPA requirement for public comment. Following resolution of comments by regulators, agencies, and the public, the final FS is scheduled to be issued in May 1995, with regulatory approval in June 1995.

The proposed plan is scheduled for submittal as a draft in July 1995 and a final in December 1995; it should be approved in January 1996. Review times are reduced for the proposed plan and the ROD, as it is a small document, and the content is likely to be similar to parts of the FS. The ROD is scheduled to be issued in draft in December 1996 and a final in March 1997; it should be approved in April 1997. It is followed by the Remedial Design Report before March 1997. Remedial action is scheduled to begin no later than June 1998. It must start a maximum of 15 months after the ROD is formally signed.

2. CHARACTERIZATION OF ENVIRONMENTAL SETTING

2.1 GEOGRAPHY

The DOE ORR is located within the corporate limits of the city of Oak Ridge in eastern Tennessee, ~16 km (10 miles) southeast of the Cumberland Mountains and 113 km (70 miles) northwest of the Great Smoky Mountains. Figure 2.1 shows the city's location ~20 miles northwest of Knoxville, Tennessee, which is east of Nashville, Tennessee, and north of Atlanta, Georgia. The area is serviced by Interstates 40 and 75, which intersect in nearby Knoxville, Tennessee, east of Oak Ridge. The reservation, 14,300 ha (35,300 acres) of federally owned land, houses three facilities (the Oak Ridge K-25 Site, ORNL, and the Oak Ridge Y-12 Plant), which are managed for DOE by Energy Systems.

The Y-12 Plant encompasses ~324 ha (800 acres) and is located adjacent to the corporate center of the city of Oak Ridge. The plant occupies a valley between Chestnut Ridge to the south and Pine Ridge to the north of the plant. The plant complex, most of which was built in the mid-1940s, is roughly divided into two portions; the western portion was previously devoted to DOE weapons-manufacturing activities, and the eastern portion is devoted to ORNL research programs, general plant operations, and maintenance activities.

Extensive geographical information concerning the Y-12 Plant, its facilities, and the surrounding area is given in Welch (1989). The Y-12 Plant is located in the Valley and Ridge Physiographic Province, which lies between the Cumberland Mountains to the northwest and the Great Smoky Mountains to the southeast. This province is characterized by roughly parallel, alternating ridges and valleys. The main facilities of the Y-12 Plant lie on the BCV floor, with auxiliary facilities located along Pine Ridge and Chestnut Ridge.

Bear Creek originates east of the former S-3 Ponds near the western margin of the Y-12 Plant. BCV OU 2 is located immediately west of the main Y-12 Plant facilities (Fig. 2.2). From east to west, the BCV OU 2 consists of the SA-1, the SY-200 Yard, and the RSA.

2.2 DEMOGRAPHY

2.2.1 Population Information

The Y-12 Plant is located at the northeast boundary of the ORR across Pine Ridge from the commercial center of the city of Oak Ridge, which has a population of 27,310 (U.S. Department of Commerce 1991). As of June 1993, the Y-12 Plant employed 6190 full-time Energy Systems employees and ~1000 on-site employees of M-K Ferguson, DOE, and ORNL. A pumping station located on the north bank of Melton Hill Lake at Clinch River supplies water to the Y-12 Plant water treatment facility and the city of Oak Ridge water treatment plant. A pumping station for domestic water is also located near mile 14.5 on the Clinch River, also within the ORR boundary.

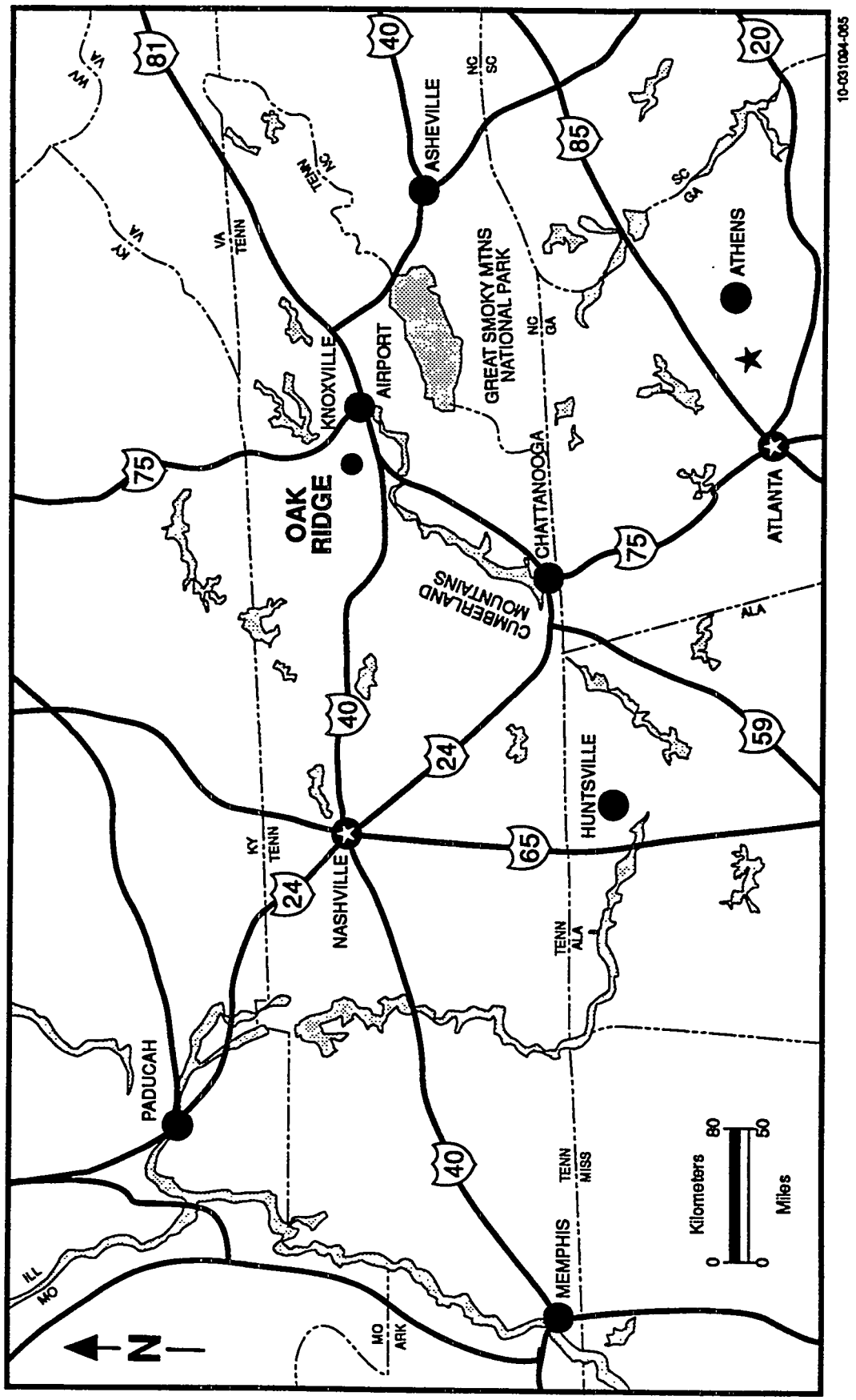


Fig. 2.1. Location of Oak Ridge.

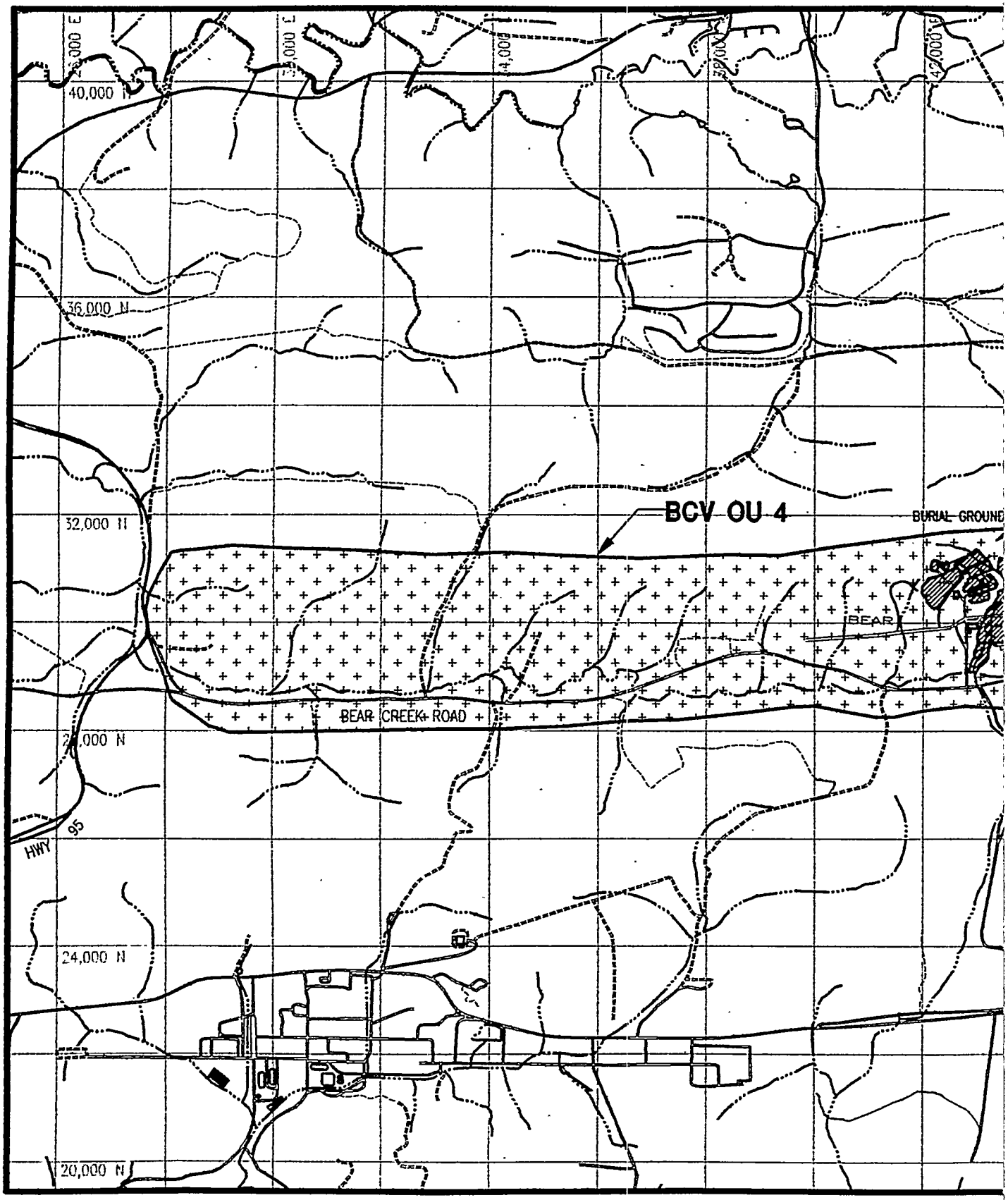
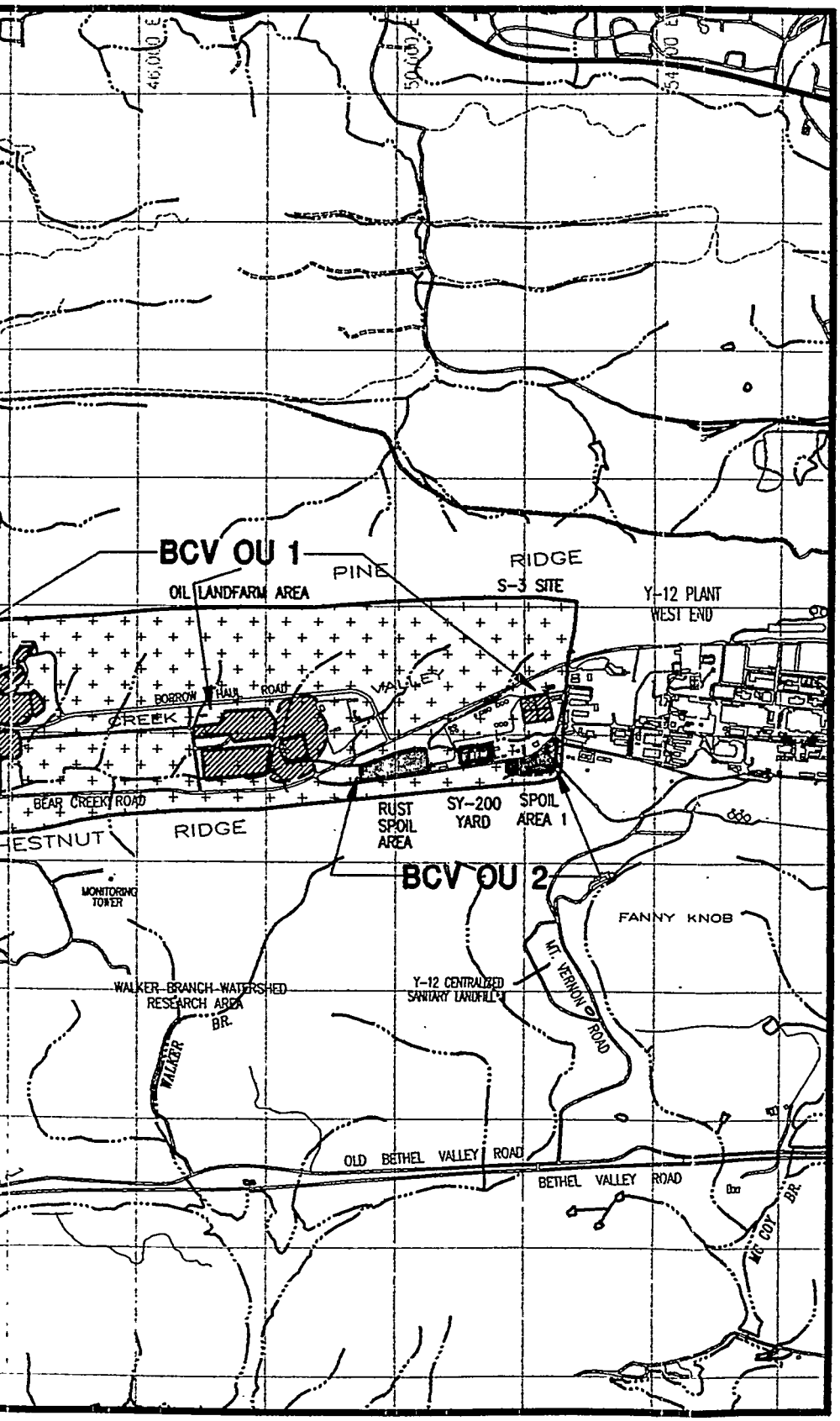


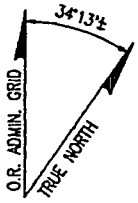
Fig. 2.2. Location of BCV OU 2



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relation to other OUs in BCV.

2.2.2 Land Use

The East Tennessee Development District, which includes the city of Oak Ridge, is rural in character. Knoxville is the district's regional center and the only city in the region with a population in excess of 50,000. Oak Ridge and other cities in the district are within the 7500 to 50,000 population range, are incorporated, and have a definite central core that provides major employment and trade opportunities. Of the district's 1,700,010 ha (4,200,800 acres), ~80% is in agricultural and forest land use (Table 2.1).

Table 2.1. Land use data for the East Tennessee Development District

Land use category	Hectares	Acres	Percent
Residential	35,074	86,670	2.1
Commercial	1,950	4,820	0.1
Industrial	20,700	51,150	1.2
Recreational	269,129	665,030	15.8
Agricultural	685,904	1,694,900	40.3
Public and quasi-public	28,430	70,250	1.7
Forest	658,823	1,627,980	38.8
Total	1,700,010	4,200,800	100.0

Source: DOE 1982.

In contrast to the district's general land use patterns, the city of Oak Ridge is an urban center with minimal agricultural activities. Land not owned by the federal government consists of 5510 ha (13,615 acres) and is divided into more than 9500 parcels. Table 2.2 categorizes urban land use data for the city of Oak Ridge. Most of this land is either residential or vacant, and more than 1903 ha (4700 acres) of the vacant land is suitable for housing (DOE 1982).

Table 2.2. Urban land use data for the city of Oak Ridge, Tennessee[a]

Land use category	Hectares	Acres	Percent
Residential	1,640	4,050	28.9
Vacant	2,247	5,550	39.6
Recreational	749	1,850	13.2
Commercial	104	256	1.8
Industrial	47	115	0.8
Public transportation, parking	480	1,185	8.5
Private transportation	33	82	0.6
Utilities and communications	52	129	0.9
Services	314	775	5.5
Total	5,666	13,992	99.8

[a]Excludes federally owned lands within the corporate city limits.
Source: DOE 1982.

Several categories of land use are close to the ORR. The nearest privately owned residential properties are in the Poplar Springs, Sugar Grove Valley, and Oak Ridge (including Wiltshire, Country Club Estates, and Scarboro) communities (Fig. 2.3). Oak Ridge is located on the northern boundary of the ORR, and Sugar Grove Valley is located adjacent to the ORR at the northwest corner. Poplar Springs is located 3.2 km (2 miles) west across the Clinch River. Other residential areas include Bradbury, Edgewood, and Lawnville. Bradbury is located across the Clinch River ~8 km (5 miles) south. Edgewood and Lawnville are located immediately west-northwest of the Poplar Springs community. Agricultural use includes limited-scale private gardening; raising of tobacco, corn, wheat, and soybeans as cash crops; raising of beef cattle; and dairy farming. Some areas are also used for commercial logging.

Industrial land use includes Phyton Technologies, Inc.; Scientific Ecology Group (SEG); and International Technology (IT) Corporation's Bear Creek Radiological Laboratory. SEG, Phyton, and the IT Corporation laboratory are within 3.2 km (2 miles) of the Y-12 Plant. Tennessee Valley Authority (TVA) facilities, including the Melton Hill Dam, the Bull Run Steam Plant, and the Kingston Steam Plant, are all more than 9.6 km (6 miles) from the Y-12 Plant.

Recreational areas near the ORR include the city of Oak Ridge parks (Big Turtle, Highland View, Briarcliff, LaSalle, Cedar Hill, Al Bissell, Elm Grove, Milt Dickens, and Scarboro); roadside parks including Elza Gate, Melton Lake, and Solway; the city of Oak Ridge swimming pools (indoor and outdoor) and sporting facilities (including tennis courts, baseball, and soccer fields); South Hills and Country Club golf courses; Watts Bar Lake Embayment/Clinch River waterway, which is used as a recreational area by both pleasure boaters and fishermen; a number of small camping areas and boat launching ramps including those at Melton Lake, Solway, and Clark Center Recreational Parks; a small dirt-surface racetrack located ~6.4 km (4 miles) south, which attracts several thousand spectators during the racing season; and public swimming areas at Melton Hill Dam and Solway and Clark Center Recreational Parks. There are no public recreational facilities, except the previously mentioned Clark Center Recreational Park within 3.2 km (2 miles) of the ORR. Sport hunting of game birds and game animals occurs seasonally in the region, and deer hunting is authorized on some parts of the ORR as a conservation measure.

The ORR lies within the corporate limits of the city of Oak Ridge. A buffer zone surrounds each of the facilities to provide security, space for expansion, and isolation from the general public. Tracts totaling ~5666 ha (14,000 acres) are allocated around operating reactors, waste disposal areas, and streams that receive routine waste releases and burial ground seepages. Acreage used for high-voltage transmission lines, pipelines, transportation corridors, and security fences amounts to ~2023 ha (5000 acres) (DOE 1982).

About 80% of the ORR is part of a comprehensive forest management program that divides the reservation into 27 compartments. These compartments range in size from 148 to 486 ha (365 to 1200 acres). Vegetational features unique to the area are excluded from timber harvest operations, and 40 individual sites are designated for environmental research.

The Y-12 Plant is situated at the eastern end of the ORR, adjacent to the commercial center of Oak Ridge, and contains ~324 ha (800 acres). Land uses associated with the Y-12 Plant facility include several waste storage or disposal areas, of which a parcel of ~61 ha (150 acres) serves as a sanitary waste landfill for solid wastes; ~26 ha (65 acres) located west

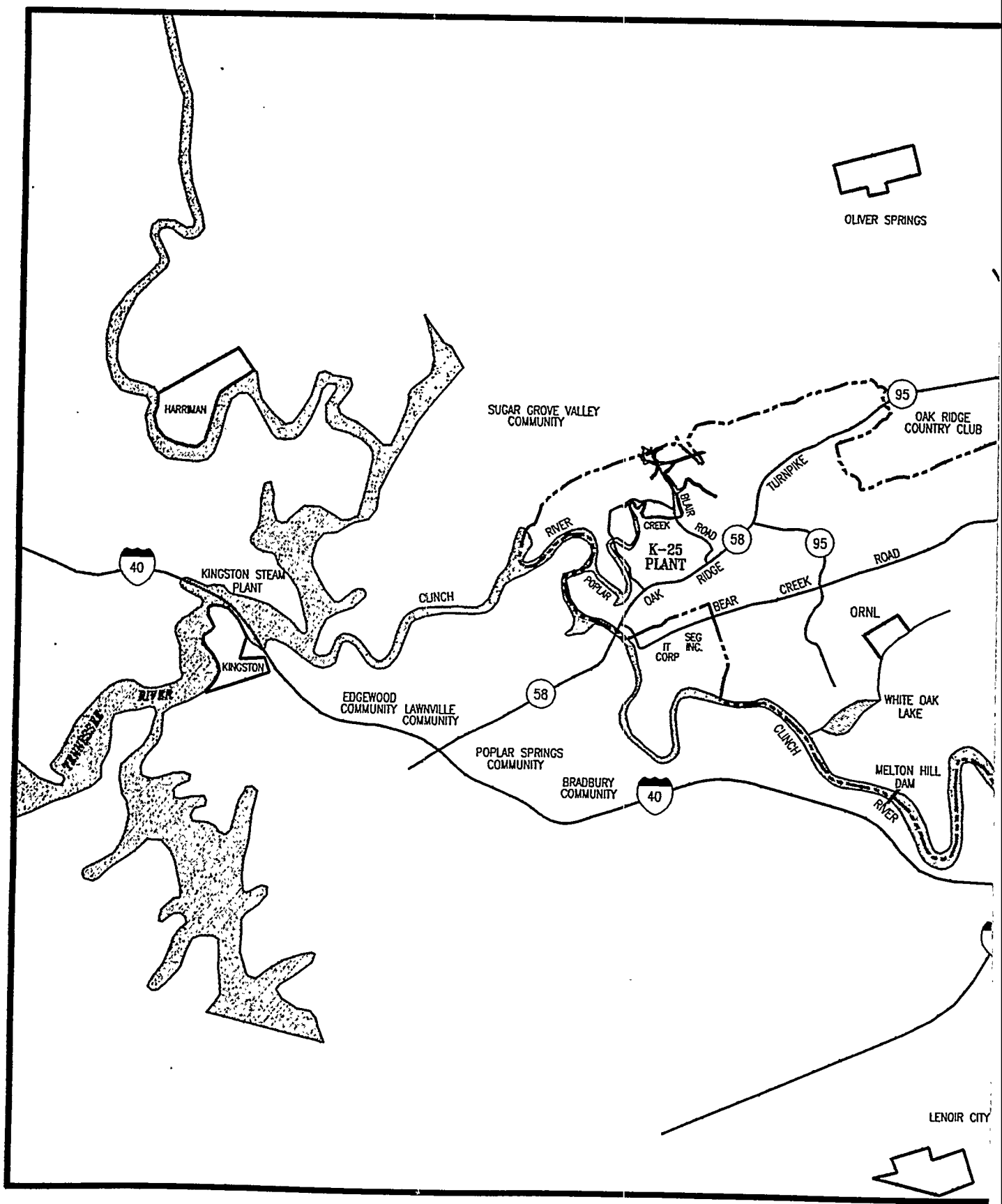
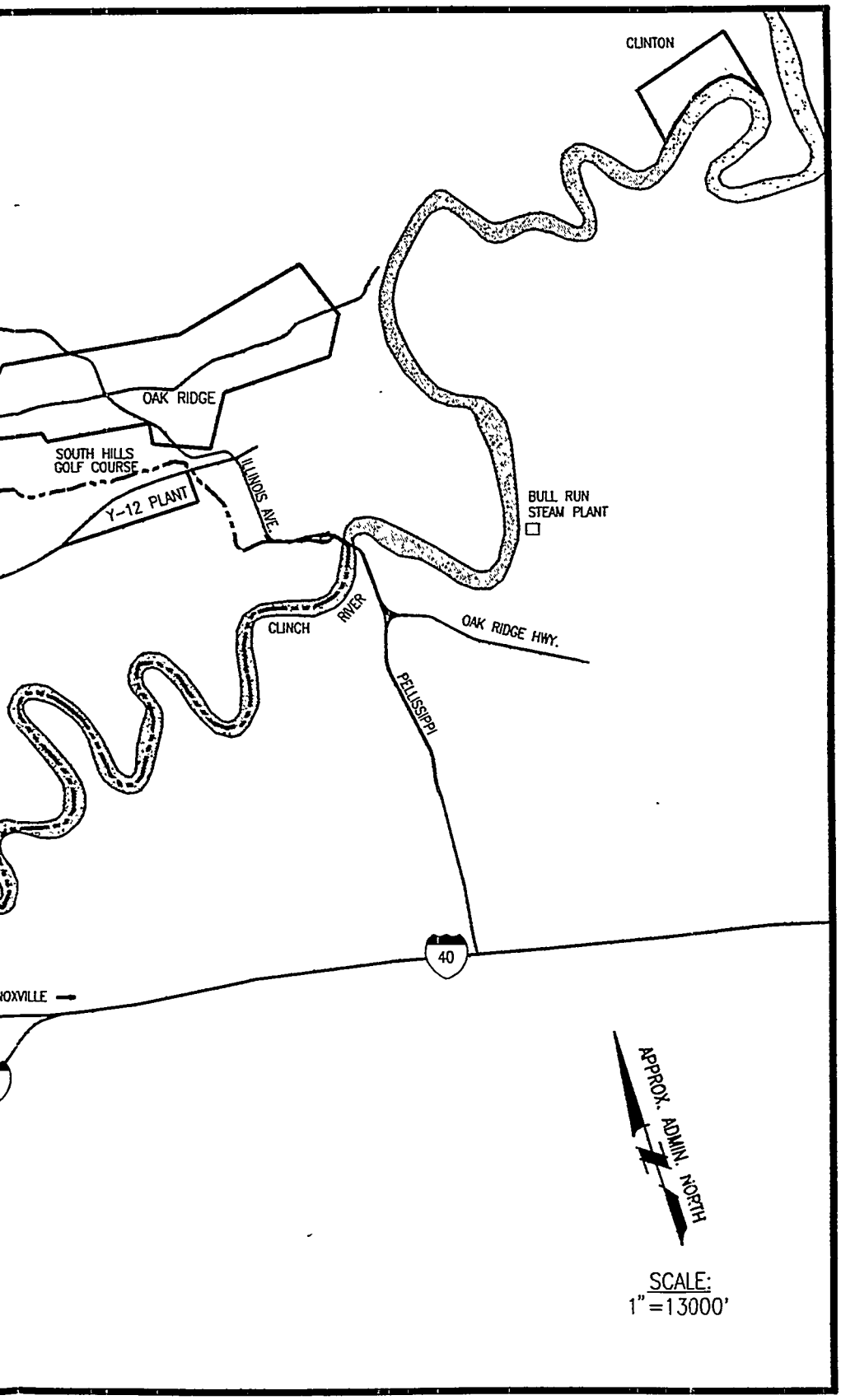


Fig. 2.3. The ORR and si



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Science Applications International Corporation

OAK RIDGE RESERVATION AND SURROUNDING COMMUNITIES

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rrounding communities.

of the main plant within the Bear Creek watershed is used as a burial ground for low-level radioactively contaminated solid wastes generated by the Y-12 Plant; and ~1.6 ha (4 acres) is an abandoned quarry outside the Bear Creek watershed that was formerly used as a disposal and dilution basin for selected nonradioactive chemical wastes, primarily sodium, lithium, and potassium from Y-12 Plant operations.

2.3 CLIMATE

Detailed discussions of climate can be found in Sect. 4.4 of Vol. I of the *RCRA Facility Investigation Plan General Document for the Y-12 Plant* (Welch 1989a) and in Sect. 3.1 of the *Clinch River RCRA Facility Investigation Plan* (Energy Systems 1990). Oak Ridge, Tennessee, is part of the southeast climatological region of the United States. This region is characterized by a moderate continental forest climate with mild winters [coldest month mean temperature above 0°C (32°F) but below 18°C (64.4°F)]. The Oak Ridge area has a temperate climate that is moderated by the Blue Ridge Mountains to the east and the Cumberland Plateau to the west.

Weather patterns in Oak Ridge are generally temperate, with warm, humid summers and cool winters. The annual mean temperature is about 15°C (58°F), with a January mean of about 3.5°C (38°F) and a July mean of about 25°C (77°F). Relative humidity in mid-afternoon averages about 55%. At night humidity is higher, averaging 85% at dawn.

Precipitation in this portion of the Tennessee Valley is seasonally distributed (McMaster 1967). The mean annual rainfall is ~136 cm (54.4 in.) (Fig. 2.4), but during the drought of 1981–88, yearly precipitation fell below this average value. Winter months usually have the most rain, with another peak in July, when thunderstorms are common. Autumn is usually the season of lowest rainfall.

Precipitation data from the Walker Branch watershed, which is located ~0.8 km (0.5 mile) south of BCV, were used to estimate rainfall in BCV during 1984. In January 1985, Energy Systems installed the Burial Grounds rain gauge to provide daily precipitation data. Comparisons between these gauges have generated confidence concerning the validity of transferring precipitation data between the two catchments.

Average loss of water to the atmosphere by evapotranspiration is ~76 cm (30.4 in.) annually in the Oak Ridge area, or ~55% of the total annual precipitation. Evapotranspiration is at a maximum from July to September, during the vegetative growing season. Runoff is greatest in the winter when evapotranspiration is at a minimum.

Prevailing winds in the area follow the general topography of the surrounding ridges (Fig. 2.5). The down-valley draft, coming from the northeast and identified with gravitational flow down local slopes and the Tennessee Valley, prevails during inversion conditions of late evening through mid-morning. Daytime up-valley flow is from the southwest when regional or synoptic flows aloft become strong enough to dominate the opposing local gravitational winds.

Oak Ridge is one of the country's calmest wind areas with an average wind speed of 7.1 km/h (4.4 mph). The Cumberland Plateau and the Great Smoky Mountains divert severe storms; local irregular ridges further minimize the air movement and wind impact.

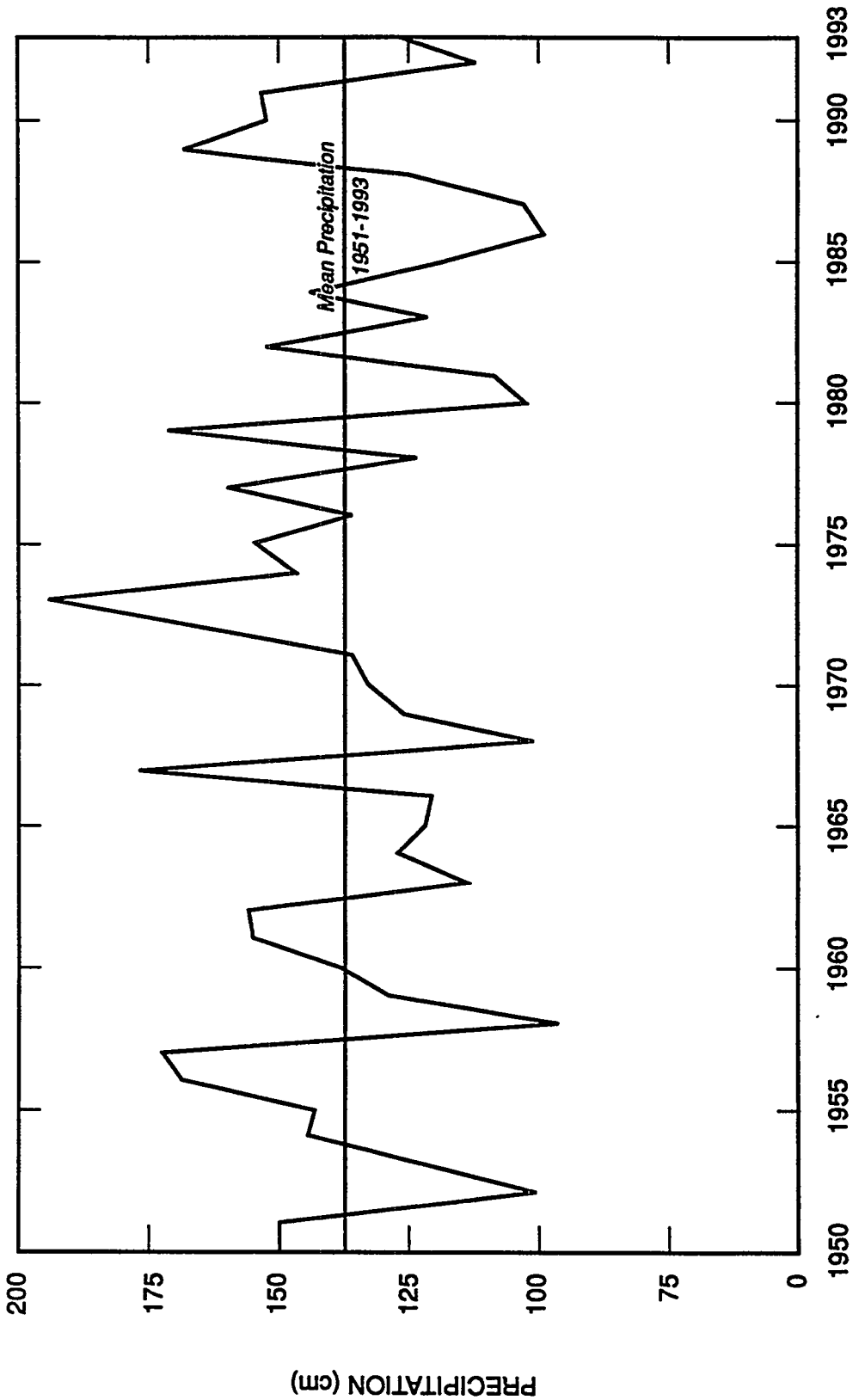


Fig. 2.4. Annual precipitation record for the Oak Ridge area.

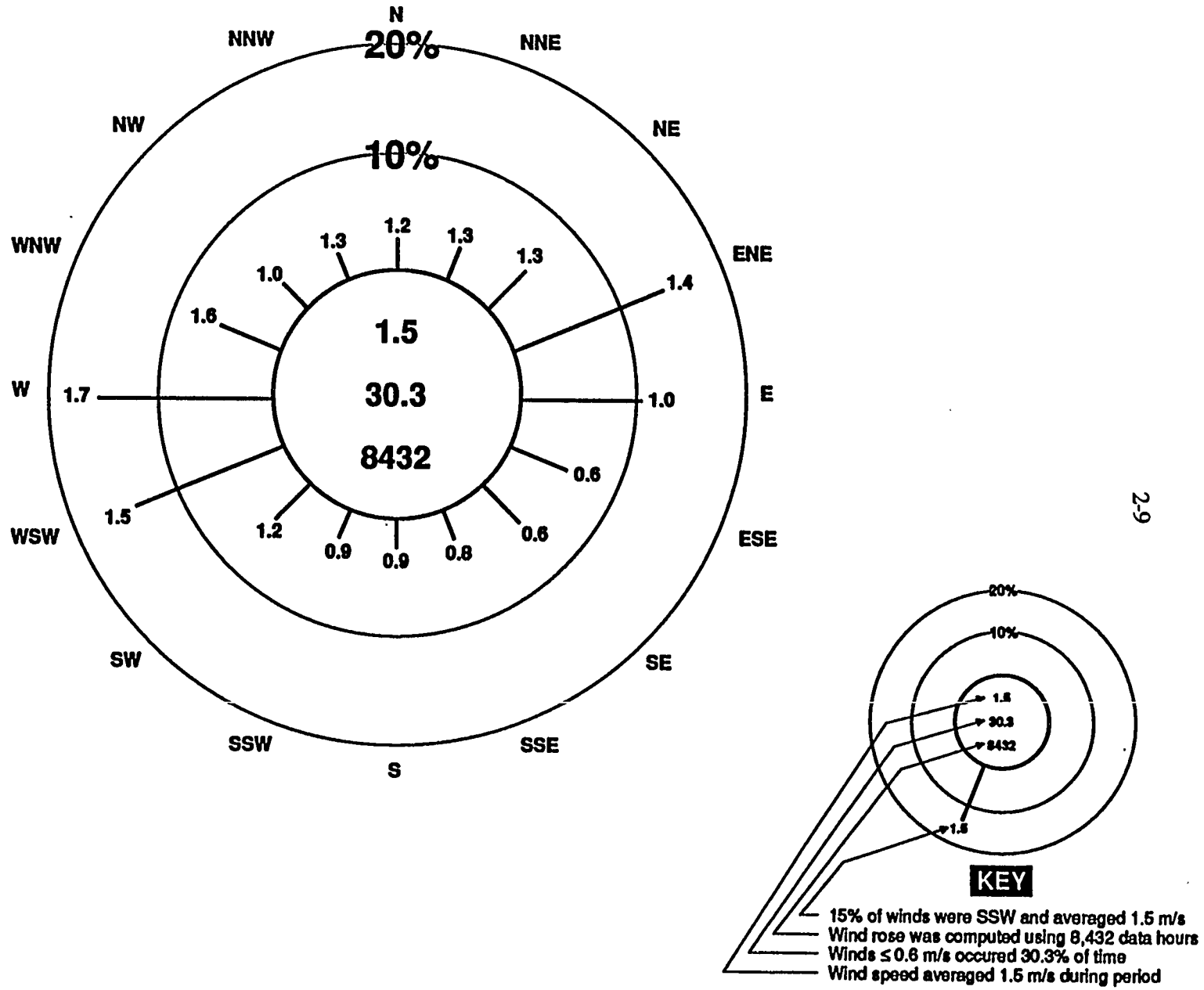


Fig. 2.5. 1993 wind rose for 10-m level at the west end of the Y-12 Plant.

2.4 TOPOGRAPHY, GEOLOGY, AND SOILS

2.4.1 Topography and General Geology

The DOE ORR, which includes BCV OU 2, is located in east Tennessee within the Valley and Ridge Physiographic Province, part of the Appalachian fold and thrust belt (Fig. 2.6). The area is characterized by a succession of east-west trending ridges and valleys, which formed as a result of differential erosion of the southeast dipping (locally 45° to vertical) clastic and carbonate lithologies that make up the individual thrust sheets.

OU 2 is located in BCV, which is bounded to the north and south (plant grid directions, plant grid is ~34° W of true north) by Pine Ridge and Chestnut Ridge, respectively. Maximum relief of the ridges is ~91 m (300 ft). The elevation of BCV is 325 ±17 m (975 ±50 ft) above mean sea level (MSL), and Pine Ridge and Chestnut Ridges have an approximate elevation of 400 ±17 m (1200 ±50 ft) above MSL. These ridges and valleys are part of the White Oak Mountain (WOM) thrust sheet, which exposes Lower Cambrian to Ordovician rock units in this area (Fig. 2.6). The stratigraphy of the area, from oldest to youngest (and exposed from grid-north to grid-south), includes the Lower Cambrian Rome Formation (exposed on Pine Ridge), the Cambrian Conasauga Group (exposed in BCV), and the Knox Group (exposed on Chestnut Ridge). The Conasauga Group, which underlies BCV OU 2, is further divided into six formations of alternating shale and carbonate-rich lithologies. From oldest to youngest, these are the Pumpkin Valley Shale, the Friendship Formation, the Rogersville Shale, the Dismal Gap Formation, the Nolichucky Shale, and the Maynardville Limestone (Table 2.3).

BCV OU 2 is primarily underlain by the Upper Cambrian Maynardville Limestone of the Conasauga Group. Sandy shales and siltstones of the Rome Formation underlie Pine Ridge to the north. Chestnut Ridge to the south is formed on siliceous dolostones of the Knox Group to the south. Bedrock throughout the valley is overlain by residuum deposits of varying thickness and composition. Geologic exposure is generally poor, and the locations of geologic contacts in BCV have been inferred for the most part from borehole data (Fig. 2.7) (HSW 1992).

2.4.1.1 Stratigraphy

The strata of greatest interest with respect to contaminant migration in groundwater in Bear Creek are the formations of the Knox Group and the Conasauga Group (Fig. 2.7), in particular the Maynardville Limestone Formation, which is considered part of the Knox aquifer (Solomon et al. 1992). The overlying residuum material, resting on the weathered bedrock surface, is in continuity with this aquifer. The Conasauga Group conformably overlies the Rome Formation, a sequence of interbedded sandstones, siltstones, and shales of variegated olive, maroon, and drab colors that form Pine Ridge. On the ORR, the Conasauga Group is characterized by an interfingering of carbonate and clastic facies. In the vicinity of BCV OU 2, the Maynardville Limestone formation of the Conasauga Group varies in thickness between 125 and 145 m (410 and 476 ft). The following discussion provides descriptions for the upper two formations of the Conasauga Group (Nolichucky Shale and Maynardville Limestone) and the Knox Group. For general descriptions of the stratigraphy of other units in the ORR, refer to Hatcher et al. (1992) for an overview of the ORR geology; to

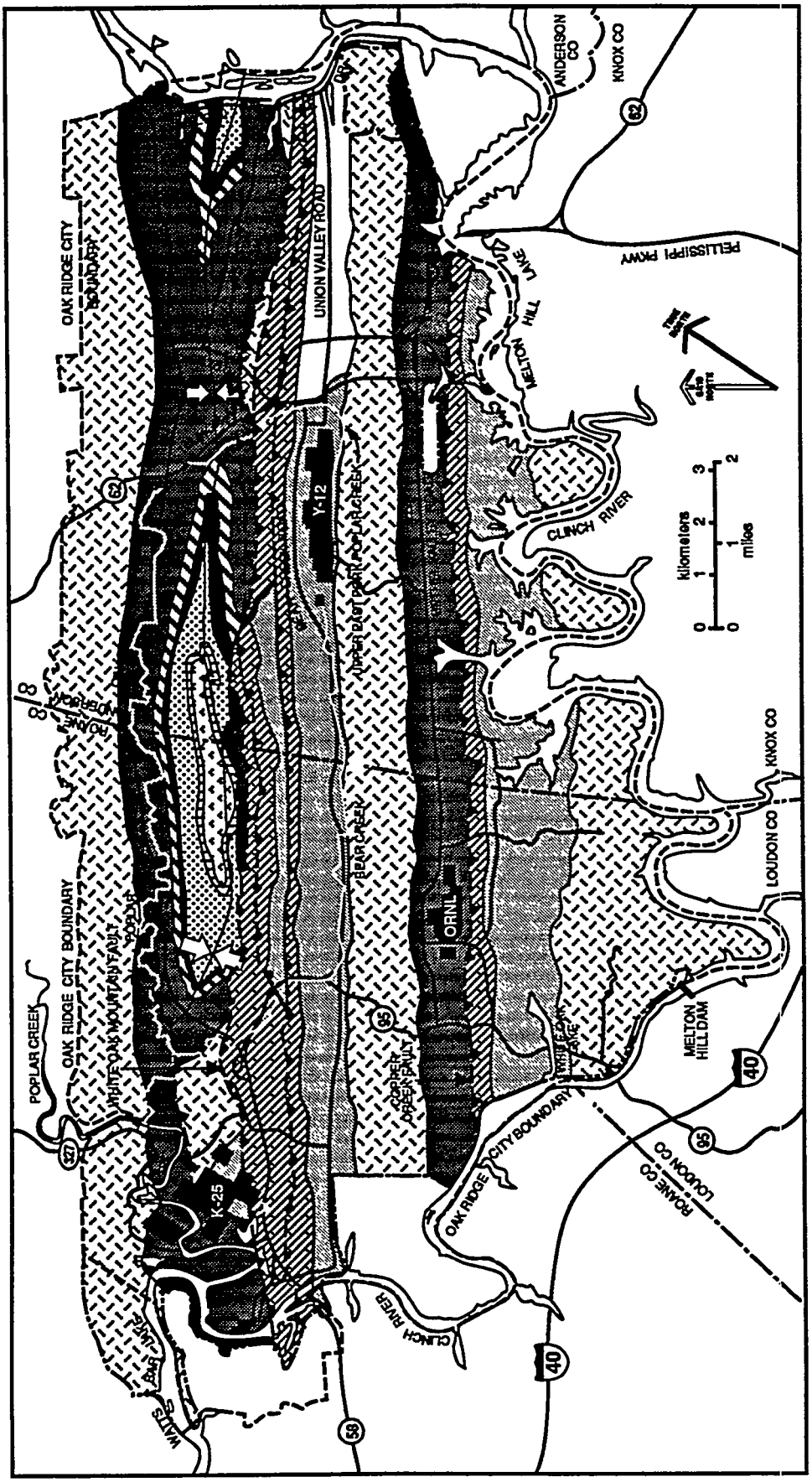


Fig. 2.6. Bedrock geology for DOE ORR.

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Table 2.3. Stratigraphy of the Y-12 Plant area

Age	Group or formation	Thickness[a] (m)	Lithology and outcrop	Aquifer/ aquitard
Upper Cambrian-Lower Ordovician	Knox Group	530–880	Massive dolomite, siliceous dolomite, bedded chert, limestone, some clastics; outcrop on Chestnut Ridge	Knox Aquifer
Middle to Upper Cambrian	Conasauga Group (outcrops in the center of BCV and on the south slope of Pine Ridge)			
	Maynardville Limestone	125–145	Dolomitic limestone, limestone	Part of the Knox Aquifer
	Nolichucky Shale	100–150	Shale, limestone	Aquitard
	Dismal Gap Formation[b]	95–120	Limestone, shale	Aquitard
	Rogersville Shale	20–35	Mudstone, shale	Aquitard
	Friendship Formation[c]	30–40	Calcareous shale, limestone	Aquitard
	Pumpkin Valley Shale	90–100	Shale, siltstone, occasional sandstone	Aquitard
Lower Cambrian	Rome Formation	90–125	Shale, siltstone, sandstone, local dolomite lenses; outcrops on Pine Ridge	Aquitard

[a]Only thicknesses of formations at the Y-12 Plant are given.
[b]Formerly the Maryville Limestone.
[c]Formerly the Rutledge Limestone.
Source: Hatcher et al. 1992.

Haase, Walls, and Farmer (1985) for the Conasauga Group and Rome Formation; to Lee and Ketelle (1987) for the Knox Group; and to Lee and Ketelle (1988) for the Chickamauga Group.

Nolichucky Shale (Foreman et al. 1991; Rothschild et al. 1984). Located immediately north of BCV OU 2, the Nolichucky Shale ranges in thickness from 161 to 168 m (528 to 550 ft) (King and Haase 1987). Shale interbedded with intraclastic limestone, thick fossiliferous limestone, and oolitic limestone is characteristic of the Nolichucky Shale in the WOM thrust sheet. Shale is the dominant lithology with an approximate shale to limestone ratio of 1:1.75. The Nolichucky Shale Formation can be subdivided into four zones based on dominant lithologies: (1) thrombolytic limestone overlying oolitic limestone and lime mudstone in the uppermost Nolichucky; (2) laminated peloidal packstone, lime mudstone, and shale as the most abundant lithologies toward the top of the Nolichucky Shale; (3) allochthonous oolitic and skeletal packstone and grainstone interbedded with shale as the dominant lithologies in the middle Nolichucky Shale; and (4) intraclastic limestone interbedded with shale and calcareous siltstone as the dominant lithologies in the lower

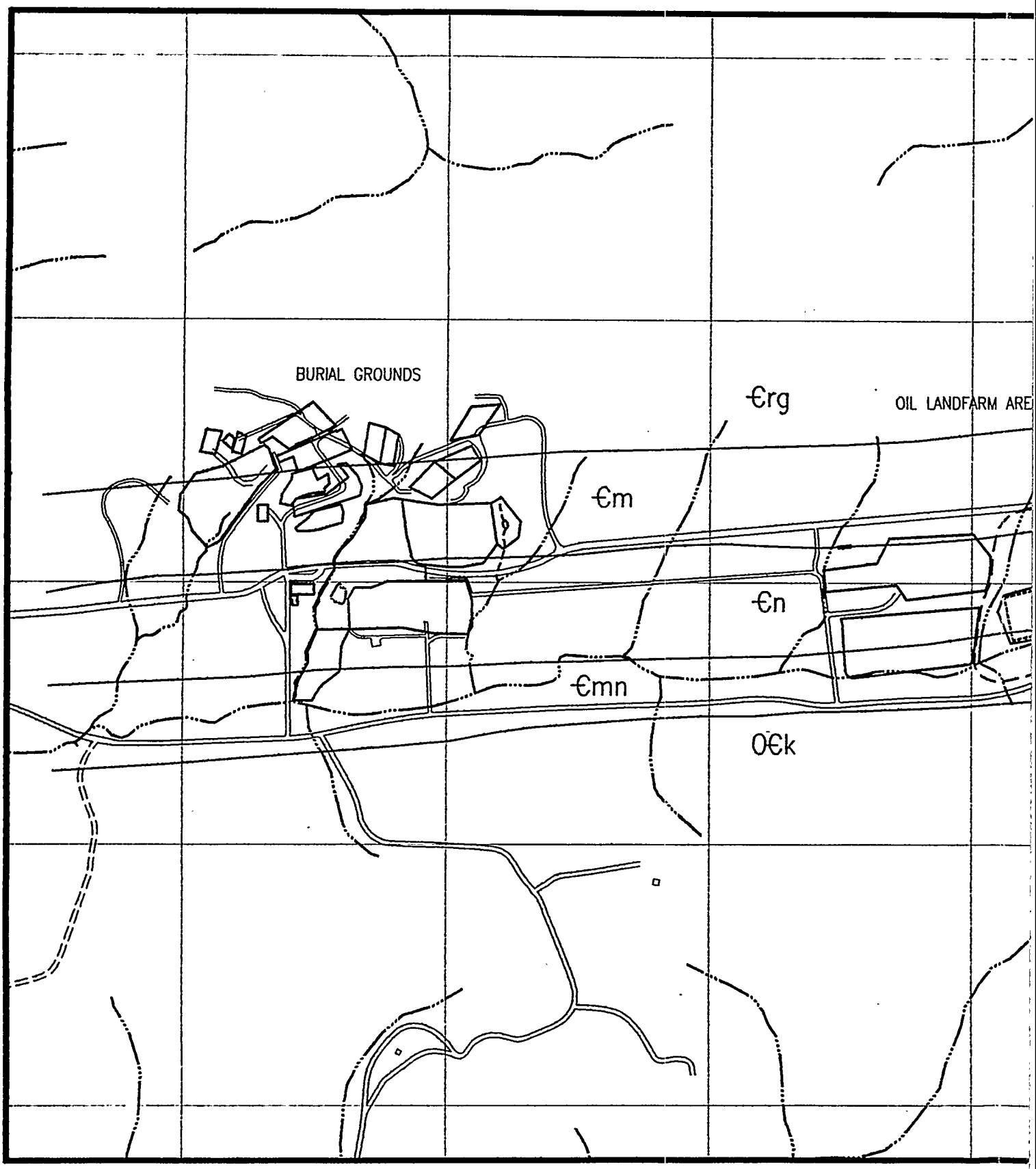
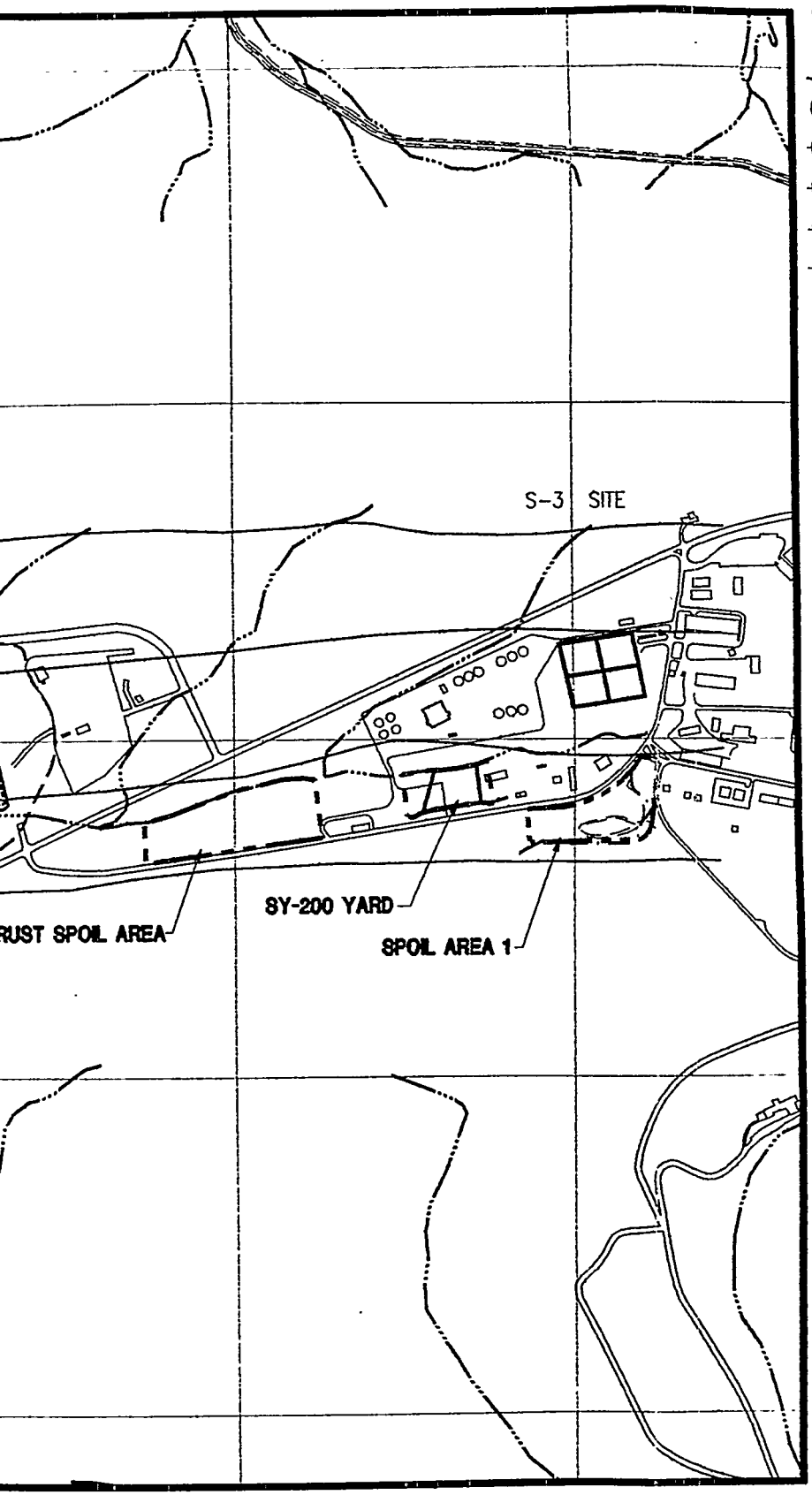


Fig. 2.7. Bedrock geology in



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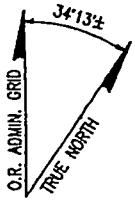
O€k.....KNOX GROUP

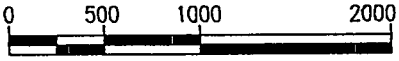
€mn.....MAYNARDVILLE LIMESTONE

€n.....NOLICHUCKY SHALE

€m.....MARYVILLE LIMESTONE

€rg.....ROGERSVILLE SHALE





SCALE: 1" = 1000'

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CV (*Source:* HSW 1992).

Nolichucky Shale (Foreman et al. 1991). The formation is massive to very thinly bedded and is characterized by a maroon-brown color. The interbedded limestones typically contain limestone-pebble conglomerates and oolite-rich beds similar to those occurring in the underlying Dismal Gap Formation. Throughout much of the Nolichucky Shale, mudstone/ shale and limestone lithologies alternate on a scale of 0.3 to 0.9 m (1 to 3 ft), giving the formation a thickly bedded appearance.

During drilling at the Y-12 Plant, solution cavities, opened fractures, and iron precipitate were commonly observed at downhole depths of up to 15 m (50 ft) in the Nolichucky Shale (Rothschild et al. 1984). A comparison of Maynardville Limestone and Nolichucky Shale descriptions suggests the solution cavity development is not as extensive in the Nolichucky Shale as it is in the Maynardville Limestone. Upon weathering, the Nolichucky Shale develops a brown-to-yellow-colored, clay-rich soil containing shale chips.

Maynardville Limestone (Shevenell, Dreier, and Jago 1992). Directly underlying the OU 2 sites, the Maynardville Limestone is the youngest formation of the Conasauga Group and consists primarily of light-gray to tan, massive to thinly bedded limestone with subordinate amounts of dolostone. Data obtained from the ongoing Maynardville Exit Pathway Monitoring Program demonstrate that on the ORR, the Maynardville is more uniformly dolomitic and exhibits more subtle vertical lithologic differentiation than that described in the type section. In BCV, the Maynardville Formation varies in stratigraphic thickness from 70 to 136 m (230 to 445 ft). The Exit Pathway Monitoring Program subdivided the Maynardville into six different informal lithologic zones and identified a seventh zone to mark the transition between the Maynardville Limestone and the overlying Copper Ridge Dolomite. The zones were divided based on the gamma log signatures and associated lithological characteristics of the individual zones.

The transition zone (Zone 7) represents the contact between Copper Ridge Dolomite and the Maynardville Limestone. The dolomitic zone is ~6.6 m (20 ft) thick and contains lithologies characteristic of both the Copper Ridge Dolomite and the Maynardville Limestone. The contact is gradational and is marked by a sudden appearance of chert in the Copper Ridge Dolomite and the appearance of vugs in the uppermost Maynardville Lime-stone. Zone 6 is a dolostone with coarsely crystalline saccharoidal texture and contains an increase in vugs. The zone has an average thickness of 100 ft. Zone 5 is characterized by the presence of thin shale stringers that occur throughout the ~18-m (54-ft) zone. Zone 4 has an average thickness of 105 ft and is recognized as a massive, light-colored, medium to coarsely crystalline sparite, with subordinate amounts of oosparite. Zone 3 is 79 ft thick and characterized by an increase in mottling. It is described as a continuation of Zone 4 with a fine to medium crystalline, massive to slightly mottled sparite. Zone 2 is characterized by a change from mottled, stylolitic micrite and oosparite to a finely crystalline, light-colored sparite exhibiting thin, discontinuous, wisp-like, shale partings. Although the thickness can vary considerably, the average thickness is ~50 m (150 ft).

The Maynardville Limestone occurs on the northern flanks of Chestnut Ridge and extends to the BCV axis. Much of the groundwater flow through the Maynardville Limestone is controlled by solutionally enlarged fractures and joint sets. Three major joint sets have been identified within the Maynardville Limestone: (1) approximately parallel to geologic strike and along bedding planes; (2) approximately perpendicular to geologic strike N10W and dipping steeply; and (3) parallel to strike and perpendicular to bedding planes (Rothschild et al. 1984; Dreier, Solomon, and Beaudoin 1987). Dissolution along joints, fractures, and bedding planes

in the Maynardville Limestone has formed solutionally enlarged zones and, in some cases, relatively large cavities that have greatly increased the overall permeability of the unit. The larger solution cavities generally occur in the upper part of the saturated zone. A combination of factors, such as structure, depth, and lithology, affect the fracture and water level distribution in the Maynardville Limestone. In general, however, the greatest likelihood of intersecting a cavity in the Maynardville Limestone occurs within Zone 6, whereas Zone 3 appears to be the least likely to contain cavities. Most of the cavities in Zones 6 through 2 were located at depths of <30.5 m (100 ft), suggesting that the active karst system may be relatively shallow in the Maynardville Limestone.

Knox Formation (Hatcher et. al 1992). The Knox Group underlies Chestnut Ridge on the ORR. The Knox Group in eastern Tennessee and adjacent states is divisible into five formations: the Cambrian Copper Ridge Dolomite, Ordovician Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite. Total thickness of the Knox Group ranges from 700 to 1000 m (2000 to 3000 ft) in eastern Tennessee, with the Copper Ridge Dolomite making up roughly one-third of the total. Lee and Ketelle (1987) studied the lower Knox Group rocks on Chestnut Ridge southeast of the Oak Ridge Y-12 Plant, along with the upper Knox in the same belt toward the southeast, and were able to characterize some of the depositional environments of those parts of the Knox.

The Upper Cambrian Copper Ridge Dolomite was named for exposures on Copper Ridge in northeastern Tennessee and southwestern Virginia. It consists dominantly of massively bedded cherty dolomite with beds ranging from 20 to 70 cm (7.8 to 27 in.) thick. The Copper Ridge Dolomite is characterized by medium to coarsely crystalline, thick-bedded dark brownish-gray saccharoidal dolomite that gives off a fetid (petroliferous) odor on fresh surfaces. This lithology dominates the lower two-thirds of the unit, but, toward the top, the medium-to-light-gray, fine-grained, medium-to-thick-bedded dolomite typical of the entire Knox Group is more common. Chert is also more common in the upper part.

The Copper Ridge is a siliceous unit, a common ride former in the Valley and Ridge, characterized by the presence of bedded oolitic chert, in which the ooids are concentrically banded with interlayered light-tan and dark-brown-to-black rings, with the dark rings dominant, and dark-gray to black algal cryptozoon chert that has a waffle iron appearance on weathered bedding surfaces and resembles cabbage heads in cross section. Most of the ooids are spherical, but oval or flattened shapes are also present. Quartz sandstone beds up to 20 cm thick cemented by either quartz or dolomite are common in the upper part of the formation, particularly at the top, and a 10-cm-thick zone of sandstone may occur at the base. Other varieties of nodular and massive bedded chert may be present in the Copper Ridge that occur throughout the Knox Group. Soils commonly are cherty and colored orange to tan to light gray; noncherty soils are colored deep red. The Copper Ridge is ~250 to 350 m (800 to 1100 ft) thick.

2.4.1.2 Structural geology

The Oak Ridge area is underlain by two major northeast/southwest trending thrust faults that dip to southeast and define thrust sheets (Hatcher et al. 1992) (Figs. 2.6 and 2.8). Pine Ridge, BCV, and Chestnut Ridge all are part of the WOM thrust sheet, which is soled by the WOM thrust fault. The WOM fault is a regional thrust fault of the Valley and Ridge, which demonstrates at least several kilometers of translation. The fault formed during the Permian-Pennsylvanian age Alleghanian Orogeny and has not been historically active. At the ORR,

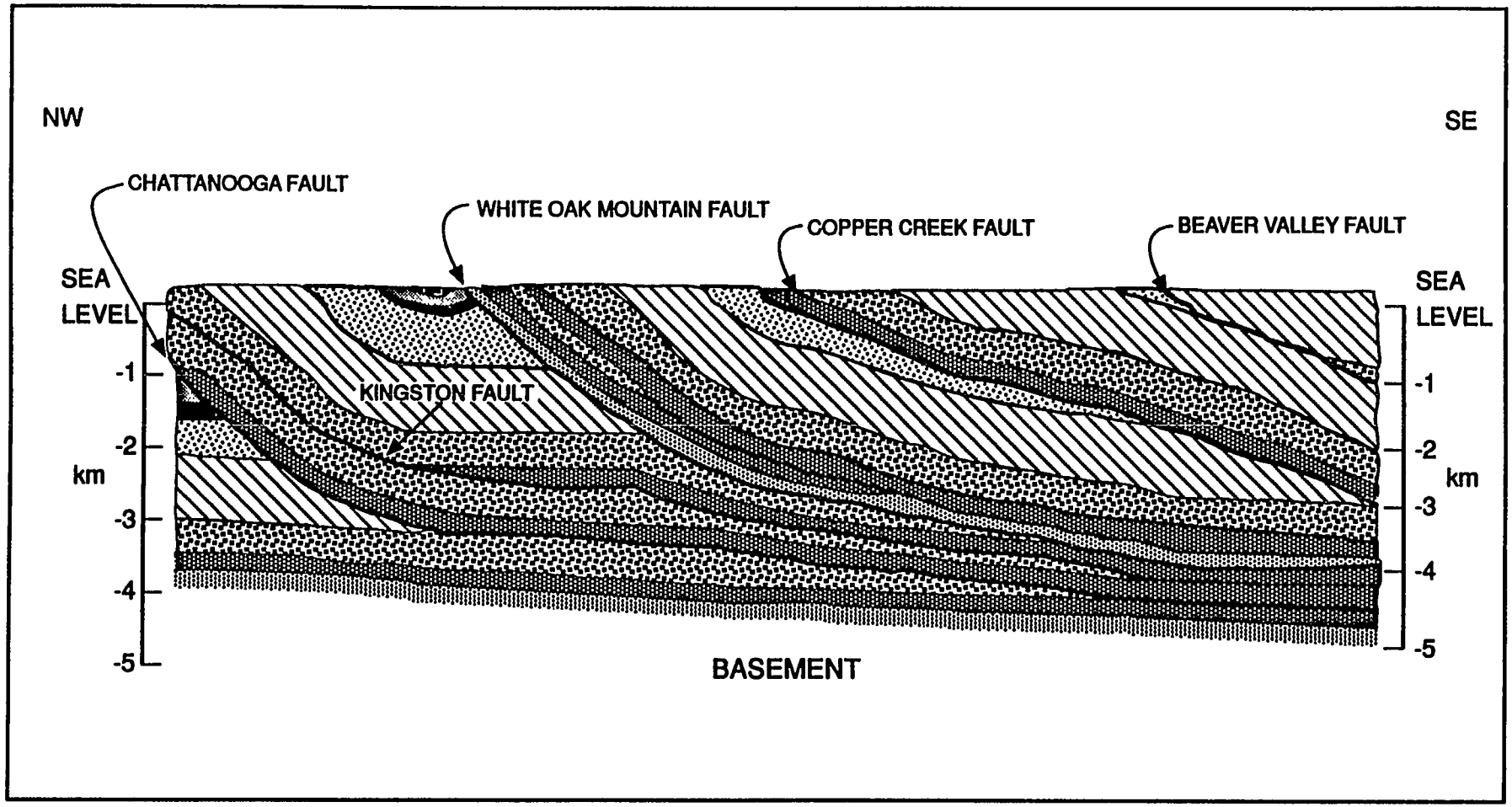


Fig. 2.8. Geologic cross-section based on seismic line on Tennessee 95 (*Source:* Hatcher et al. 1992).

the fault trends parallel to regional strike (N55E) and dips steeply (45°) to the southeast (King and Haase 1987). Bedding plane dip values measured in outcrops cluster around 45° but may steepen to vertical as a result of localized small-scale folding or faulting. Elevations within the study area range from 222 to 390 m (740 to 1300 ft) above MSL.

The WOM thrust fault north of Pine Ridge is very complex and is characterized by a sequence of cross-cutting imbricate fault splays that repeatedly stack the Rome Formation. In the vicinity of Bear Creek, this fault superposes the Cambrian Rome Formation over the younger Cambrian Copper Ridge Dolomite member of the Knox Group. In addition, north of the WOM thrust fault, in the underlying Kingston thrust sheet, Bear Creek flows over slices of the Knox Group and Chickamauga Group that have been complexly stacked and rotated as a result of footwall deformation associated with displacement along the WOM fault. Because of the complex deformation associated with the WOM thrust fault and the immediately underlying Kingston sheet, it is anticipated that this region contains numerous fault-related fracture zones forming areas of enhanced permeability.

Bear Creek is characterized by numerous cross-strike streams that have a consistent north/south trend and are fairly evenly spaced along the valley, usually between 366 to 610 m (1200 to 2000 ft) apart. Such a consistent orientation suggests that the location of these creek beds may be controlled by geological structural features, such as minor tear faults or a prominent fracture trend. Both features are possible, and in Melton Valley, the White Oak Creek Tear Fault shows a similar north trend. If these structures are faults, they show minor displacement but may have produced an associated fracture zone.

Fractures. Because of the large-scale faulting, all geologic units in the ORR are highly fractured. Detailed investigations of Conasauga Group core by Lutz and Dreier (1988) show that five fracture sets occur consistently throughout the unit. One set is parallel to bedding, but the other four are generally perpendicular to bedding. The parallel bedding fractures are mainly release joints. Recent studies elsewhere in the Appalachians suggest that release joints can form at depths up to a kilometer (0.6 mile) (Engelder 1985). Assuming a regional strike of N55E, the strikes of the high angle sets are approximately N55E, N75W, N15E, and N20W.

Fracture density varies throughout the cores. The two variables that have the greatest effect on density are lithology and bedding thickness. Density is inversely proportional to bedding thickness. High fracture densities are found in shales and interbedded limestone and shale, whereas limestones exhibit lower densities. Mineralization of fracture planes is almost entirely confined to limestone beds. All fracture sets exhibit vein development; however, the N55E direction is the most commonly mineralized.

2.4.2 General Soil Characteristics

Unconsolidated material overlying bedrock in the BCV consists of weathered bedrock (referred to as residuum), man-made fill, alluvium, and colluvium (Petrich et al. 1984). Residuum comprises most of the unconsolidated material in this area. The depths to unweathered bedrock differ throughout the valley because of the different thicknesses of fill and alluvium and the particular weathering characteristics of the bedrock units (Geraghty and Miller 1985). The total thickness of these materials in the BCV typically ranges from 3 to 15 m (10 to 50 ft) (Hoos and Bailey 1986). Figure 2.9 shows the generalized distribution of different unconsolidated material types in BCV.

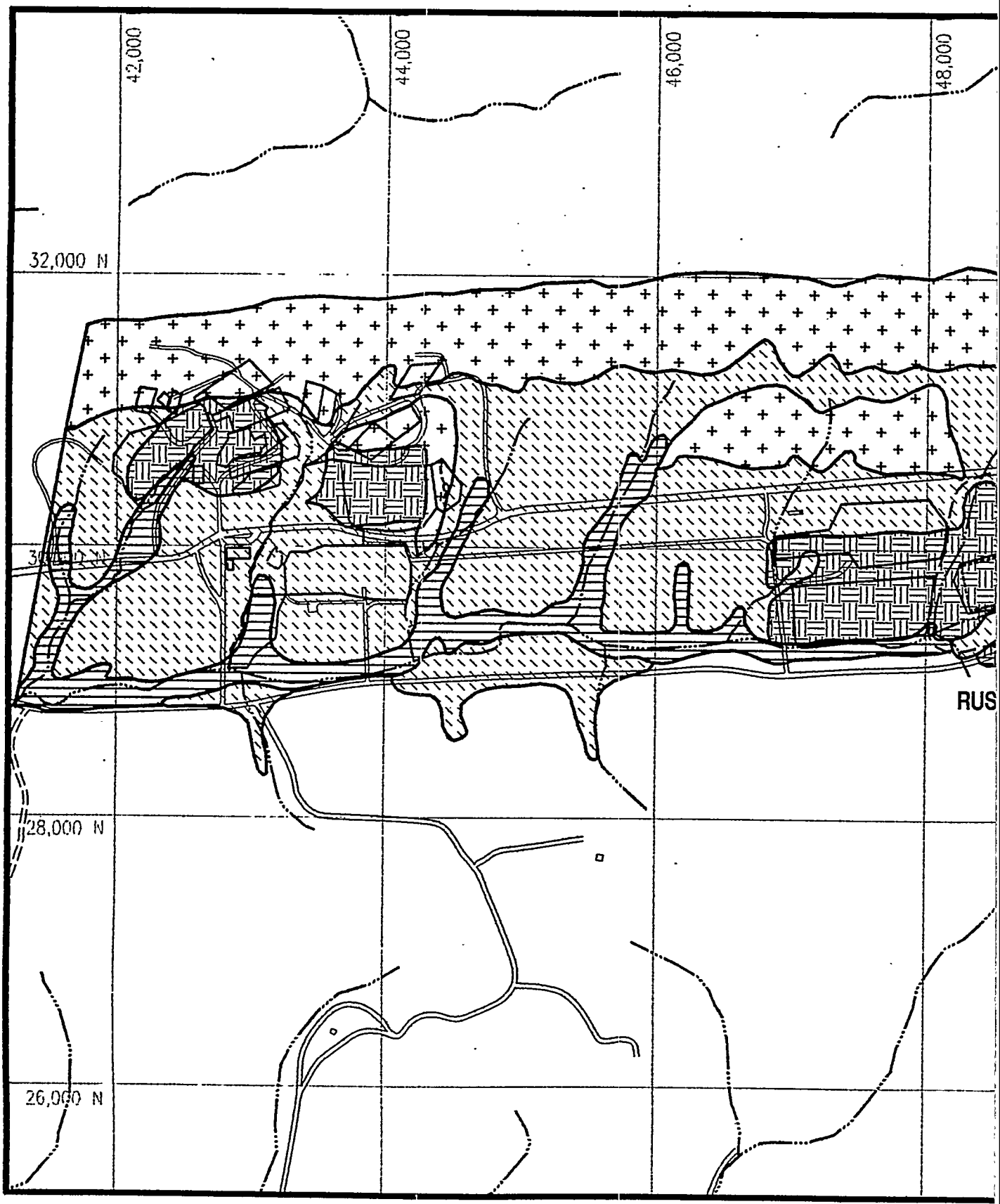
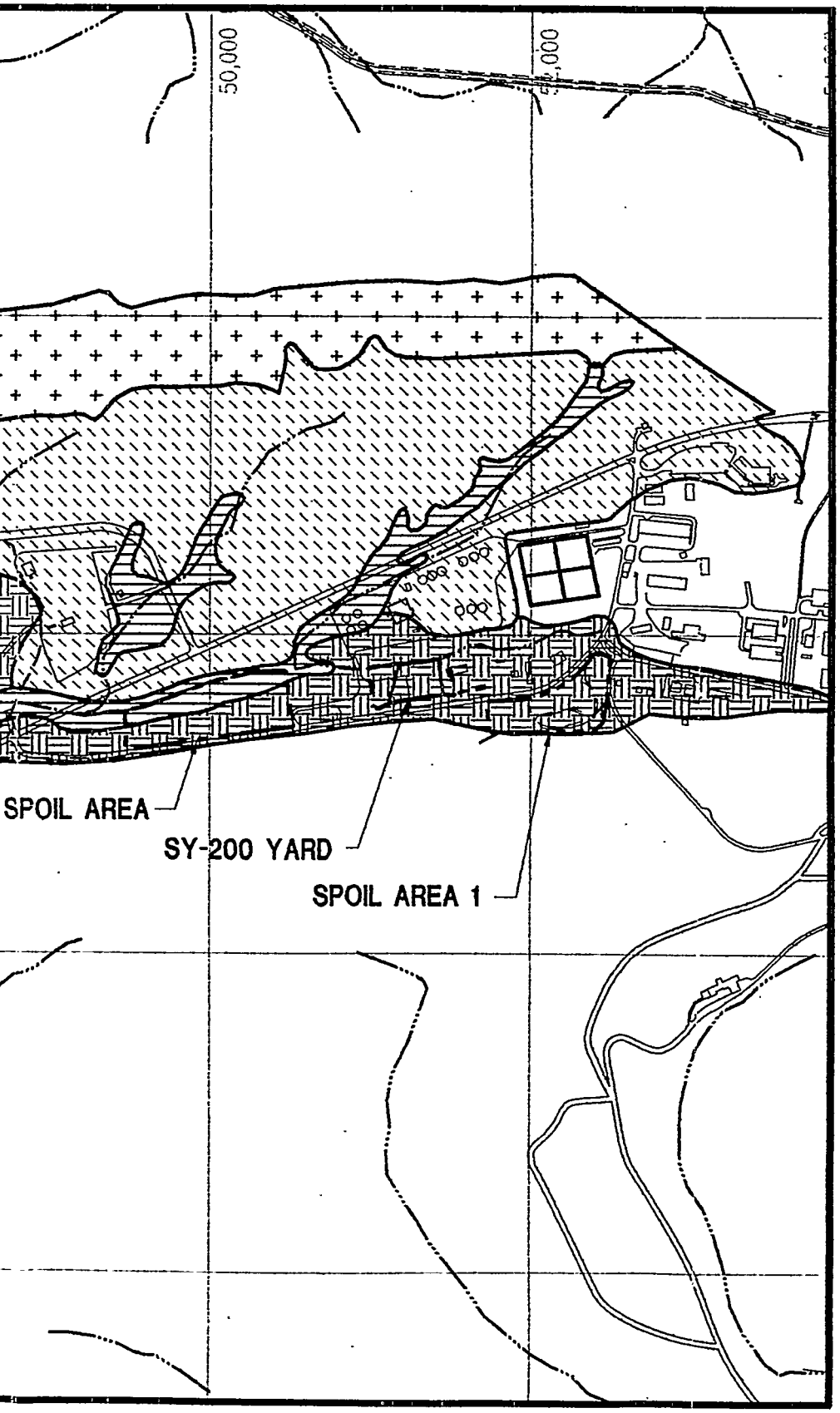


Fig. 2.9. Generali



LEGEND:

- UPPER SLOPE SOILS
- LOWER SLOPE SOILS
- FLOODPLAIN SOILS
- FILL MATERIAL

34°13'4
O.R. ADMIN. GRID
TRUE NORTH

0 500 1000 2000

SCALE: 1" = 1000'

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d soils map for Upper BCV.

Much of the fill material consists of asphalt, cement blocks, wire, wood, plastic, excavated weathered shale, limestone, and chert intermixed with clay. In many places, a relict soil horizon has been noted below the fill. Rothschild et al. (1984) gives the following description of fill material in the subsurface at the Y-12 Plant: "Color ranges from grey to red brown to yellow brown and dark brown. Generally, it contains angular gravel-sized clasts of dolomite and weathered shale up to 2 in. across mixed with clay. In some cores, pieces of asphalt, wood roots, and wire are found in the fill. The percentage of dolomite and shale clasts varies greatly and ranges up to ~90% in thin (less than 4 in.) zones. The shale clasts are often stained by manganese oxide and exhibit bedding structure. In some cores, the upper part of the fill is composed dominantly of dolomite clasts, and is highly porous and very unconsolidated. Compactness and consolidation of the fill increases with depth."

Alluvium is present in Bear Creek and its tributaries along present and former stream courses. The alluvium typically is an organic clayey silt with minor amounts of sandy clay, chert, and limestone pebbles. A thin layer of colluvium has been observed at the base of Pine Ridge and Chestnut Ridge in some areas. The colluvium is predominantly a clayey silt containing weathered rock fragments.

Residuum overlies bedrock throughout the valley except in scattered outcrop areas and ranges from silty to sandy clay overlying shale units to a slightly sandy clay overlying limestone units; predominant colors are shades of brown, orange, and grey. With increasing depth, the colors darken and the clay grades to weathered rock that has retained its structural characteristics (saprolite). Bedding planes and joint surfaces in the weathered bedrock commonly are marked by dark reddish-brown and yellow-brown oxide coloration, indicating a high degree of weathering by circulating groundwater (Rothschild et al. 1984).

2.4.2.1 Soil characteristics

As described in Sect. 2.4.1.1, the BCV OU 2 sites are predominantly underlain by the Upper Cambrian Maynardville Limestone. However, the presence and extent of virgin soils below the OU 2 site are not well known due to the extensive excavation and filling that took place during its operational lifetime. Aerial photographs and discussions with plant personnel indicate that most if not all of this fill material was taken from the adjacent north-facing slope of Chestnut Ridge (see Sect. 3.1). As stated in Sect. 2.4.1.1, Chestnut Ridge is underlain by the Upper Cambrian–Lower Ordovician Knox Group. The lower-most member of the Knox is the Copper Ridge Dolomite, the residuum of which formed the Copper Ridge soils.

The residuum of Copper Ridge Dolomite has high silt plus clay content and highly variable chert content. A Background Soil Characterization Project (BSCP) was recently completed for the ORR (DOE 1993). Descriptions of the Copper Ridge Horizon C from sample locations near the OU 2 site indicate that the residuum is red to mottled red and yellow or yellowish brown cherty clay and clay-plugged saprolitic materials. The soil characterization is typically Paleudults to Hapludults; clayey, kaolinitic to mixed, and thermic.

Detailed lithologic logs from historical soil borings at the OU 2 site provided much of the existing soils information for the site; these logs are included in Appendix A along with the lithologic logs from the current RI soil borings at RSA and the SY-200 Yard and groundwater well installations at SA-1. To determine an appropriate background soil for comparison with BCV OU 2 data, the Data User Guidelines from the BSCP report were

followed. Specifically, the BSCP states that "if the sample was collected from fill materials or cover above waste trenches, and if you can identify the geologic formation source of those soil materials, then compare data with the appropriate C Horizon data. If the fill material came from Chestnut Ridge or from Melton Hill on the ORR, then you should be able to use the appropriate C Horizon data from the Copper Ridge or Chepultepec formations or the Knox (Group)." The C Horizon or substratum is defined as that depth (3 ft or more below the surface) in the soil where there is minimal evidence of translocated clay and where there is minimal expression of pedogenic soil structure. The sampling depth to the Copper Ridge C Horizon at BSCP sample locations closest to the OU 2 site ranged from 100 cm to 170 cm (40 in. to 68 in.) (DOE 1993).

Based on the comparison of lithologic logs and description of soil types provided in the BSCP and the evidence that most of the fill material was taken from Chestnut Ridge, the soil found at the OU 2 site is consistent with the Copper Ridge Horizon C soils. Tables 2.4 and 2.5 contain a summary of current soil background data for the Knox Group (which includes the Copper Ridge) Horizon C taken from the final BSCP report (DOE 1993). Chemical and physical properties for the Knox Group soils are given in Tables 2.6 and 2.7.

2.5 GROUNDWATER

2.5.1 Bear Creek Hydrologic Regime

The groundwater system for the Bear Creek Hydrologic Regime (BCHR) generally consists of four parts: the stormflow zone, vadose zone, groundwater zone, and the aquiclude. Contamination affecting groundwater moving through the stormflow and vadose zones is considered in the RI for each source unit in BCV OU 2. The following are descriptions of the subsections of the hydrological conceptual model for the ORR with the groundwater subsection emphasized (Fig. 2.10). Thorough discussions of the hydrological conceptual model can be found in Moore (1988), Solomon et al. (1992), and Moore and Toran (1992), from which the following is summarized.

2.5.1.1 Stormflow zone

Detailed water budgets indicate that ~90% of active subsurface flow occurs through the 1- to 2-m (3.3- to 6.6-ft) deep stormflow zone (Fig. 2.10) (Moore 1988; Solomon et al. 1992). Natural areas of the ORR are heavily vegetated, and the stormflow zone corresponds approximately to the root zone. Infiltration tests indicate that this zone is as much as 1000 times more permeable than the underlying vadose zone. According to this conceptual model, during rain events, the stormflow zone partially or completely saturates and then transmits water laterally to the surface water system. When the stormflow zone becomes completely saturated, overland flow occurs.

Between rain events, as the stormflow zone drains, flow rates decrease dramatically and flow becomes nearly vertical toward the underlying vadose zone. The transmissive capability of the stormflow zone is created primarily by root channels, worm holes, clay aggregation, fractures, etc., collectively referred to as large pores. Although highly transmissive, large pores comprise only ~0.2% of the total void volume of the stormflow zone. Because most of the water mass resides within less transmissive small pores, advective-diffusive exchange between

Table 2.4. Summary statistics for Knox Group (which includes Copper Ridge) Horizon C inorganics on the ORR (*Source:* DOE 1993a) (Estimates and confidence bounds are in milligrams per kilogram)

Analyte	N[a]	I[b]	D[c]	Median	UCB95[d]	X95[e]	LCB9595[f]
Aluminum	8	0	8	17700	19200	22000	20100
Antimony	8	0	0	–	–	–	–
Arsenic	7	0	7	45.00	67.50	131.0	80.90
Barium	8	0	8	17.5	24.0	43.0	29.3
Beryllium	8	0	5	0.662	0.792	1.020	0.832
Boron	8	1	1	2.57	5.64	10.40	4.96
Cadmium	24	0	0	–	–	–	–
Calcium	7	0	7	214	322	633	386
Chromium	8	0	8	27.9	31.4	39.0	33.8
Cobalt	8	0	4	3.38	6.17	15.90	8.2
Copper	8	0	7	26.1	30.20	39.0	32.80
Cyanide	13	0	0	–	–	–	–
Iron	8	0	8	37700	40400	45900	42200
Lead	8	0	8	26.6	36.2	63.7	43.9
Lithium	8	1	5	6.26	8.20	12.60	9.14
Magnesium	8	0	8	576	677	910	749
Manganese	8	0	8	138	237	641	333
Mercury	8	0	8	0.2000	0.2360	0.3220	0.2580
Molybdenum	8	1	5	2.93	3.75	5.55	3.87
Nickel	8	0	7	17.70	21.20	29.5	23.70
Potassium	8	0	8	983	1150	1550	1270
Selenium	7	0	6	0.689	1.030	1.970	1.170
Silicon	5	0	5	595	736	956	747
Silver	24	0	0	–	–	–	–
Sodium	8	0	8	344	362	398	372
Strontium	8	0	2	0.331	0.577	1.11	0.639
Sulfate	8	1	4	10.9	17.1	35.2	21.2
Thallium	6	1	0	0.2650	0.410	0.466	0.308
Vanadium	8	0	8	67.3	74.4	89.3	79.2
Zinc	8	0	7	149.0	182.0	261.0	205.0

[a]N = number of observations, possibly averages over replicates at sites.
[b]I = number of interval censored observations (see text).
[c]D = number of true detects (see text).
[d]UCB95 = 95% upper confidence bound (UCB) for median.
[e]X95 = estimate of 95th percentile.
[f]LCB9595 = 95% lower confidence bound for 95th percentile.

Table 2.5. Summary statistics for Knox Group (which includes Copper Ridge) Horizon C radionuclides on the ORR (*Source:* DOE 1993a)
(Estimates and confidence bounds are in picocuries per gram)

Analyte	N[a]	I[b]	D[c]	Median	UCB95[d]	X95[e]	LCB9595[f]
^{137}Cs (gamma)	15	0	0	–	–	–	–
^{247}Cm (gamma)	3	0	0	–	–	–	–
^{238}Pu (alpha)	2	0	0	–	–	–	–
^{239,240}Pu (alpha)	2	0	0	–	–	–	–
^{40}K (gamma)	6	0	6	7.99	11.30	18.90	12.40
^{226}Ra (alpha)	8	0	8	1.440	1.770	2.57	2.01
^{228}Th (alpha)	8	0	8	1.220	1.78	3.53	2.240
^{230}Th (alpha)	8	0	8	1.540	1.860	2.63	2.090
^{232}Th (alpha)	8	0	8	1.230	1.600	2.61	1.890
^{234}Th (beta)	7	1	0	0.892	1.03	1.12	0.964
^{233,234}U (alpha)	8	0	8	1.570	1.85	2.50	2.05
^{235}U (alpha)	8	0	7	0.1220	0.1770	0.348	0.2220
^{235}U (gamma)	8	0	1	0.1100	0.1620	0.2090	0.1490
^{236}U (alpha)	16	0	0	–	–	–	–
^{238}U (alpha)	8	0	8	1.650	1.98	2.75	2.21
^{238}U (gamma)	8	0	0	–	–	–	–

[a]N = number of observations, possibly averages over replicates at sites.
[b]I = number of interval censored observations (see text).
[c]D = number of true detects (see text).
[d]UCB95 = 95% upper confidence bound (UCB) for median.
[e]X95 = estimate of 95th percentile.
[f]LCB9595 = 95% lower confidence bound for 95th percentile.

Table 2.6. Soil chemical properties
Source: Lietzke, Lee, and Lambert 1988.

	Corrosivity		Estimated cation exchange capacity (CEC)[a]		
Soil group	Steel	Concrete	pH	Surface	Subsoil
		Residuum			
Rome	low	moderate-high	4.5–6.0	5–15	10–20
Conasauga	moderate	moderate	4.5–6.0	10–15	15–20
Knox	high	moderate-high	4.5–5.5	5–10	8–20
		Colluvium			
Rome/Conasauga	low-moderate	moderate-high	4.5–6.0	5–10	5–10
Knox	moderate	moderate	4.5–5.5	5–10	5–10
		Alluvium			
Holocene/Modern	moderate-high	low-moderate	4.5–7.8	5–10	5–10
Pleistocene	moderate	moderate	4.5–5.5	5–10	5–10

[a]Milliequivalents per 100 g of soil.

large and small pores substantially reduces contaminant migration rates relative to fluid velocities in large pores (Solomon et al. 1992).

The effectiveness of stormflow in disturbed areas, such as the sites in OU 2, is not known at this time. Although large pores created by root channels, etc., may not exist at these sites, fill material and disturbed soils are likely to contain other pores through which stormflow may operate. In this case, stormflow would be equally important to these disturbed sites.

2.5.1.2 Vadose zone

A vadose zone exists throughout the ORR except where the water table is at land surface, such as along perennial stream channels. The thickness of the vadose zone is greatest beneath ridges and thins toward valley floors. Beneath ridges underlain by the Knox aquifer (Copper Ridge, Chestnut Ridge, McKinney Ridge, and Black Oak Ridge), the vadose zone commonly is as much as 50 m (160 ft) thick, whereas beneath ridges underlain by the Rome Formation (Haw Ridge and Pine Ridge) the vadose zone is typically <20 m (65 ft) thick. In lowland areas near streams, a permanent vadose zone does not exist because the stormflow zone intersects the water table. The vadose zone consists of regolith composed mostly of clay and silt (Fig. 2.10), most of which is derived from fill materials and the weathering of bedrock materials and which has significant water storage capacity. Most recharge through the vadose zone is episodic and occurs along discrete permeable features that may become saturated during rain events, even though surrounding micropores remain unsaturated and contain trapped air. During recharge events, flow paths in the vadose zone are complex, controlled

Table 2.7. Soil physical and engineering properties of the predominant soil groups in the Y-12 Plant area[a] (Revised March 10, 1989)

	Surface					Subsoil				
Group	Shrink-swell	LL (%)[b]	PI[c]	Unified class	K factor[d]	Shrink-swell	LL (%)	PI	Unified class	K factor
					Residuum					
Rome	low	20–30	NP-8	ML,CL	0.24	low	15–40	NP-13	GM, SM	0.28
Conasauga	low	20–40	5–15	ML,CL	0.32	mod	45–75	17–40	MH,ML,CL,CH	0.37
Knox	low	15–30	3–15	ML,CL	0.28	mod	40–70	20–40	MH,ML	0.24
					Colluvium					
Rome/ Conasauga	low	20–35	2–10	SM,SC	0.28	low	20–35	2–10	GM,SM,ML	0.28
Knox	low	20–30	NP-10	ML,CL	0.34	low	20–30	5–15	CL,GC	0.28
					Alluvium					
Holocene/ Modern	low	<30	NP-10	ML,CL	0.32	low	20–40	4–20	ML,CL	0.43
Pleistocene	low	20–30	3–10	ML,CL	0.37	low	40–70	10–25	CL,ML	0.32

[a]Adapted from Lietzke, Lee, and Lambert 1988.
[b]LL = liquid point.
[c]PI = plastic index.
[d]K = soil erodibility factor as defined by the Universal Soil Loss Equation (Sect. 3.2.5).

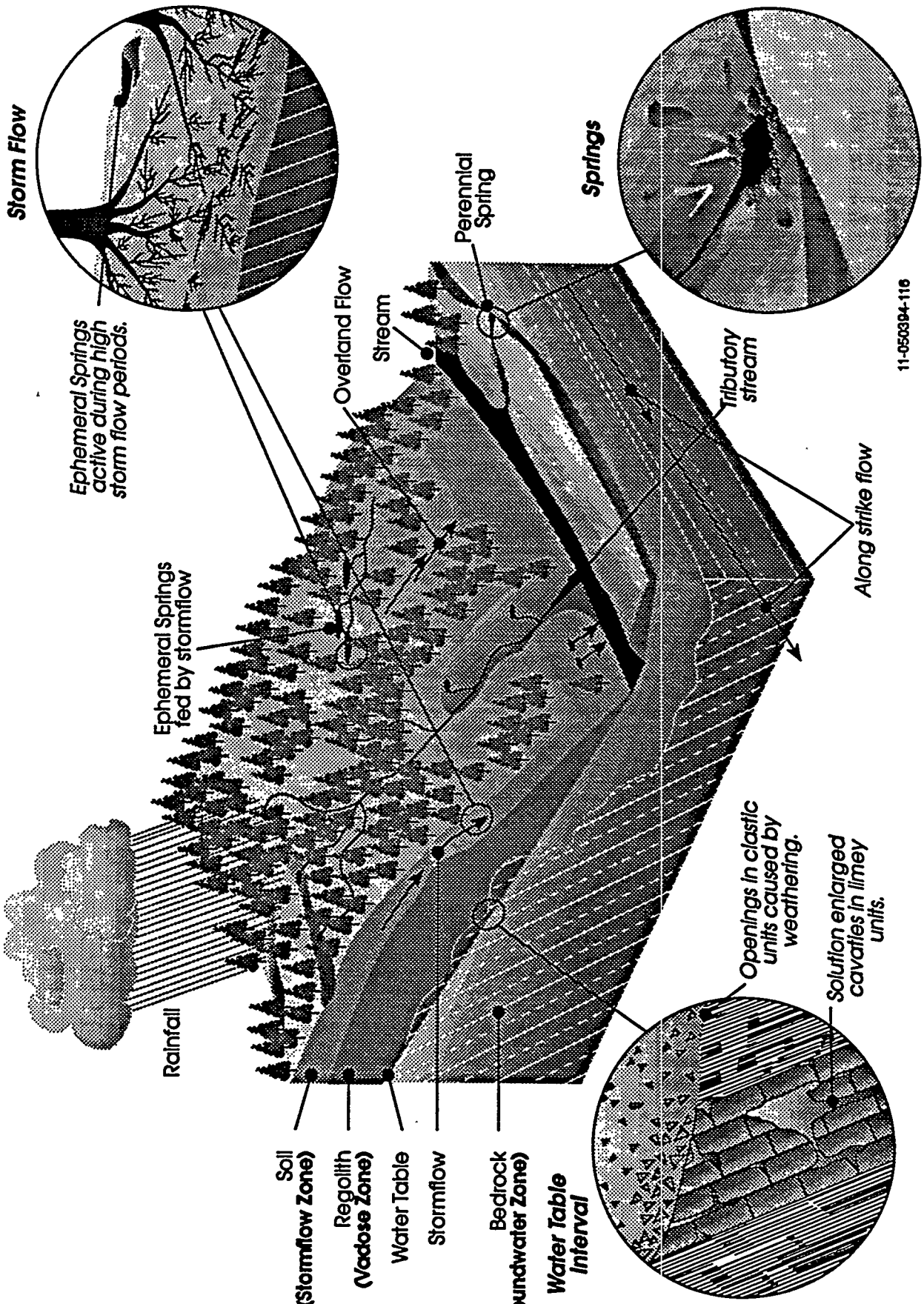


Fig. 2.10. A schematic showing conceptual groundwater flow in the ORR.

by the orientation of structures of the materials, such as relict fractures. Between recharge events, flow rates decrease dramatically, and flow paths are toward the groundwater zone.

2.5.1.3 Groundwater zone

The permanent water table typically is near the transition from regolith to bedrock at depths of <1 to 5 m (3.3 to 16 ft). Changes in hydraulic parameters and changes in major ion chemistry with depth suggest vertical subdivision of the groundwater zone into three intervals: (1) a water table interval, (2) an intermediate interval, and (3) a deep interval. The depth and thickness of these intervals vary, especially between the ORR aquitards and the Knox aquifer.

A thin [~1- to 3-m (3- to 9-ft) thick] permeable interval may be present near the water table. Spatial and temporal differences in the saturated thickness and transmissivity of this interval explain both the configuration of the water table and most of the fluctuations in groundwater discharge to streams. The water table is near the contact between regolith and weathered bedrock because a large flux has formed regolith at shallower levels by solution of the rock cement; fresh bedrock at deeper levels indicates a smaller water flux. Seasonal declines in water table elevation can nearly drain this interval. The resulting changes in transmissivity explain an order-of-magnitude fluctuation in groundwater discharge rates even though contours of water table elevation at the times of annual high and low water levels show little change in hydraulic gradients.

Changes in saturated thickness with the inverse of hydraulic gradient from one topographic location to another explain the common observation that the water table is a subdued replica of land surface, because the product of transmissivity and hydraulic gradient is nearly constant at all locations along any flow path. The concept of a thin water table interval is new, and detailed studies designed to directly define this interval have not been conducted. Groundwater movement below the water table interval is dominated by flow through fractures, which can be separated into the larger and well connected water-producing fractures and those smaller ones that make up the matrix.

More than 600 values of transmissivity have been measured by slug tests (primarily) and other tests in the study area. A cumulative probability graph of transmissivity data from both water-producing openings and matrix fractures shows two slopes, thereby indicating two different populations. The upper population represents water-producing intervals in the shallow groundwater zone, and the geometric mean of transmissivity is 0.23 m^2/d (2.43 ft^2/d). The minimum transmissivity value in the upper population is the same as the maximum transmissivity in the lower population and is 0.0055 m^2/d (0.0585 ft^2/d). The lower population represents the matrix intervals, and the geometric mean of transmissivity is 0.0011 m^2/d (0.0117 ft^2/d) (Solomon et al. 1992).

The deeper groundwater zone occurs below any water-producing intervals and generally has the same hydrologic characteristics as matrix intervals within the shallow groundwater zone. The fracture porosity of the deeper groundwater zone has not been determined but probably is smaller than water-producing intervals of the shallow groundwater zone. There is a smaller spatial frequency of open fractures at depth, and average aperture is smaller because of a larger overburden pressure. A typical effective porosity in the deeper groundwater zone might be in the range of 1×10^{-5} to 1×10^{-4}, and the geometric mean of transmissivity in the deeper groundwater zone is 0.00044 m/d (0.00143 ft/d).

The small geometric mean of transmissivity in the deeper groundwater zone, as compared to water-producing intervals in the shallow groundwater zone, indicates that rates and quantities of groundwater flow are much smaller than those in the shallow groundwater zone.

Water level data are collected, at a minimum, each time monitoring wells are sampled as part of the Y-12 Plant compliance program; semiannual water level measurements independent of sampling events were initiated in August 1992 on more than 600 wells in BCV (Fig. 2.11). The results of water level measurements throughout BCV are summarized in the annual Groundwater Quality Assessment Report (GWQAR) (HSW 1992). Recent results reveal a groundwater piezometric surface (Fig. 2.12) sloping in from recharge areas on ridges to discharge along Bear Creek. The piezometric surface suggests a groundwater divide just east of the S-3 Ponds and SA-1 areas as the eastern boundary of the BCHR.

Depth to groundwater in the BCHR varies both spatially and temporally. The configuration of the water table generally is a subdued replica of the surface topography, being at high elevations beneath hills and at lower elevations in the valley bottoms. In general, elevations of the water table are lowest from October to December and highest from January to March.

An upward hydraulic gradient generally is present in the shale formations of the Conasauga Group throughout the BCHR at depths ranging from 14 to 152 m (45 to 500 ft). Data obtained from monitoring well clusters at the S-3 Ponds in the vicinity of the OU 2 sites indicate upward hydraulic gradients in the shale formations of the Conasauga Group of between 0.003 and 0.129 (Geraghty and Miller 1986). Water level data from the Maynardville Limestone indicate downward flow in this formation, with gradients ranging from 0.008 to 0.124. At shallow depths, the vertical gradients may be reversed at times in response to recharge events (Geraghty and Miller 1986). Recharge to the shallow groundwater system occurs through the surface veneer of unconsolidated materials.

2.5.2 Flow Direction and Rate

Groundwater movement in the BCHR is influenced locally by the surface drainage system and its associated solution cavities. Figure 2.13 illustrates the general pattern of groundwater flow. Results of numerous studies (e.g., Geraghty and Miller 1988; Bailey and Lee 1991) within BCV and along its bounding ridges demonstrate that recharge of this flow component occurs along the ridges through infiltration of precipitation. Groundwater flow paths typically are directed away from the bounding ridges and generally follow the topography, converging within the valley in the vicinity of Bear Creek. In the zone underlying Bear Creek, the direction of groundwater flow is southwest along the valley axis. These results are consistent with those obtained in other regions of BCV.

The direction of groundwater movement generally is controlled by the potentiometric gradient and the permeability of the medium. In a completely isotropic aquifer, the flow direction of groundwater should be normal to the equipotential contours of the aquifer. However, in anisotropic formations such as those in the Conasauga and Knox Groups, the local flow directions are strongly controlled by the orientation of the bedding planes, fractures, and joints as well as by the distribution of solution cavities. Thus, a map of potentiometric contours based on observed head differences in wells in BCV indicates only the general direction of groundwater flow.

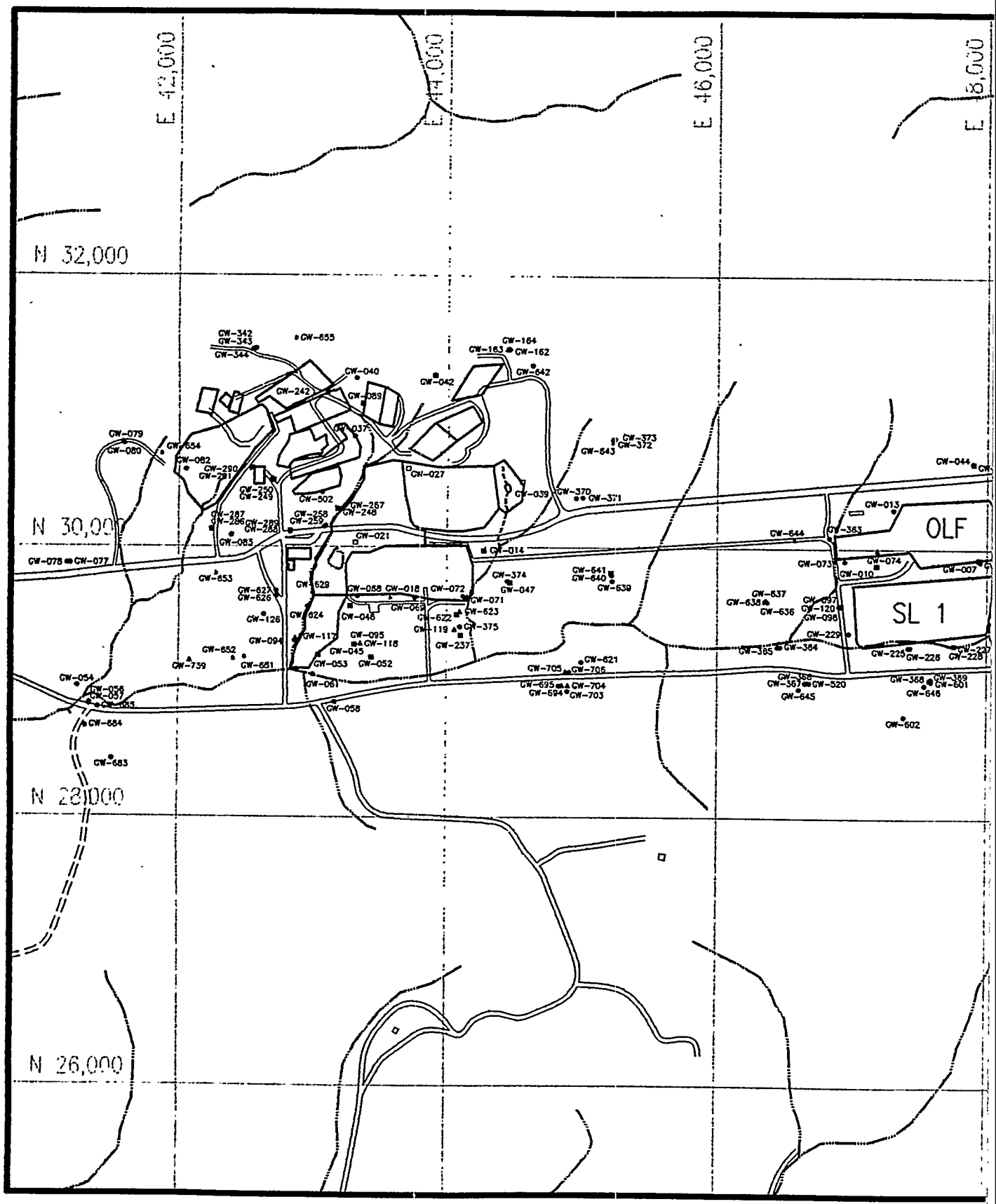
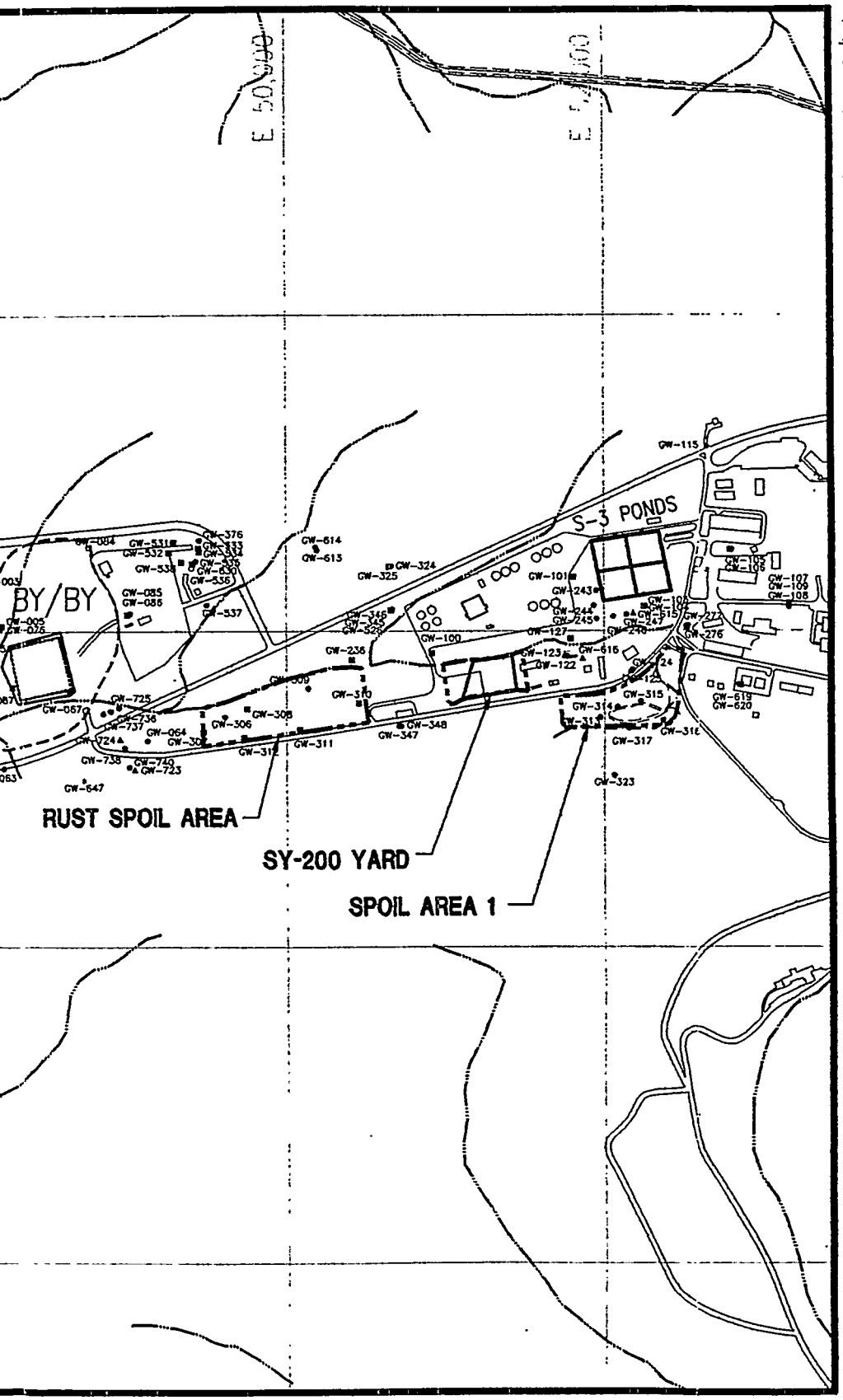
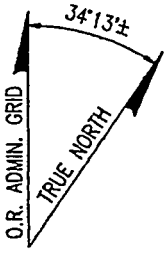


Fig. 2.11. Location of groundwater (*Source:* HSW 1992).



LEGEND:

- ●.....BEDROCK WELLS < 200'
- ○... ABANDONED BEDROCK WELLS < 200'
- □.....UNCONSOLIDATED WELLS
- ■....ABANDONED UNCONSOLIDATED WELLS
- ▲.....BEDROCK WELLS > 200'
- ✳..1993 COMPLIANCE SAMPLING LOCATIONS



0 500 1000 2000

SCALE: 1" = 1000'

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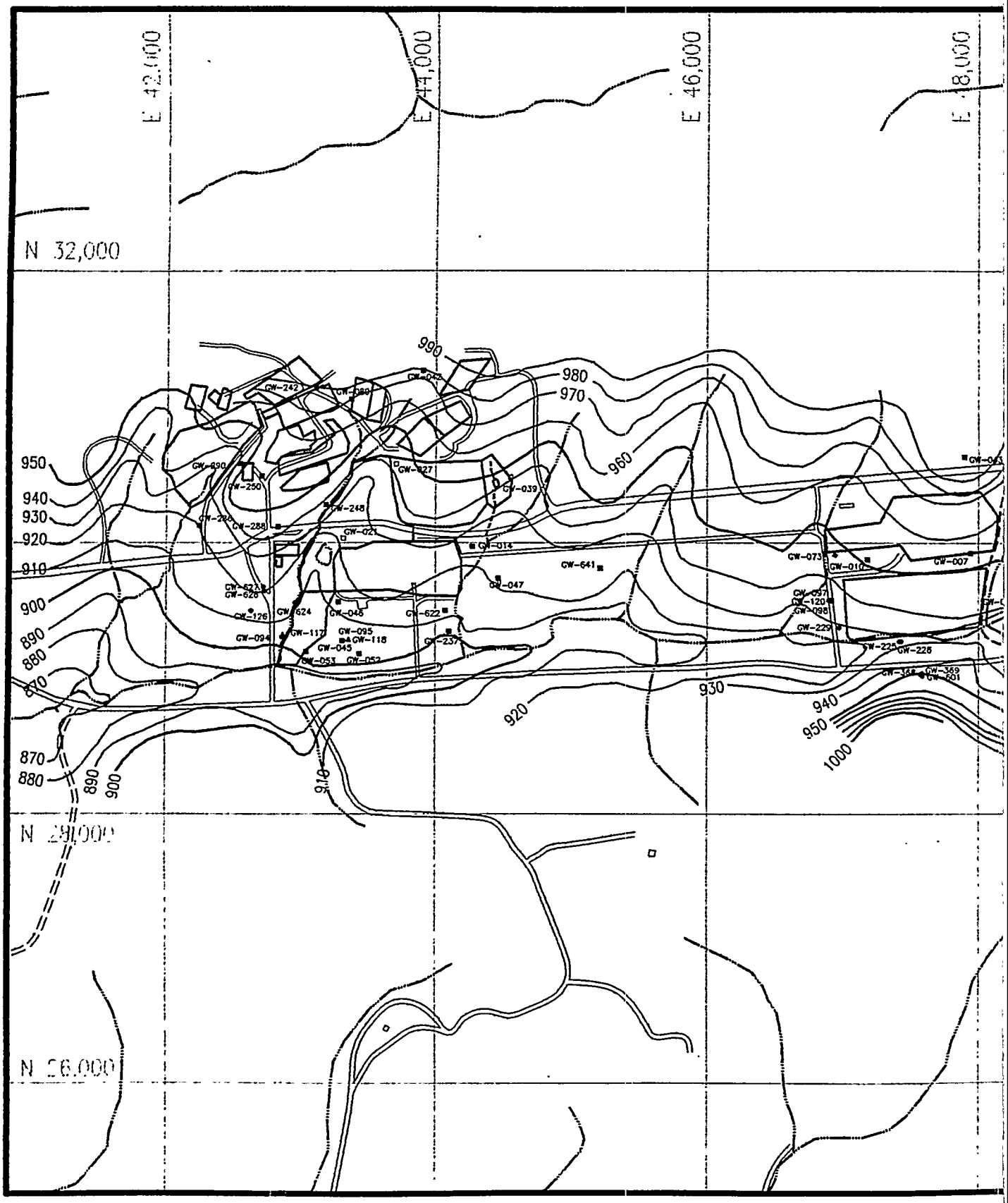
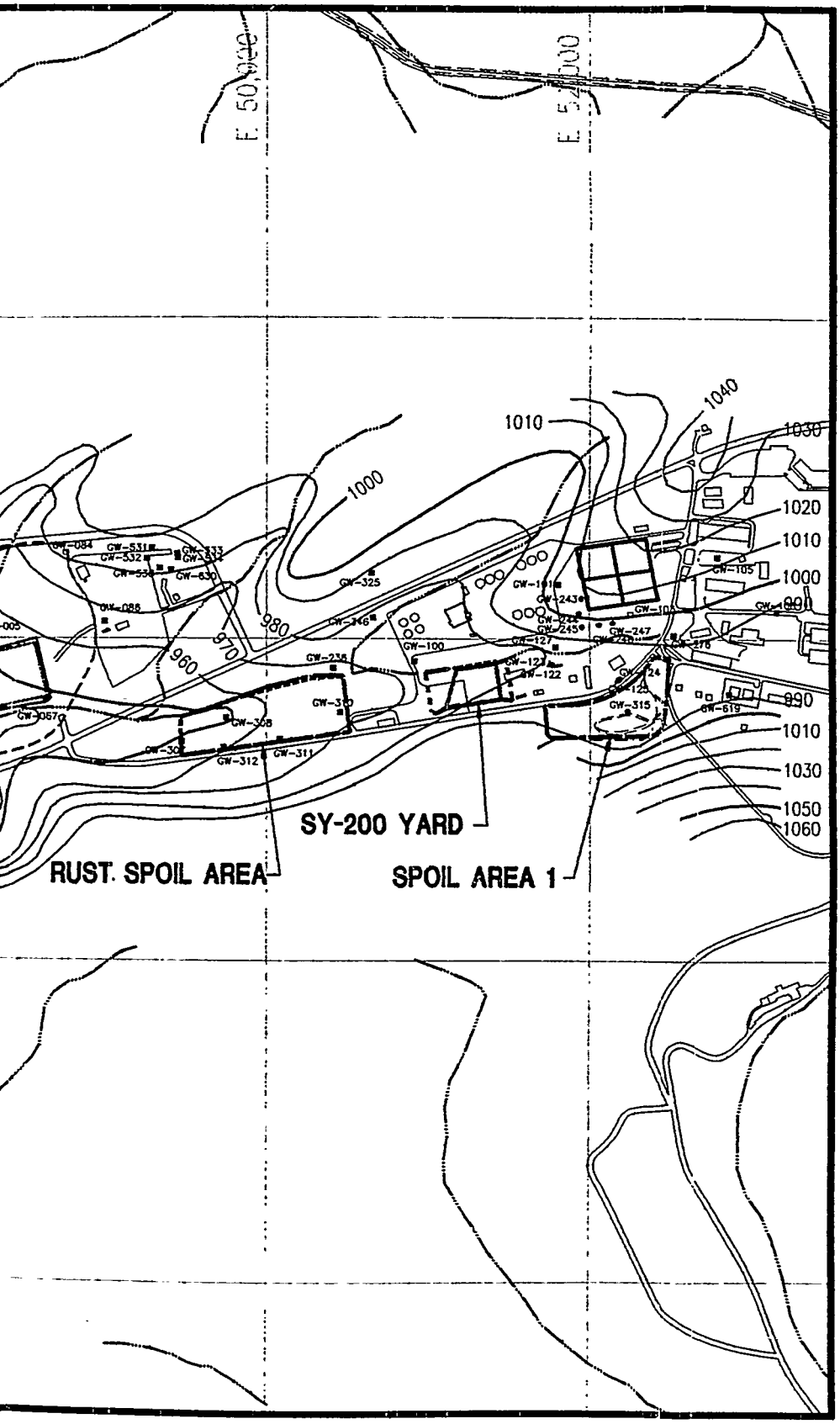


Fig. 2.12. Groundwater elevations in the unc



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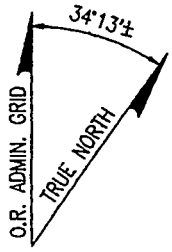
□.....UNCONSOLIDATED WELLS

■... ABANDONED UNCONSOLIDATED WELLS

— 880 —....GROUND WATER CONTOURS

NOTES:

1.) GROUND WATER CONTOUR DATA FROM APRIL 29 TO MAY 3, 1991 CONTOUR INTERVAL = 10 FEET.



0 500 1000 2000

SCALE: 1" = 1000'

Science Applications International Corporation

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	BEELER/HOLM	S. REID	03-17-94

XREFERENCES	PLOT FILES
/94003/XREF/BASEMAP /94003/XREF/GWCONT /94003/XREF/MANGAREA /94003/XREF/OU4WELLS	/94003/PLOT/576BC2-6

SHT. 1 OF 1 DRAWING # | /94003/DWGS/576BC2-6 CAD FILE # | N/A ROT. ANGLE

solidated aquifer in BCV (*Source:* HSW 1992).

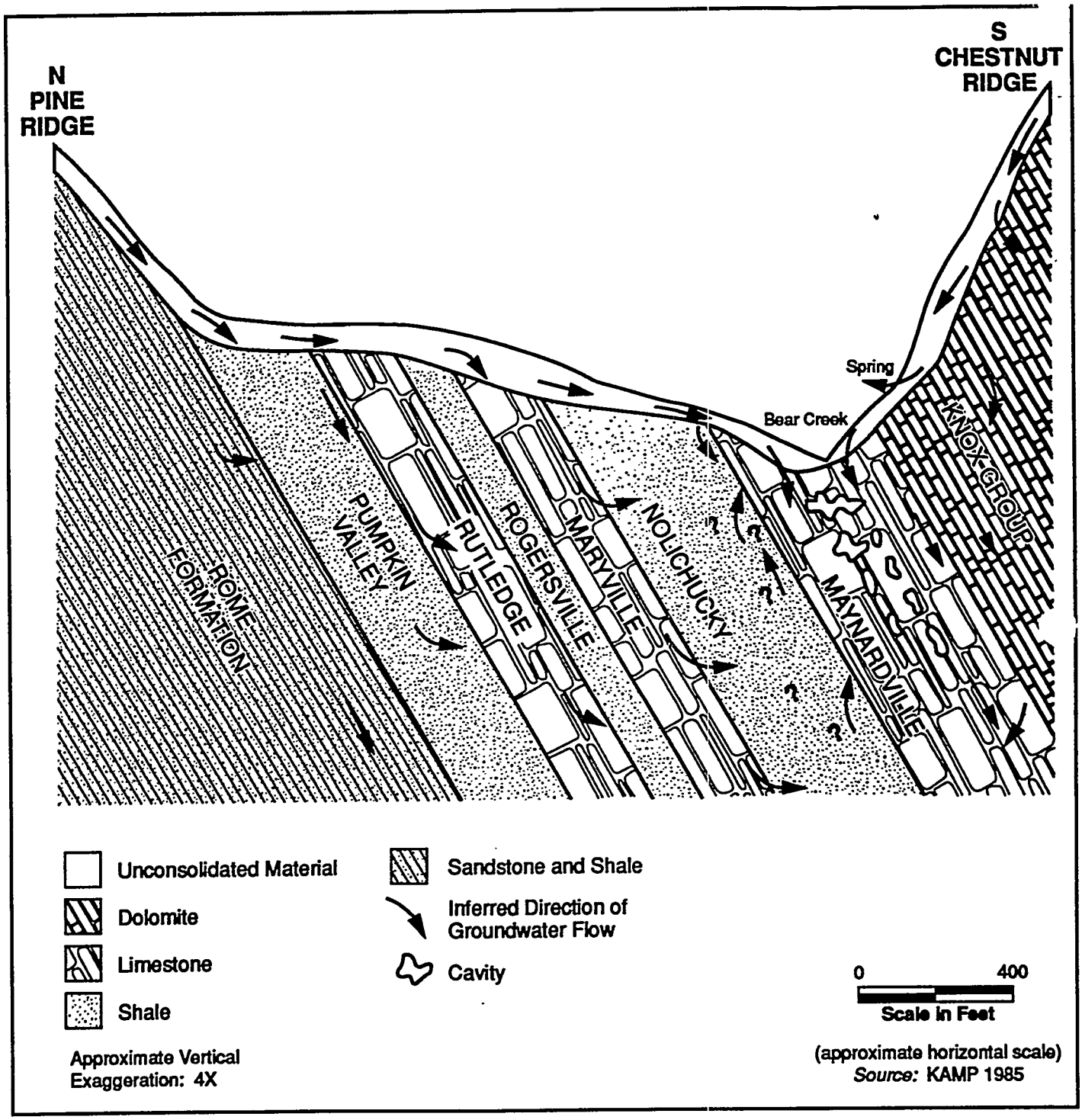


Fig. 2.13. Generalized cross-section of BCV showing inferred groundwater flow paths.

For example, several recent studies have investigated the fractures in bedrock material obtained from coreholes along a transect across BCV near the head of Bear Creek (Lutz and Dreier 1988). These studies demonstrate that several major fracture sets exist, dominated by a strike-parallel set. The results of these studies provide reasonable confirmation for observations from a pumping test performed in this area which showed that hydraulic properties of bedrock are not isotropic (Geraghty and Miller 1987). Rather, hydraulic conductivity values in the strike-parallel direction are at least several times larger than in any other direction. Anisotropy in hydraulic properties means that the direction of groundwater flow deviates somewhat from that predicted by the potentiometric contours such as those presented in Fig. 2.12.

In addition to small-scale deformation features such as the fracture sets discussed above, it is probable that large-scale features, including fracture zones and faults, exist in BCV and influence groundwater flow. The nearly parallel southerly flow of most tributaries draining the southern slope of Pine Ridge is one example of the type of surface expression anticipated from parallel fracture zones. At present, the identity of these structural features and their potential for affecting groundwater flow paths, contaminant migration, and the interaction between shallow and deep hydrologic components are unknown.

Figure 2.12 is a contour map of the water table at the BCHR based on water levels recorded in wells in 1991 (HSW 1992). In the Maynardville Limestone underlying Bear Creek, the direction of groundwater flow is southwest along the valley axis. The water table map is representative of the general water table configuration observed over the past several years (Geraghty and Miller 1986, 1987, 1988, 1989a; HSW 1991, 1992, and 1993). Although the water table fluctuates throughout the year, the pattern of fluctuation is similar in all wells, so that the water table slope remains essentially unchanged. No recent reversals of horizontal hydraulic gradient have been observed within the BCHR.

The average rate of groundwater flow in the Nolichucky Shale and the Maryville Limestone ranges from ~43 to 762 m/year (140 to 2500 ft/year) (Geraghty and Miller 1989a). An average flow rate in the Maynardville Limestone was calculated at 4 m/d (12.8 ft/d); however, a tracer test in the Maynardville Limestone in the Bear Creek drainage basin yielded a rate of travel of ~61 m/d (200 ft/d) through structural/solution features to a spring (Geraghty and Miller 1989a). Poor estimates of groundwater flow rate are to be expected when the Darcy equation for groundwater flow is applied to an anisotropic aquifer like this one. The assumptions made for using this equation, such as that groundwater flow paths are parallel to hydraulic gradient, may not apply and, therefore, may give misleading results.

2.5.3 Aquifer Characteristics

The hydraulic properties of the geologic units that exert the greatest influence on contaminant transport at BCV OU 2 have been quantified by field tests. Hydraulic conductivity tests have been conducted in the unconsolidated zone and bedrock zone wells at several sites in BCV. In the unconsolidated zone, these values commonly range from 3.4 to 91.4 m/year (11 to 300 ft/year) (BNI 1983, 1984). In shallow bedrock, the values range from 0.3 to 12 m/year (1 to 40 ft/year) in the Nolichucky Shale and 274 to 1280 m/year (900 to 4200 ft/year) in the Maynardville Limestone. At the S-3 Site near BCV OU 2, hydraulic conductivity values range from 30 to 232 m/year (98 to 760 ft/year) in the unconsolidated zone and 3 to 12 m/year (10 to 40 ft/year) in the shallow bedrock zone (Geraghty and Miller 1987). Results of tests conducted in deep bedrock wells were far lower, with the lowest being

0.01 m/year (0.02 ft/year), indicating a significant decrease in conductivity with depth (Geraghty and Miller 1987).

Mean values for hydraulic conductivity in the Nolichucky Shale and the Maryville Limestone, estimated using the U.S. Geological Survey (USGS) MODFLOW groundwater flow model, range from 0.1 to 0.5 m/d (0.4 to 1.7 ft/d) in the Nolichucky Shale and from 0.06 to 0.2 m/d (0.2 to 0.7 ft/d) in the Maryville Limestone (Geraghty and Miller 1989a). Effective porosities ranging from ~1 to 2% were determined in all samples from the Pumpkin Valley Shale in nearby Melton Valley (deLaguna et al. 1963) and are assumed to be representative of the remainder of the formations in the Conasauga Group, except the Maynardville Limestone.

Hydraulic characteristics of the Conasauga Group, including transmissivity and storage coefficients, have been calculated from data obtained from aquifer pumping tests. The anisotropy of the aquifer was confirmed by these tests, each being characterized by elliptical water level cones of depression, elongate in the direction of the strike of strata, which indicates a higher degree of transmissivity in that direction.

The transmissivity of the Nolichucky Shale has been determined by pumping tests performed near the S-3 Site. Transmissivity values determined in wells open only to bedrock ranged from 380 to 440 Lpd/m (100 to 115 gpd/ft), and storage coefficients ranged from 1×10^{-4} to 4×10^{-4} (Geraghty and Miller 1986). Each of the tests in the Nolichucky Shale was characterized by a low discharge rate, 19 L/min (5 gpm), with considerable water level drawdown in the pumped well.

2.5.4 Recharge/Discharge Relationships

Groundwater recharge in the BCV area is from local precipitation, which averages 137.5 cm/year (55 in./year). Recharge to the bedrock zone is most effective in places where the unconsolidated zone is thin or very permeable. This generally is the case on Pine Ridge, believed to be a major recharge area for the formations of the Conasauga Group in the BCV. Short losing sections of Bear Creek also may act locally to recharge the aquifer.

Natural groundwater discharge in the BCV is through streams, springs, and evapotranspiration. Bear Creek, its tributaries, and the solution cavity system along Bear Creek are the major discharge areas for shallow and intermediate depth groundwater moving through the interbedded strata of the BCV. Groundwater discharges sustain the base flow of Bear Creek (Geraghty and Miller 1985).

In the vicinity of Bear Creek, the interaction between the creek and the shallow groundwater component has not been systematically investigated. It is believed that an extensive network of solution channels within the Maynardville Limestone that underlies Bear Creek makes it an efficient drain for the local groundwater component and is the principal cause for the existence of losing reaches along the length of the stream. The results of a tracer study (Geraghty and Miller 1989a) clearly demonstrate that some spring discharge is composed of water that enters the groundwater in an upstream losing reach.

2.6 SURFACE WATER AND SEDIMENTS

2.6.1 Surface Water Network

The surface water system in BCHR comprises Bear Creek and its tributaries (Fig. 2.14). Headwaters of Bear Creek are located at the west end of the Y-12 Plant near the S-3 Ponds. In its upper reaches, Bear Creek follows a relatively straight course along geologic strike that lies very close to the contact between the Conasauga and Knox Groups. The original channel, located on the west side of the S-3 Ponds site, was filled with rubble during pond construction and rerouted to its present location (Law 1983). Approximately 7.2 km (4.5 miles) downstream of its headwaters, Bear Creek turns northward through a gap in Pine Ridge and empties into EFPC ~9.7 km (6 miles) upstream of the Clinch River.

The headwaters of Bear Creek are characterized by a relatively steep-banked channel cut to a depth of about 5 ft or more into the silts and clays of the fill and unconsolidated material. Bear Creek tributaries have been numbered, beginning with North Tributary 1 (NT-1) near the S-3 Ponds (Fig. 2.14). The average gradient of the creek from the headwaters at Bear Creek Kilometer (BCK) 12.8 (mile 8.0) to the confluence with EFPC is 5.7 m/km (30 ft/mile). The area of the flood-of-record floodplain is 164 acres, with an average width of 169 ft.

The drainage area of the Bear Creek watershed is 18.3 km^2 (7.4 $miles^2$). Bear Creek is fed by small tributaries originating on the slopes of Pine and Chestnut Ridges, which border the valley, and by springs emanating mainly from the base of Chestnut Ridge. The trellis type drainage pattern is strongly influenced by the underlying geologic structure. The parallel alignment of the tributaries located in the shale units in BCV is believed to represent the surface expression of joint and fracture patterns in the bedrock (Geraghty and Miller 1985) and/or other structural features.

2.6.2 Bear Creek Surface Water Hydrology

The channel of Bear Creek along much of its course through BCV is formed in the shallow alluvium overlying the Maynardville Limestone. Drilling activities in areas proximal to Bear Creek have indicated that a zone of potentially interconnected solution cavities is present in the upper part of the saturated zone in this formation. Because of the hydraulic interaction between the creek and this solution cavity system, the Bear Creek channel contains losing reaches where surface water discharges from the creek to the groundwater system and gaining reaches where groundwater discharges to the creek.

A dye tracer test was performed in 1989 to evaluate the hydrologic interaction between Bear Creek and the Maynardville Limestone (Geraghty and Miller 1989a). During this study, a review of historic stream-flow data for Bear Creek was performed. Results of this review indicated that Bear Creek loses flow to the groundwater system during extreme low-flow conditions over much of its length from near the S-3 Ponds to a spring located at BCK 4.56 (mile 2.7). During normal flow conditions, Bear Creek loses flow to the groundwater system in its upper reaches and gains flow in its lower reaches downstream of BCK 9.41 (mile 5.6) (Geraghty and Miller 1989a). It was concluded from the dye-tracer test that there was strong evidence indicating that surface water lost in losing reaches of Bear Creek between BCK 11.64 (mile 6.9) and BCK 9.41 (mile 5.6) is substantially discharged back into Bear Creek from spring SS-5 (Geraghty and Miller 1989a).

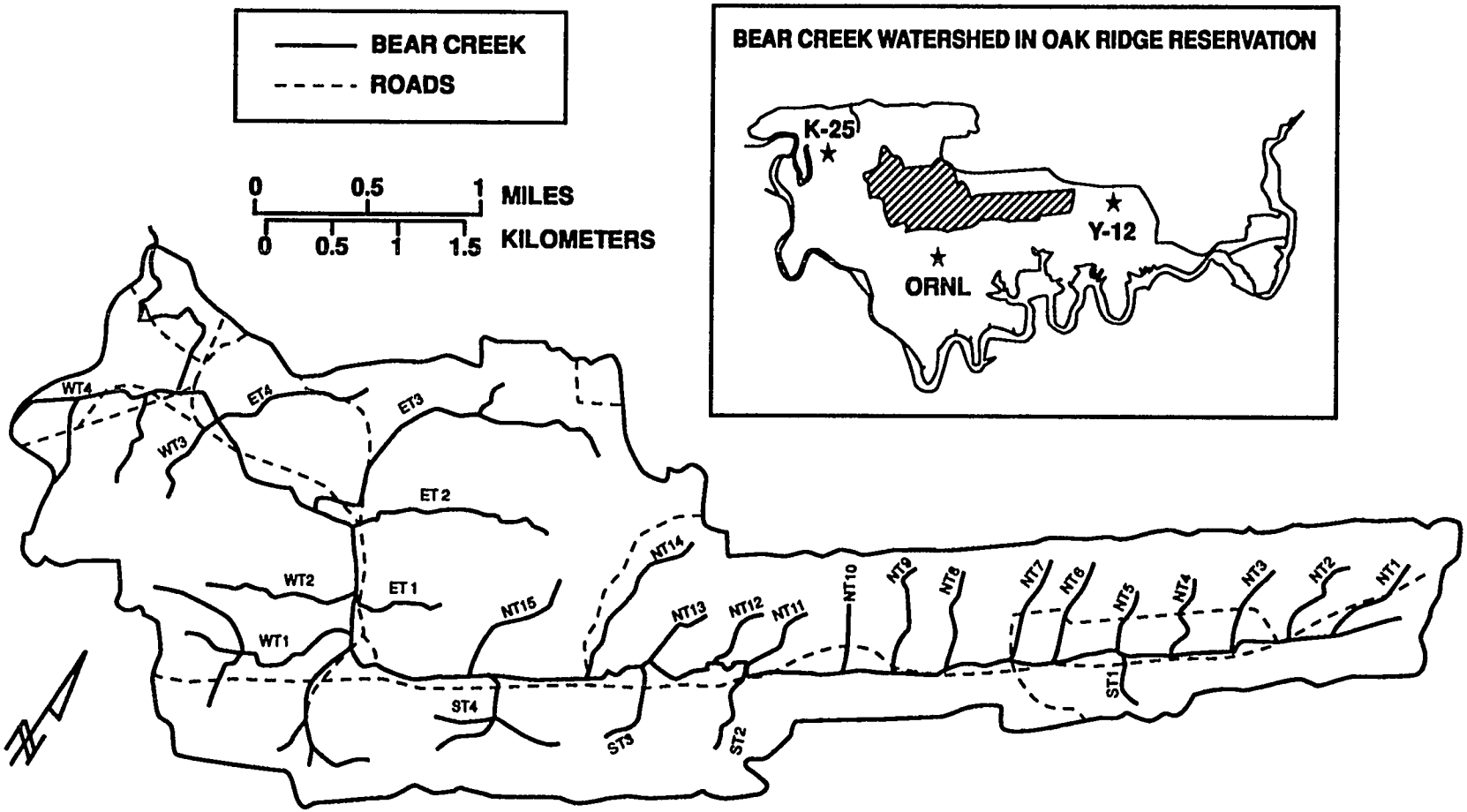


Fig. 2.14. Bear Creek watershed.

2.6.2.1 Stream flow data collection

Discharge data have been collected in the upper part of Bear Creek at many locations over different periods from 1986 through 1990. Monitoring stations are shown in Fig. 2.15, and their locations are listed according to BCK.

Periodic flow monitoring in Bear Creek has been carried out by the USGS since 1986. Flow and limited chemical data have been monitored by staff in the Environmental Sciences Division at ORNL. Details of past surface water sampling activities along Bear Creek are given in Turner et al. (1991). Flow data collected on Bear Creek and selected tributaries from 1985 through 1987 by both USGS and Environmental Sciences Division personnel are summarized in Table 2.8.

Flow data in the main stem, tributaries, and springs allow the different sections of the stream to be classified as losing or gaining reaches. The data also indicate flow in solution cavities in the Maynardville Limestone underlying Bear Creek. This flow apparently conducts water from the upper reaches between BCK 9.53 (mile 5.7) and BCK 12.46 (mile 7.5) to lower reaches of Bear Creek.

2.6.3 Bear Creek Hydrograph

The 3-year hydrograph for lower Bear Creek at the National Pollutant Discharge Elimination System (NPDES) monitoring station (BCK 4.55) (mile 2.7) was dominated by extensive periods of low flow in both 1986 and 1987 (Fig. 2.16). In both years, the mean annual flow at BCK 4.55 (mile 2.7) (Table 2.8) was ~50% of that estimated by McMaster (1967) for the period 1936–1960. From late July through October of 1986 and 1987, mean daily flow was consistently below 10 L/s (2.6 gal/s) and contrasted sharply with 1985 when stream flow never fell below 10 L/s. Minimum flows were always more than double the 7Q10 (i.e., the lowest mean discharge for 7 consecutive days with a recurrence interval of 10 years) of 2.8 L/s (0.73 gal/s), but in 1986 and 1987 flows were less than the estimated 7Q2 of 8.5 L/s (2.21 gal/s) for this site (McMaster 1967).

The occurrence of minimum flows at BCK 4.55 (mile 2.7) in excess of the 7Q10 during a period of severe drought can probably be attributed to the location of the site just below two large springs (SS-7 and -8). Upstream at BCK 9.53 (mile 5.7), which is located just above the SS-5 spring, the minimum flow was zero in both 1986 and 1987 compared with the estimated 7Q10 and 7Q2 for that site of 0.85 and 0.57 L/s (0.22 and 0.15 gal/s), respectively (McMaster 1967). Because the flow rates of springs are less variable than those of other tributaries, reaches of Bear Creek immediately below these springs are less affected by extended periods of drought than other reaches not in proximity to upstream springs.

Because of below-normal precipitation during the study period, especially during the period from November to April, the Bear Creek hydrograph exhibited infrequent periods of high flow. There were eight major storms (i.e., greater than 5 cm of precipitation in a 24-h period) during 1985–87, but only one had a recurrence interval greater than 1.5 years. The maximum 24-h rainfall during this period occurred on August 16–17, 1985, when 10.9 cm (4.36 in.) of rain was recorded at the Atmospheric Turbulence and Diffusion Laboratory (ATDL) station in Oak Ridge (NOAA 1985, 1986, 1987). A storm of this magnitude has a recurrence interval of 3 years (Sheppard 1974). Runoff from the August 1985 storm resulted in a peak flow (2240 L/s) (582 gal/s) in Bear Creek that was similar to those observed in the

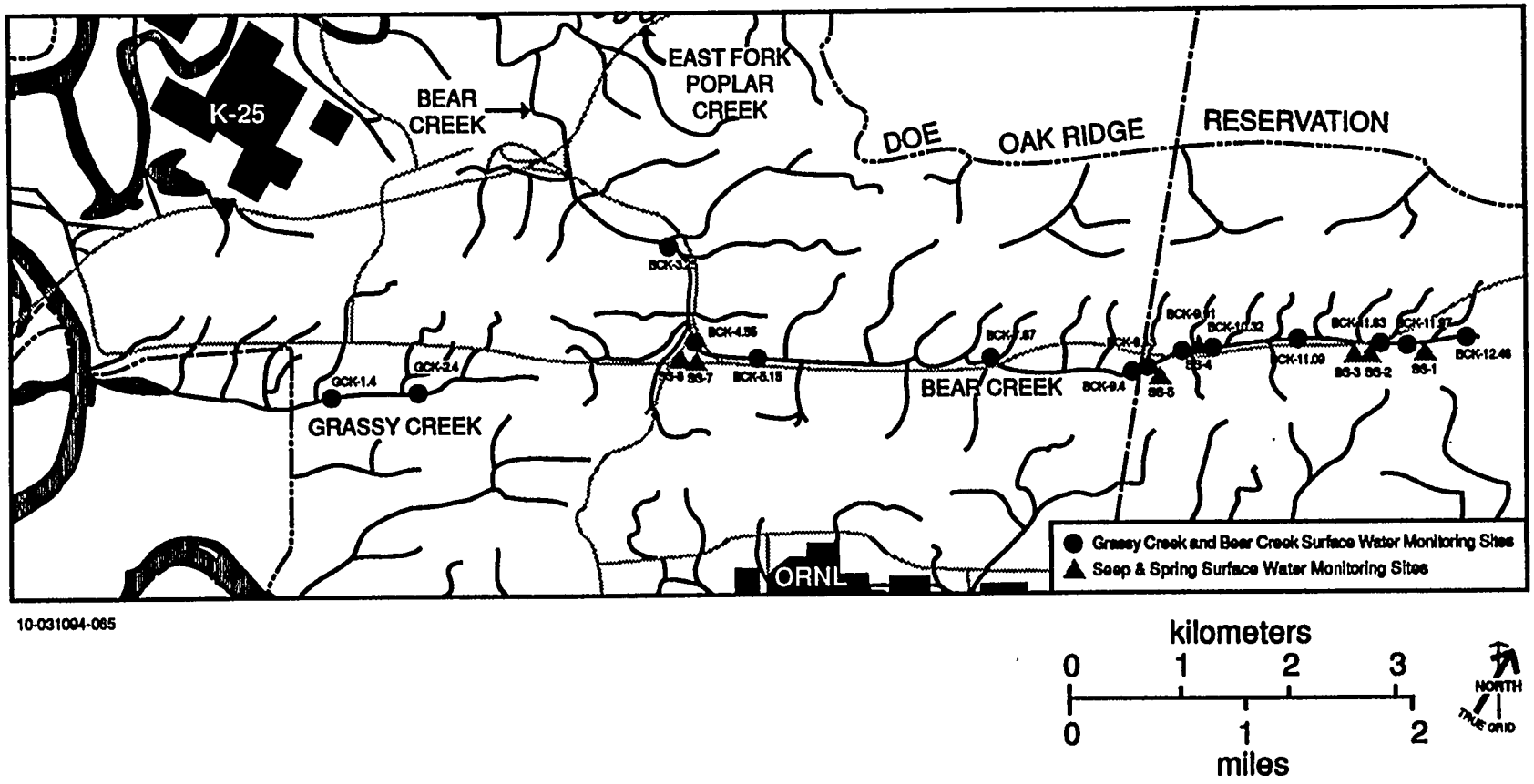


Fig. 2.15. Location of previously sampled surface monitoring sites near Bear Creek.

Table 2.8. Mean, standard deviation (SD), and range of stream flows in Bear Creek and selected tributaries, 1985–87[a]

Site	Drainage area (km^2)	1985 (L/S)			1986 (L/S)			1987 (L/S)		
		X	SD	Range	X	SD	Range	X	SD	Range
BCK 12.46	0.43	0.76	0.54	0.08–2.6	0.71	0.85	0.06–5.1	1.53	3.82	0.06–20.7
BCK 11.64	1.57	7.4	6.8	1.13–26.3	7.9	12.7	0.28–67.7	10.2	19.5	0.0–118.4
BCK 11.17	1.91	9.1	9.1	0.3–34.0	11.9	22.1	0.0–124.0	18.4	59.8	0.0–388.0
BCK 10.41	2.81	9.6	12.7	0.0–51.5	13.3	28.3	0.0–160.3	20.4	70.5	0.0–456.0
BCK 9.53	3.92	13.6	16.4	1.1–63.4	16.4	36.2	0.0–217.5	23.2	68.5	0.0–436.7
BCK 9.41[b]	4.07[c]	28.3	24.6	5.4–95.7	29.2	51.8	0.8–302.4	37.4	88.6	0.8–557.3
BCK 7.87	5.96	32.3	31.7	2.8–138.8	38.5	71.9	1.4–431.9	47.6	123.2	1.4–791.0
BCK 6.24[d]	8.29		NA[e]			_[f]		63.8	191.4	0.3–2974
BCK 4.70	NA	46.2[g]	45.3	3.7–199.4	74.2	160.6	0.0–965.4	83.3	192.6	0.0–1186
BCK 4.55[d]	11.03	103.9[h]	159.8	12.2–2237	106.0	227.6	6.5–2436	110.9	232.9	5.4–2974
BCK 3.88[d]	12.95		NA			_[i]		119.9	351.4	6.8–5579
				Tributaries[j]						
SS-1 (BCK 12.38)[k]	0.10	0.45	0.31	0.03–1.42	0.34	0.31	0.0–1.70	0.42	0.57	0.0–3.40
SS-2 (BCK 11.68)	NA		NA			_[l]		1.6	1.8	0.23–6.8
SS-3 (BCK 11.67)	0.23	0.76	0.68	0.17–2.55	0.68	0.88	0.08–3.40	1.02	1.19	0.06–5.10
SS-4 (BCK 10.14)	0.22	4.0	1.7	1.7–9.3	3.7	2.8	0.6–11.9	3.7	2.8	0.4–11.0

Table 2.8 (continued)

Site	Drainage area (km^2)	1985 (L/S)			1986 (L/S)			1987 (L/S)		
		X	SD	Range	X	SD	Range	X	SD	Range
SS-5 (BCK 9.41)	0.12	11.9	6.8	4.0–27.5	9.9	12.2	0.8–63.2	10.2	10.8	0.8–45.0
NT14d (BCK 6.24)	0.78	4.0	4.2	0.6–18.1	5.1	11.6	0.03–74.2	7.6	19.8	0.31–124.6
NT15d (BCK 5.32)	0.36		NA			_[i]		2.7	9.2	0.0–141.6
ET1d (BCK 4.07)	0.36		NA			_[i]		2.2	6.9	0.0–102.0

[a]Flows were measured weekly except at those USGS sites on lower Bear Creek where stream flow is monitored continuously and average daily values are computed. Number of samples (N) = 45 in 1985, 47 in 1986, and 42 in 1987, except the USGS sites and unless noted otherwise.
[b]Tabular values based on summation of flows at BCK 9.53, NT8, and SS-5.
[c]BCK 9.42 (McMaster 1967).
[d]USGS station; tabular data are based on average daily values.
[e]NA = no data available.
[f]N = 98 in 1986 and N = 365 in 1987.
[g]N = 40 in 1985 because monitoring was initiated on February 21, 1985.
[h]N = 306 in 1985 because monitoring was initiated on March 1, 1985. N = 365 in 1986 and N = 360 in 1987.
[i]N = 92 in 1986 and N = 360 in 1987.
[j]Tributaries are named sequentially from the headwaters of Bear Creek; NT and ET denote rain-fed streams and SS denotes spring-fed streams.
[k]Confluence with Bear Creek is given in parentheses.
[l]N = 6 in 1986.
[m]USGS data in parentheses.

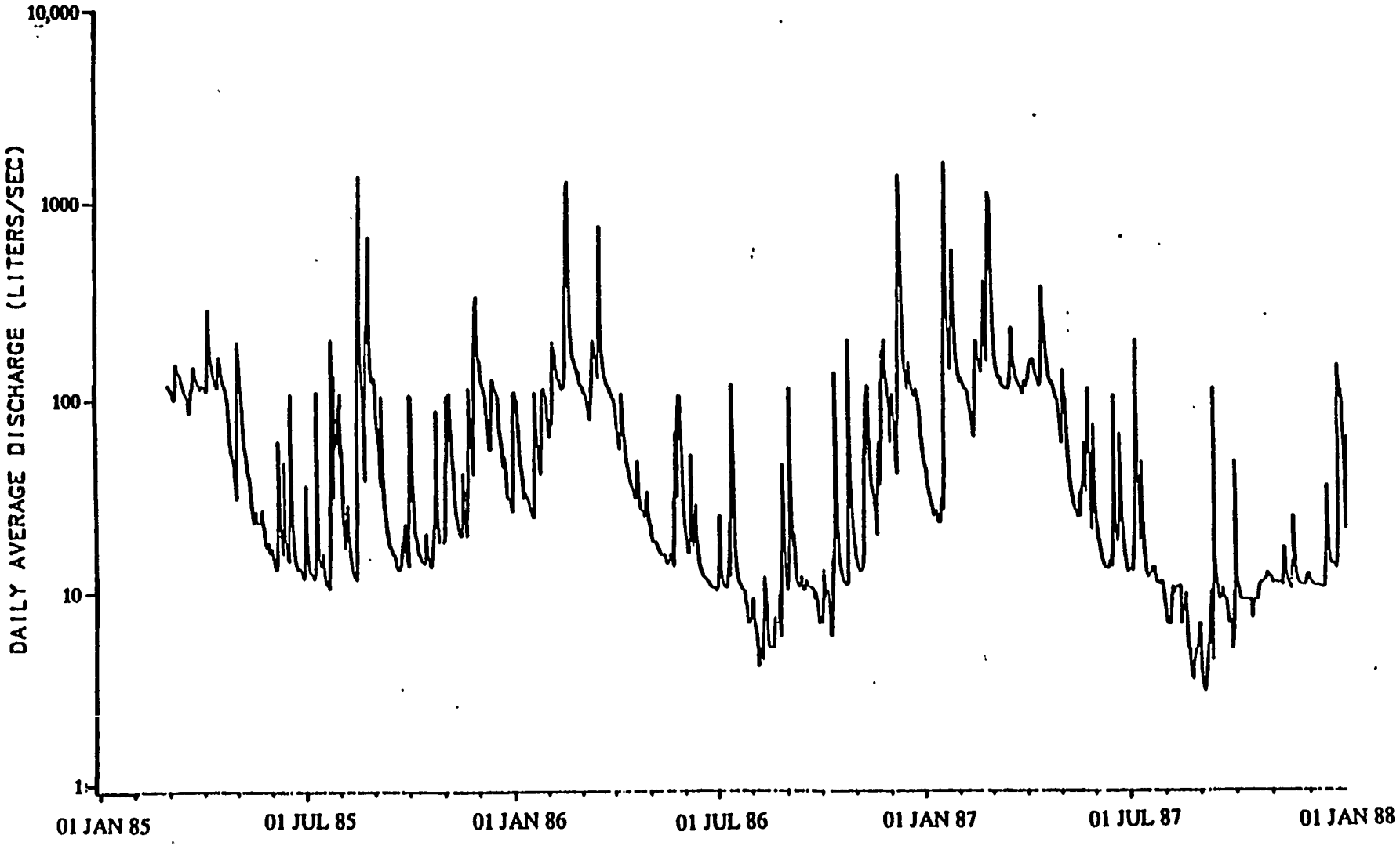


Fig. 2.16. Mean daily stream flow in Bear Creek at USGS gauging station 03538270 at BCK 4.55, March 1985–December 1987. The mean flow during this period was 107.1 L/s. *Source:* Lowery et al. (1986, 1987, 1988).

winter and early spring, when runoff is usually high because of minimal evapotranspiration. This peak in flow was more than an order of magnitude greater than the peak flows that occurred during the summer and fall of 1986 and 1987.

2.6.4 Effects of the Solution Cavity System

The solution cavity system within the Maynardville Limestone, which conducts flow westward under Bear Creek, plays an important role in the surface water hydrology of BCV. The cavity system is thought to be an important avenue for contaminant transport because contaminants in the surface water can be lost to the system, which extends outside the BCHR. Although the precise outlets of the cavity system are unknown, there is evidence that at least some flow from the cavity system emerges in springs discharging from solution openings along bedding planes and joints in the rock units adjacent to Bear Creek.

The numerous springs that originate on the north slope of Chestnut Ridge are a dominant feature of the hydrograph of upper Bear Creek, especially during drought periods. At such times, most of the flow in the main-stem Bear Creek is contributed by springs. The best example of the importance of these springs occurred in the fall of 1987, a time of low precipitation (e.g., rainfall was 24% and 47% of normal in October and November, respectively) that followed a period of extended drought. Four of the five flow-monitoring stations on the main-stem Bear Creek above the SS-5 spring were dry (Fig. 2.15). The only flow in this reach of stream was immediately below the SS-2, -3, and -4 springs and in the headwaters (BCK 12.46) (mile 7.5) below the S-3 Ponds.

The springs in upper Bear Creek differ greatly in flow rate. Flow rates are highest in the SS-5 spring at BCK 9.41 (mile 5.6) and lowest in the SS-1 spring at BCK 12.38 (mile 7.4), where flow was intermittent between late August and mid-October 1987. Several springs also occur downstream of the SS-5 spring, and two of the largest (SS-7 and -8) are located less than 100 m above the USGS/NPDES monitoring station at BCK 4.55 (mile 2.7). Although flow at this site was never zero, a section of stream at BCK 4.70 (mile 2.8) immediately above the SS-7 and -8 springs was periodically dry in both 1986 and 1987. Thus, springs in this limited section of Bear Creek, like those in the 3-km (1.8-mile) reach above the SS-5 spring, provide a significant portion of the flow in Bear Creek during periods of low rainfall.

2.6.5 Stormflow System

The stormflow system was described in detail under groundwater in Sect. 2.5.1, Bear Creek Hydrologic Regime. It is also considered as a component of the surface water system due to the rapid transmission of water laterally from the stormflow zone to the surface water system during rain events.

During rain events, the stormflow zone becomes partially or completely saturated and then transmits water laterally to the surface water system. Between rain events, as the stormflow zone drains, flow rates decrease dramatically, and flow becomes nearly vertical toward the underlying vadose zone. The effect of this rapid transmission of water from the stormflow system can be readily seen in the hydrograph for Bear Creek (Fig. 2.16). There is a sharp increase in mean daily flow rates, at times from 10 L/s to >1000 L/s (2.6 to >260 gal/s), followed by an equally rapid decrease in flow.

2.6.6 Thermal Characteristics

Continuous monitoring of water temperatures began in September 1985 at the SS-5 spring and three sites in Bear Creek located just above, immediately below, and 1.5 km (0.9 mile) below the spring. In April 1987, two additional sites, BCK-11.98 and Grassy Creek, a reference stream, were added to the monitoring program.

Springs are important in stabilizing flows, but they also influence the thermal regime of Bear Creek, especially in the upper reaches, where springs are numerous and flows are intermittent in summer and early fall. The thermal characteristics at a given site depend, in part, on the proximity of springs. Mean temperatures at BCK 9.40 (mile 5.6) just below the SS-5 spring were ~2–3°C warmer in the winter and 4–8°C cooler in the summer than BCK 9.91 (mile 5.9) above the spring (Fig. 2.15). The temperature differential between the two sites was greater in summer than in winter because of the seasonal difference in flow and smaller effect of the spring on main-stem flows in winter. Although BCK 9.91 (mile 5.9) is 250 m (825 ft) below the SS-4 spring, the flow rate of this spring is only one-third that of the SS-5 spring. The thermal regime at BCK 9.91 (mile 5.9) is nearly identical to that at BCK 7.87 (mile 4.7), ~1.5 km (0.9 mile) below the SS-5 spring. These comparisons indicate that the moderating effect of springs on mean temperatures in Bear Creek is highly localized.

The effect of springs on temperature extremes, however, was more pronounced and extended over greater distances. The maximum temperature at BCK 9.91 (mile 5.9) was 24.9°C (76.8°F), which was similar to that at BCK 9.40 (mile 5.6) [23.4°C (74°F)] but 6.7°C (12.06°F) below the maximum observed at BCK 7.87 (mile 4.7). Temperatures as high as 38°C (108.4°F) were recorded at BCK 11.98 (mile 7.2) during a period of near-zero flow in July and August 1987. This site is not significantly influenced by springs; the nearest upstream spring is SS-1, which was dry in late August 1987. Minimum winter temperatures were higher at BCK 9.91 (mile 5.9) than at BCK 7.87 (mile 4.7) and, like the trend in maximum temperatures, indicate a greater moderating effect on temperature at BCK 9.91 (mile 5.9), the site nearest a spring.

Springs have their greatest influence on stream temperatures during periods of low rainfall in summer and fall. Both the mean and maximum temperatures in August 1987 exceeded those in June and July at BCK 9.91 (mile 5.9) and BCK 7.87 (mile 4.7). At BCK 9.40 (mile 5.4), however, August temperatures were actually lower than those observed in the two previous months. Rainfall for August 1987 totaled only 3.2 cm (1.28 in.) in the Bear Creek Burial Grounds (51% of normal at the Oak Ridge site), and no precipitation occurred on 22 consecutive days before August 2. Thus, the importance of springs in moderating the effects of elevated stream temperatures caused by decreased stream flow during a drought is directly related to the severity of the drought.

2.6.7 General Sediment Description

The substrate materials of Bear Creek vary considerably among several general types, including rock ledges, sand/gravel bars, indurated cohesive clay, flocculent precipitates/clays, and mixtures of these types. In most areas, the creek is stable to degradational with respect to net sediment accumulation. The supply of sediment from upland areas and the floodplain is small with respect to the ability of stream flow to export sediment from the watershed. A high percentage of forest cover and stabilization of bank deposits by riparian vegetation limit significant soil erosion during peak stream flows. Thus, the most voluminous sediment deposits

tend to be fairly coarse-grained, the finer material having been winnowed and exported out of the watershed. Between high flow events, fine-grained sediment deposits do accumulate in low-energy environments (pools, leeward of obstacles, inside of bends) in the creek. These deposits are typically silty sands or sandy silts, with small and variable amounts of gravel and clay. Figure 2.17 exhibits sediment size distributions for several locations on Bear Creek. These distributions were measured on samples collected for chemical analysis and may be biased in favor of fine particles.

Although no mineralogical investigations have been conducted on Bear Creek sediment, such investigations carried out on streams flowing over rocks and soils derived from the Knox, Conasauga, and Rome Groups have reported illite, quartz, and feldspar, with minor amounts of hematite and hydrous manganese oxides. Common clay minerals include kaolinite, mica, vermiculite, hydroxy-interlayered vermiculite, and gibbsite. White to yellowish-white precipitates occur in the upper reaches (above BCK 11.83) and are presumed to be amorphous aluminum hydroxide resulting from the neutralization of acidic groundwater that originates from the plume of the former S-3 Ponds (Turner and Kamp 1984).

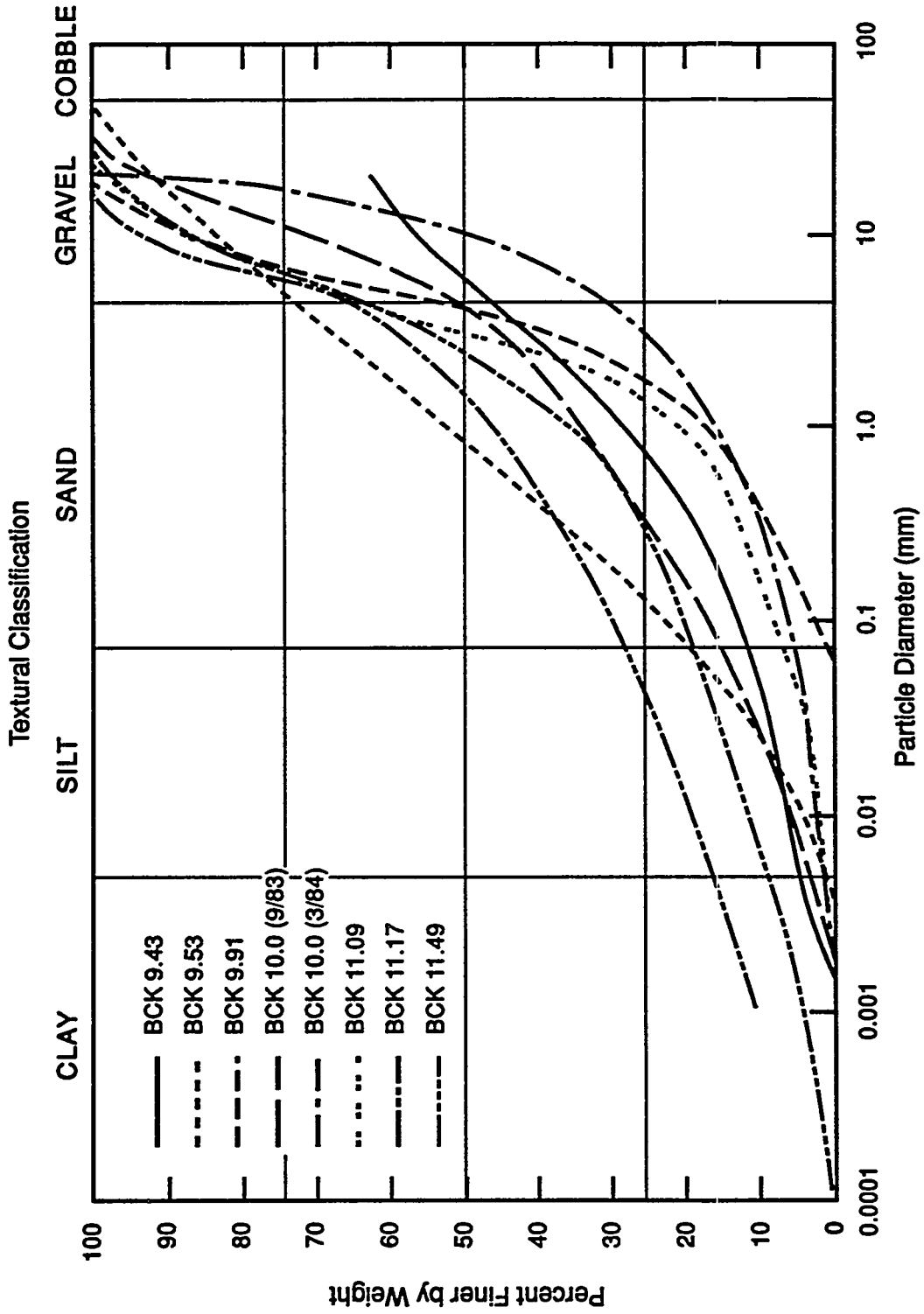
2.7 ECOLOGY

BCV OU 2 lies outside the main Y-12 Plant complex and as such is in close proximity to areas of potential ecological sensitivity. Ecological studies of the Bear Creek watershed were initiated in May 1984 and are continuing now. A summary of the results of the sampling conducted from May 1984 through early 1990 is presented in Southworth et al. (1992). These studies were conducted in numerous National Environmental Research Park (NERP) Natural Areas (NAs) and consisted of an initial detailed characterization of the benthic invertebrate and fish communities in Bear Creek, followed by an ongoing monitoring phase (Fig. 2.18) with reduced sampling intensities. The characterization phase involved two approaches: (1) in-stream sampling of benthic invertebrate and fish communities in Bear Creek to identify spatial and temporal patterns in distribution and abundance and (2) laboratory bioassays of water samples from Bear Creek and selected tributaries to identify potential sources of toxicity to biota. The monitoring phase of the ecological program relates to the long-term goal of identifying and prioritizing contaminant sources and assessing the effectiveness of remedial actions. Activities of the characterization phase are continuing at less frequent intervals.

Before 1940, most of BCV was cleared and used for agriculture (Southworth *et al.* 1992). Most of the agricultural land has been planted in pines, with a strip of pines and mixed hardwoods bordering much of the stream. About 65% of the BCV watershed is wooded (McMaster 1967). The following subsections describe the ecological setting for BCV as a background for the detailed ecological description of OU 2 presented in Sect. 6.1.

2.7.1 Flora

Vegetation in the Bear Creek watershed is predominantly oak, oak-hickory associations on the upper slopes and ridgetops, and planted pine along the creek and floodplain area. Pine Ridge is generally an oak, oak-hickory association with chestnut oak, red oak, tulip poplar, white oak, and hickory as the dominant species. The lower areas along Bear Creek and Bear Creek Road are mainly planted loblolly pine with some scattered areas of planted shortleaf, natural pine, and oak-hickory communities. Also of interest is a large area of big bluestem grass that grows along Bear Creek Road. Large stands of this species are uncommon in east



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Fig. 2.17. Particle size distribution of sediment samples collected in Bear Creek for chemical analysis.

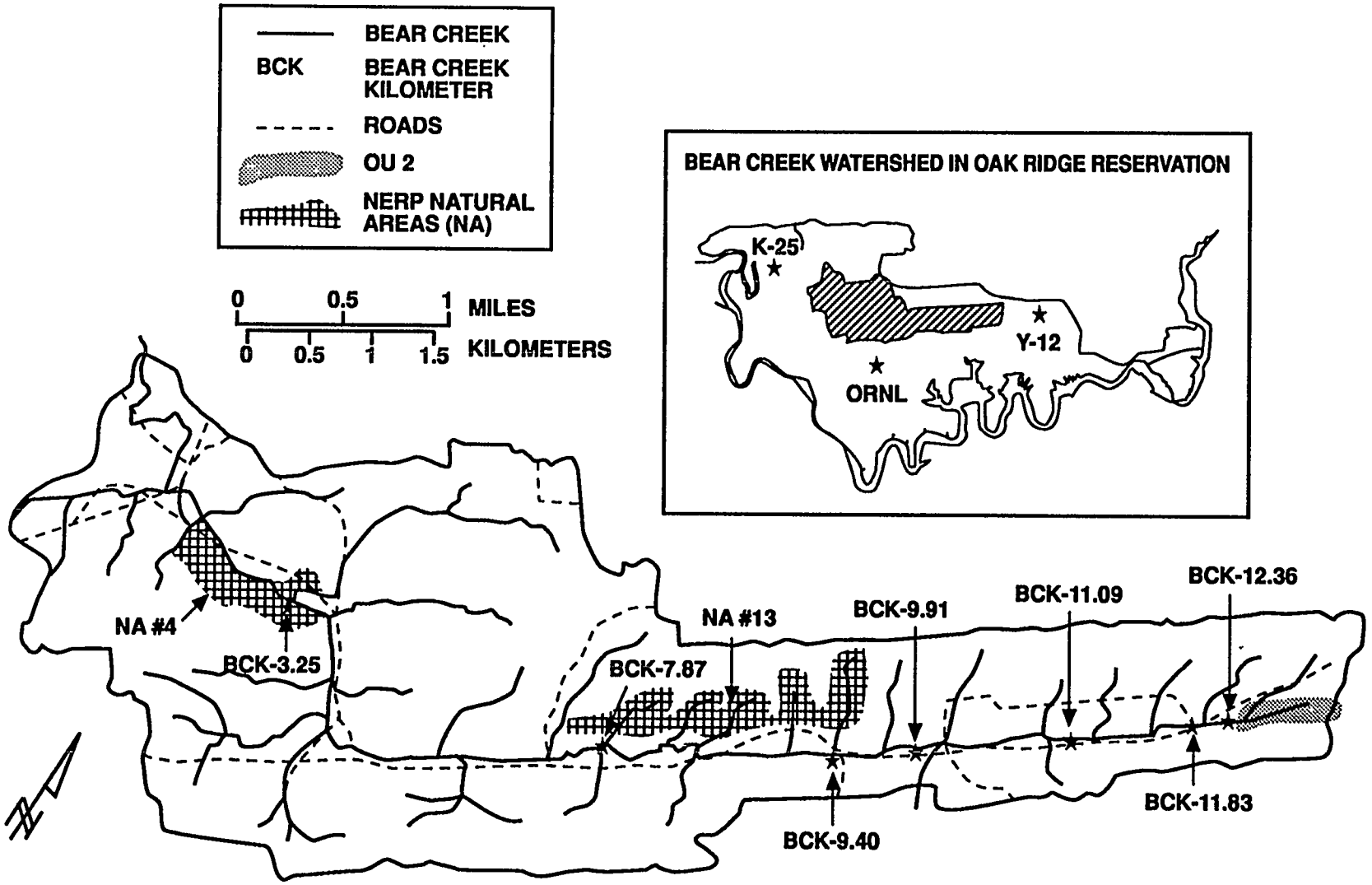


Fig. 2.18. Locations of existing biological monitoring sites.

Tennessee. Plant communities in Bear Creek are depicted in Fig. 2.19 as components of the general plant communities found on the ORR (Welch 1989). The BCV OU 2 site is within the "grassland, devegetated areas, and cultural features" zone just west of the Y-12 Plant. This site is being considered as a National Environmental Research Park (NERP) Reference Area. More detailed information is available for portions of the Bear Creek watershed area on forest compartment maps and in various documents (Bradburn and Rosenbalm 1984; Parr and Pounds 1987). Table 2.9 lists rare flora and fauna found within the ORR.

2.7.1.1 Rare plant species

Two areas contain rare plant populations, and these have been designated NERP Natural Areas (Fig. 2.18). The Canada lily (*Lilium canadense*) occurs in NERP Natural Area (NA) 13 at the base of Pine Ridge. It grows along the forested edges of the powerline right-of-way in the Bear Creek drainage area. This plant species is state listed as threatened. The other site, NERP NA 4, contains the southern rein orchid (*Platanthera flava*). This is forested area with numerous wetlands around seeps and contains old stream or flood channels. An uncommon aquatic plant, *Orontium aquaticum*, occurs here also. The southern rein orchid is state listed as a species of special concern. The site has also been registered as a State Natural Area in an agreement between DOE and TDEC. Other recently documented rare plant species on the ORR that could potentially be found along BCV are listed in Table 2.9.

2.7.2 Terrestrial Fauna

BCV contains elements of most wildlife habitat types found on the ORR (Fig. 2.20); therefore, the expected terrestrial fauna is that described for the entire reservation (Welch 1989). BCV OU 2 on this figure is located in the old field and grassland habitat zone just west of the Y-12 Plant.

Hardwood and mixed hardwood/conifer habitats are the most abundant habitat types in Bear Creek watershed, followed by pine plantation and grassland habitats, with considerable riparian habitat along the length of Bear Creek. Species commonly found in these habitats are listed below.

Hardwood and mixed hardwood/conifer habitats. In wooded areas the eastern gray and southern flying squirrels, southeastern shrew, eastern mole, short-tailed shrew, white-footed mouse, white-tailed deer, and eastern chipmunk may be found. Predators such as the bobcat and weasel occur here. Birds commonly found in forest areas include the yellow-shafted flicker, red-bellied woodpecker, hairy woodpecker, downy woodpecker, blue jay, Kentucky warbler, pine warbler, ovenbird, Carolina chickadee, tufted titmouse, and scarlet tanager. Hawks (red-shouldered, red-tailed, and broad-winged) are commonly found on the ORR, as are wild turkeys, which have been reintroduced to the area in recent years. Amphibians and reptiles found in the forest habitat include the dusky salamander, American toad, eastern box turtle, ground skink, worm snake, black racer, rat snake, black king snake, milk snake, and copperhead.

Pine plantation habitat. Very early stages of planted pine areas contain species similar to those in old-field habitats, and the small mammals present are much the same as in the late stages of old fields. The populations tend to be smaller, though, because of less tree diversity. Pine plantations with a dense canopy and no understory are essentially barren of both small and large mammals except around the edges. As plantations are thinned and canopies opened,

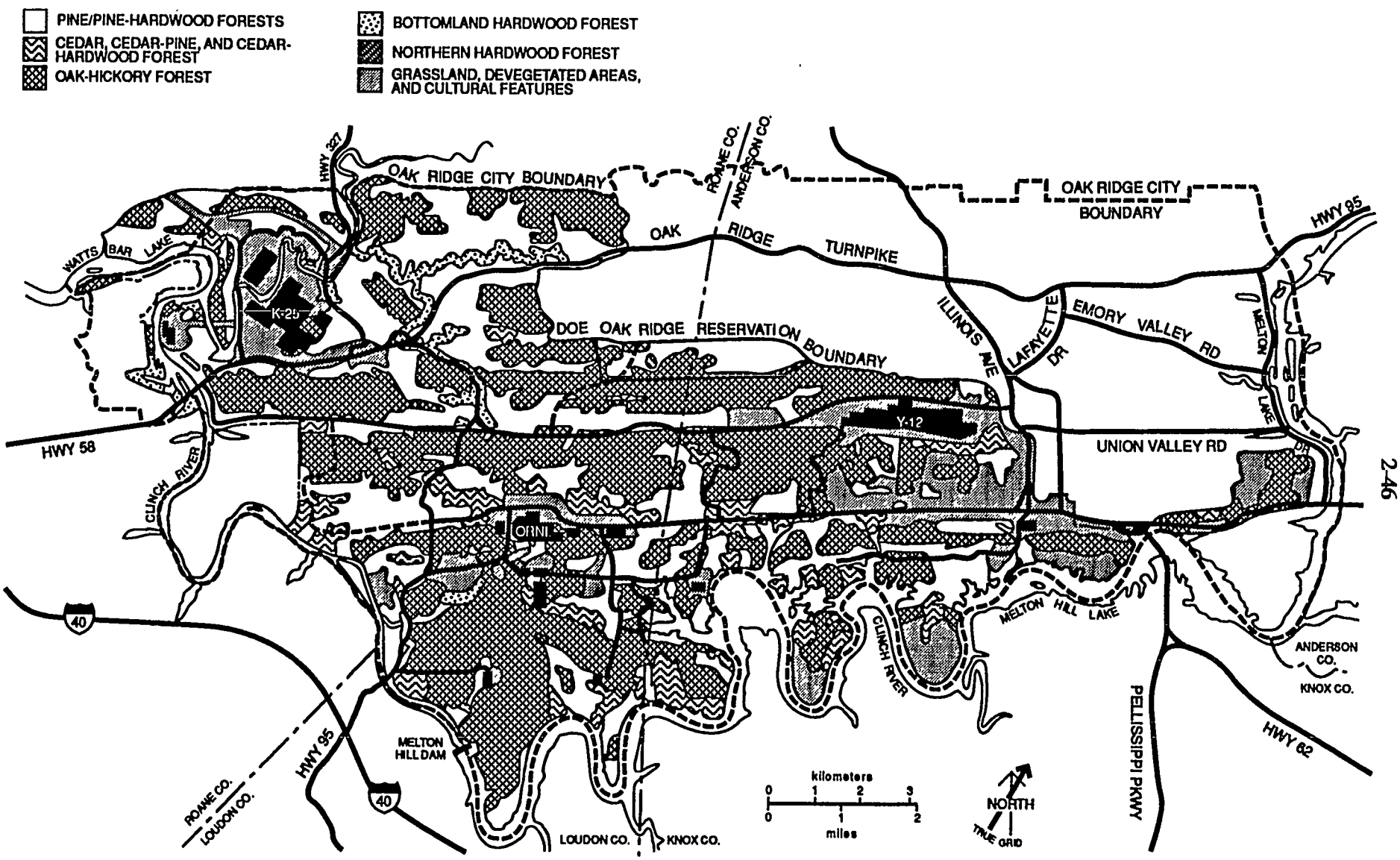


Fig. 2.19. General vegetation cover types on the ORR (*Source:* DOE 1980).

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Table 2.9. Recently documented rare plants and animal species on the Oak Ridge Reservation

Scientific name	Common name	Status	
		Federal[a]	State[b]
	Flora		
Aureolaria patula	Spreading false foxglove	C1	E
Carex gravida	Gravid sedge		S
Cimicifuge rubifolia	Appalachian bugbane	C2	T
Cypripedium acuale	Pink lady's slipper		E*
Delphinum exaltatum	Tall larkspur	C2	E
Diervilla lonicera	Northern bush honeysuckle		T
Elodea nuttallii	Nuttall waterweed		S
Fothergilla major	Mountain witch alder		T
Hydrastis canadensis	Golden seal		T
Juglans cinerea	Butternut	C2	T
Lilium canadense	Canada lily		T
Liparis loeselii	Fen orchid		E
Panax quinqifolius	Ginseng	3C	T
Platanthera flava v. herbiola	Tuberculed rein orchid		T
Platanthera peramoena	Purple fringeless orchid	3C	T
Saxifraga careyana	Carey saxifrage	C3	S
Spiranthes ovalis	Lesser ladies tresses		S
	Mammals		
Myotis sodalis	Indiana bat	E	E
	Birds		
Haliaeetus leucocephalus	Bald eagle	E	E
Pandion haliaetus	Osprey		
Accipiter striatus	Sharp-shinned hawk		E
Accipiter cooperii	Cooper's hawk		T
Ammodramus savannarum	Grasshopper sparrow		T
Nycticorax nycticorax	Black-crowned night heron		D
Coragyps atratus	Black vulture		D
Buteo lineatus	Red-shouldered hawk		D
Tyto alba	Barn owl		D

Table 2.9 (continued)

Scientific name	Common name	Status	
		Federal[a]	State[b]
	Fish		
Phoxinus tennesseensis	Tennessee dace		D

[a]Federal status codes:
E = Endangered.
T = Threatened.
C1 = Taxa for which the USFWS has on file substantial information on biological vulnerability and threats to support the appropriateness to list them as endangered or threatened species. Included are those taxa whose status in recent past is known, but may have already become extinct.
C2 = Taxa for which information now in possession of the service indicated that proposing to list them as endangered or threatened is appropriate, but for which substantial data on biological vulnerability and threat(s) are not currently known or on file to support a proposed rule.
C3 = Taxa that are no longer being considered for listing as threatened or endangered species.
3C = Taxa that have proven to be more abundant or widespread than was previously believed and/or those that are not subject to any identifiable threat.
[b]State status codes:
E = Endangered.
E* = Endangered due to commercial exploitation.
T = Threatened.
S = Special concern.
D = Deemed in need of management.
Source: Cunningham et al. 1993. *Resource Management Plan for the Oak Ridge Reservation, Vol. 29: Rare Plants on the Oak Ridge Reservation,* ORNL/NERP-7. Oak Ridge, Tenn., August, and Memorandum from R. Kroodsma, Energy Systems, to R. E. Ambrose, SAIC, July 28, 1994.

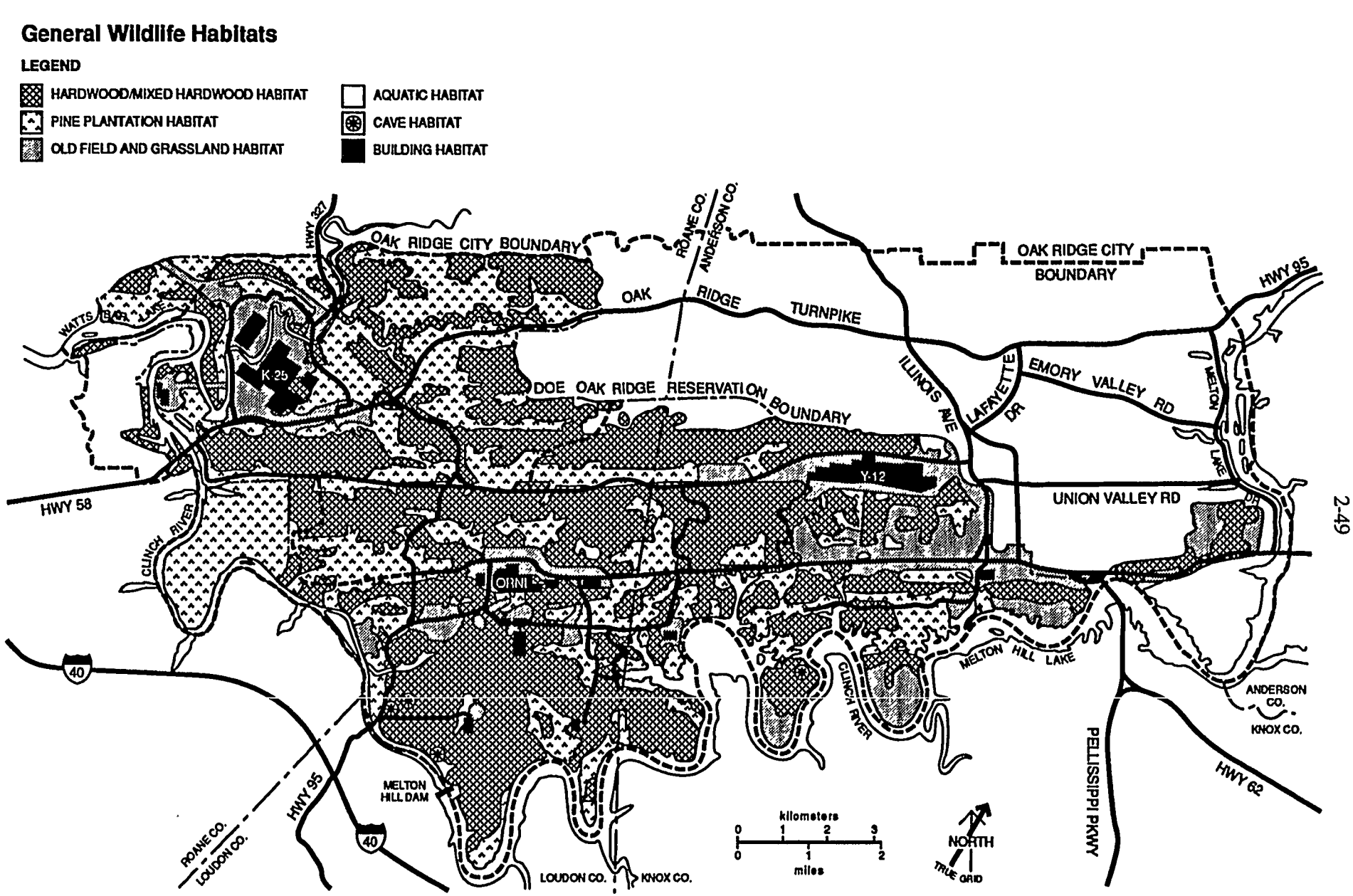


Fig. 2.20. General wildlife habitats on the ORR (*Source:* DOE 1980).

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undergrowth develops and provides habitat for species similar to those found in early- to mid-stage hardwood-mixed and hardwood/conifer forests. Avian species have a low preference for the pure pine areas bordering the transmission line corridors. Pine warblers and white-throated sparrows are common, but few other species are evident. These habitats are little used by reptiles or amphibians (Johnson 1964).

Old-field and grassland habitat. In the grassland/forb stage of vegetation, the principal species of small mammals are the southeastern shrew, least shrew, short-tailed shrew, eastern harvest mouse, hispid cotton rat, pine mouse, and the eastern cottontail rabbit. The eastern mole occurs in areas of loose soil. Closely mowed or grazed areas and dense kudzu growth is good habitat for the groundhog. Also found there are the striped skunk, coyote, red fox, and white-tailed deer. In more brushy vegetation, the white-footed mouse, golden mouse, and opossum may be found. Bird species found in this habitat include bobwhite, red-tailed hawk, field sparrow, towhee, blue grosbeak, meadowlark, and red-winged blackbird. The eastern bluebird population has increased with the establishment of bluebird nesting boxes. The yellow-breasted chat is found in old fields. Numerous frog, toad, lizard, and snake species are found in the old field areas.

Aquatic and riparian habitats. Many reptiles and amphibians occur in the various aquatic and wetland areas, including turtles, queen snakes, water snakes, salamanders, and frogs. The muskrat and beaver are bound closely to aquatic habitats. Rice rats, mink, and raccoons are also found in these areas. Many large mammals come frequently to this habitat to drink, and various small species are present at the water's edge. The American bald eagle occurs occasionally as a transient. Canada geese, great blue herons, and green-backed herons nest on the ORR.

Threatened and endangered species. One mammal species, the Indiana bat (*Myotis sodalis*) on the federal list of endangered animals, has been documented on the ORR, as has the Bald eagle (*Haliaeetus leucocephalus*) (Kroodsma 1994). Other birds recently documented on the ORR and listed by the state as endangered include the Cooper's hawk (*Accipiter striatus*) and the Grasshopper sparrow (*Ammodramus savannarum*). The Bald eagle and the Indiana bat are also listed as endangered by the Tennessee Wildlife Resources Agency (TWRA). The Black-crowned night heron (*Nycticorax nycticorax*), Black Vulture (*Coragyps atratus*), Red-shouldered hawk (*Buteo lineatus*), and Barn Owl (*Tyto alba*) are also listed by TERA as deemed in need of management, as is the Tennessee dace (fish) (*Phoxinus tennesseensis*). Table 2.9 lists all rare animal species that have been identified on the ORR recently, and the federal and/or state status of each.

2.7.3 Aquatic Fauna

There have been 19 species of fish found in Bear Creek in recent quantitative monitoring efforts conducted at 7 sites along virtually the entire length of the creek (Southworth *et al.* 1992). Minnows [blacknose dace (*Rhinichthys atratulus*) and Tennessee dace (*Phoxinos tennesseensis*)], stoneroller (*Campostoma anomalum*), and creek chub (*Semotilus atromaculatus*) were the predominant fish species found upstream from the weir at BCK 4.55. Below the weir, larger species (northern hogsucker (*Hypentelium nigricans*), white sucker (*Catastomus commersoni*), and rockbass (*Ambloplites rupestris*) were more common; the diversity of minnow species increased; and darters were found. Conclusions of the recent fish-monitoring studies were that much of Bear Creek had limited fish fauna (low species richness) characterized by robust population parameters (high densities and biomass). The uppermost

site (BCK 12.36) had no stable, resident fish population. Water from this site was commonly toxic to fathead minnow larvae in toxicity testing and contained high levels of dissolved salts as a result of input of contaminated groundwater from the S-3 Site. The next two monitoring sites downstream, BCK 11.83 and BCK 11.09, had low fish density and biomass in 1984 and 1985 but showed recovery in later sampling. No impacts on the fish of Bear Creek were evident in the vicinity of inputs from the Burial Grounds (BCK 9.91 and BCK 9.40) despite the fact that qualitative surveys found no fish in the tributaries (NT-6-8) draining that site.

The yellowfin madtom (*Noturus flavipinnis*), listed by the state as endangered, has been found in Bear Creek. The Tennessee dace, a major constituent of the fish population above the weir at BCK 4.55, is listed as a species in need of management. Its habitat is protected by the state of Tennessee (Starnes and Etnier 1980). In Bear Creek, it occurs at every site above the weir and in at least four tributaries (NT-13, NT-14, NT-18, and ST-7).

Quantitative sampling of benthic invertebrates was conducted monthly at nine sites from BCK 12.36 to BCK 3.25 during June 1984–May 1985 as part of Phase 1 of the ecological monitoring program for Bear Creek and at quarterly intervals thereafter (Southworth *et al.* 1992). A total of 126 distinguishable taxa were collected in Bear Creek, including crustaceans (Isopoda, Amphipoda, and Decapoda); aquatic worms (Oligochaeta); snails (Gastropoda); mussels (Pelecypoda); and insects (Insecta). There were 11 orders of insects collected in Bear Creek, including springtails (Collembola), mayflies (Ephemeroptera), dragonflies and damselflies (Odonata), crickets and grasshoppers (Orthoptera), stoneflies (Plecoptera), true bugs (Hemiptera), alderflies and fishflies (Megaloptera), caddisflies (Tricoptera), butterflies and moths (Lepidoptera), beetles (Coleoptera), and true flies (Diptera).

The invertebrate fauna of Bear Creek showed a pattern of increasing density, biomass, and taxonomic diversity and richness with increasing distance downstream from the uppermost sampling site (BCK 12.36) (Southworth *et al.* 1992). The paucity of benthic invertebrates in the upper reaches of Bear Creek contrasted sharply with reference sites (unimpacted streams of similar size), which had relatively diverse and abundant assemblages of macroinvertebrates.

In toxicity tests run in March 1988, water from BCK 12.36 and BCK 11.83 was toxic to *Ceriodaphnia*, an invertebrate test species, but not to fathead minnow larvae. At the time of these tests, stream flow in Bear Creek was higher than normal, and contaminants from the S-3 Ponds groundwater plume were diluted more than would be the case under baseflow conditions. Under low-flow conditions, it is likely that Bear Creek water would be toxic to *Ceriodaphnia* as far downstream as BCK 9.4. While evidence of adverse effects on the fish communities of Bear Creek was not noted at sites downstream from BCK 11.83, the benthic fauna appeared to be more sensitive, with clear differences in faunal composition from unimpacted reference sites at all sites except BCK 3.25, where complete recovery appears to have occurred.

Species intolerant of pollution (mayflies, stoneflies, and caddisflies) were absent in the upper reaches and became more common downstream. Mayflies, which are particularly sensitive to toxic metals, were virtually absent at all sites except BCK 3.25. Unlike the fish data, which provide evidence of ecological recovery in Bear Creek since 1984, the benthic macroinvertebrate fauna do not appear to have changed in a manner indicative of either improving or degrading water quality since 1984 (Southworth *et al.* 1992).

No threatened or endangered species of aquatic macroinvertebrates have been collected in Bear Creek.

A limited amount of data have been collected on the bioaccumulation of contaminants by aquatic biota in Bear Creek. Fish collected from lower Bear Creek contained elevated levels of mercury (0.2 to 0.5 μg/g, wet weight) in 1982 (Van Winkle *et al.* 1984) and in 1984 (TVA 1986). While well below the U.S. Food and Drug Administration (FDA) action level, these data do indicate the presence of biologically available mercury in the Bear Creek system. Fish from lower Bear Creek were also analyzed for Cd, Cr, Ag, As, and Ni in 1984 (TVA 1986), and levels were found to be typical of fish from uncontaminated environments.

Polychlorinated biphenyl (PCB) contamination in fish from Bear Creek was evident in 1982, when rockbass collected from the lower reaches of the creek were found to contain 0.65 ± 0.29 ppm (wet weight) PCBs (Turner et al. 1988). TVA analyzed fish from lower Bear Creek for organic priority pollutants, including PCBs in 1984; levels of all substances were below detection limits. Fish were collected from lower Bear Creek in 1987 as part of an effort to evaluate the importance (relative to other sources) of the upper EFPC discharge at New Hope Pond as a source of PCB contamination to lower Poplar Creek and the Clinch River. In this collection, PCBs in rockbass averaged 0.28 ± 0.12 ppm (n=8), a value comparable to the level of contamination found in sunfish in the lower third of EFPC and well above the level typical of fish from uncontaminated sites (0.02 ± 0.01 ppm). Clams held in Bear Creek (BCK 4.55) for 1 month as part of the same study accumulated 1.01 ppm PCBs (versus 0.05 ppm in controls), indicating that Bear Creek now contains a source of biologically available PCBs.

PCB contamination has been observed in fish in EFPC, Poplar Creek, and the Clinch River/Watts Bar Reservoir downstream from Bear Creek (TVA 1986). It is unlikely that a substantial fraction of this contamination is attributable to Bear Creek because sources of PCBs and similar body burdens are found in EFPC far upstream from the mouth of Bear Creek (TVA 1986). A similar situation exists for mercury (TVA 1986).

3. SITE HISTORY AND CURRENT CONDITIONS

This chapter discusses the results of past investigation at the sites in BCV OU 2 and presents the findings of the current investigation. The main objectives of this portion of the RI are the following: (1) to further define the nature and extent of contamination in the media of concern (i.e., soil), (2) to gather information for the needs of the human health and ecological risk assessments (Chaps. 5 and 6), and (3) to provide a basis for the development of remedial alternatives presented in the FS Report. More specific objectives include the following:

- to determine the source of VOC contamination identified in historical investigations of SA-1;
- to define the nature of soil contamination at the SY-200 Yard;
- to define the extent (vertical and horizontal) of soil contamination at the SY-200 Yard;
- to verify the nature and extent of soil contamination at the RSA;
- to define the interaction (transfer mechanism) between soil contamination and shallow groundwater; and
- to define the relative contribution of BCV OU 2 contaminants to BCV groundwater and surface water contamination.

Chapter 3 contains three main parts: (1) a site description and discussion of the site history (Sect. 3.1), (2) a discussion of the historical and RI-derived data (Sect. 3.2), and (3) a discussion of the data quality derived from the RI (Sect. 3.3).

Section 3.1 includes an overview of the three BCV OU 2 sites: SA-1, the SY-200 Yard, and the RSA. Access to historical studies and general site knowledge provided sufficient information to design an investigation that would identify probable contaminants and migration pathways for this RI.

Section 3.2 reports on the data available for use in this investigation. It describes the historical studies conducted on the BCV OU 2 sites and the studies performed during this RI. The site conceptual model and the data collection considerations are summarized in the introduction to this section to provide a perspective for the data presented. A more detailed explanation of the site conceptual model is included in Sect. 3.2.5. The presentation and evaluation of data collected during this investigation are divided into the following sections by physical media and then by site:

3.2.1 Surface Water Data
3.2.2 Sediment Data
3.2.3 Groundwater Data (including seep)
3.2.4 Soil Chemical Data
3.2.5 Contaminant Fate and Transport
3.2.6 Biomonitoring Data
3.2.7 Air Data
3.2.8 Radiation Survey Data

Section 3.3 is a report on the data quality for the BCV OU 2 RI.

3.1 SITE DESCRIPTION

3.1.1 Geographic Information

OU 2 is located in BCV in Anderson County ~0.4 miles west of the Y-12 Plant on Old Bear Creek Road (Fig. 3.1). The OU consists of three discrete areas: the SA-1, the SY-200 Yard, and the RSA. Just north of SA-1 is the S-3 Waste Ponds, which will be evaluated during the BCV OU 1 RI in late 1994. Figures 3.2–3.4 are aerial views of the three sites showing their relation to the Y-12 Plant and the S-3 Ponds. The photographs were taken between 1983 and 1988.

3.1.2 Background Information

The Oak Ridge Y-12 Plant was built by the U.S. Army Corps of Engineers in 1943 as part of the Manhattan Project. The original mission of the Plant was to separate the fissionable isotope of uranium (^{235}U) using an electromagnetic separation process. After World War II, this process was discontinued in favor of a more economical gaseous diffusion process conducted at the nearby Oak Ridge K-25 Site (Welch 1989a).

Since the early years, the Y-12 Plant has developed into a highly sophisticated manufacturing and developmental engineering facility. Recent manufacturing activities at the Y-12 Plant included chemical processing of lithium and uranium compounds and precision fabrication of components from lithium, uranium, and many other materials. In support of these activities, areas were needed for disposal of uncontaminated fill and construction debris (SA-1 and RSA) and for the temporary storage of equipment (the SY-200 Yard). The current mission of the Y-12 Plant is to serve as a key manufacturing technology center for the development and demonstration of unique materials, components, and services of importance to DOE and the nation. This is accomplished through the reclamation and storage of nuclear materials, manufacture of nuclear materials, manufacture of components for the nation's defense capabilities, support to national security programs, and services provided to other customers as approved by DOE.

3.1.3 Operational Information and Releases

The following sections contain descriptions of the wastes managed in each of the BCV OU 2 sites as well as information about their generation and disposal methods. A chronological listing of major site activities, including construction events, subsequent treatment or cleanup activities, and preliminary results of monitoring data, follows the discussion.

3.1.3.1 SA-1

SA-1 is located west of the Y-12 Plant on Old Bear Creek Road near the junction with West Patrol Road (Fig. 3.1). Various renovation, maintenance, and construction operations at the Y-12 Plant produced construction debris that included concrete, asphalt, brick, brush, rock, and tile (Table 3.1). Solid waste (spoil material) generated during these operations has been disposed of in SA-1 since about 1980 (Fig. 3.5), but the RFI plan for this site (Battelle

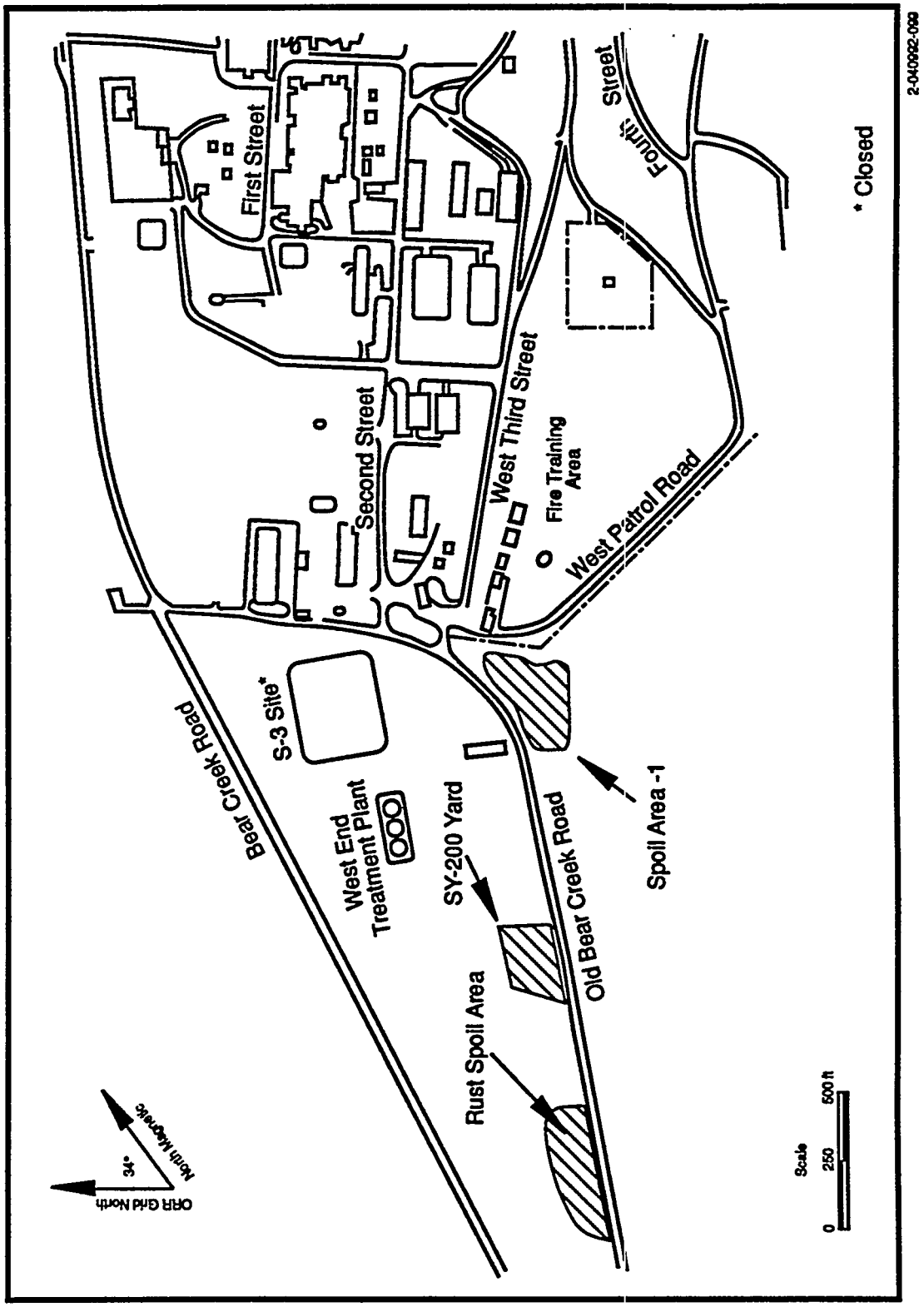


Fig. 3.1. BCV OU 2.

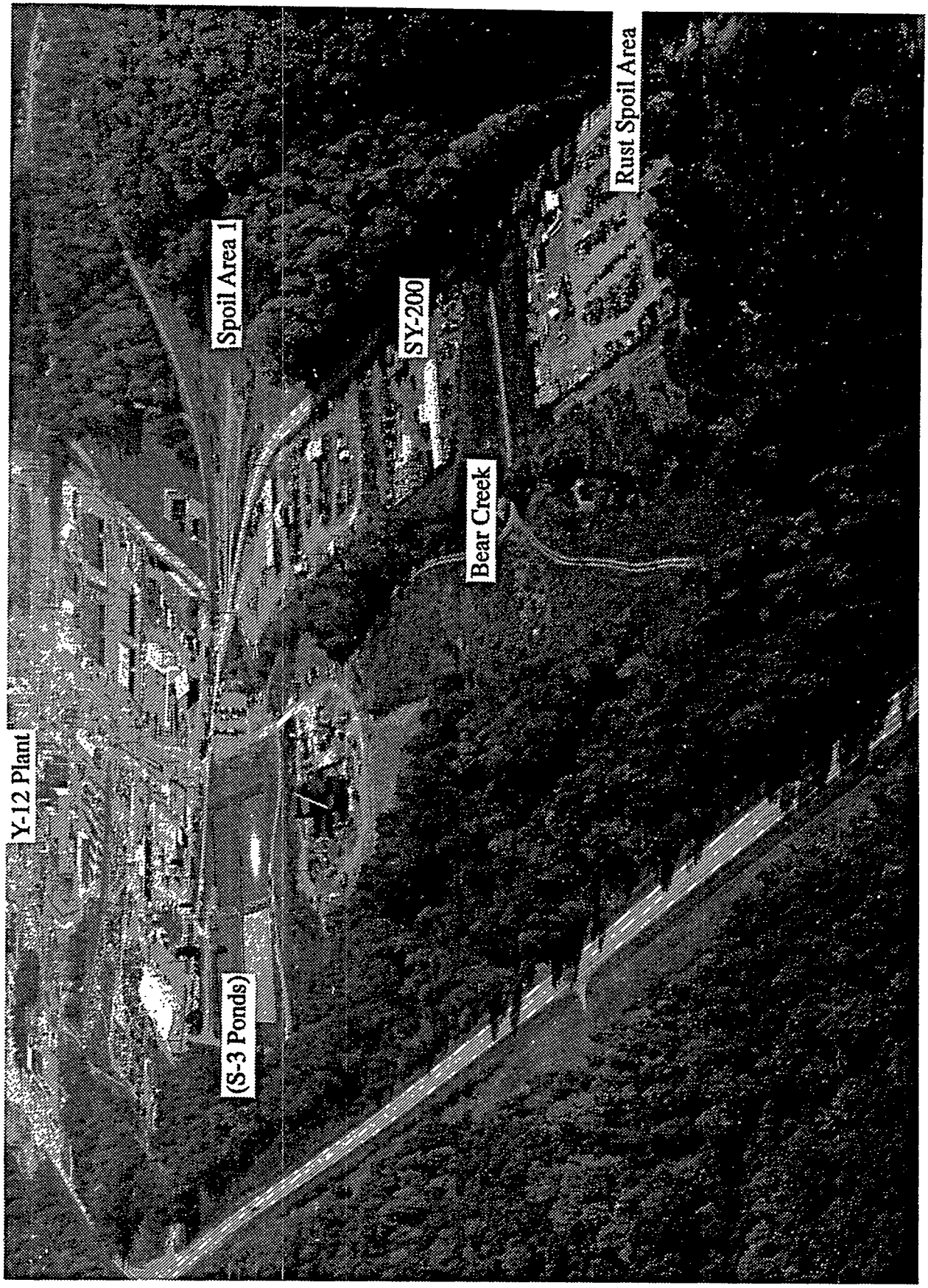


Fig. 3.2. Aerial photograph showing BCV OU 2 sites, circa 1983.

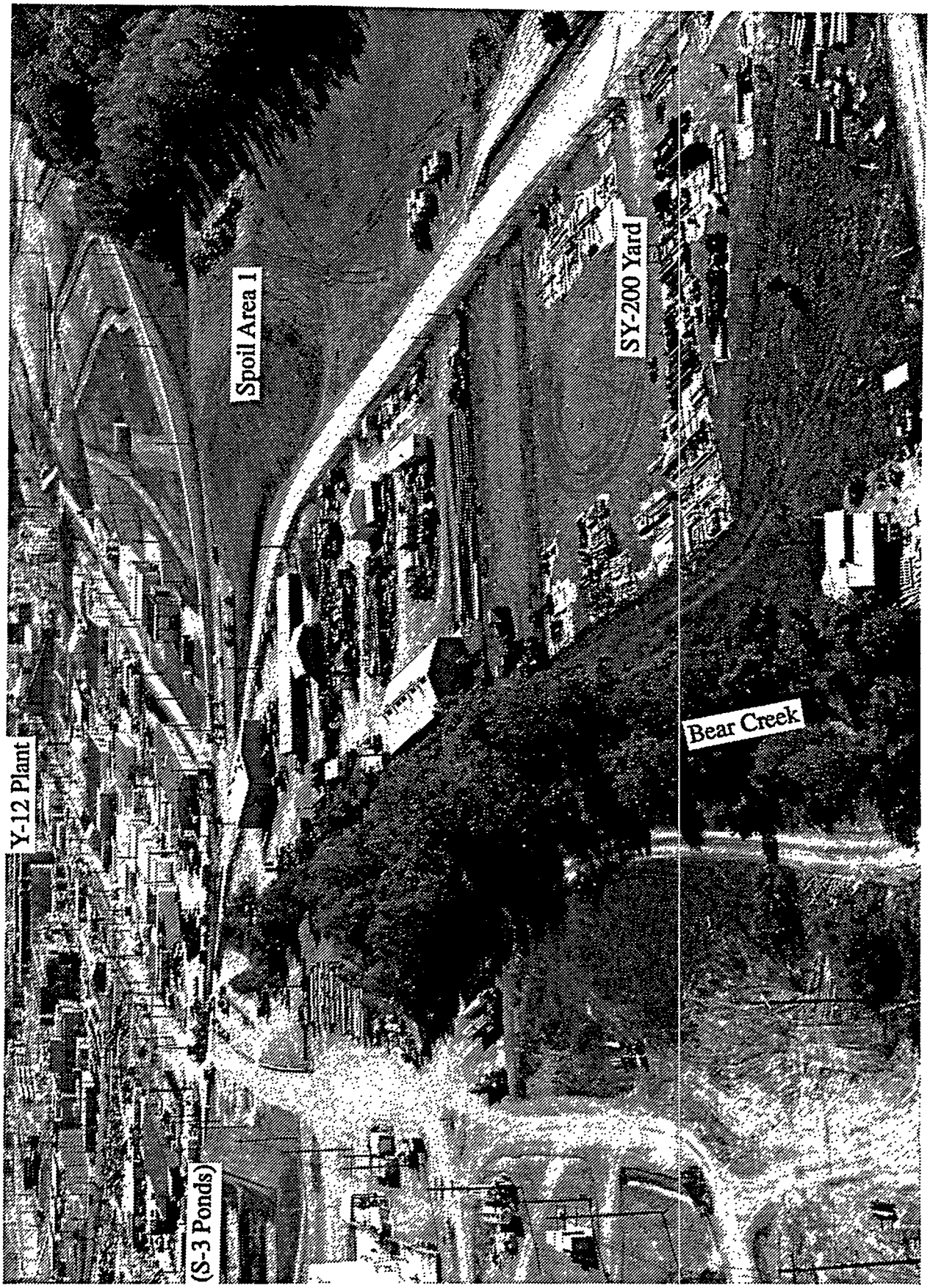


Fig. 3.3. BCV OU 2 sites, 1987.

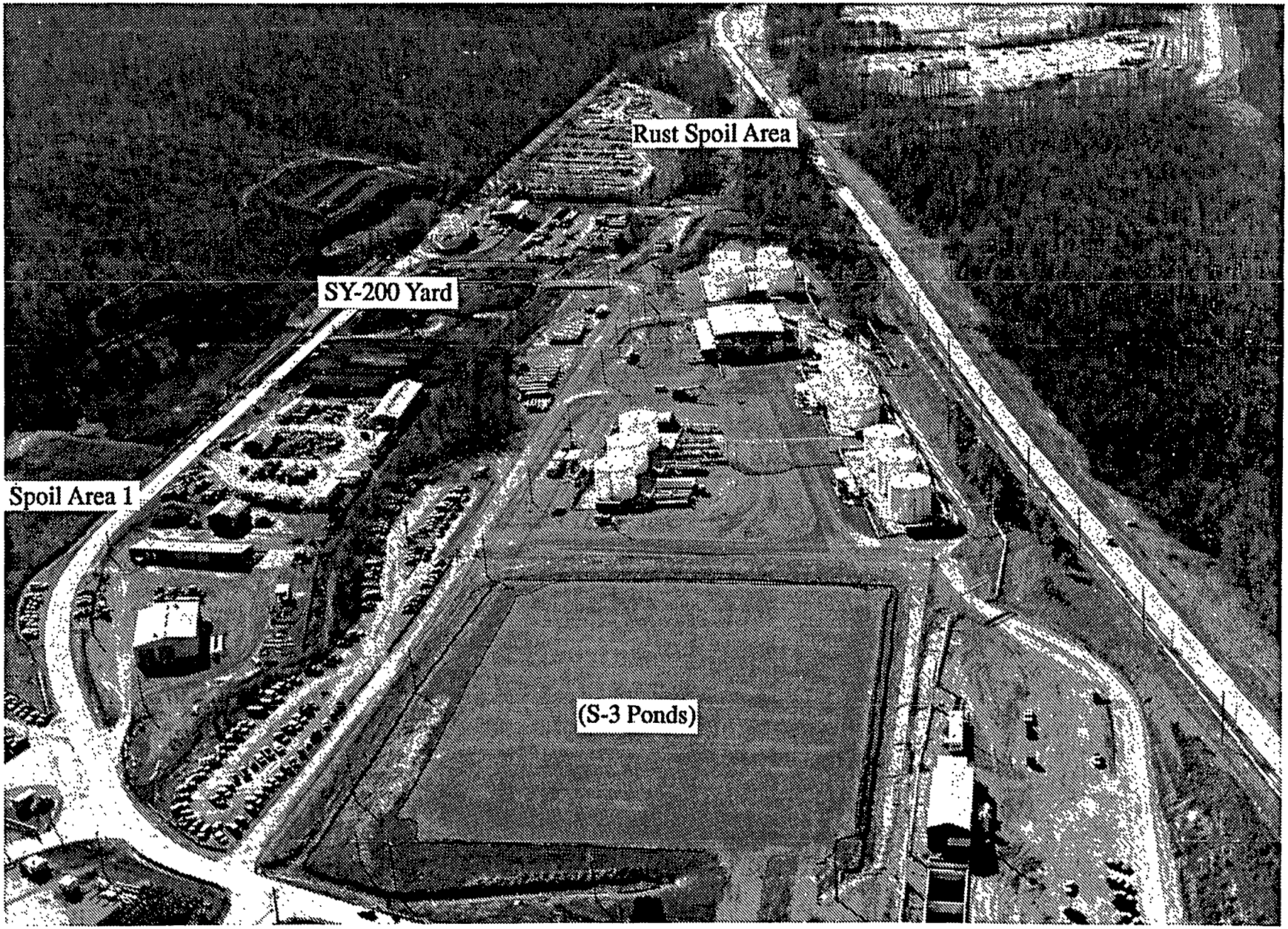


Fig. 3.4. BCV OU 2 sites, 1988.

Table 3.1. Chronological listing of major activities at SA-1

Date	Activity
Pre-1980	Historic photographs show excavation of hillside before disposal of waste spoil materials
1980	Disposal operations began on the ~5-acre site. Disposal material included nonhazardous, nonradioactively contaminated construction debris from various renovation, maintenance, and construction operations at the Y-12 Plant. The bulk of the solid waste known to have been disposed of included asphalt, brick, concrete, roofing materials, brush, metal, rock, and tile. The waste spoil material was spread in 1- to 2-ft layers known as cells and compacted. Clay soil from a borrow area located immediately west of the site was spread over the cells in 0.5-ft layers. If a cell did not receive any waste spoil material within 1 month, the cell was covered with a 1-ft compacted clay layer. The cells were constructed in stepped layers to maintain a stepped shape at the site
1985	SA-1 received a permit from TDEC as a landfill for rubble and noncombustible, nonputrescible solid waste
1985	Closure activities began by placing a clay soil cover (minimum of 2 ft) over the site after final deposition of the waste and establishing a grass ground cover
1987	Intermediate (bedrock) monitoring wells GW-313, -314, -315, -316, -317, and -323 were installed to monitor groundwater at the SA-1 site
1988	The monitoring well network at SA-1 was sampled quarterly from February 1988 to June 1989. Results indicated elevated concentrations of radioactivity, total coliform bacteria, total organic carbon, total organics halides, iron, and nitrate
1989	RFI work plan prepared by Battelle Corporation listed COPCs as asbestos, uranium, mercury, beryllium, thorium, and others
1990	Six soil borings were installed within the SA-1 site boundary. Soils were analyzed for volatile organic compounds (VOCs), metals and cyanide, selected radiologicals, and semivolatile organic compounds (SVOCs)
1991	Results of soil and groundwater studies in the area confirmed the presence of heavy metals and radiological contamination
1993	The RI work plan listed the COPCs as arsenic, beryllium, barium, chromium, lead, mercury, fluoranthene, phenanthrene, pyrene, radium, and uranium
1993	The RI field activities at the site were completed in October. Two shallow unconsolidated groundwater monitoring wells were installed and sampled, and samples from three sediment sample locations and two surface water sample locations were collected



Fig. 3.5. SA-1, early operations circa 1980.

1989b) indicates that no detailed disposal records are available. The site is ~5 acres. Since 1985, SA-1 has had a permit from TDEC as a landfill for rubble and noncombustible, nonputrescible solid waste. Closure activities began in 1985 by placing a 2-ft minimum clay soil cover over the site after final deposition of the waste and establishing a grass ground cover (Fig. 3.6).

It is estimated that ~100,000 yd^3 of non-uranium-contaminated construction debris had been disposed of at the site (Battelle 1989b). The waste was determined to be nonradioactively contaminated according to health physics requirements established for the Y-12 Plant, although construction material disposed of in this area may have contained minor amounts of asbestos, mercury, beryllium, uranium, thorium, and other contaminants, according to the RFI plan. As shown in Table 3.1 and detailed in Sect. 3.2, both the RI work plan and RI revealed the presence of additional COPCs.

3.1.3.2 The SY-200 Yard

The SY-200 Yard is located west of the Y-12 Plant on Old Bear Creek Road between SA-1 and the RSA (Fig. 3.1). From the 1950s to 1986, the SY-200 Yard was an above-ground outside graveled area (~300 ft × 200 ft) used for temporary storage of equipment, machinery, and miscellaneous items (Fig. 3.2, Table 3.2, Fig. 3.7). No chemicals or waste materials were stored at the site, and all container materials (e.g., tanks) at the site were empty and stored for future use (Geraghty and Miller 1989a). The site was surrounded by a 1.8-m (6-ft) fence with gate access. During operation there were no underground utilities or piping at the site. The Y-12 Plant operations divisions that used the yard included the Assembly Division, Engineering Technology Division, Metal Preparation Division, and the ORNL Fusion Energy Division. Items stored at the site were segregated with respect to ownership by the various operating divisions using the yard.

There are no detailed records available on the items that were stored and removed during the early operational period of the SY-200 Yard. All items stored at the site were removed by September 1986 to prepare the area as the future site for an ESF that was to include a maintenance shop, office complex, tanker terminal, and security portal. Before removal, all items stored at the site were surveyed by the Y-12 Plant HPD and flagged for proper disposal and handling. Table 3.3 summarizes an inventory of items removed from the site before closure in 1986. This inventory is based on available records and discussions with Y-12 Plant personnel. Some items were labeled by HPD as contaminated with radioactivity. Five transformers stored at the site could be a source of PCB and oil contamination, and lead shielding plates may have been a source of lead contamination (Geraghty and Miller 1989a).

Fill soil was placed in the SY-200 Yard area in the 1950s, but there are no records of the sources of this soil fill. The presence and extent of native soils at the SY-200 Yard are not well known due to the extensive cutting and filling that took place during plant construction. Figure 3.8 shows the approximate areal extent of fill materials in the area (U.S. Army Corps of Engineers 1954). The fill is composed primarily of clay, sand, and gravel, limestone boulders, and also contains asphalt, wood, and excavated weathered geologic materials. During ESF construction activities (see details in Table 3.2), there was evidence of mercury contamination in the fill materials. North of the site and Bear Creek are known areas of mercury-contaminated fill materials (Geraghty and Miller 1989a). The known site inventory of the SY-200 Yard does not provide a probable source of mercury contamination; therefore, it is believed that the presence of mercury did not originate from the SY-200 Yard. No

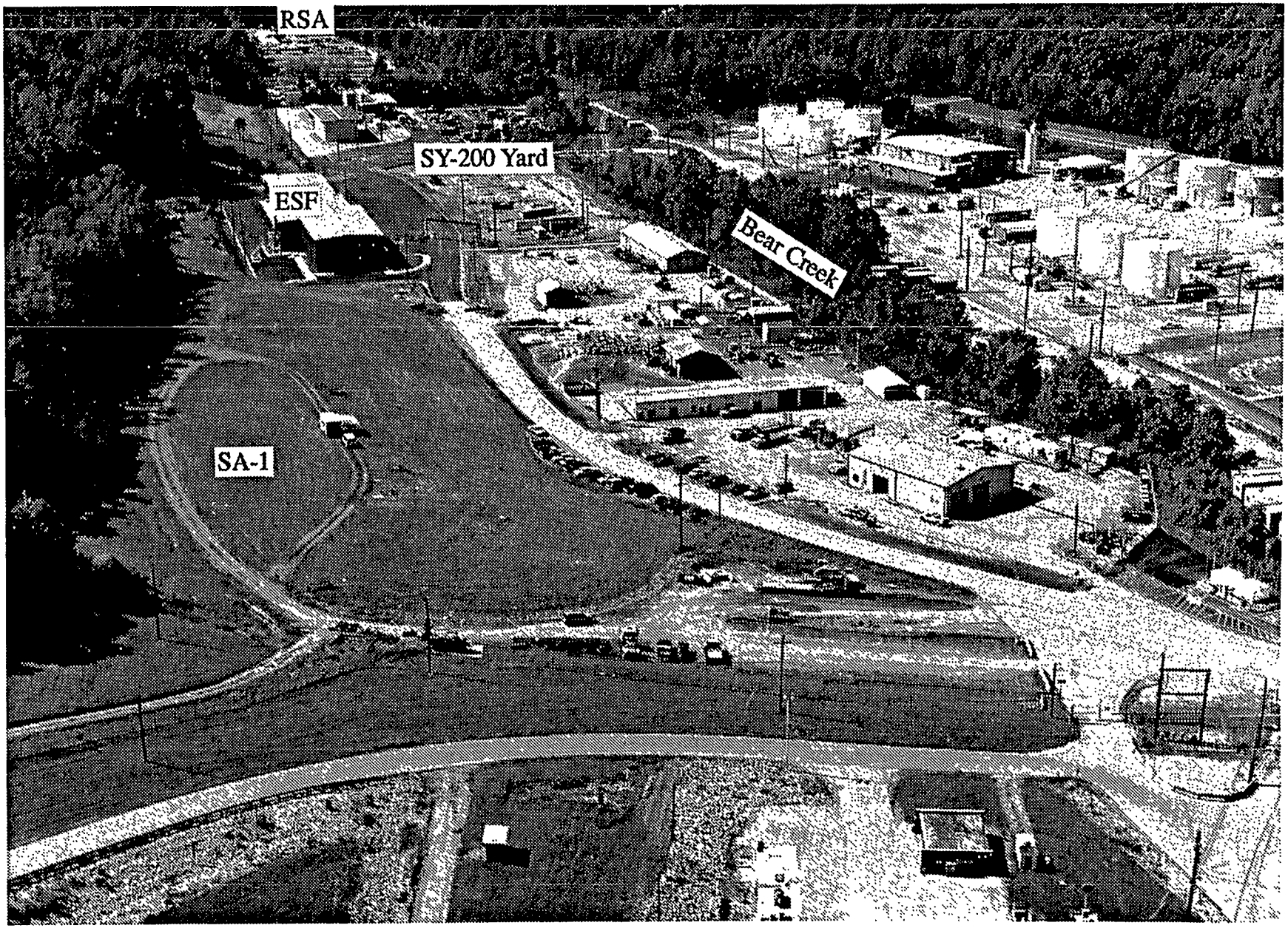


Fig. 3.6. Current aerial photograph showing SA-1 with established vegetative cover, the newly completed EST building across Old Bear Creek Road from the SY-200 Yard, and the RSA in the distance.

Table 3.2. Chronological listing of major activities at the SY-200 Yard

Date	Activity
1950	U.S. Army Corps of Engineers map showed that fill soils were placed in the SY-200 Yard and surrounding areas
1959–1986	The area was used as a temporary storage area for equipment, machinery, and miscellaneous items including electrical transformers, piping, tanks, and mercury flasks. All stored items were removed in 1986
1986	In July, six soil samples were collected from the lead shielding storage areas and the transformer storage areas. Analytical results indicated mercury and PCB contamination
1988	In January, 15 soil samples were collected from four boreholes and analyzed for alpha, beta, and gamma activity, PCBs, EPA primary drinking water metals, and extraction procedure (EP) toxicity metals. The analytical results indicated radiological, trace PCB, mercury, barium, and chromium contamination were present
1988	The fence surrounding the SY-200 Yard was removed in December, and a larger one encompassing the location of the future ESF was erected
1988	Construction of the ESF began
1988	The top 0.5 ft of gravel and soil were removed from the ESF construction area for the building foundation and stored in the southwest corner of the SY-200 Yard in December
1988	The ESF foundation was excavated further by removing 8 ft of soil. The soil was bermed along the northeast corner of the foundation area. Construction activities in the area ceased because no natural soils were encountered during the excavation process
1989	RFI work plan prepared by Geraghty and Miller listed COPCs as PCBs, mercury, and lead
1989	In January, 22 composite samples were taken from the bermed soil piles and analyzed for thorium, uranium, percent ^{235}U, and mercury. The analytical results confirmed the presence of these analytes in the soil
1989	Construction activities resumed in September and the top 0.5 ft of soil that had been removed in December 1988 were spread and graded over the bottom of the excavation
1989	Late in the year, the excavated material bermed in the northeast corner of the foundation was spread along the northeast corner of the construction site
1990	Early in the year, the material bermed along the northeast corner of the ESF excavation was placed back in the excavated area and covered with about 5 ft of borrow material
1990	An estimated 175 pilings were driven ~60-80 ft deep to support the ESF structure. Of these, ~120 on the western end of the excavation are located under concrete pads. The remainder of the pilings on the eastern end are exposed (Fig. 3.7)
1990	Construction of the ESF was postponed due to the presence of mercury and asbestos in some of the excavated soils
1993	The RI work plan listed the COPCs as barium, chromium, lead, mercury, PCBs, and uranium
1993	The RI field activities at the site were completed in December. During the investigation, 59 soil borings and 3 groundwater monitoring wells were installed and sampled, and samples from 3 surface water and sediment sample locations were collected

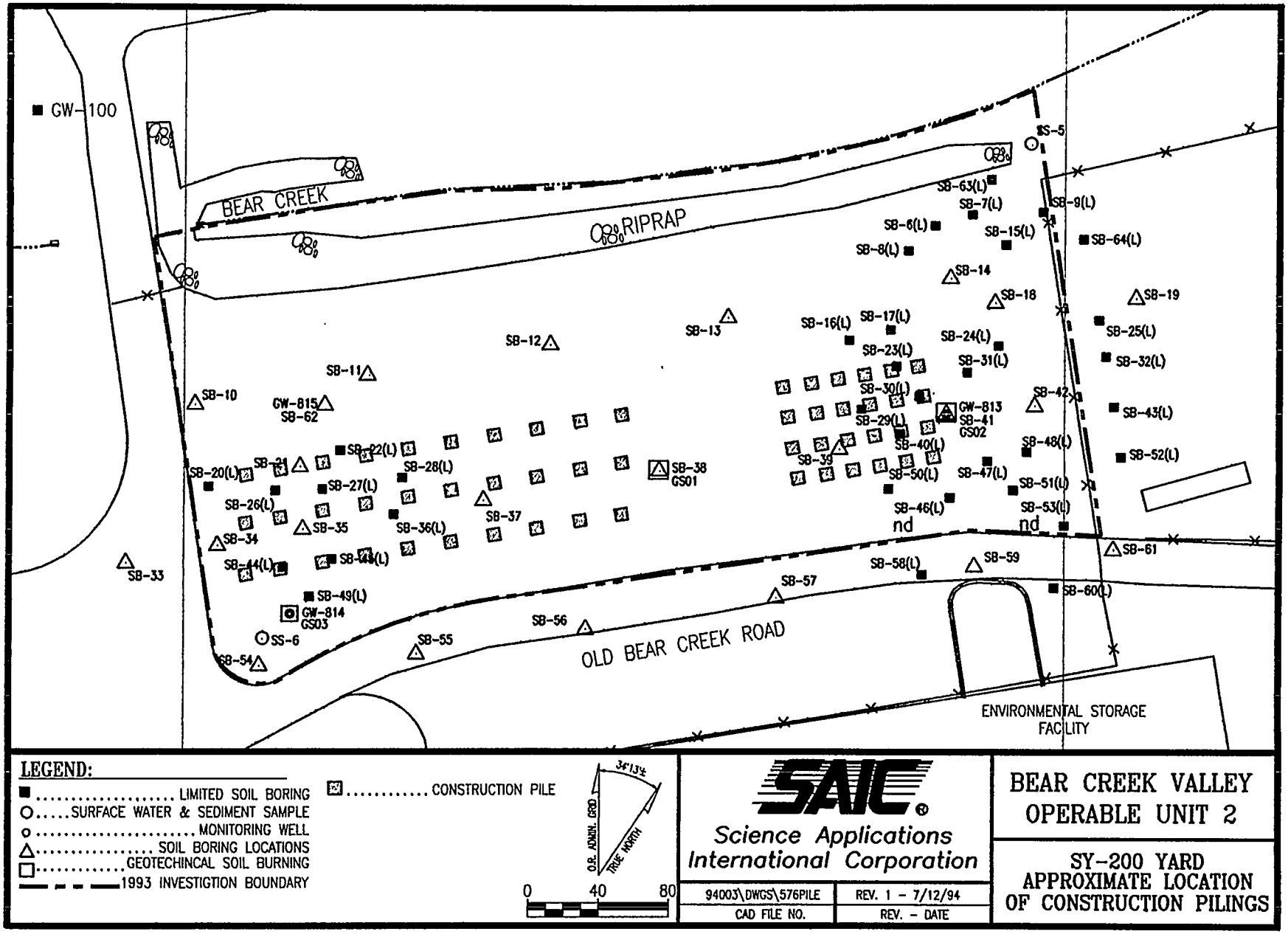


Fig. 3.7. Location of concrete pilings at the SY-200 Yard.

Table 3.3. Summary of 1986 inventory at the SY-200 Yard

Rubber-lined steel tank	Pit furnace hearth
Nickel plating tank	Work roll bearings
Caustic exhaust fan	Plate lifting arms
Plating tank liner	Shaft heat treat fixture
Head tank F5000-7	Drive and sleeve set
Plating tanks	Vacuum tank for DCX2
Waste storage tank	Transformers (five)
Ni strip fix K-25 gas DF	Radiators for power supply
Handling FXT for bells	Lead shielding plates
Tank BRK LND 12×15×8 deep	Aluminum plate and buss
Tank 13 RK BOTM	Cooling fins (12 crates)
Fiberglass tank liner	CRBRP demineralizer
31D1A × 30 length exhaust fan	CRBRP chemical feed equipment
Support tanks	Lube oil cooler
Duct ext 48-diam fiberglass	Bullard hood
E10 pipe 4 for Lindberg	Conveyor roller
Flange Lindberg furnace	High rise rack with shelving
Retort hold furnace cover	Hardware for shelving
E-K evaporator parts	Well cabinets
TurbaFilm evaporator parts	Well positioner
100-gal tank	Table stand with racks
6-in. stainless steel piping	Braces for racks
B-1 col. dissolver parts (13)	Bed plate
DPU retort	Loading frames
Steam coil for F6005	48×48×60 steel tank
Nitric acid still	Railroad ties
Table roll parts	Blocks
Used table roll	Bricks
Backup roll lift fixture	Fencing material
Strip pallets	

Source: Perkins 1989

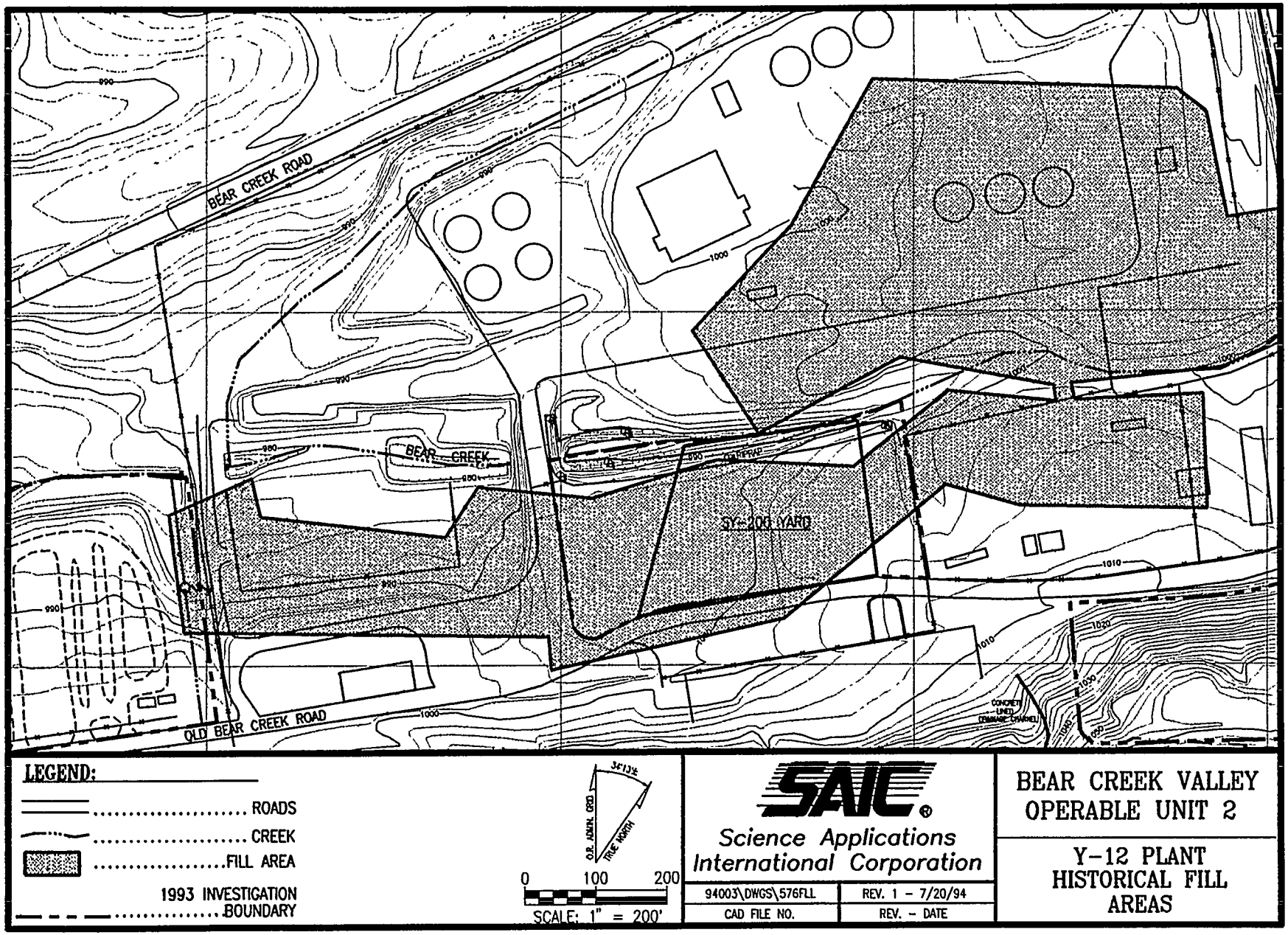


Fig. 3.8. Aerial extent of fill areas.

records are available as to the source of the fill materials, and no additional records or information are available to indicate other contaminant sources.

The ESF recently completed construction immediately south of Old Bear Creek Road (Fig. 3.6). Old Bear Creek Road was moved north ~75 ft to make room for the ESF parking area. This places the new location of the road across the southern part of the SY-200 Yard.

3.1.3.3 RSA

Rust Engineering, formerly a DOE prime contractor, conducted various renovation, maintenance, and construction operations at the Y-12 Plant (Table 3.4). Solid waste (spoil material) generated during these operations was disposed of west of the Y-12 Plant on Old Bear Creek Road near the junction with Bear Creek Road (Fig. 3.1). The RSA was operated from 1975 to 1983. The RSA was originally operated as a disposal area with periodic grading (typically once a month) to promote positive drainage. Disposal progressed northward from Old Bear Creek Road. As dumping occurred, the natural topography was elevated and a portion of the Bear Creek channel was filled. Eventually, the stream channel course was relocated to the north to compensate for the outslope progression. Based on a review of maps depicting the topography before and after the disposal operations, it is estimated that <100,000 yd^3 of construction debris and spoil were disposed of at the site. The RSA underwent site closure activities during 1983–1984 (Table 3.4). The site was covered with a minimum of 2 ft of soil, and vegetative growth was established over disturbed areas. The site is currently used as an equipment and supply storage yard (Fig. 3.9). Equipment at the site is segregated into lots for storage (Fig. 3.2).

The RFI plan for the RSA (Battelle 1989a) indicates that no detailed disposal records are available for the wastes disposed of at the site. The bulk of the waste is reported to consist of demolition debris, including soil, masonry materials (brick and concrete), and metal (steel rebar in concrete). A portion of the demolition debris was packaged and disposed of in open-top metal containers, which were determined by the Y-12 Plant Health Physics Department (HPD) to be nonradioactively contaminated. The RFI plan also indicated the possibility that minor amounts of solvent-contaminated material, and material containing asbestos, mercury, and uranium, may have been disposed of in this area. As shown in Table 3.1 and detailed in Sect. 3.2, both the RI work plan and RI revealed the presence of additional COPCs. The 5.4-acre site measures ~300 × 900 ft in area (Battelle 1989a).

3.2 SUMMARY OF EXISTING DATA

BCV OU 2 Conceptual Site Model

As detailed in Sect. 3.1, the operational histories of SA-1 and RSA consisted primarily of disposing of construction debris from renovation and maintenance operations. Disposal activities in these areas have been discontinued for several years and clay covers (at least 2 ft thick) have been applied to SA-1 and RSA. Since disposal activities at the RSA ceased, the site has been used as an above-ground temporary storage area for equipment and machinery.

The SY-200 Yard was used primarily as an above-ground temporary storage yard. Storage activities at the site were discontinued in 1986. It is known that the site contains fill soil material that was placed in the area in the 1950s. In addition, construction activities were

Table 3.4. Chronological listing of major activities at the RSA

Date	Activity
1975	Disposal operations on the 5.4-acre site began. Disposal material included solid waste (spoil material) generated from renovation, maintenance, and construction operations at the Y-12 Plant. The bulk of the material disposed of included soil, masonry material, and metal. In addition, possible small quantities of asbestos, mercury, uranium, and solvents may have been disposed of at the site. Disposal operations included periodic grading and progressed from Old Bear Creek Road to the north. As dumping occurred, the natural topography was elevated and a portion of the Bear Creek channel was filled. Eventually, the stream channel course was relocated to the north to compensate for the outslope progression
1983	Site closure activities began in the fall with the preparation of a closure plan. The plan called for evacuation of ~7250 yd^3 of spoil from along the outer slope of the area and placed on top of the spoil pile, grading and shaping the existing fill, and covering the entire fill area with a minimum of 2 ft of soil and establishment of a vegetative growth over the disturbed areas
1984	Closure activities were completed in mid-1984
1985	The RSA began current use as an equipment/supply above-ground storage yard
1987	Unconsolidated (shallow) and bedrock (Maynardville Limestone) groundwater monitoring wells, GW-306, -307, -308, -309, -310, -311, and -312, were installed within the RSA boundary
1988	Quarterly sampling of the monitoring well network in the RSA began in February. Results of the analysis indicated elevated concentrations of radioactivity, nitrate, chloride, sulfate, and VOCs
1989	The RFI work plan prepared by Battelle Corporation listed COPCs as asbestos, mercury, uranium, and solvent contaminated material
1993	The RI work plan lists the COPCs as arsenic, beryllium, lead, mercury, selenium, thorium, uranium, and tetrachloroethene
1993	The RI field activities at the site were completed in September. Samples were collected from five soil boring locations and three sediment/surface water locations

conducted in the SY-200 Yard that included disruption and extensive reworking of the soil. During the construction period a soil cover (at least 3 ft thick) was applied to the area.

The diversity of the material disposed of at the site, the inconsistent and variable nature of the disposal operations, and the multiple site uses have caused small amounts of contamination to be heterogeneously distributed throughout each site. With the exception of material disposal there is no reported activity that could have consistently contaminated soils. Due to the contaminant types and the varied distribution, contamination is expected to be encountered as sporadic detects, detected in a wide range of concentrations (i.e., the nugget effect).

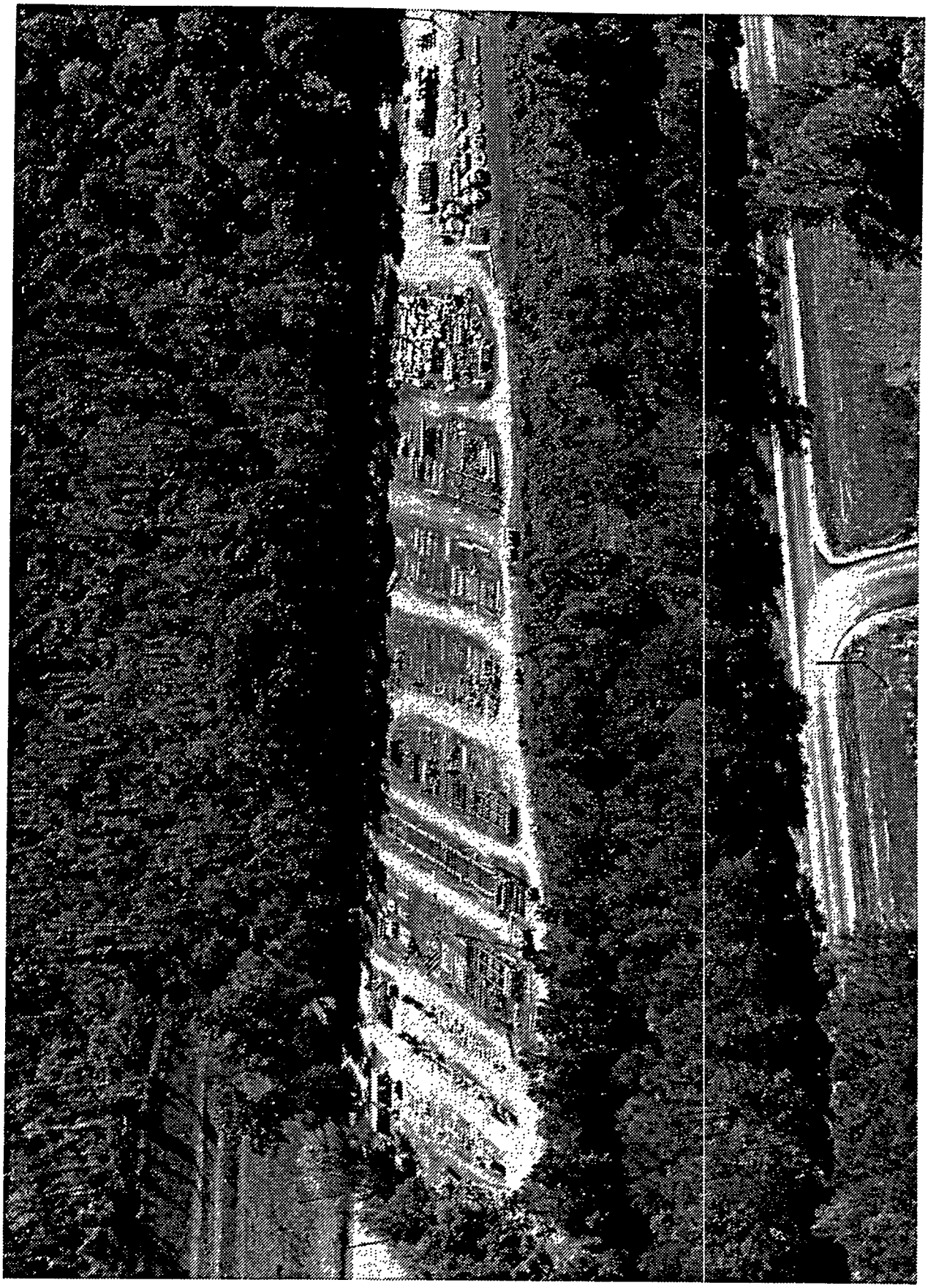


Fig. 3.9. Late 1993 aerial photograph showing equipment storage at the RSA.

Previous soil sampling activities in all three areas (Tables 3.1-3.3 and Sect. 3.2.4), indicated that the contaminants associated with the sites for soil included metals and PCBs at the SY-200 Yard, metals and radiological contaminants at RSA, and metals and volatile organic compounds (VOCs) at SA-1.

Migration Pathways and Transport Mechanisms

For BCV OU 2, the following media were considered as migration pathways: soil, sediment, surface water, and shallow groundwater. The primary sources of contaminants are debris and soil within the SA-1, the SY-200 Yard, and RSA. The primary and secondary release mechanisms are chemical releases (including leaks and spills), runoff, infiltration/percolation, and groundwater recharge/discharge. The relationships of potential contaminant transport within these media is shown in Fig. 3.10.

Source	Transport mechanism	Contaminated media
primary → secondary		primary (secondary)
	direct	soils
	precipitation/ infiltration	groundwater (soils, surface water)
debris → soils	surface runoff	surface water (sediments) receptor
	erosion	sediment (surface water)
	volatilization/ suspension	air

Fig. 3.10. Site conceptual model for transport of contaminants within BCV.

The soil is a potential pathway of migration via runoff to surface water, and percolation/infiltration into groundwater. Leachate produced by water moving through the soil may provide aqueous transport for dissolved chemicals within the unsaturated soil sequence. In a porous, homogeneous soil, contaminants tend to move primarily downward within the unsaturated zone through diffusion and mass flow mechanisms until they reach the water table or an impermeable horizon. However, contaminants also move laterally through dispersion and diffusion caused by changes in the soil structure or composition, or fractures, of seasonally water-saturated soil. In addition, debris buried in spoil areas can affect contaminant migration. Buried debris can create impermeable layers that laterally divert leachate or that enhance vertical movement of leachate because of density or compaction difference. Therefore, contaminant migration in the soil medium within spoil areas may be enhanced both vertically and horizontally.

Existing evidence from previous investigations indicates that the majority of the metal contaminants at SA-1 is migrating from the fill material present at the site and is being

absorbed in the underlying native soil residuum. This process of absorption of contaminants into the soil matrix is believed to inhibit the transport of certain contaminants into the groundwater medium especially if the soil matrix possesses a neutral or basic pH. A few of the metals, in particular mercury, barium, and chromium, appear to be relatively immobile in the soil and are expected to be retained in the fill and debris of the landfill. In addition, the semivolatile organic compounds (SVOCs) detected in soils at RSA are characterized by relatively low volatility and low solubility in water. The SVOCs are expected to be relatively immobile in the soil and to remain partitioned in the fill and debris of the landfill.

For the purpose of risk assessment (Chaps. 5 and 6) the soil exposure medium is divided into soil (associated with the source OU) and soil/sediment (the BCV floodplain soil). Resuspension of particles (wind-generated dust) and volatilization of contaminants into the air from soil were also evaluated in the BRA for the inhalation exposure route, in addition to soil ingestion, dermal contact, and external exposure to radionuclides in the soil. For the BERA, uptake into plants and animals was considered as an additional migration pathway.

The surface water exposure medium is believed to have a potential for off-site OU contaminant migration. The potential for contaminant movement into groundwater is increased due to surface water infiltration to groundwater. Additionally, groundwater can discharge to surface water. The flow of surface water over and through areas of contaminated soil provides a potential for transportation and redeposition of contamination. The potential for surface water transport of contaminants at the spoil areas could be somewhat reduced by capping these sites with compacted clay. However, site histories indicate only a 2–3 ft soil cover has been placed on the sites, leaving them susceptible to the potential effects of surface water on contamination migration. In addition, surface water will eventually erode and penetrate the soil cover, thereby increasing the potential for surface water transport of contaminants at the site.

The most likely mechanism for contaminant transport is precipitation infiltration resulting in contaminant leaching into the groundwater system (Fig. 3.10). As previously mentioned in the discussion of SA-1, the potential for contaminant movement into the groundwater system is reduced because the sorptive properties of the soils and contaminants restrict the mobility of the contaminants. These conditions are also expected to occur in the SY-200 Yard. Nonetheless, groundwater has the greatest potential for contaminant migration at each site. Surface water, sediment, and groundwater will be evaluated in greater detail in the valley-wide risk assessment to be performed as part of BCV OU 4.

The approach to evaluating the fate and transport of contaminants is presented in Sect. 3.2.5. This section further develops the conceptual model by modeling the concentrations and transport pathways of the contaminants. The approach to evaluate the biotic (human and ecological) receptors is explored in Chaps. 5 and 6. The human health risk assessment fully develops the conceptual site model to include the exposure pathways to the potential receptors. The BERA uses direct exposure and simple food-web modeling to demonstrate impact to the ecological receptors.

Sampling Design

The conceptual site model was used as the basis to guide the RI sampling design. Site boundaries (heavy dashed lines on site figures) were selected to include both current and historic sampling points. Sampling strategies were designed for each site to evaluate the

components of the conceptual model: soil, surface water, sediment, groundwater, air, and biological media. Based on the presentation and discussion of existing monitoring and characterization data available for BCV OU 2, several data needs were identified. Specifically, data were needed to fully characterize several possible contaminant migration pathways and to evaluate the relative contribution of the BCV OU 2 sites to contaminants in BCV groundwater, surface water, and sediment. A summary of all the samples collected with corresponding QA/QC samples is presented in Table 3.5. In addition, Table 3.6 presents the analytical methods and detection limits for all media investigated.

Although previous soil sampling activities have been conducted at the SY-200 Yard, subsequent construction activities have redistributed the soil such that the horizontal and vertical distribution of contamination cannot be defined using the historical data. Therefore, the soil sampling plan for the RI at the SY-200 Yard was designed to determine the nature and extent of contamination. The soil sampling plan for the RSA was designed to verify the nature and extent of soil contamination at the RSA that previous investigations had identified. A soil sampling plan was not required for SA-1 because characterization of the soil at SA-1 has already been accomplished using data from previous investigations and no data gaps were identified.

Groundwater was determined to have the greatest potential for contamination migration at each site. Previous groundwater investigation and sampling activities have been conducted for SA-1 and RSA only. The groundwater sampling plan was designed to evaluate the contaminant contribution of SA-1 and the SY-200 Yard to shallow groundwater and to the BCV groundwater contaminant plumes. At the SY-200 Yard monitoring wells were proposed to provide local groundwater quality both upgradient and downgradient. At SA-1 one monitoring well was installed to support the conclusion made from previous sampling activities that the contamination was migrating to the fill/residuum boundary. Another well was installed to try to resolve the shallow groundwater flow direction in the area and to help identify the source of VOC contamination observed in SA-1 groundwater during previous investigations. Seep samples were also collected at SA-1 to supplement groundwater contamination determinations at the site. A groundwater sampling plan was not designed for RSA because characterization of the shallow groundwater in this area was determined to be sufficient.

Surface water/sediment sampling was conducted to define the contribution of the BCV OU 2 sites to Bear Creek contamination, to determine especially in the cases of SA-1 and the SY-200 Yard whether the lack of sufficient capping of the site leads to significant contaminant transport to surface water. In order to address this the sample plan was configured to try to isolate the contribution to runoff from the study sites from that of other facilities in the area (e.g., the waste oil and PCB facility between RSA and the SY-200 Yard).

BCV OU 2 Data Objectives

The primary objectives of the RI are to provide the data necessary for evaluation of risk and remedial alternatives and to ensure that the results of analysis of all environmental samples are adequate for their intended use. To achieve these objectives for the BCV OU 2 RI, a three-part data objective process was used:

Table 3.5. Summary analysis by medium

Medium	Analysis	Sites	Samples	Duplicates	Trip blanks	Field blanks	Equipment rinsates	Total samples
Soil	Asbestos	2	98	7	0	0	0	105
	Cyanide	2	125	11	0	6	6	148
	Grain size, sieve	1	3	0	0	0	0	3
	Gross alpha and beta	2	259	25	0	10	10	304
	Isotopic uranium	2	259	25	0	10	10	304
	Lead	2	66	9	0	10	10	95
	Metals except lead	2	259	25	0	10	10	304
	PCBs, only	2	134	14	0	3	2	153
	Permeability	1	3	0	0	0	0	3
	Pesticides and PCBs	2	125	11	0	10	10	156
	SVOCs	2	125	11	0	6	6	148
	VOCs	2	126	11	24	6	6	173
Sediment	Gross alpha and beta	3	9	1	0	0	1	11
	Isotopic uranium	3	9	1	0	0	1	11
	Metals	3	9	1	0	0	1	11
	Organic petroleum hydrocarbons	3	3	0	0	0	1	4
	Pesticides and PCBs	3	9	1	0	0	1	11
	SVOCs	3	9	1	0	0	1	11
	VOCs	3	9	1	1	0	1	12
Groundwater	Alkalinity	2	5	1	0	0	0	6
	Anions	2	5	1	0	0	1	7
	Gross alpha and beta	2	5	1	0	0	1	7
	Gross alpha and beta, dissolved	2	5	1	0	0	0	6
	Isotopic uranium	2	5	1	0	0	1	7

Table 3.5 (continued)

Medium	Analysis	Sites	Samples	Duplicates	Trip blanks	Field blanks	Equipment rinsates	Total samples
	Isotopic uranium, dissolved	2	5	1	0	0	0	6
	Metals	2	5	1	0	0	1	7
	Metals, dissolved	2	5	1	0	0	0	6
	Pesticides and PCBs	2	5	1	0	0	1	7
	SVOCs	2	5	1	0	0	1	7
	Total dissolved solids	2	5	1	0	0	0	6
	Total suspended solids	2	5	1	0	0	0	6
	Turbidity	2	5	1	0	0	0	6
	VOCs	2	5	1	2	0	1	9
Surface water	Alkalinity	3	8	1	0	0	0	9
	Anions	3	8	1	0	0	0	9
	Gross alpha and beta	3	8	1	0	0	0	9
	Gross alpha and beta, dissolved	3	8	1	0	0	0	9
	Isotopic uranium	3	8	1	0	0	0	9
	Isotopic uranium, dissolved	3	8	1	0	0	0	9
	Metals	3	8	1	0	0	0	9
	Metals, dissolved	3	8	1	0	0	0	9
	Pesticides and PCBs	3	8	1	0	0	0	9
	SVOCs	3	8	1	0	0	0	9
	Total dissolved solids	3	8	1	0	0	0	9
	Total suspended solids	3	8	1	0	0	0	9
	Turbidity	3	8	1	0	0	0	9
	VOCs	3	8	1	2	0	0	11
Seep water	Alkalinity	1	1	0	0	0	0	1

Table 3.5 (continued)

Medium	Analysis	Sites	Samples	Duplicates	Trip blanks	Field blanks	Equipment rinsates	Total samples
	Anions	1	1	0	0	0	0	1
	Gross alpha and beta	1	1	0	0	0	0	1
	Gross alpha and beta, dissolved	1	1	0	0	0	0	1
	Isotopic uranium	1	1	0	0	0	0	1
	Isotopic uranium, dissolved	1	1	0	0	0	0	1
	Metals	1	1	0	0	0	0	1
	Metals, dissolved	1	1	0	0	0	0	1
	Pesticides and PCBs	1	1	0	0	0	0	1
	SVOCs	1	1	0	0	0	0	1
	Total dissolved solids	1	1	0	0	0	0	1
	Total suspended solids	1	1	0	0	0	0	1
	Turbidity	1	1	0	0	0	0	1
	VOCs	1	1	0	1	0	0	2

Table 3.6. Analytical methods, parameters, and quantitation limit goals for water and soil/sediment samples

	Analytical methods		Quantitation limit goals[a]	
Parameters	Water	Soil/sediment	Water (μg/L)	Soil/sediment (μg/kg)
VOCs	CLP SOW[b]	CLP SOW[b]		Low soil/sediment[c]
Chloromethane			10	10
Bromomethane			10	10
Vinyl chloride			10	10
Chloroethane			10	10
Methylene chloride			5	5
Acetone			10	10
Carbon disulfide			5	5
1,1-Dichloroethene			5	5
1,1-Dichloroethane			5	5
1,2-Dichloroethene (total)			5	5
Chloroform			5	5
1,2-Dichloroethane			5	5
2-Butanone			10	10
1,1,1-Trichloroethane			5	5
Carbon tetrachloride			5	5
Bromodichloromethane			5	5
1,2-Dichloropropane			5	5
cis-1,3-Dichloropropene			5	5
Trichloroethene			5	5
Dibromochloromethane			5	5
1,1,2-Trichloroethane			5	5
Benzene			5	5
trans-1,3-Dichloropropene			5	5
Trichlorotrifluoroethane			10	10
4-Methyl-2-pentanone			10	10
2-Hexanone			10	10
Tetrachloroethene			5	5
Toluene			5	5
1,1,2,2-Tetrachloroethane			5	5

Table 3.6 (continued)

Parameters	Analytical methods		Quantitation limit goals[a]	
	Water	Soil/sediment	Water (μg/L)	Soil/sediment (μg/kg)
Chlorobenzene			5	5
Bromoform			5	5
Ethylbenzene			5	5
Styrene			5	5
Xylenes (total)			5	5
SVOCs	CLP SOW[b]	CLP SOW[b]		Low soil/sediment[c]
Phenol			10	330
bis(2-Chloroethyl) ether			10	330
2-Chlorophenol			10	330
1,3-Dichlorobenzene			10	330
1,4-Dichlorobenzene			10	330
1,2-Dichlorobenzene			10	330
2-Methylphenol			10	330
bis(2-Chloroisopropyl) ether			10	330
4-Methylphenol			10	330
n-Nitroso-di-n-dipropylamine			10	330
Hexachloroethane			10	330
Nitrobenzene			10	330
Isophorone			10	330
2-Nitrophenol			10	330
2,4-Dimethylphenol			10	330
bis(2-Chloroethoxy) methane			10	330
2,4-Dichlorophenol			10	330
1,2,4-Trichlorobenzene			10	330
Naphthalene			10	330
2-Chloroaniline			10	330
Hexachlorobutadiene			10	330
4-Chloro-3-methylphenol			10	330
2-Methylnaphthalene			10	330
Hexachlorocyclopentadiene			10	330
2,4,6-Trichlorophenol			10	330
2,4,5-Trichlorophenol			25	800

Table 3.6 (continued)

Parameters	Analytical methods		Quantitation limit goals[a]	
	Water	Soil/sediment	Water (μg/L)	Soil/sediment (μg/kg)
2-Chloronaphthalene			10	330
2-Nitroaniline			25	800
Dimethylphthalate			10	330
Acenaphthylene			10	330
2,6-Dinitrotoluene			10	330
3-Nitroaniline			25	800
Acenaphthene			10	330
2,4-Dinitrophenol			25	800
4-Nitrophenol			25	800
Dibenzofuran			10	330
2,4-Dinitrotoluene			10	330
Diethylphthalate			10	330
4-Chlorophenyl-phenyl ether			10	330
Fluorene			10	330
4-Nitroaniline			25	800
4,6-Dinitro-2-methylphenol			25	800
n-Nitrosodiphenylamine			10	330
4-Bromophenyl-phenylether			10	330
Hexachlorobenzene			10	330
Pentachlorophenol			25	800
Phenanthrene			10	330
Anthracene			10	330
Carbazole			10	330
Fluoranthene			10	330
Pyrene			10	330
Butylbenzylphthalate			10	330
3,3'-Dichlorobenzidine			10	330
Benzo(a)anthracene			10	330
Chrysene			10	330
bis(2-Ethylhexyl)phthalate			10	330
Di-n-octylphthalate			10	330
Benzo(b)fluoranthene			10	330
Benzo(k)fluoranthene			10	330

Table 3.6 (continued)

Parameters	Analytical methods		Quantitation limit goals[a]	
	Water	Soil/sediment	Water (μg/L)	Soil/sediment (μg/kg)
Benzo(a)pyrene			10	330
Indeno(1,2,3-c,d)pyrene			10	330
Dibenzo(a,h)anthracene			10	330
Benzo(g,h,i)perylene			10	330
Pesticides	CLP SOW[b]	CLP SOW[b]		Low soil/sediment[c]
Aldrin			0.05	1.7
α-BHC			0.05	1.7
β-BHC			0.05	1.7
δ-BHC			0.05	1.7
γ-BHC (Lindane)			0.05	1.7
α-Chlordane			0.05	1.7
γ-Chlordane			0.05	1.7
Endrin ketone			0.1	3.3
4,4'-DDD			0.1	3.3
4,4'-DDE			0.1	3.3
4,4'-DDT			0.1	3.3
Dieldrin			0.1	3.3
Endosulfan I			0.05	1.7
Endosulfan II			0.1	3.3
Endosulfan sulfate			0.1	3.3
Endrin			0.1	3.3
Endrin aldehyde			0.1	3.3
Heptachlor			0.05	1.7
Heptachlor epoxide			0.05	1.7
Methoxychlor			0.5	17
Toxaphene			5	170
PCBs	CLP SOW[b]	CLP SOW[b]		Low soil/sediment[c]
Aroclor-1016			1.0	33.0
Aroclor-1221			2.0	67.0
Aroclor-1232			1.0	33.0
Aroclor-1242			1.0	33.0

Table 3.6 (continued)

Parameters	Analytical methods		Quantitation limit goals[a]	
	Water	Soil/sediment	Water (μg/L)	Soil/sediment (μg/kg)
Aroclor-1248			1.0	33.0
Aroclor-1254			1.0	33.0
Aroclor-1260			1.0	33.0
Metals TAL	CLP SOW[d]	CLP SOW[d]		(mg/kg)[c]
Aluminum			200	20
Antimony			3	0.3
Arsenic GFAA			5	0.5
Barium			200	20
Beryllium			5	0.5
Cadmium			5	0.5
Calcium			5000	500
Chromium			10	1
Cobalt			50	15
Copper			25	2.5
Iron			100	10
Lead GFAA			3	0.3
Magnesium			5000	500
Manganese			15	1.5
Mercury CVAA			0.2	0.1
Nickel			40	4
Potassium			5000	500
Selenium GFAA			5	0.5
Silver			10	1
Sodium			5000	500
Thallium GFAA			5	0.5
Vanadium			50	5
Zinc			20	2
Anions				
Cyanide	SOW 3/90[d]	SOW 3/90[d]	10	1
Chloride	300.0[e]	N/A	1 mg/L	N/A
Nitrate/nitrite	300.0[e]	N/A	0.05 mg/L	N/A
Sulfate	300.0[e]	N/A	1 mg/L	N/A
Fluoride	340.2[e]	N/A	0.1 mg/L	N/A

Table 3.6 (continued)

Parameters	Analytical methods: Water	Analytical methods: Soil/sediment	Quantitation limit goals[a]: Water (µg/L)	Quantitation limit goals[a]: Soil/sediment (µg/kg)
Miscellaneous				
TSS	160.2[e]	N/A	4 mg/L	N/A
TDS	160.1[e]	N/A	10 mg/L	N/A
Turbidity	180.1[e]	N/A	1 NTU[f]	N/A
Alkalinity	310.1[e]	N/A	N/A	N/A
TPH	418.1[e]	SW3550/ E418.1[e]	1 mg/L	10 mg/kg
Asbestos	N/A	9002[g]	N/A	N/A
Radiochemical				
Gross alpha	9310	9310[h]	10 pCi/L	20 & 30 pCi/g[i]
Gross beta	9310	9310[h]	5 pCi/L	20 pCi/g
Isotopic uranium	907[j]	907[j]	1 pCi/L	1 pCi/g

CVAA = cold vapor atomic absorption
GFAA = graphite furnace atomic absorption
NA = Not applicable
TAL = target analyte list
TDS = total dissolved solids
TPH = total petroleum hydrocarbons
TSS = total suspended solids

[a]These are expected quantitation limits based on reagent-grade water or a purified solid matrix. Actual quantitation limits may be higher depending upon the nature of the sample matrix. The limit reported on final laboratory reports will take into account the actual sample column or weight, percent solids (where applicable), and the dilution factor, if any. The quantitation limits for additional analytes attached to the TAL of contract laboratory program statements of work (CLP SOWs) may vary, depending upon the results of laboratory studies.

[b]EPA 1990b. Quantitation limits are contract-required quantitation limits (CRQLs) with the exception of additional organic compounds. The minimum quantitation limits will be reported by the laboratory.

[c]Medium soil/sediment CRQLs are 120 times the low soil/sediment CRQLs for VOCs and 30.3 times the low soil/sediment CRQLs for SVOCs. Estimated detection limits for metals in soil are based on a 1-gram sample diluted to 200 mL.

[d]EPA 1990a. Determination limits are CRDLs except for tin and molybdenum. The minimum detection limits will be reported by the laboratory.

[e]EPA 1983.

[f]Nephelometric Turbidity Unit.

[g]Asbestos in bulk material samples by polarized light microscopy, based on NIOSH Method No. 9002 (NIOSH 1989).

[h]EPA 1986.

[i]The gross alpha detection limit was raised to 30 during the project to facilitate quicker turn-around time.

[j]EPA Prescribed Procedures for Measurement of Radioactivity in Drinking Water, August, 1980.

- identify decision types,
- identify data uses/needs, and
- design a data collection program.

In bullet 1, decision types were identified by addressing the data users and their involvement and by evaluating the available information, the site conceptual model, and the RI objectives.

Bullet 2 identified the data uses/needs by considering the data uses, types, quantity, and quality, and evaluating sampling and analysis options and reviewing and utilizing precision, accuracy, representativeness, completeness and comparability (PARCC) information (Sect. 3.3). Table 3.7 summarizes the data objectives of the BCV OU 2 RI by listing sampling plan objectives, required sample media and analytical parameters, and the ultimate use of the data for each of the three sites within BCV OU 2.

The assembly and development of the data collection components and documentation were addressed in Stage 3. The details of this stage were developed into the Field Sampling Plan.

QA Program

A Quality Assurance Project Plan (QAPjP) was developed for use during the BCV OU 2 RI to ensure that appropriate levels of QA and QC were achieved. The QAPjP was divided into two plans. The Field QAPjP, located in Chap. 8 of the BCV OU 2 RI work plan (SAIC 1993a), defines the procedures that were developed for use in the site preparation and the sampling collection activities while the Laboratory QAPjP, Chap. 9 of the BCV OU 2 RI work plan, defines the procedures that will be followed in the custody, analysis, and handling of data used. The procedures were intended to define the methods applied to achieve the data objectives established for the project.

The Field and Laboratory QAPjP is designed to comply with both the EPA Quality Assurance Management Staff (QAMS) *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*, QAMS-005/80, (EPA 1980a) and the American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) NQA-1 guidelines and the ER Division Quality Assurance Program Plan (Energy Systems 1991b).

The work conducted for the BCV OU 2 RI integrated 18 elements from NQA-1 and QAMS-005/80 into both QAPjPs which provide the framework within which project participants operate (Table 3.8). The requirements stated in the 18 criteria were achieved, in part, by adherence to standard operating procedures developed for the various field activities. These procedures were furnished to BCV OU 2 team members through controlled distribution of the QA Technical Procedures Manual. Table 3.9 lists the procedures used for all sampling tasks. These procedures were designed to produce technically and legally defensible data. The use of these procedures during the RI field activities is discussed in detail in Sect. 3.2. The use and application of the laboratory procedures and the data quality are discussed in Sect. 3.3.

Table 3.7. Data objectives for BCV OU 2 RI

Sampling plan objective	Priority	Sample media	Parameters						Data use				Data validation level[a]
			Metals	Rad	VOC	SVOC	TPH	Asb	PCB	SC	RA	EA	
Define the nature and extent of soil contamination at the SY-200 Yard	High	Soil	X	X	X	X		X	X	X	X	X	III, IV
Verify nature and extent of soil contamination at RSA	High	Soil	X	X	X	X			X	X	X	X	III, IV
Define the contribution of the SY-200 Yard and SA-1 to BCV OU 2 groundwater contamination	High	Groundwater[b]	X	X	X	X				X	X	X	III, IV
Define the contribution of all sites to Bear Creek surface water and sediment contamination	High	Surface water and sediment	X	X	X	X	X		X	X	X	X	III, IV

Asb = asbestos
EA = evaluation of alternatives
PCB = polychlorinated biphenyls
RA = risk assessment
Rad = radiological
SC = site characterization
SVOC = semivolatile organic compounds
TPH = total petroleum hydrocarbons
VOC = volatile organic compounds
[a]Level III validation will be done on all samples. Level IV validation will be done on 10% of all samples.
[b]Includes seep sample.

Table 3.8. Cross reference of EPA QAMS 005/80 with BCV OU 2 RI work plan sections

	EPA QAMS 005/80	Location in RI work plan
1.	Title Page	Title Page, Chaps. 8, 9
2.	Table of Contents	Table of Contents
3.	Project Description	Executive Summary
4.	Project Organization and Responsibility	Sect. 7.5
5.	QA Objectives	Sects. 8.1, 9.1
6.	Sampling Procedures	Sects. 8.2, 9.2, 8.6
7.	Sample Custody	Sects. 8.3, 9.4
8.	Calibration Procedures and Frequency	Sects. 8.4, 9.5
9.	Analytical Procedures	Sect. 9.3
10.	Data Reduction, Validation, and Reporting	Sects. 8.7, 9.7
11.	Internal QC Checks	Sects. 8.8, 9.8
12.	Performance and System Audits	Sects. 8.9, 9.9
13.	Preventive Maintenance	Sects. 8.5, 9.6
14.	Specific Routine Procedures Used to Assess Data PARCC Parameters	Sects. 8.10, 9.10
15.	Corrective Actions	Sects. 8.11, 9.11
16.	QA Reports to Management	Sects. 8.12, 9.12

Table 3.9. Environmental technical support RI technical procedures

No.	Procedure title	Rev. no.	Date
ER/C-P1719	Controlling and Documenting Field Changes to Approved Field Sampling Plans	0	9/08/93
ER/C-P2302 IAD	Sample Classifying, Packaging, Marking, Labeling, and Shipping for Analysis through the K-25 and Y-12 Environmental Restoration Programs	0	9/08/93
ESP-301-1	Water Sampling Using a Dipper	0	9/08/93
ESP-302-1	Groundwater Sampling Procedures: Water Level Measurements Using Water Level	0	9/08/93
ESP-302-2	Groundwater Sampling Procedures: Guidelines for Well Purging	0	9/08/93
ESP-302-3	Groundwater Sampling Procedures: Using a Bailer	0	9/08/93
ESP-303-2	Soil Sampling with an Auger	0	9/08/93
ESP-303-4	Penetration Test and Split-Barrel Sampling	0	9/08/93
ESP-303-5	Subsurface Soil Sampling with Shelby Tubes	0	9/08/93
ESP-304-1	Sediment Sampling Procedures: Streambeds	0	9/08/93
ESP-307-1	Field Measurements Procedures: Temperature	0	9/08/93
ESP-307-2	Field Measurements Procedures: pH (Hydrogen Ion Concentration)	0	9/08/93
ESP-307-6	Field Measurements Procedures: Organic Vapor Detection	0	9/08/93
ESP-307-7	Field Measurements Procedures: Operation of Radiation Survey Instruments	0	9/08/93
ESP-307-8 IAD	Field Measurements Procedures: Specific Conductance	0	9/08/93
ESP-308-1	Composite Procedures	0	9/08/93
ESP-500	Manual Chain-of-Custody Procedures	0	9/08/93
ESP-600	Groundwater Sampling Procedures: Well Installation, Development and Abandonment	0	9/08/93
ESP-701	Sample Preservation and Container Materials	0	9/08/93
ESP-800	Packaging Environmental Samples for Transportation	0	9/08/93
ESP-900	Cleaning and Decontaminating Sample Containers and Sampling Devices	0	9/08/93
ESP-901	Equipment Decontamination	0	9/08/93
ESP-1000	Waste Management	0	9/08/93
FTP-451	Operations of Radiation Survey Instruments	2	10/13/93

Table 3.9 (continued)

No.	Procedure title	Rev. no.	Date
FTP-750	Field Measurement Procedures: Organic Vapor Detection	3	10/13/93
FTP-752	Field Measurement Procedures: Combustible Gas Detection	2	10/13/93
FTP-753	Field Measurement Procedures: Operation of Mercury Vapor Analyzer	0	9/13/93
FTP-880	Field Measurement Procedures: pH, Temperature, Salinity, and Conductivity	3	10/13/93

COPCs

The investigation was designed to evaluate and verify the nature and extent of contaminants, supplement contamination determinations from historical investigations, and to define the relative contributions of contamination from BCV OU 2 source areas to Bear Creek. Each medium was initially considered to be a potential migration pathway for contamination. A target list of analytes for each site was developed in the RI work plan (SAIC 1993a) from the historical sampling data results. These analytes were selected to meet the specific sampling plan objectives that were defined for each site (Table 3.7). The chemicals in this group were evaluated in the investigation.

After the data were collected for the RI, a comprehensive list of COPCs was developed by evaluating both historical and current RI data. The COPCs were developed by medium (soil, sediment, and groundwater) for each site by statistically comparing the 95% upper confidence bound (UCB) of the background median to the UCB of the site median. This means that, assuming a lognormal distribution of data values, there is a 95% probability that the median is at or below the value indicated. In some cases, the calculated median was greater than the maximum values. This was usually due to a small data set (few data points on which to run statistical analysis) but could also be the result of a normal, rather than lognormal, distribution of data values. In either case, when the 95% UCB median was greater than the maximum value, the maximum value was used. The 95% UCB data comparisons were chosen because the Background Soil Characterization Project (DOE 1993) provided data calculated to the 95% UCB, so comparisons to background soil data were more readily facilitated by this method. The Copper Ridge Soil Horizon C (DOE 1993) was chosen for the soil and sediment background comparisons, and groundwater monitoring well GW-317, located in SA-1, was chosen for groundwater background comparisons. The basis for selection of these two background reference points is discussed more fully in Sects. 3.2.3 and 3.2.4. Any sample analyte with a UCB medium concentration greater than the background UCB median concentration for that analyte was determined to be a COPC for that particular site. Tables 3.10, 3.11, and 3.12 present the list of COPCs by medium for SA-1, the SY-200 Yard, and RSA, respectively. This COPC list was used for contaminant fate and transport analysis (Sect 3.2.5), and was provided to the risk assessors as the initial basis for the risk assessments discussed in Chaps. 5 and 6. Data for surface water were compared to SDWA, maximum contaminant levels (MCLs), and groundwater preliminary remediation goals (PRGs) to determine a list of surface water COPCs. This comparison is detailed in Sect. 3.2.1. The surface water COPCs are also listed in Tables 3.10, 3.11, and 3.12, but were not evaluated by the risk assessors.

The COPCs for each medium are discussed in detail in their respective sections. For each site, the COPCs are compared to benchmark values such as MCLs or PRGs, the proportion of detects to nondetects is listed, and the maximum detected values compared to the 95% upper confidence limit (UCL) on the mean value are presented in tables, and each COPC is qualitatively evaluated based on these comparisons. PRGs were calculated using the most conservative risk criteria of a Hazard Index (HI) >1 for noncarcinogens and a risk of 10^{-6} for carcinogenic analytes. HI and risk are described in detail in Chap. 5. The 95% UCL differs from 95% UCB in that for UCL the 95% probability is that the mean will be at or below the value indicated, rather than the media as is the case for the UCB. Discussion in the text is based on this qualitative evaluation and limited to a focused list of COPCs that are regularly detected in a medium at or above one or more benchmark values.

Table 3.10. BCV OU 2 COPCs for SA-1[a]

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
Anions	Chloride		✓		
	Fluoride		✓		
	Nitrate as N		✓		
	Nitrate/nitrite		✓		
	Sulfate		✓		
Metals	Aluminum	✓	✓		✓
	Antimony		✓		✓
	Barium	✓	✓	✓	
	Beryllium	✓	✓		
	Cadmium	✓	✓		
	Calcium	✓	✓	✓	
	Chromium VI	✓[d]		✓	
	Cobalt	✓	✓	✓	
	Copper	✓			
	Cyanide	✓			
	Lead	✓	✓		✓
	Iron				✓
	Magnesium	✓		✓	
	Manganese	✓	✓	✓	
	Mercury	✓[d]	✓	✓	
	Nickel	✓			
	Niobium	✓	✓		
	Phosphorus	✓			
	Potassium	✓	✓		
	Selenium			✓	
	Strontium		✓		
	Vanadium		✓		
	Zirconium		✓		
SVOCs	2-methylnaphthalene	✓			
	Acenaphthene	✓			

Table 3.10 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Acenaphthylene	✓			
	Anthracene	✓			
	Benzo(a)anthracene	✓			
	Benzo(a)pyrene	✓			
	Benzo(b)fluoranthene (g,h,i)	✓			
	Benzo(g,h,i)perylene	✓			
	Benzo(k)fluoranthene	✓			
	Benzoic acid	✓			
	Benzyl butyl phthalate	✓			
	Bis(2-ethylhexyl)phthalate	✓	✓		
	Chrysene	✓			
	Dibenzofuran	✓			
	Dimethyl phthalate	✓			
	Dimethyl phthalate	✓			
	Fluoranthene	✓			
	Fluorene	✓			
	Indeno(1,2,3-cd)pyrene (c,d)	✓			
	Naphthalene	✓			
	Phenanthrene	✓			
	Pyrene	✓			
VOCs	1,1,2-trichloro-1,2,2-trifluoro		✓		
	1,1-dichloroethane	✓			
	1,2-dichloroethene		✓		
	1,2-dichloroethene (total)	✓			
	2-butanone	✓			
	4-methyl-2-pentanone	✓	✓		
	Acetone	✓	✓		
	Benzene	✓			
	Bromodichloromethane				
	Carbon disulfide	✓	✓		

Table 3.10 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Chloroform	✓	✓		
	Methylene chloride	✓	✓		
	Tetrachloroethene	✓	✓		
	Toluene	✓			
	Trichloroethene		✓		
	Vinyl acetate		✓		
	Xylene (total)	✓			
Other analyses	Alkalinity		✓		
	Alkalinity (HCO^3)		✓		
	Total uranium (fluorometric)	✓			
Radionuclides	Gross alpha	✓	✓		
	Gross beta	✓	✓		
	^{234}U				
	^{235}U				
	^{238}U				
	Total Radium	✓			

[a]From program coctab.pgm on 08APR94. Soil COPCs determined by comparison of site 95% UCB (of median) with 95% UCB of background soil data. Groundwater COPCs determined by comparison of site 95% UCB with 95% UCB for reference well (GW-317). Because of the small sample size, sediment COPCs were determined by comparison of all values above detects with the maximum value of background soil data.

[b]Because of the small sample size, surface water COPCs were determined by comparison of all values above detects to MCLs and PRGs.

[c]Surface water samples were not evaluated in the risk assessments.

[d]These COPCs added during human health risk assessment phase.

Table 3.11. BCV OU 2 COPCs for the SY-200 Yard[a]

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
Anions	Chloride		✓		
	Fluoride		✓		
	Sulfate		✓		
Metals	Aluminum		✓	✓	✓
	Antimony	✓	✓		
	Barium	✓	✓	✓	
	Beryllium	✓		✓	
	Cadmium	✓			
	Calcium	✓	✓	✓	
	Chromium		✓	✓	
	Cobalt	✓	✓	✓	
	Copper		✓	✓	
	Cyanide	✓	✓		
	Iron		✓		✓
	Lead	✓	✓	✓	✓
	Magnesium	✓	✓	✓	
	Manganese	✓	✓	✓	
	Mercury	✓	✓		
	Nickel	✓	✓	✓	
	Potassium	✓	✓	✓	
	Silver	✓			
	Sodium		✓		
	Thallium	✓			
	Vanadium		✓		
	Zinc		✓	✓	
Pesticide/PCBs	4,4′-DDE	✓			
	Aroclor-1254	✓			
	Aroclor-1260	✓			
	Endrin	✓			
	p,p′-methoxychlor	✓			

Table 3.11 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
SVOCs	1,2,4-trichlorobenzene	✓			
	1,4-dichlorobenzene	✓			
	2,4-dinitrotoluene	✓			
	2-chlorophenol	✓			
	2-methylnaphthalene	✓			
	4-chloro-3-methylphenol	✓			
	4-nitrophenol	✓			
	Acenaphthene	✓			
	Acenaphthylene	✓			
	Anthracene	✓			
	Benzo(a)anthracene	✓			
	Benzo(a)pyrene	✓			
	Benzo(b)fluoranthene	✓			
	Benzo(g,h,i)perylene	✓			
	Benzo(k)fluoranthene	✓			
	Bis(2-ethylhexyl)phthalate	✓	✓		
	Butylbenzylphthalate	✓	✓		
	Carbazole	✓			
	Chrysene	✓			
	Di-n-butylphthalate	✓	✓		
	Dibenzo(a,h)anthracene	✓			
	Dibenzofuran	✓			
	Diethylphthalate	✓	✓		
	Dimethylphthalate	✓			
	Fluoranthene	✓			
	Fluorene	✓			
	Indeno(1,2,3-c,d)pyrene	✓			
	n-nitroso-di-n-propylamine	✓			
	Naphthalene	✓			
	Pentachlorophenol	✓			

Table 3.11 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Phenanthrene	✓			
	Phenol	✓			
	Pyrene	✓			
VOCs	1,1,2-trichloro-1,2,2-trifluoro	✓			
	2-butanone	✓			
	4-methyl-2-pentanone	✓			
	Acetone	✓			
	Benzene	✓			
	Carbondisulfide	✓			
	Chloroform		✓		
	Ethylbenzene	✓			
	Methylenechloride	✓			
	Tetrachloroethene		✓		
	Toluene	✓			
	Trichloroethene		✓		
	Xylene,total	✓			
Other analyses	Alkalinity		✓		
Radionuclides	Gross alpha	✓	✓		
	Gross beta	✓	✓		
	^{234}U				
	^{235}U				
	^{238}U				

[a]From program coctab.pgm on 08APR94. Soil COPCs determined by comparison of site 95% UCB (of median) with 95% UCB of background soil data. Groundwater COPCs determined by comparison of site 95% UCB with 95% UCB for reference well (GW-317). Because of the small sample size, sediment COPCs were determined by comparison of all values above detects with the maximum value of background soil data.

[b]Because of the small sample size, surface water COPCs were determined by comparison of all values above detects to MCLs and PRGs.

[c]Surface water samples were not evaluated in the risk assessments.

Table 3.12. BCV OU 2 COPCs for the RSA[a]

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
Anions	Chloride		✓		
	Nitrate as N		✓		✓
	Sulfate		✓		
Metals	Aluminum		✓		✓
	Antimony	✓	✓	✓[d]	✓
	Arsenic		✓		
	Barium	✓	✓	✓	
	Beryllium	✓[e]	✓		
	Boron		✓		
	Cadmium	✓	✓	✓[e]	
	Calcium	✓	✓	✓	
	Chromium		✓		
	Cobalt	✓	✓	✓	
	Copper			✓	
	Cyanide	✓			
	Iron		✓		✓
	Lead	✓		✓	✓
	Lithium		✓		
	Magnesium	✓		✓	
	Manganese	✓	✓	✓	✓
	Mercury	✓			
	Nickel	✓		✓	
	Niobium	✓	✓		
	Potassium	✓	✓		
	Silver	✓		✓[d]	
	Sodium		✓		
	Strontium		✓		
	Thallium	✓		✓[d]	
	Thorium	✓			
	Vanadium		✓		
	Zinc			✓	

Table 3.12 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Zirconium		✓		
Pesticide/PCBs	Aroclor-1254	✓			
	Aroclor-1260	✓		✓[d]	
	Endosulfan I	✓			
	Heptachlor	✓			
	p,p'-methoxychlor	✓			
SVOCs	1,2,4-trichlorobenzene	✓			
	1,2-dichlorobenzene	✓			
	2,4-dimethylphenol	✓			
	2-methylnaphthalene	✓			
	4-methylphenol	✓			
	4-nitrophenol	✓			
	Acenaphthene	✓			
	Acenaphthylene	✓			
	Anthracene	✓			
	Benzo(a)anthracene	✓			
	Benzo(a)pyrene	✓			
	Benzo(b)fluoranthene	✓			
	Benzo(g,h,i)perylene	✓			
	Benzo(k)fluoranthene	✓			
	Bis(2-ethylhexyl)phthalate	✓			
	Butylbenzylphthalate	✓			
	Carbazole	✓			
	Chrysene	✓			
	Di-n-butylphthalate	✓			
	Di-n-octylphthalate	✓			
	Dibenzo(a,h)anthracene	✓			
	Dibenzofuran	✓			
	Dimethylphthalate	✓			
	Fluoranthene	✓		✓	
	Fluorene	✓			

Table 3.12 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Indeno(1,2,3-c,d)pyrene	✓			
	Naphthalene	✓			
	Pentachlorophenol	✓			
	Phenanthrene	✓			
	Phenol	✓			
	Pyrene	✓			
VOCs	1,1,1-trichloroethane	✓	✓		
	1,1,2,2-tetrachloroethane	✓			
	1,1,2-trichloro-1,2,2-trifluoro	✓			
	1,1,2-trichloroethane	✓			
	1,1-dichloroethane	✓	✓		
	1,1-dichloroethene	✓			
	1,2-dichloroethane	✓			
	1,2-dichloroethene	✓	✓		
	1,2-dichloropropane	✓			
	2-butanone	✓			
	2-hexanone	✓			
	4-methyl-2-pentanone	✓	✓		
	Acetone	✓	✓		
	Benzene	✓			
	Bromodichloromethane	✓	✓		
	Bromoform	✓			
	Bromomethane	✓			
	Carbon disulfide	✓			
	Carbon tetrachloride	✓	✓		
	Chlorobenzene	✓			
	Chloroethane	✓			
	Chloroform	✓	✓		
	Chloromethane	✓			
	Cis-1,3-dichloropropene	✓			
	Dibromochloromethane	✓			

Table 3.12 (continued)

Analysis	Contaminant	Soil COPC	Groundwater COPC	Sediment COPC	Surface water COPC[b,c]
	Ethylbenzene	✓			
	Methylene chloride	✓			
	Styrene	✓			
	Tetrachloroethene	✓		✓	
	Toluene	✓			
	Trans-1,3-dichloropropene	✓			
	Trichloroethene	✓	✓		
	Vinyl acetate	✓	✓		
	Vinyl chloride	✓			
	Xylene, total	✓			
Other analyses	Alkalinity (CO^3)		✓		
	Phosphorus	✓			
	Total uranium (fluorometric)		✓		
Radionuclides	^{137}Cs				
	Gross alpha	✓	✓		
	Gross beta	✓	✓		
	^{90}Sr				
	^{99}Tc				
	^{232}Th				
	Uranium, total	✓			
	^{234}U				
	^{235}U				
	^{238}U				

[a]From program coctab.pgm on 08APR94. Soil COPCs determined by comparison of site 95% UCB (of median) with 95% UCB of background soil data. Groundwater COPCs determined by comparison of site 95% UCB with 95% UCB for reference well (GW-317). Because of the small sample size, sediment COPCs were determined by comparison of all values above detects with the maximum value of background soil data.

[b]Because of the small sample size, surface water COPCs were determined by comparison of all values above detects to MCLs and PRGs.

[c]Surface water samples were not evaluated in the risk assessments.

[d]These COPCs added during BERA phase.

[e]These COPCs added during human health risk assessment phase.

3.2.1 Surface Water Data

The BCV OU 2 sites are located near the headwaters of Bear Creek. Chapter 2 describes the physical characteristics of the surface water system at the BCV OU 2 sites. Surface water samples were collected at nine locations throughout BCV OU 2 during or immediately after a rainfall event. One sample was collected from a perennial stream and the remaining samples were obtained from intermittent drainage ditches with intermittent flow. The primary objective of this sampling is to determine whether the lack of sufficient clean soil cover at SA-1 and the SY-200 Yard results in contaminant transport to Bear Creek from these sites. A secondary objective is to isolate the contaminant contribution to runoff from the BCV OU 2 sites from that of other facilities in the area (e.g., the waste oil and PCB facility between the RSA and the SY-200 Yard). Historical surface water investigations were evaluated, but because of the historic contaminations of surface water and sediments resulting from operations at the S-3 Site, were found to yield inclusive results regarding the BCV OU 2 sites. The surface water data obtained for this investigation were evaluated using the following step-wise process: (1) identify all contaminants present above detection limits (2) remove all chemicals analyzed for but not detected from further consideration, and (3) identify all contaminants above detection limits that exceed SDWA MCLs and/or groundwater PRGs to produce a surface water COPC list. Surface water COPCs are included in Tables 3.10, 3.11, and 3.12 but were not included in the risk assessments (Chaps. 5 and 6). The PRGs were calculated using a residential scenario for toxic ingestion and carcinogenic ingestion.

Surface water samples were collected in accordance with procedure ESP 301-1, *Water Sampling Using a Dipper* (Kimbrough et. al. 1990). Prior to each sampling event, all sampling equipment was decontaminated following ESP-901, *Area and Material Decontamination.* All samples were put in containers, preserved, and handled in accordance with ESP-400, *Field Quality Control*; ESP-701, *Sample Preservation and Container Materials*; and ESP-800, *Packaging Environmental Samples for Transportation* (Kimbrough et. al. 1991). The samples were analyzed for VOCs, SVOCs, PCBs, metals, radiological (gross alpha, gross beta, and isotopic uranium), total suspended solids, total dissolved solids, turbidity, alkalinity, and total petroleum hydrocarbons. Specific chemicals analyzed are included in Table 3.6.

3.2.1.1 Historical investigations

Periodic flow monitoring in Bear Creek has been conducted by the USGS since 1983. Flow and limited chemical data have also been monitored by staff in the Environmental Sciences Division at ORNL. Details of past surface water sampling activities along Bear Creek are presented in Turner et. al. (1991). Historical water quality data collection locations referenced as BCK 12.46 and 11.97 are shown on Fig. 3.11. These sites are monitored once per week for radiological and nonradiological parameters in response to Section IV, Part 4 of a memorandum of understanding agreed to by DOE, EPA, and TDEC. These historical sampling locations in the vicinity of BCV OU 2 are located in the main channel of Bear Creek. Historically, contaminants detected in the surface water with the upper reaches of Bear Creek are strongly influenced by the S-3 Site, thus, surface water contamination resulting from runoff from the BCV OU 2 sites cannot be assessed from the historical data.

3.2.1.2 SA-1 surface water sampling effort

Surface water sampling at SA-1 was conducted at locations SS-2, SS-3, and SS-4 (Fig. 3.12) during December 1993. Each location was sampled once during or immediately

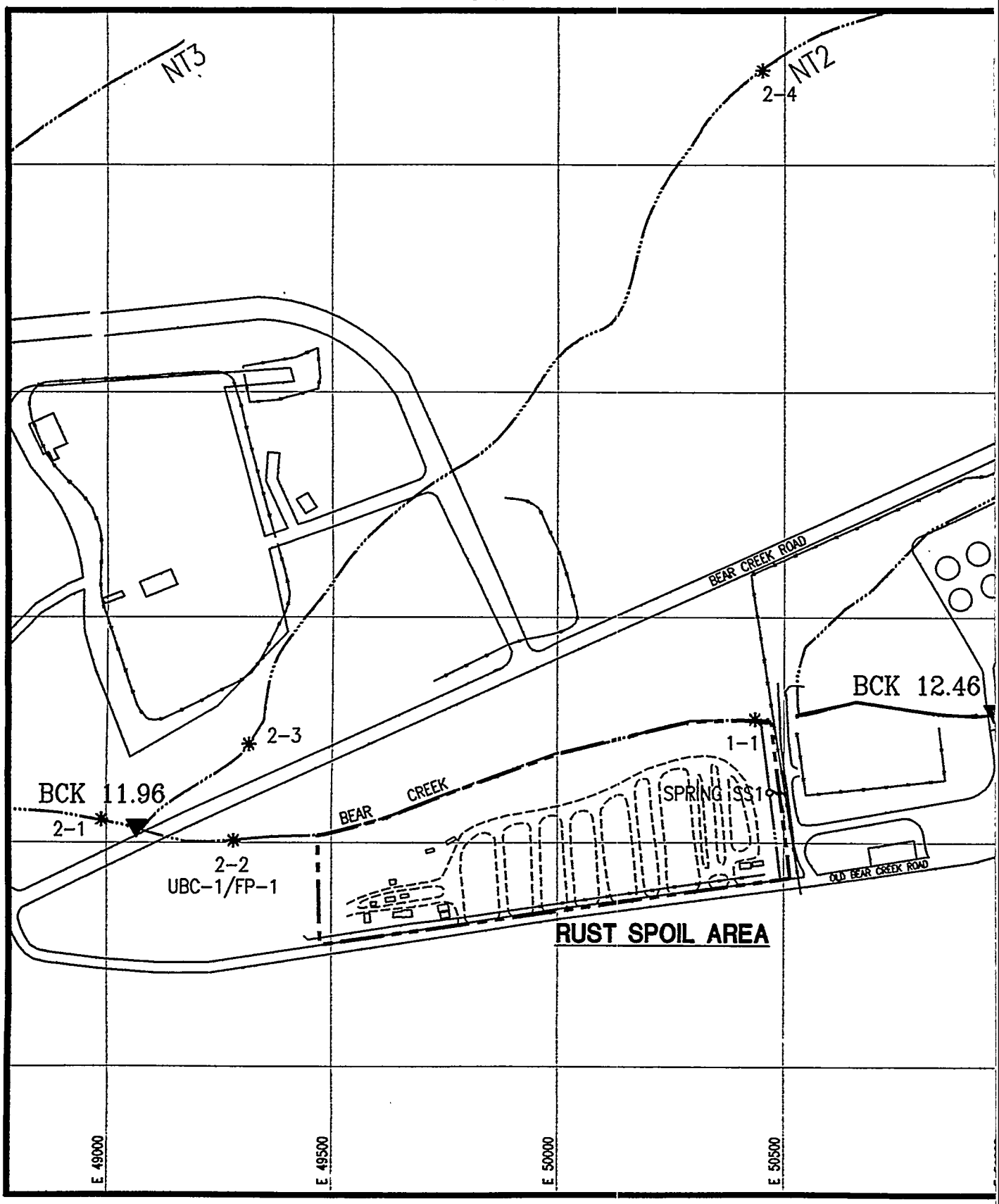
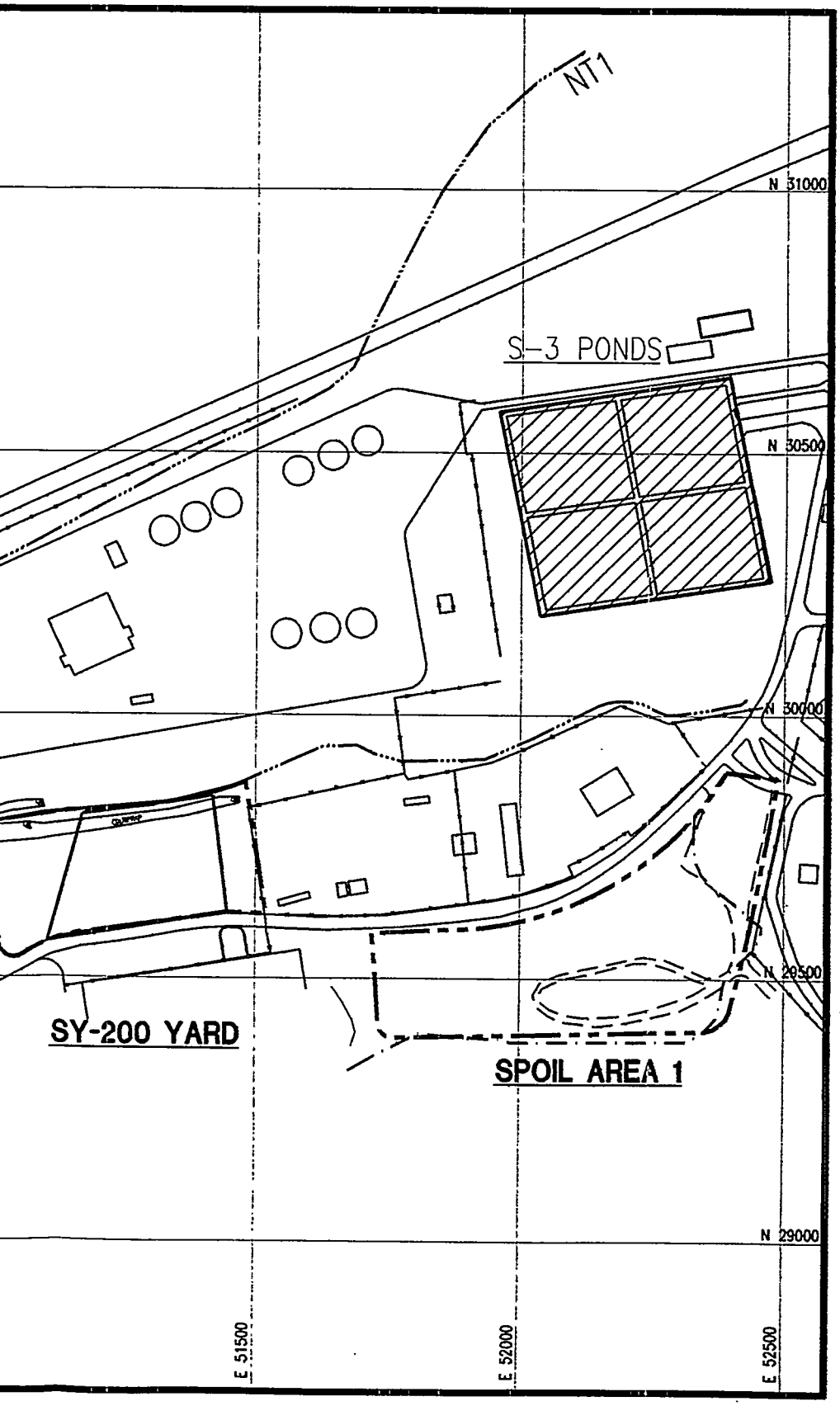


Fig. 3.11. BCV OU 2 historical s



LEGEND:

- 1993 INVESTIGATION BOUNDARY
- CREEK
- RCRA CAPPED DISPOSAL UNIT
- STREAM GAUGING STATION/ HISTORICAL SURFACE WATER SAMPLING LOCATION (KORNEGAN, 1992)
- *2-1 SURFACE WATER SAMPLE (McCAULEY, 1985)

34°13'± O.R. ADMIN. GRID TRUE NORTH

0 100 200 300 600

SCALE: 1" = 300'

Science Applications International Corporation

BEAR CREEK VALLEY, OU 2 HISTORICAL SURFACE WATER DATA

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	P. HOLM	S. LANTER	4/20/94
1	R. HADDEN		7/19/94

XREFERENCES	PLOT FILES
94003/XREF/BASE2	94003/PLOT/666SURF.PLT

94003	/DWGS/666SURF	N/A
DRAWING #	CAD FILE #	ROT. ANGLE

face water data.

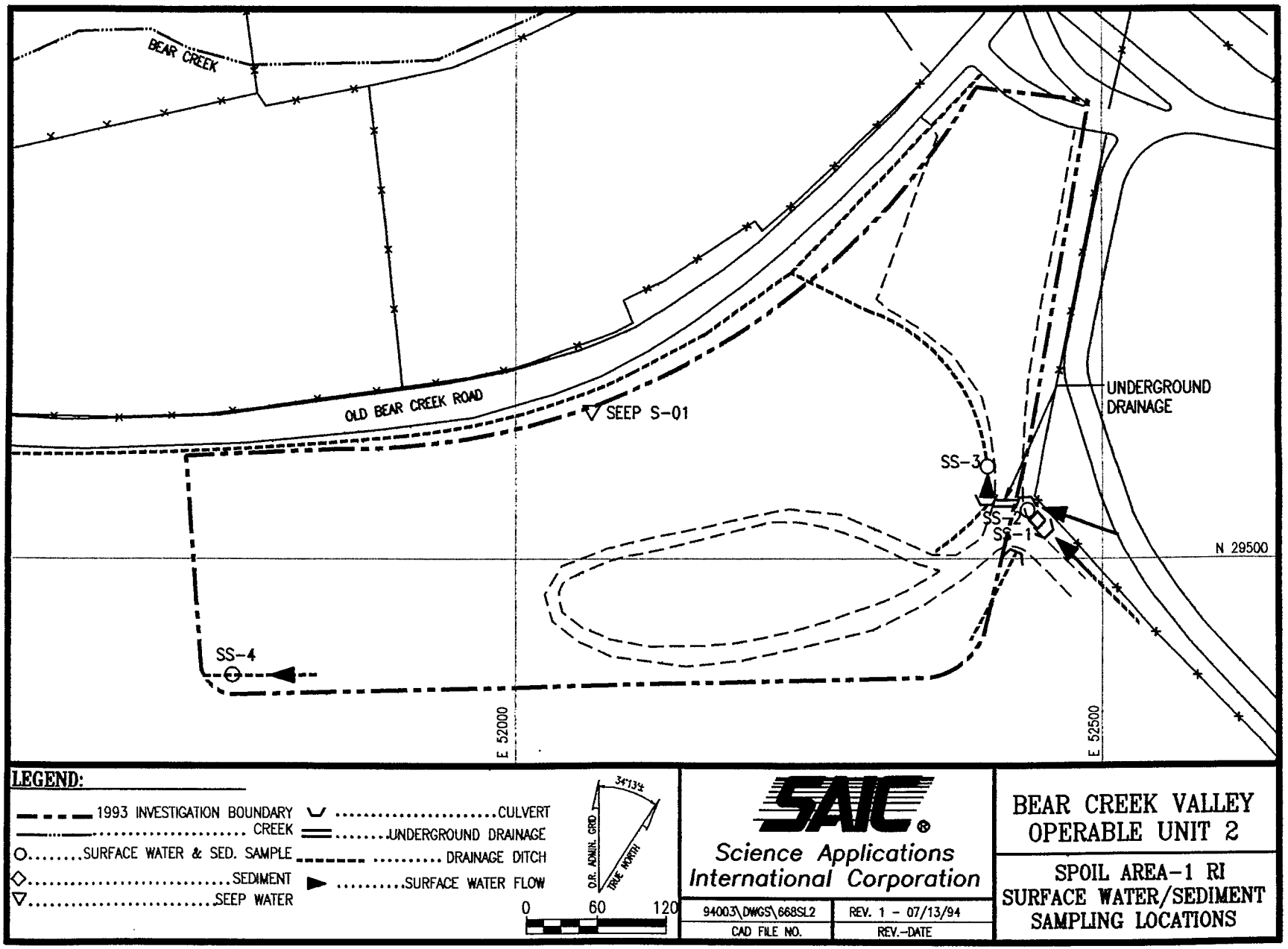


Fig. 3.12. SA-1 RI surface water/sediment sampling locations.

after a rainfall event. The surface water sampling stations at SA-1 are located in drainage channels surrounding SA-1. Drainage on the east side of SA-1 is complicated, and two sampling points (SS-2 and SS-3) were required to separate the component of runoff associated with SA-1 from that associated with facilities located further up the ridge. SS-1 was dry and was not sampled during the investigation. The sample locations SS-1, SS-2, and SS-3 refer to sites specific to this RI and do not correspond to spring and seep locations along BCV.

Chemicals analyzed for but not detected are listed in Appendix B. Statistical summaries for analytes present above detection limits are presented in Appendix B. COPCs identified above SDWA MCLs and/or groundwater PRGs are listed in Table 3.13. If an MCL was not available, the chemical was compared to TDEC MCLs.

Using the contaminant screening process described above, three analytes were found to exceed the MCL and/or PRG for at least one sample from SA-1. COPCs determined to be above MCLs and/or PRGs included dissolved antimony and total metals (aluminum and iron). Of these COPCs aluminum and iron are common constituents in the soils and bedrock in the area and are not considered to be contamination. Antimony exceeded the MCL value of 6 μg/L at sample station SS-3 with a value of 10 μg/L. The average detection limit for antimony was 3 μg/L, thus, the maximum value for antimony was only three times greater than the detection limit and, thus the importance of this value cannot be established with any degree of confidence. Table 3.14 gives the results from the radiological parameters sampled.

3.2.1.3 The SY-200 Yard surface water sampling effort

Two surface water stations (SS-5 and SS-6) were sampled for this investigation at the SY-200 Yard (Fig. 3.13). Using the contaminant screening process described in Sect. 3.2.1, three analytes were found to exceed MCLs (Table 3.13). Of the three COPCs identified, aluminum and iron are not considered to be contamination, based on the fact that these elements are common constituents found in the bedrock and soil on the ORR. Lead was found to exceed the TDEC Action Limit of 5 μg/L for the dissolved sample collected at SS-6. The average detection limit for lead was 3 μg/L for water samples analyzed for this investigation. The maximum dissolved lead concentration observed was 22 μg/L and the total lead value for this location was 5.4 μg/L. Because the dissolved lead concentration at SS-6 is higher than the total lead concentration and the large amount of variance associated with analytes present in quantities near the detection limit, the environmental importance of lead in the surface water at the SY-200 Yard cannot be established.

3.2.1.4 RSA surface water sampling effort

Three surface water stations (SS-7, SS-8, and SS-9) were sampled for this investigation at the RSA (Fig. 3.14). Using the contaminant screening process described in Sect. 3.2.1, eight analytes were found to exceed MCLs (Table 3.13). Of the eight COPCs identified, aluminum, iron, and manganese are not considered to be contamination, based on the fact that these elements are common constituents found in the bedrock and soil on the ORR. Nitrate and total dissolved solids exceeded the MCL once out of the three samples analyzed. The maximum nitrate concentration detected was 31 mg/L and total dissolved solids was 701 mg/L. These concentrations were detected at SS-9. Because of the relatively low concentration of nitrate and total dissolved solids detected, and the fact that they were only found in one sample, these COPCs should not be considered as drivers for the risk assessment and the FS.

Table 3.13. Chemicals detected above ARARs and PRGs

Contaminant (units)	Proportion >detection limit	Minimum detect	Maximum detect	Average result	Standard deviation	Detects >ARARs	ARAR	ARAR source	Detects >PRG	Exceed at locations
				RSA						
Nitrate (mg/L)	1/3	31.00	31.00	10.40	17.84	1/3	10	SDWA	0/3	SS-09
Dissolved antimony (μg/L)	3/3	4.90	8.20	6.10	1.83	1/3	6	SDWA	0/3	SS-07
Dissolved lead (μg/L)	3/3	2.00	16.50	6.90	8.31	1/3	15	TDEC		SS-07, -08, -09
Total aluminum (μg/L)	2/3	3050	26,500	9873	14,480	2/3	200	TDEC		SS-07, -08
Total iron (μg/L)	2/3	5410	42,600	16,030	23,160	2/3	300	TDEC		SS-07, -08
Total lead (μg/L)	3/3	1.60	172	60.90	96.29	3/3	15	TDEC		SS-07, -08, -09
Total manganese (μg/L)	2/3	79.80	1660	582.50	933.90	2/3	50	TDEC	1/3	SS-07, -08
Total dissolved solids (mg/L)	3/3	167	701	353	301.60	1/3	500	TDEC		SS-09
				SA-1						
Dissolved antimony (μg/L)	3/3	2.10	10.30	5.4	4.33	1/3	6	SDWA	0/3	SS-03
Dissolved lead (μg/L)	3/3	4.40	11.70	6.87	4.19	0/3	15	TDEC		SS-02, -03, -04

Table 3.13 (continued)

Contaminant (units)	Proportion >detection limit	Minimum detect	Maximum detect	Average result	Standard deviation	Detects >ARARs	ARAR	ARAR source	Detects >PRG	Exceed at locations
Total aluminum (μg/L)	2/3	533	2120	902.20	1082	2/3	200	TDEC		SS-03, -04
Total iron (μg/L)	2/3	822	3730	1542	1931	2/3	300	TDEC		SS-03, -04
Total lead (μg/L)	3/3	1.20	6.0	4.27	2.66	0/3	15	TDEC		SS-02, -04, -05
				SY-200 Yard						
Dissolved lead (μg/L)	2/2	2.10	22.20	12.15	14.21	1/2	15	TDEC		SS-05, -06
Total aluminum (μg/L)	2/2	749	968	858.50	154.90	2/2	200	TDEC		SS-05, -06
Total iron (μg/L)	2/2	960	1520	1420	396	2/2	300	TDEC		SS-05, -06
Total lead (μg/L)	2/2	5.40	5.70	5.55	0.21	0/2	15[a]	TDEC		SS-05, -06

[a] EPA Action Level; not an MCL

Table 3.14. Summary of radionuclides for surface water

Analysis (units)	Proportion >detection limit	Minimum result	Maximum result	Average result	Standard deviation	Standard error of mean	1 Sigma rad count uncertainty	Detects >ARAR	SWDA MCL	Detects >PRG	PRG
					RSA						
Beta activity (pCi/L)	6/6	6.08	68	35.46	31.11	12.7	1.452		.		.
Gross alpha (pCi/L)	3/3	6.34	55	28.75	24.56	14.18	4.579	2/3	15		.
^{234}U (pCi/L)	6/6	2.6	14.6	7.327	5.49	2.241	0.2035		.		.
^{235}U (pCi/L)	2/3	0.117	0.734	0.3277	0.352	0.2032	0.03637		.		.
^{238}U (pCi/L)	6/6	3.19	14.5	7.895	4.797	1.959	0.2098		.		.
					SA-1						
Beta activity (pCi/L)	5/6	1.64	6.89	4.28	2.05	0.837	0.4306		.		.
Gross alpha (pCi/L)	2/3	2.73	6	3.823	1.885	1.088	0.9405	0/3	15		.
^{234}U (pCi/L)	6/6	1.26	6.21	3.44	1.872	0.764	0.1383		.		.
^{235}U (pCi/L)	2/3	0.0081	0.277	0.1327	0.1355	0.07825	0.02146		.		.
^{238}U (pCi/L)	6/6	0.62	1.75	1.203	0.4603	0.1879	0.08063		.		.
					SY-200 Yard						
Beta activity (pCi/L)	3/4	0.09	14.5	8.175	6.321	3.161	0.5806		.		.
Gross alpha (pCi/L)	2/2	5.36	21.2	13.28	11.2	7.92	1.602	1/2	15		.
^{234}U (pCi/L)	3/4	0.109	9.83	5.046	5.369	2.684	0.189		.		.
^{235}U (pCi/L)	2/2	0.0703	0.378	0.2242	0.2176	0.1539	0.0307		.		.
^{238}U (pCi/L)	3/4	0.0273	7.43	3.798	4.179	2.089	0.1595		.		.

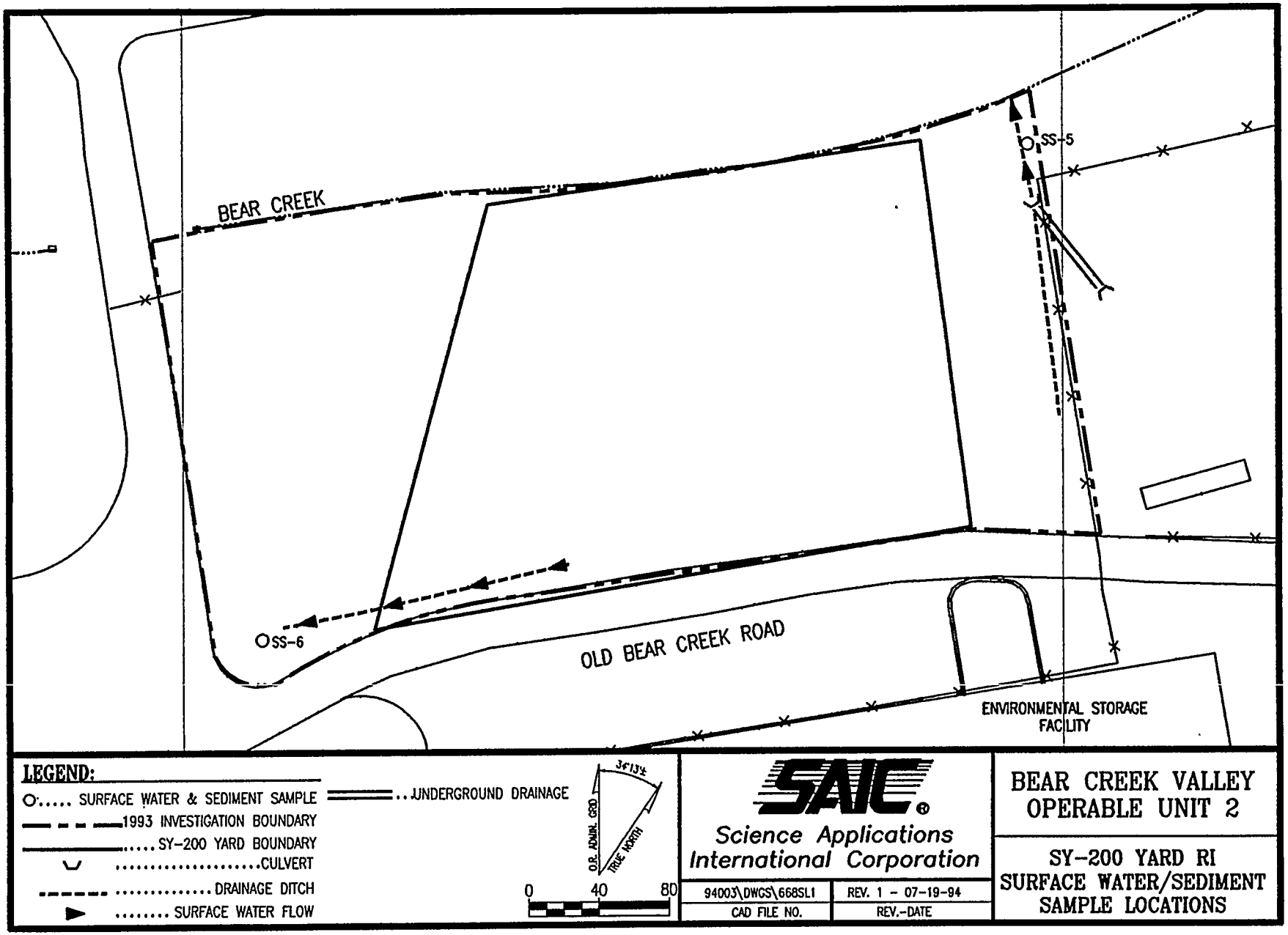


Fig. 3.13. SY-200 Yard RI surface water/sediment sampling locations.

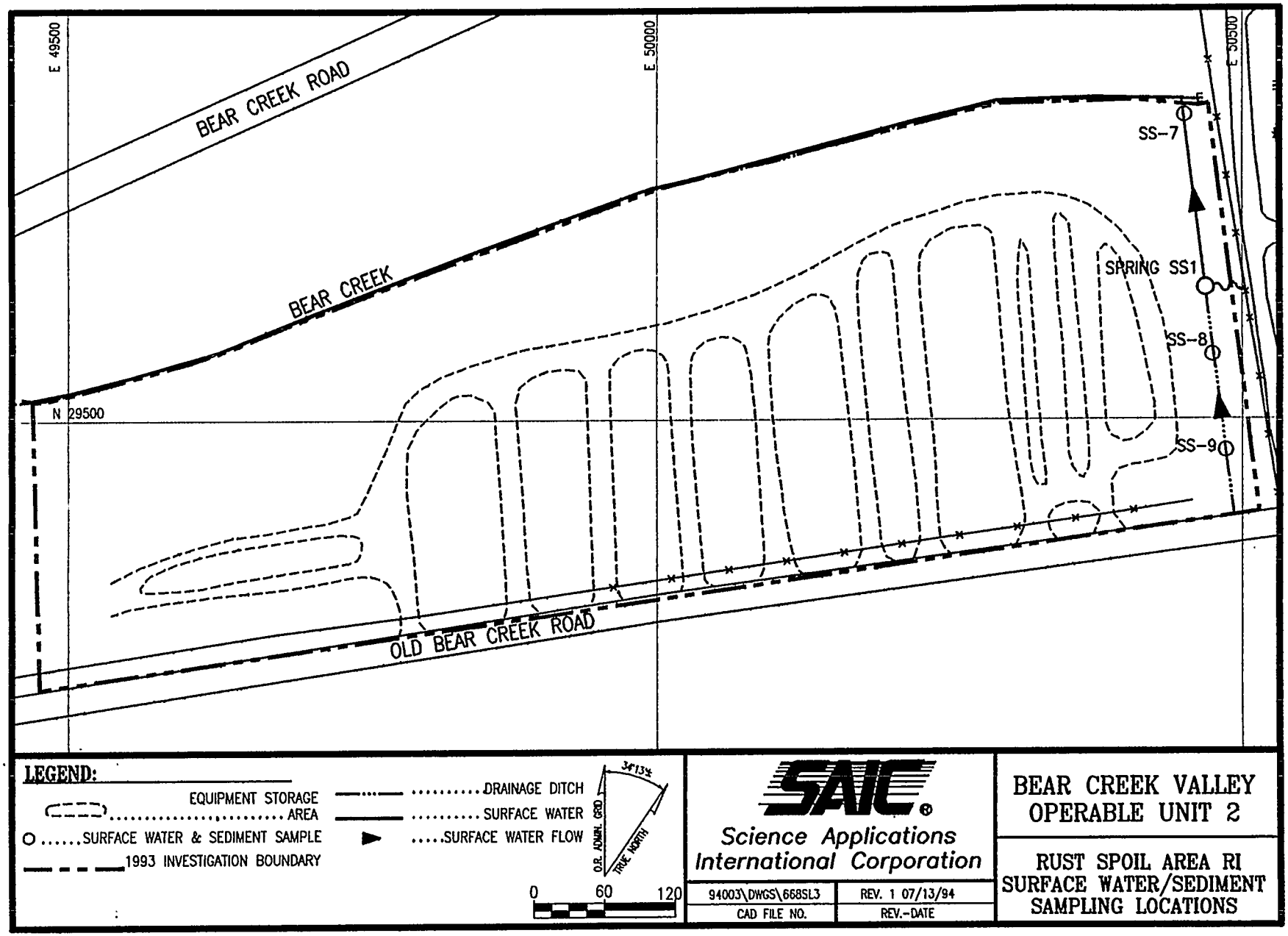


Fig. 3.14. RSA RI surface water/sediment sampling locations.

Antimony exceeded the MCL at SS-7, however, the maximum value detected was 8.2 μg/L which is too close to the detection limit to establish the importance of this analyte. Dissolved lead exceeded the TDEC Action limit at SS-9, and total lead exceeded the TDEC MCL at SS-7. The dissolved lead concentration is near the detection limit and its environmental importance cannot be determined from the data. The maximum total lead value obtained was 172 μg/L.

Transport of contaminants via the surface water pathway is not significant. This statement is substantiated by the following facts: (1) Very few chemicals exceeded MCLs or PRGs. (2) Aluminum, iron, and manganese exceed MCLs, but are common constituents found in the soil and bedrock and are not contamination. (3) All but one of the other COPCs that exceeded the PRG or MCL were detected at concentrations close to the detection limit and their environmental significance is most likely very minor.

Total lead exceeded the action limit by a factor of 11 at SS-7 in the RSA. Thus, lead could be entering Bear Creek from the RSA.

3.2.2 Sediment Data

The purpose of sampling the BCV OU 2 sediment was to define the contribution of the BCV OU 2 sites to Bear Creek. Sediment samples were collected at nine locations. The primary objective of this sampling was to determine whether the lack of sufficient clean soil cover at SA-1 and the SY-200 Yard contribute to contaminant transport to Bear Creek. A secondary objective of the sampling was to isolate the contaminant contribution to runoff from the BCV OU 2 sites from that of other facilities in the area (e.g., waste oil and PCB facility between the RSA and the SY-200 Yard). The sediment data obtained for this investigation were evaluated using the following step-wise process: (1) identify all contaminants present above detection limits (2) remove all chemicals analyzed for but not detected from further consideration, and (3) identify all contaminants above detection limits that exceed reference value to produce a list of sediment COPCs. Sediment COPCs are included in Tables 3.10, 3.11, and 3.12. Two sediment samples were incorporated into the BERA (Chap. 6). The reference value corresponds to the maximum concentration obtained from four soil samples from Chestnut Ridge Horizon C soils.

The samples were collected in accordance with ESP 304-1, *Sediment Sampling Procedures Streambeds* (Kimbrough et. al. 1990). Prior to each sampling event, all sampling equipment was decontaminated following ESP-901, *Area and Material Contamination*. All samples were put in containers, preserved, and handled in accordance with ESP-400, *Field Quality Control*; ESP-701, *Sample Preservation and Container Materials*; and ESP-800, *Packaging Environmental Samples for Transportation* (Kimbrough et. al. 1991). The samples were analyzed for VOCs, SVOCs, PCBs, metals, radiological (gross alpha, gross beta, and isotopic uranium), total suspended solids, total dissolved solids, turbidity, alkalinity, and total petroleum hydrocarbons. Specific chemicals analyzed for are included in Table 3.6.

Historical sediment data exist for the main channel of Bear Creek in the vicinity of Bear Creek. Contaminants detected in this portion of Bear Creek are dominated by the S-3 Site, thus sediment contamination resulting from runoff from the BCV OU 2 sites cannot be isolated using historical data.

3.2.2.1 SA-1 sediment sampling effort

One sample was collected from each of four locations (SS-1, -2, -3, and -4) at SA-1 (Fig. 3.12). Analytical results from these samples were screened using the criteria described above. Chemicals analyzed for but not detected are listed in Appendix B. Statistical summaries for chemicals present above detection limits are presented in Appendix B. COPCs identified above reference values are listed in Table 3.15. If a reference value was not available, the significance of the chemical was evaluated relative to the chemical detection limit. Table 3.16 presents the radiological results for SA-1 sediment samples.

Ten analytes exceeded the reference values (Table 3.15). Of these ten COPCs calcium, magnesium, and manganese are common constituents found in soils and bedrock throughout the ORR and are not contamination. Barium exceeded the reference criteria by a factor of 2, however, the detected values for barium were only slightly higher than the detection limit of 20 mg/kg. Thus barium is present in small concentrations and is not considered to be contamination. Chromium exceeded the reference value in two of the samples, however all the chromium results are within the same order of magnitude as the reference values. The average detection limit for cobalt was 15 mg/kg, thus the cobalt results are not considered significant. Mercury exceeded the reference value of 0.3 mg/kg at one of the sample locations, however, the highest observed mercury value was only 0.52 mg/kg and is not considered to be significant. Selenium exceeded the reference value at two locations, however the maximum selenium value (2.2 mg/kg) is within the same order of magnitude as the reference value of 1.3 mg/kg. Uranium-234 and ^{235}U exceeded the reference value of 2.6 and 0.3 mg/kg, respectively. However, the maximum values detected are well within the range of the reference value shown in Table 3.16.

Organic chemicals that were detected in the sediment samples collected at SA-1 included aroclor-1260, naphthalene, 4-methyl-2-pentanone, and acetone. Aroclor-1260, naphthalene, and acetone were only detected in one out of four samples, and the maximum values are near the detection limit. 4-Methyl-2-pentanone was detected four out of four times but all detected values were very near the detection limit. Statistical summaries for these analytes are listed in Appendix B.

3.2.2.2 The SY-200 Yard sediment sampling effort

One sample was collected from both SS-5 and SS-6 at the SY-200 Yard (Fig. 3.13). The sample collected from SS-6 was later considered to be a soil sample because it was determined to be indigenous to the area and is not included in this discussion. Analytical results from these samples were screened using the criteria described in Sect. 3.2.2 to produce a COPC list. Chemicals analyzed for but not detected are listed in Appendix B. Statistical summaries for chemicals present above detection limits are presented in Appendix B. COPCs identified above reference values are listed in Table 3.15. If a reference value was not available, the significance of the chemical was evaluated relative to the chemical detection limit. Table 3.16 presents the radiological results for SY-200 Yard sediment samples.

Thirteen analytes were found to exceed reference values (Table 3.15). Of these 13 COPCs, aluminum, calcium, magnesium, manganese, and potassium are common constituents found in soils and bedrock throughout the ORR and are not contamination. Barium exceeded the reference criteria by a factor of 2, however, the detected values for barium were only slightly higher than the detection limit of 20 mg/kg. Thus, barium is present in small concen-

Table 3.15. Summary of BCV OU 2 sediment data collected in 1993 that exceed reference data from the ORR background soil characterization study[a]

Analysis (units)	Proportion detected	Minimum[b]	Maximum	Average[c]	Proportion >reference	Reference criteria[d]
			RSA			
Barium (mg/kg)	3/3	25.70	47.90	38.97	3/3	14.2
Calcium (mg/kg)	3/3	1510.00	87100.00	30726.67	3/3	219.0
Cobalt (mg/kg)	3/3	19.70	103.00	47.77	3/3	4.2
Copper (mg/kg)	3/3	25.10	131.00	65.50	2/3	35.9
Lead (mg/kg)	3/3	66.40	114.00	88.23	3/3	39.2
Magnesium (mg/kg)	3/3	639.00	1350.00	1026.33	2/3	722.0
Manganese (mg/kg)	3/3	737.00	6060.00	2554.00	3/3	106.0
Nickel (mg/kg)	3/3	21.80	147.00	66.60	3/3	21.3
Zinc (mg/kg)	3/3	123.00	302.00	206.67	2/3	148.0
			SA-1			
Barium (mg/kg)	4/4	17.90	73.10	40.08	4/4	14.2
Calcium (mg/kg)	4/4	958.00	62600.00	27064.50	4/4	219.0
Chromium (mg/kg)	4/4	29.10	48.80	37.40	2/4	35.7
Cobalt (mg/kg)	4/4	2.40	10.00	6.65	3/4	4.2
Magnesium (mg/kg)	4/4	487.00	4950.00	2421.75	3/4	722.0
Manganese (mg/kg)	4/4	55.80	932.00	483.45	3/4	106.0
Mercury (mg/kg)	4/4	0.10	0.52	0.23	1/4	0.3
Selenium (mg/kg)	2/4	2.00	2.20	1.12	2/4	1.3

Table 3.15 (continued)

Analysis (units)	Proportion detected	Minimum[b]	Maximum	Average[c]	Proportion >reference	Reference criteria[d]
			SY-200 Yard			
Aluminum (mg/kg)	1/1	34500.00	34500.00	34500.00	1/1	23400.0
Barium (mg/kg)	1/1	29.00	29.00	29.00	1/1	14.2
Beryllium (mg/kg)	1/1	1.60	1.60	1.60	1/1	1.0
Calcium (mg/kg)	1/1	1360.00	1360.00	1360.00	1/1	219.0
Chromium (mg/kg)	1/1	49.10	49.10	49.10	1/1	35.7
Cobalt (mg/kg)	1/1	21.90	21.90	21.90	1/1	4.2
Copper (mg/kg)	1/1	45.70	45.70	45.70	1/1	35.9
Lead (mg/kg)	1/1	96.10	96.10	96.10	1/1	39.2
Magnesium (mg/kg)	1/1	1630.00	1630.00	1630.00	1/1	722.0
Manganese (mg/kg)	1/1	406.00	406.00	406.00	1/1	106.0
Nickel (mg/kg)	1/1	40.80	40.80	40.80	1/1	21.3
Potassium (mg/kg)	1/1	1460.00	1460.00	1460.00	1/1	1040.0
Zinc (mg/kg)	1/1	170.00	170.00	170.00	1/1	148.0

[a]Produced by sedminmx.pgm using BCV OU 2 validated data on 20 Apr 94.
[b]Maxima and minima are for detected concentrations only (nondetects omitted).
[c]Nondetects set to 1/2 detection limit for calculation of the mean and standard deviation.
[d]Background reference criteria is the maximum detected value from the ORR Background Soil Characterization Study, DOE 1993a.

Table 3.16. Summary of radionuclide concentrations for BCV OU 2 sediment samples collected in 1993[a]

Analysis (pCi/g)	Proportion detected	Minimum[b]	Maximum	Average	Standard deviation	Standard error of mean	Counting error[c]	Proportion >reference	Reference criteria[d]
				RSA					
Gross alpha	2/3	21.90	23.30	16.08	11.31	6.53	7.92	—	—
Gross beta	3/3	20.60	29.10	25.83	4.58	2.64	5.74	—	—
^{234}U	3/3	2.56	3.86	3.05	0.71	0.41	0.22	2/3	2.6
^{235}U	3/3	0.18	0.40	0.27	0.11	0.06	0.06	1/3	0.3
^{238}U	3/3	2.57	3.95	3.15	0.72	0.41	0.22	2/3	2.7
				SA-1					
Gross alpha	2/4	19.00	20.30	12.33	8.50	4.25	6.60	—	—
Gross beta	4/4	8.68	21.10	15.12	5.93	2.96	4.53	—	—
^{234}U	4/4	1.71	2.93	2.14	0.54	0.27	0.17	1/4	2.6
^{235}U	4/4	0.11	0.43	0.25	0.14	0.07	0.05	1/4	0.3
^{238}U	4/4	1.43	2.03	1.78	0.26	0.13	0.15	0/4	2.7
				SY-200 Yard					
Gross alpha	1/1	18.80	18.80	18.80	—	—	14.20	—	—
Gross beta	1/1	15.20	15.20	15.20	—	—	9.08	—	—
^{234}U	1/1	1.87	1.87	1.87	—	—	0.30	0/1	2.6
^{235}U	1/1	0.12	0.12	0.12	—	—	0.07	0/1	0.3
^{238}U	1/1	1.84	1.84	1.84	—	—	0.29	0/1	2.7

[a]Produced by sedminmx.pgm using BCV OU 2 validated data on 20 April 94.
[b]Maxima and minima are for detected concentrations only (nondetects omitted).
[c]2 σ counting error.
[d]Background reference value is the maximum value reported in the ORR background soil characterization study, DOE 1993.

trations and is not considered to be important for this investigation. Beryllium concentrations only slightly exceed the reference value and are not considered significant. Chromium exceeded the reference value, however the chromium result is within the same order of magnitude of the reference values. The average detection limit for cobalt was 15 mg/kg, thus, the cobalt result is not considered significant. The copper value only slightly exceeded the reference value and is not considered to be of environmental importance. Lead exceeded the reference value by a factor of about 2.5. Because this value is only one data point and is a relatively low concentration the significance of this COPC cannot be established at this time. Nickel and zinc only slightly exceeded reference values and are not considered to be contamination.

Organic chemicals that were detected in the sediment of SA-1 included 4-methyl-2-pentanone and acetone. The values obtained for these chemicals are very near the detection limit and thus, these chemicals are not considered to be significant. Statistical summaries for these analytes are listed in Appendix B.

3.2.2.3 RSA sediment sampling effort

One sample was collected from each location (SS-7, -8, and -9) at the RSA (Fig. 3.14). Analytical results from these samples were screened using the criteria described in Sect. 3.2.2 to produce a COPC list. Chemicals analyzed for but not detected are listed in Appendix B. Statistical summaries for chemicals present above detection limits are presented in Appendix B. COPCs identified above reference values are listed in Table 3.15. If a reference value was not available, the significance of the chemical was evaluated relative to the chemical detection limit. Table 3.16 presents the radiological results for the RSA sediment samples.

Twelve analytes were found to exceed reference values (Table 3.15). Of these 12 COPCs, calcium, magnesium, and manganese are common constituents found in soils and bedrock throughout the ORR and are not contamination. The maximum barium value exceeded the reference criteria by a factor of 2, however, the detected values for barium were only slightly higher than the detection limit of 20 mg/kg. Thus, barium is present in small concentrations and is not considered to be important. The maximum cobalt value is 25 times in excess of the reference value and 7 times in excess of the detection limit and may be the result of contamination. The two other cobalt values were 20.6 and 19.7 mg/kg. However, these values were qualified with data validation flags and the true concentration may be higher. Two out of three copper values exceeded the reference value. The maximum copper value only exceeded the reference value by a factor of 5 and is not considered to be significant. The maximum lead value exceeded the reference value by a factor of about 3. Because this is a relatively low concentration the significance of this COPC cannot be established at this time. The maximum nickel value exceeded the reference value by a factor of about 7 and may be the result of contamination. Zinc exceeds the reference value by a factor of 2 and is not considered to be environmentally significant. Uranium-234, ^{235}U, and ^{238}U exceeded their reference values of 2.6, 0.3, and 2.7 mg/kg, respectively. However, the maximum values detected are well within the range of the reference value shown in Table 3.16.

Organic chemicals that were detected in the sediment of RSA included total petroleum hydrocarbons and aroclor-1260. The values obtained for these chemicals are very near the detection limit and thus, these chemicals are not considered to be significant. Statistical summaries for these analytes are listed in Appendix B.

Transport of chemicals from the BCV OU 2 sites by the sediment pathway is unlikely because the concentration of contaminants identified within the sediment is fairly low. Transport of lead above unacceptable concentrations could potentially occur at the SY-200 Yard. Transport of cobalt, lead, and nickel above unacceptable concentrations could potentially occur at the RSA.

3.2.3 Groundwater Data

The following sections describe the nature and extent of groundwater contamination at the BCV OU 2 site using data from past and current investigations. Section 3.2.3.1 presents a summary of previous monitoring as reported in the GWQARs for the BCV Hydrologic Regime at the Y-12 Plant. Section 3.2.3.2 identifies the COPCs for groundwater and presents the analytical data for the COPCs. Section 3.2.3.3 defines the nature and extent of groundwater contamination at the BCV OU 2 site based on past and current monitoring data. Section 3.2.3.4 describes the characteristic hydrogeochemistry at the BCV OU 2 site.

3.2.3.1 Summary of sampling activities

Historical Investigations. Groundwater monitoring as part of the GWQAR was implemented at SA-1 and the RSA beginning in 1988 and is ongoing. Sampling of the wells in Bear Creek was scheduled to take place on a quarterly basis; however, the monitoring frequency has been reduced, and many of the wells were not sampled every quarter or every year. Table 3.17 shows the frequency of sampling each well. Water levels in the wells were also collected as part of the GWQAR activities. The lowest water levels generally occur in the summer months and continue into the fall with the higher water levels occurring in late winter and the spring. These fluctuations reflect seasonal variations in precipitation and evapotranspiration.

The historical monitoring well network at SA-1 includes GW-313, -314, -315, -317, and -323 (Fig. 3.15). These wells have been sampled periodically since 1988. All of the wells in SA-1 are screened in the bedrock aquifer. Historic well GW-317 was chosen as a groundwater reference well since it is located upgradient from the other wells and the lithology log (Appendix A) indicates the absence of fill material. Therefore, the SA-1 site investigation boundary shown in Fig. 3.15 does not include this well, nor were data on this well considered as part of the SA-1 site. The groundwater quality results from the remaining wells from 1988 to the 4th quarter 1993 are summarized in Sect. 3.2.3.2.

Prior to the 4th quarter 1993 no groundwater monitoring wells existed at the SY-200 Yard. Groundwater east and west of the site has been monitored since 1986 in accordance with RCRA assessment monitoring at TSD units.

The monitoring well network at the RSA includes GW-306, -307, -308, -309, -310, -311, and -312. These wells have been sampled periodically since 1988. GW-306 and -309 are screened in the bedrock aquifer while GW-307, -308, -310, -311, and -312 are screened in the unconsolidated zone. The groundwater quality results for these wells from 1988 to the 4th quarter 1993 are described in Sect. 3.2.3.2.

BCV OU 2 RI Field Activities. Five groundwater monitoring wells were installed at BCV OU 2 during the field activities that occurred from September 1993 to December 1993. The RI work plan specified that two piezometer wells constructed of polyvinyl chloride materials

Table 3.17. Frequency of sampling and the type of analysis performed for the wells in BCV OU 2

Site	1988		1989		1990		1991		1992		1993	
	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses
						SA-1						
GW-313	1,2,3	A	NS	—	1,2,3,4	B	1,2,3,4	B	1,2,3	B	NS	—
GW-314	1,2,3,4	A	NS	—	1,2,3,4	B	1,2,3,4	B	1,2,3	B	NS	—
GW-315	1,2,3,4	A	NS	—	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B
GW-316	1,2,3,4	A	NS	—	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B
GW-323	1,2,3,4	A	NS	—	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B	1,2,3,4	B
GW-811											4	C
GW-812											4	C
						SY-200 Yard						
GW-813											4	C
GW-814											4	C
GW-815											4	C
						RSA						
GW-306	1,2,3,4	A	2,4	B	1,2,3,4	B	1,2	B	NS	—	NS	—
GW-307	1,2,3,4	A	4	B	1,2,3,4	B	1,2	B	NS	—	NS	—
GW-308	1,2	A	2,3,4	B	1,2,3,4	B	1,2	B	NS	—	NS	—
GW-309	1,2	A	2,3,4	B	1,2,3,4	B	1,2,3,4	B	1,2,3	B	NS	—
GW-310	1,2,3,4	A	2,3,4	B	1,2,3,4	B	1,2	B	NS	—	NS	—
GW-311	1,2,4	A	2,3,4	B	1,2,3,4	B	1,2	B	NS	—	1,2,3,4	B

Table 3.17 (continued)

Site	1988		1989		1990		1991		1992		1993	
	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses	Quarter sampled	Analyses
GW-312	1,2,4	A	2,3,4	B	1,2,3,4	B	1,2	B	NS	—	1,2,3,4	B

A = Analyses included major ions, metals, herbicides, pesticides, PCBs, and radionuclides
B = Analyses included major ions, metals, VOCs, and radionuclides
C = Analyses included major ions, metals, VOCs, SVOCs, herbicides, pesticides, PCBs, and radionuclides
NS = Not sampled
MW 1,2,3,4,5 were installed in 4th quarter 1993
Source: GWQAR 1988-1993

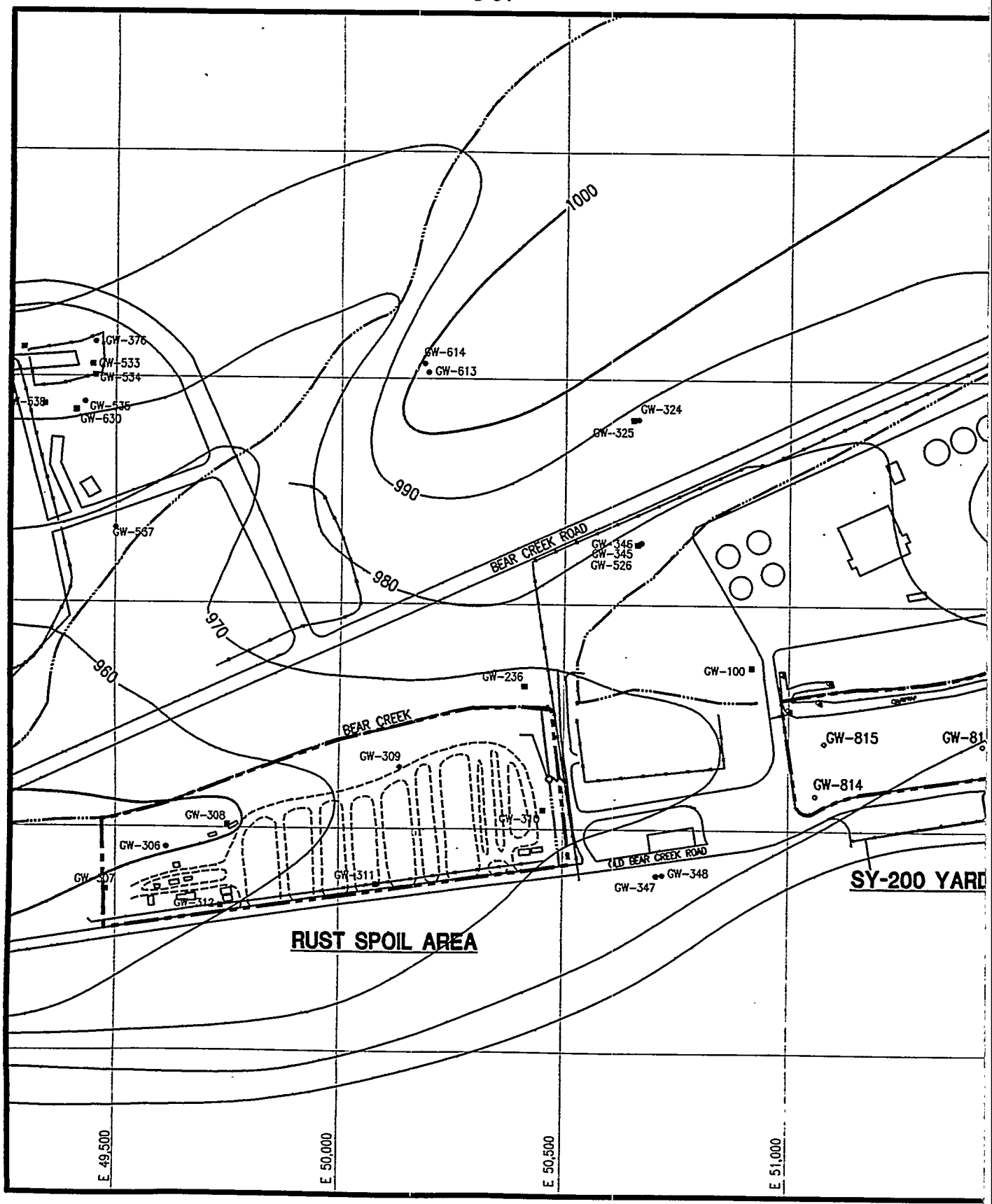
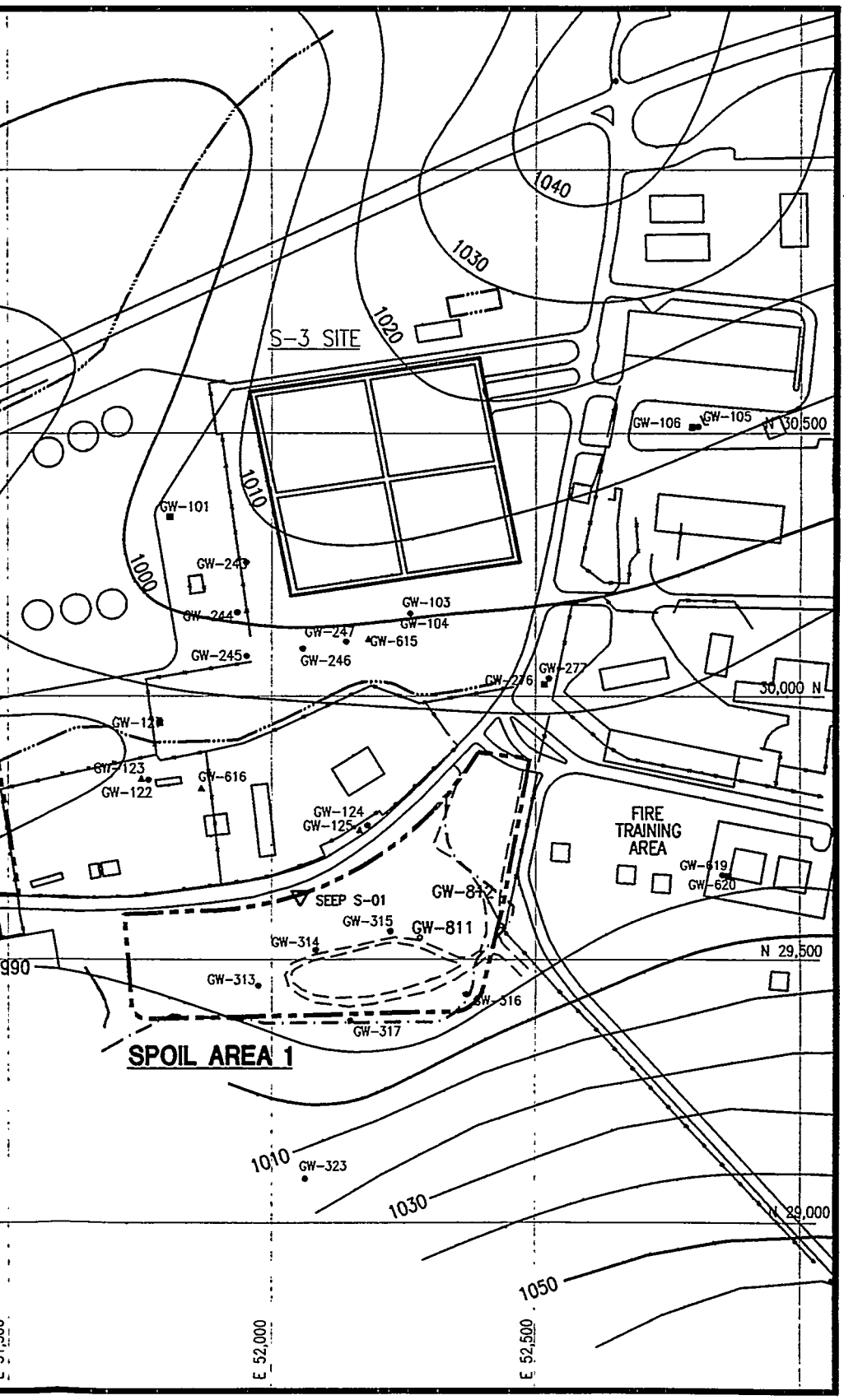


Fig. 3.15. Contour map of groundwater lev



LEGEND:

1993 INVESTIGATION BOUNDARY

MONITORING WELL

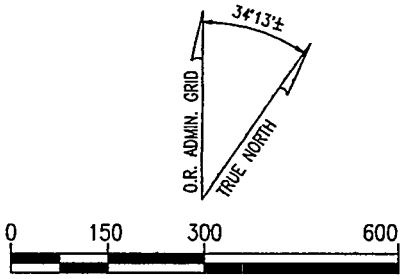
SEEP

GROUND WATER CONTOUR

GROUND WATER CONTOUR DATA FROM APRIL 29 TO MAY 3, 1991. CONTOUR INTERVAL = 10 FT.

EXISTING GROUNDWATER WELLS

- SHALLOW – ACTIVE
- INTERMEDIATE – ACTIVE
- DEEP – ACTIVE



SCALE: 1" = 300'

Science Applications International Corporation

BEAR CREEK VALLEY OPERABLE UNIT 2 GROUNDWATER CONTOURS

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	P. HOLM	L. ROBERTSON	4/19/94
1	B. HADDEN	S. REID	7/19/94

XREFERENCES	PLOT FILES
94003/XREF/BASE2 94003/XREF/MANGAREA	94003\PLOT\576GW.PLT

94003	DWGS\576GW	N/A
DRAWING #	CAD FILE #	ROT. ANGLE

s in wells in upper BCV Hydrologic Regime.

and three stainless steel monitoring wells would be installed. However, during the RI field activities it was decided to construct all the wells using stainless steel so that they could be incorporated into the Y-12 Groundwater Quality Assessment Monitoring Program at the completion of field activities. A field change order was issued to document this change in the work plan and is included in Appendix A. As defined in the data needs portion of the data objectives (Sect. 3.2), all five wells were installed in the unconsolidated zone. Existing wells at the RSA are screened in the unconsolidated and shallow- to intermediate-depth bedrock ranges. Because the SY-200 Yard had no existing groundwater wells, the RI included installation of three shallow wells (GW-813, -814, and -815). GW-813 (SB-41) and GW-815 (SB-62) in the SY-200 Yard were converted from soil borings to wells. The SA-1 site had five existing shallow- to intermediate-depth bedrock wells, and two additional unconsolidated wells (GW-811 and -812) were added as part of this RI. These wells were installed to fill two data gaps identified in the RI Work Plan. GW-812 was installed between SA-1 and the Fire Training Area to determine if VOC contamination previously recorded at SA-1 could originate from the Fire Training Area. GW-811 was installed to determine if VOCs that were observed in the bedrock monitoring wells at SA-1 were present at the water table (residuum). Wells in the SY-200 Yard were installed in the residuum and the SA-1 wells were installed to the residuum/bedrock interface. Figure 3.15 shows the location of the five wells installed during the RI in addition to the existing wells for BCV OU 2. This figure also shows the contoured water table map for the upper BCV Hydrologic Regime from April to May 1991. Water levels measured in the 4th quarter 1993 correspond closely to those measured in 1991.

During the drilling and installation of the three wells at the SY-200 Yard, a possible perched water table was encountered in the fill material ~15–20 ft below ground surface. Observations from soil borings indicate that a water table is located in residuum, ~25–35 ft below ground surface, and a clay-rich layer, located between the fill material and the deeper residuum, may form the base for the perched water table in the SY-200 Yard. Values for nitrate were nondetects for all three monitoring wells in the SY-200 Yard. This may support the inference that the water sampled was from a water body (Fig. 3.16) not connected to the bedrock aquifer. The aquifer at the SY-200 Yard should probably show contamination with nitrate derived from the S-3 Ponds.

Monitoring Well Construction, Development, and Sampling. All activities involving well construction, development, and sampling were in accordance with applicable 1992 Energy Systems Environmental Surveillance Procedures. Before beginning work, the drill rig and all drilling equipment were decontaminated to ensure that there were no possible sources of external contamination. In addition, the rig was decontaminated when conditions of the rig warranted it and upon completion of work. Decontamination procedures were in accordance with ESP-900, *Cleaning and Decontaminating Sample Containers and Sample Devices* and ESP-901, *Equipment Decontamination,* where applicable. The wells were installed using an all terrain vehicle-mounted Central Mining Equipment 550 rig with 10-1/4 in. outside diameter, 8-1/4 in. inside diameter hollow stem augers. Augers were 5 ft in length. The boreholes were drilled 11 in. in diameter and the stainless steel casing was 4 in. Detailed well construction logs from these five wells are also included as part of Appendix A. Wells were drilled to refusal or groundwater. If refusal was met before water was encountered, the location of the borehole was moved ~6 ft and the well was drilled again. The process was repeated until water was encountered. Wells were then installed and developed in accordance with ESP-600, *Groundwater Sampling Procedures: Well Installation, Development and Abandonment.* Monitoring wells were developed no sooner than 24 h following the comple-

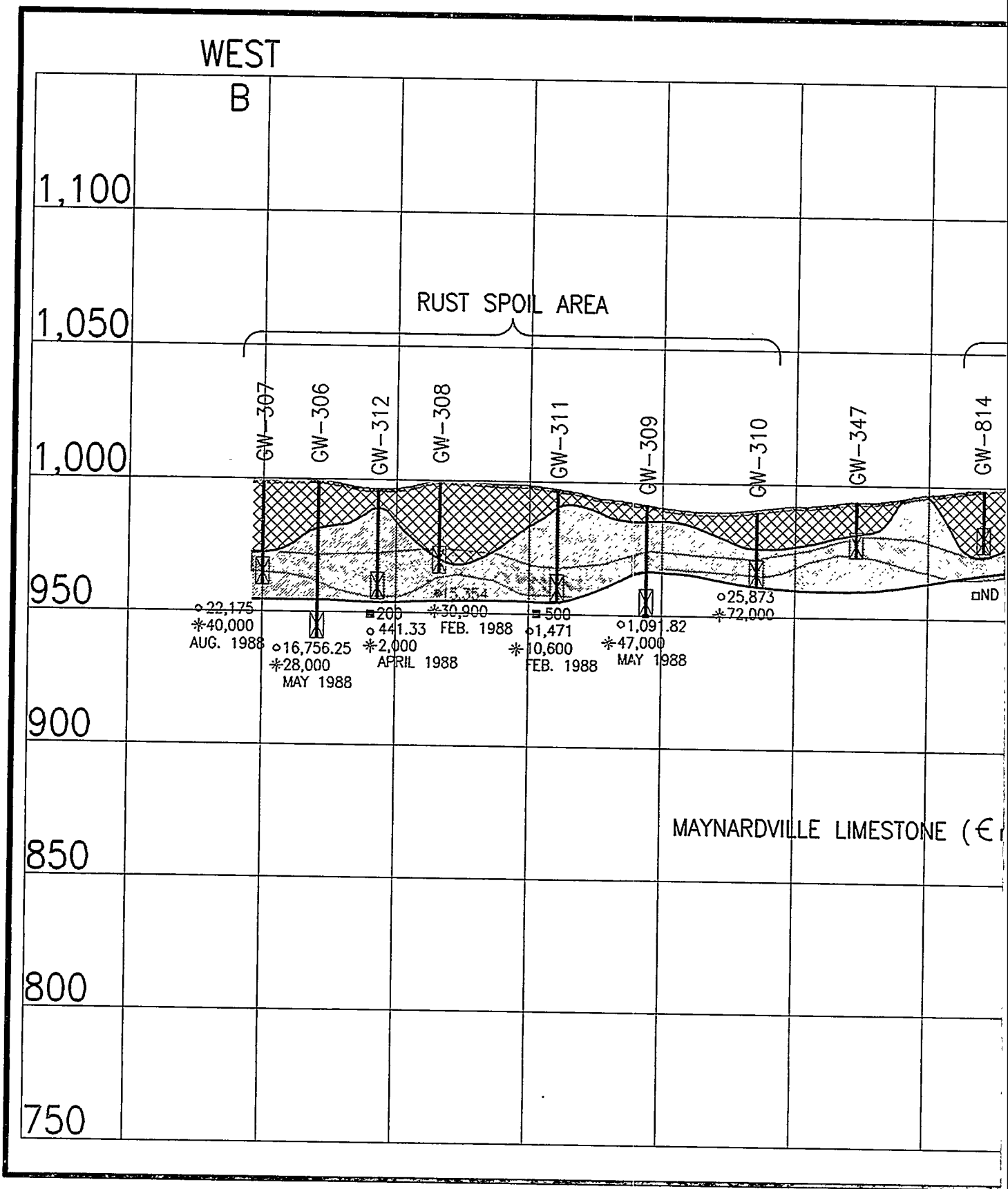
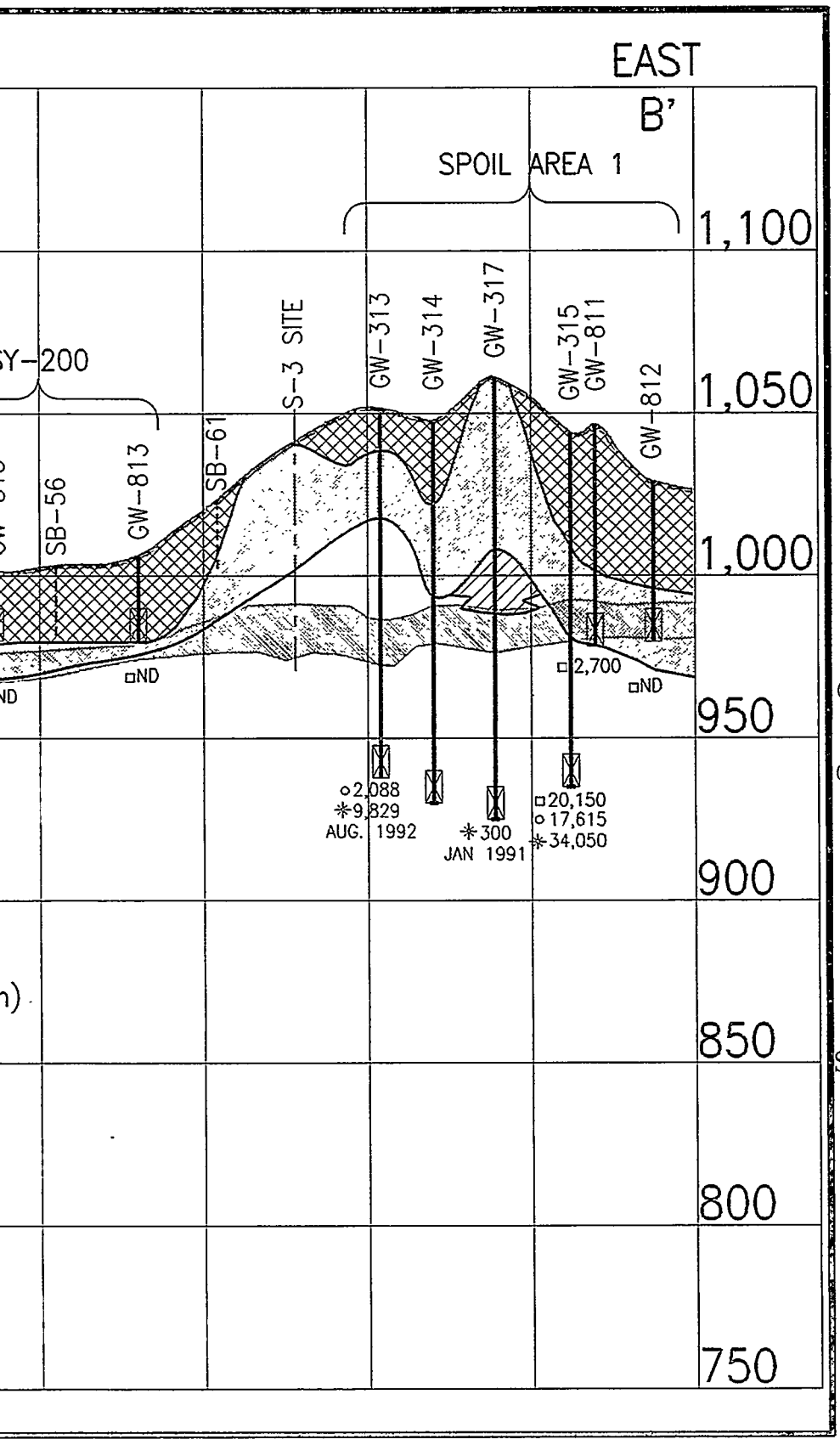


Fig. 3.16. Cross section east to west along strik
Maynardville Limestone and overlying residuum in up



LEGEND:

- FILL
- RESIDUUM/WEATHERED BEDROCK
- KNOX GROUP (OЄK)
- MARYVILLE LIMESTONE (Єmn)
- WELL LOCATION
- SCREENED INTERVAL
- TOTAL DEPTH OF HOLE
- WATER LEVEL RANGE
- GEOLOGIC CONTACT
- INFERRED GEOLOGIC CONTACT

ND..... NON-DETECT
□..... CURRENT VALUES (4th QTR. 1993)
○..... MEAN HISTORICAL VALUES
✳..... MAXIMUM HISTORICAL VALUES
JAN. 1991... DATE FOR MAX. HISTORICAL DATA

NOTES:

1.) WATER LEVELS INDICATE A RANGE FROM 1986 THROUGH 1993.
2.) VALUES INDICATED ARE FOR NITRATE AND ARE IN PPM.
3.) GW-317 IS THE REFERENCE OF BACKGROUND WELL.
4.) MCL VALUE FOR NITRATE IS 10,000 PPB.

0 25 50 100
VERTICAL SCALE: 1" = 50'

0 200 400 800
HORIZONTAL SCALE: 1" = 400'

SAIC
Science Applications International Corporation

BEAR CREEK VALLEY OU2 SECTION B-B' GEOLOGY AND NITRATE CONCENTRATIONS

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	RODNEY BEELER	LEE ROBERTSON	04-19-94
1	B. HADDEN		07-13-94

XREFERENCES	PLOT FILES
	/94003/DWGS/576PNIT.PLT

SHT. 1 OF 1 (DRAWING #) | /94003/DWGS/576PNIT (CAD FILE #) | N/A (ROT. ANGLE)

showing nitrate concentrations in the
er BCV Hydrologic Regime.

tion of the well construction. Well development was continued for a minimum of three well volumes and until the water column was free of visible sediment or until the pH, specific conductance, and temperature had stabilized. These parameters were measured using the following procedures: ESP-307-1, *Field Measurement Procedures: Temperature*; ESP-307-2, *Field Measurement Procedure: pH*; and ESP-307-8 IAD, *Field Measurement Procedure: Specific Conductance.* Wells were purged using ESP-302-2, *Groundwater Sampling Procedures: Guidelines for Well Purging.* Purging and development information for the five wells (GW-811, -812, -813, -814, and -815) is included in Appendix A.

Groundwater samples were collected from each monitoring well no sooner than 24 h following well development in accordance with ESP-302-3, *Groundwater Sampling Procedures: Using a Bailer.* Static water levels were taken and referenced to an established point on the top of the well casing. Measurements were correlated with a mean sea level datum point and measured using an electronic water level indicator in accordance with ESP-302-1, *Groundwater Sampling Procedure: Water Level Measurements Using a Water Level Indicator.* Immediately following the collection of samples, samples were preserved with the appropriate preservatives based on the type of analysis to be performed in accordance with ESP-701, *Sample Preservation and Container Materials.* They were then labeled, placed in a sealed plastic bag, and stored at ~4°C. At the time the samples were transmitted to the respective laboratory for analysis, a chain-of-custody form was completed for all samples according to ESP-500, *Manual Chain-of-Custody Procedures.* Analytical parameters for groundwater sampling as part of the RI are outlined in Table 3.6 and include metals, volatile organic analysis (VOA), SVOCs, pesticides, PCBs, and radionuclides.

During the RI field investigation, a seep sample (S-1) was also taken on the downslope face of SA-1 to supplement groundwater contamination determinations at SA-1 (Fig. 3.15). Field observations indicate that S-1 was taken from a bedrock outcropping in the Maynardville Limestone on the north slope of SA-1 and was sampled during a period of wet weather flow. Field observations also indicate that the seep water was not present during drier periods, suggesting that the flow runs along storm-activated flowpaths.

Prior to collecting the S-1 sample, all sampling equipment was decontaminated in accordance with ESP-900, *Cleaning and Decontaminating Sample Containers and Sampling Devices* and ESP-901, *Equipment Decontamination.* Seep samples were collected in accordance with ESP-301, *Water Sampling Using a Dipper* and samples were placed in containers, preserved, and handled in accordance with ESP-701, *Sample Preservation and Container Materials* and ESP-800, *Packaging Environmental Samples for Transportation.* S-1 was analyzed for metals, radiologicals, VOCs, SVOCs, PCBs, and asbestos. The analytical results for S-1 are included in Appendix B and are discussed in Sect. 3.2.3.2.

3.2.3.2 Groundwater evaluation

The concentration analytes in groundwater were quantitatively evaluated by comparing historical and current groundwater quality data to water quality data for a well that is representative of background concentrations (GW-317). The list of COPCs for each site was derived from this comparison and is used in the risk assessment to quantify risk via groundwater pathways at sites in the BCV OU 2. For the purpose of describing the nature and extent of contamination in groundwater, the COPC list was further compared to other relevant benchmarks [PRGs, MCLs, and a well representative of contamination in the S-3 Site plume (GW-122)] and evaluated for the frequency of detections. This comparison is

shown in Tables 3.18, 3.19, and 3.20. Discussion of COPCs that warrant further evaluation is included in the text.

Derivation of COPCs. Groundwater monitoring data in the GWQARs from 1988 to present as well as the current groundwater data collected for the BCV OU 2 RI were used for the groundwater evaluation. To derive the groundwater COPC list, the UCB median value of the concentration for each analyte at each site was compared to the UCB median value of the concentration for that analyte at the reference well (GW-317). GW-317 was chosen as the reference well for background values because of its location hydrologically upgradient of all the sites in BCV OU 2 and of the other waste sites in the BCV Hydrologic Regime and the upper EFPC Hydrologic Regime. Although GW-323 is located 250 ft hydraulically upgradient from SA-1 and GW-317, it is screened in the Knox Group bedrock, and the bedrock wells investigated in BCV OU2 are screened in the Maynardville limestone. Historical and current RI data indicate GW-317 is relatively free of contamination, particularly nitrate which may originate at the S-3 Ponds (Fig. 3.15). Drilling logs (Appendix A) for the reference well also show that this well did not contain any fill material that could have contributed contaminants to groundwater. In addition, concentrations of nitrate were below the detection limits (0.2 mg/L) indicating that this well is outside the boundaries of the S-3 Site groundwater plume.

An analyte was listed as a COPC if the UCB median value of the analyte at a given site was found to exceed the UCB median value for data from the reference well. A list of the groundwater COPCs can be found in Tables 3.18, 3.19, and 3.20.

Benchmark Screening. The concentrations of COPCs that were detected in historical and current data at a frequency >5% at each site were compared to PRGs, MCLs, and a well within the S-3 groundwater plume (GW-122). Although GW-317 is a reasonable reference well for determining background values for the BCV Hydrologic Regime, the sites in BCV OU 2 lie downgradient of the former S-3 Ponds. The S-3 Ponds have been a major contributor to groundwater contamination in the upper BCV Hydrologic Regime. One aim of this RI is to identify groundwater contamination that can be attributed to the sites in BCV OU 2; identifying contamination at each site in BCV OU 2 that is attributable to sites outside of BCV OU 2 is part of this goal. GW-122 is located upgradient of the SY-200 Yard and RSA, and is recognized as being in the S-3 groundwater plume from the elevated concentrations of nitrate in historical samples and the proximity of the well to the S-3 Site (HSW 1992). Comparison of groundwater quality data from wells at each site to GW-122 allows a screen for contaminants that may have resulted from the S-3 Site.

Examples of a benchmark comparison include these:

- Antimony was detected in 3 out of 180 samples. In accordance with EPA guidance, it is therefore considered an outlier because it was detected in <5% of the samples and is not discussed in detail.
- TCE was detected in 82 out of 82 samples in wells at the RSA. The site UCL for TCE is 0.0521 mg/L, the UCL for TCE in the S-3 plume reference well is 0.0036 mg/L, no PRG was calculated for TCE, and the MCL for TCE is 0.005 mg/L (SDWA). At RSA, TCE is a common contaminant in groundwater, and the site UCL exceeds the MCL value. The site UCL also exceeds the UCL mean concentrations observed in the S-3

Table 3.18. List of COPCs for groundwater at SA-1 showing relevant benchmark values (Lognormal distribution assumed and UCB on median compared to determine COPCs)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
			Anions					
Chloride (mg/L)	84/85	5.281	6.355	18.3	157.683	NA	250	None
Fluoride (mg/L)	1/2	0.075	NA	0.1	NAF	NA	4	None
Nitrate (mg/L)	81/83	12.511	25.910	34.05	936.721	58	10	C
Nitrate/Nitrite	1/2	1.400	NA	2.70	NAF	NA	NA	None
Sulfate (mg/L)	83/85	9.272	11.863	39.8	29.402	NA	400	None
			Metals					
Aluminum (mg/L)	66/85	0.128	0.207	93.7	4.815	NA	.2	C,D
Antimony (mg/L)	1/85	0.026	0.028	0.002	ND	0.015*	.006	A,B,C,E,F
Barium (mg/L)	85/85	0.044	0.052	0.4	10.302	2.6*	2	D
Beryllium (mg/L)	6/85	0.000	0.000	0.006	ND	0.00002**	.004	A,B,D
Cadmium (mg/L)	9/85	0.002	0.002	0.010	62.501	0.018*	.005	D
Calcium (mg/L)	85/85	82.117	88.780	120.0	881.464	NA	NA	None
Cobalt (mg/L)	2/85	0.003	0.003	0.064	21.005	NA	NA	D,E
Lead (mg/L)	2/6	0.058	0.473	0.24	NAF	NA	.015[c]	C,D,F
Manganese (mg/L)	70/85	0.028	0.059	3.93	0.221	0.18*	.050	C,D
Mercury (mg/L)	1/2	0.000	NA	0.001	NAF	0.011*	.002	None

Table 3.18 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
Niobium (mg/L)	2/18	0.005	0.006	0.017	ND	NA	NA	A,D
Potassium (mg/L)	85/85	3.150	3.636	18.3	28.862	NA	NA	None
Strontium (mg/L)	83/83	0.091	0.107	0.2	22.985	NA	NA	None
Vanadium (mg/L)	2/85	0.003	0.004	0.201	ND	0.26*	NA	A,E
Zirconium (mg/L)	1/18	0.002	0.005	0.017	ND	NA	NA	A,E
			SVOCs					
Bis(2-ethylhexyl)phthalate (mg/L)	2/2	0.002	[d]	0.002	NAF	0.0061**	.006	D
			VOCs					
1,1,2-Trichloro-1,2,2-trifluoroethane	1/2	0.004	[d]	0.003	NAF	1100*	NA	None
1,2-Dichloroethene (mg/L)	43/67	0.011	0.016	0.15	ND	0.33*	NA	A,D
4-Methyl-2-pentanone (mg/L)	6/67	0.005	0.005	0.004	0.005	2.9*	NA	A,D
Acetone (mg/L)	10/67	0.006	0.007	0.081	0.005	3.7*	NA	A,D
Bromodichloromethane (mg/L)	7/67	0.003	0.003	0.004	ND	0.0014**	.100	A,B
Carbon disulfide (mg/L)	1/67	0.003	0.003	0.002	ND	3.7*	NA	A,D,E,F
Chloroform (mg/L)	10/67	0.003	0.003	0.011	0.003	0.014*	NA	A,D
Methylene chloride (mg/L)	9/67	0.003	0.003	0.017	0.003	0.011**	.005	A,D
Tetrachloroethene (mg/L)	47/67	0.012	0.015	0.055	0.003	0.37*	.005	A,C,D
Trichloroethene (mg/L)	46/67	0.005	0.006	0.022	0.004	NA	.005	A,C

Table 3.18 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
Vinyl acetate (mg/L)	1/65	0.005	0.005	0.002	ND	37*	NA	A,E,F
			Radionuclides					
Gross Beta (pCi/L)	85/85	34.027	44.252	163	487.631	NA	NA	D
Gross Alpha (pCi/L)	84/84	3.251	7.204	63.1	46.880	NA	.015	C,D
^{238}U (pCi/L)	2/2	1.33	[d]	1.70	NAF	NA	NA	D
^{234}U (pCi/L)	2/2	1.93	[d]	2.51	NAF	NA	NA	D
^{235}U (pCi/L)	2/2	.028	[d]	0.041	NAF	NA	NA	None

Nondetects set to 1/2 the reported detection limit. Generated by program gwtab1_2.sas on 06APR94 from validated SEIMS and historical data.
NA = Not available
NAF = Not analyzed for
ND = Nondetect
[a]Ingestion pathway, * non-carcinogenic (HI), ** carcinogenic (10^{-6})
[b]A = Site UCL exceeds S-3 Well UCL, B = Site UCL exceeds PRG, C = Site UCL exceeds MCL, D = Analyte is a COPC in soil, E = Analyte is an outlier (<5% detects), F = Site UCL exceeds maximum value
[c]EPA Action Level; not an MCL
[d]Insufficient data to calculate site UCL

Table 3.19. List of COPCs for groundwater at the SY-200 Yard showing relevant benchmark values (Lognormal distribution assumed and UCB on median compared to determine COPCs)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
			Anions					
Chloride (mg/L)	2/4	489.888	NA	487	157.683	NA	250	A,C
Fluoride (mg/L)	2/4	0.082	.530	0.13	NAF	NA	4	F
Sulfate (mg/L)	3/4	13.355	NA	26.4	29.402	NA	400	D,F
			Metals					
Aluminum (mg/L)	4/4	8.515	NA	14.1	4.815	NA	0.200	A,C
Antimony (mg/L)	1/4	0.001	.004	0.002	844.208	0.015*	0.006	D,F
Barium (mg/L)	4/4	0.332	NA	0.55	10.302	2.6*	2	D
Calcium (mg/L)	4/4	247.288	NA	355	881.464	NA	NA	None
Chromium (mg/L)	4/4	0.016	0.100	0.019	ND	0.18*	0.100	A,C,F
Cobalt (mg/L)	2/4	0.036	NA	0.066	21.005	NA	NA	D
Copper (mg/L)	3/4	0.013	NA	0.017	177.88	NA	1.3	None
Cyanide (mg/L)	1/4	0.007	0.0708	0.014	NAF	0.73*	0.200	D,F
Iron (mg/L)	4/4	10.194	NA	15.1	1.657	NA	0.300	A,C,F
Lead (mg/L)	4/4	0.019	0.752	0.030	NAF	NA	0.015[c]	C,D,F
Magnesium (mg/L)	4/4	31.704	NA	43.9	176.866	NA	NA	None
Manganese (mg/L)	4/4	4.51	6.473	5.67	0.221	0.18*	0.050	A,B,C,F
Mercury (mg/L)	3/4	0.001	NA	0.002	NAF	0.011*	0.002	A,D

Table 3.19 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
Nickel (mg/L)	3/4	0.014	NA	.0169	ND	0.73*	0.100	A,D
Potassium (mg/L)	4/4	8.515	NA	12.9	28.862	NA	NA	None
Sodium (mg/L)	4/4	82.046	NA	140	107.035	NA	NA	A
Vanadium (mg/L)	4/4	0.018	NA	0.027	ND	0.26*	NA	A
Zinc (mg/L)	4/4	0.043	0.070	0.053	NAF	11*	5	F
			SVOCs					
Bis(2-ethylhexyl)phthalate (mg/L)	4/4	0.002	NA	0.004	NAF	0.0061**	0.006	D
Butylbenzylphthalate (mg/L)	1/4	0.004	NA	0.002	NAF	7.3*	0.006	D
Di-n-butylphthalate (mg/L)	2/4	0.004	NA	0.003	NAF	3.7*	0.006	D
Diethylphthalate (mg/L)	1/4	0.004	NA	0.002	NAF	29*	0.006	D
			VOCs					
Chloroform (mg/L)	1/4	0.002	NA	0.001	0.003	0.014*	NA	None
Tetrachloroethene (mg/L)	3/4	0.002	0.004	0.003	0.003	0.37*	0.005	A,F
Trichloroethene (mg/L)	1/4	0.002	0.003	0.002	0.004	NA	0.005	F
			Radionuclides					
Beta activity (pCi/L)	3/3	317.15	NA	463	487.631	NA	NA	D
Gross Alpha (pCi/L)	4/4	20.103	NA	38.1	46.880	NA	0.015	C,D
^{234}U (pCi/L)	4/4	2.015	NA	7.38	NAF	NA	NA	None

Table 3.19 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
^{235}U (pCi/L)	4/4	0.226	NA	0.428	NAF	NA	NA	None
^{238}U (pCi/L)	4/4	1.719	NA	8.58	NAF	NA	NA	None

Nondetects set to 1/2 the reported detection limit. Generated by program gwtab1_2.sas on 06 Apr 94 from validated SEIMS and historical data.
NA = Not available
NAF = Not analyzed for
ND = Nondetect
[a]Ingestion pathway, * noncarcinogenic (HI), ** carcinogenic (10^{-6})
[b]A = Site UCL exceeds S-3 Well UCL, B = Site UCL exceeds PRG, C = Site UCL exceeds MCL, D = Analyte is a COPC in soil, E = Analyte is an outlier, (<5% detects), F = Site UCL exceeds maximum value
[c]EPA Action Level, not an MCL

Table 3.20. List of COPCs for groundwater at RSA showing relevant benchmark values (Lognormal distribution assumed and UCB on median compared to determine COPCs)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
			Anions					
Chloride (mg/L)	107/108	31.486	44.755	68	157.683	NA	250	None
Nitrate (mg/L)	107/108	25.902	43.778	72	936.721	58*	10	C
Sulfate (mg/L)	107/108	73.285	105.344	165	29.402	NA	400	A
			Metals					
Aluminum (mg/L)	101/108	2.059	3.993	10	4.815	NA	.200	C
Antimony (mg/L)	3/108	0.027	0.028	0.2	ND	0.015*	.006	A,B,C,D,E
Arsenic (mg/L)	8/82	0.029	0.031	0.085	4438.08	0.011*	.050	B
Barium (mg/L)	108/108	0.059	0.065	0.23	10.302	2.6*	2	D
Beryllium (mg/L)	17/108	0.000	0.000	0.001	ND	0.00002**	.004	A,B,D
Boron (mg/L)	92/108	0.128	0.210	1.2	0.460	3.3*	NA	None
Cadmium (mg/L)	15/108	0.002	0.002	0.021	62.501	0.018*	.005	D
Calcium (mg/L)	108/108	162.254	172.775	390	881.464	NA	NA	None
Chromium (mg/L)	42/108	0.013	0.016	0.15	ND	0.18*	.100	A
Cobalt (mg/L)	3/108	0.003	0.003	0.006	21.005	NA	NA	D,E
Iron (mg/L)	105/108	1.702	3.869	20	1.657	NA	.300	A,C
Lithium (mg/L)	9/26	0.006	0.016	0.05	NAF	NA	NA	None
Manganese (mg/L)	105/108	1.156	3.295	3.8	0.221	0.18*	.050	B,C,D

Table 3.20 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
Niobium (mg/L)	6/26	0.005	0.006	0.016	ND	NA	NA	A
Potassium (mg/L)	108/108	6.525	7.825	150	28.862	NA	NA	None
Sodium (mg/L)	108/108	12.253	14.300	75	107.035	NA	NA	None
Strontium (mg/L)	108/108	0.356	0.415	3.1	ND	NA	NA	A
Vanadium (mg/L)	13/108	0.003	0.003	0.016	ND	0.26*	NA	A
Zirconium (mg/L)	4/26	0.003	0.004	0.01	ND	NA	NA	A
			Volatiles					
1,1,1-Trichloroethane (mg/L)	24/82	0.003	0.003	0.004	ND	NA	.200	A,D
1,1-Dichloroethane (mg/L)	15/82	0.003	0.003	0.004	ND	3.7*	NA	A,D
1,2-Dichloroethene (mg/L)	52/82	0.014	0.019	0.2	ND	0.33*	NA	A,D
4-Methyl-2-pentanone (mg/L)	10/82	0.005	0.005	0.008	0.005	2.9*	NA	D
Acetone (mg/L)	12/82	0.006	0.006	0.04	0.005	3.7*	NA	A,D
Bromodichloromethane (mg/L)	1/82	0.003	0.003	0.001	ND	0.0014**	.100	A,B,E
Carbontetrachloride (mg/L)	35/82	0.003	0.003	0.004	ND	0.00066**	.005	A,B
Chloroform (mg/L)	54/82	0.003	0.003	0.006	0.003	0.014**	NA	A,D
Trichloroethene (mg/L)	82/82	0.044	0.052	0.12	0.004	NA	.005	A,C,D
Total Organic Carbon (mg/L)	133/165	2.081	2.320	6.00	4.13	NA	NA	None

Table 3.20 (continued)

COPC	Proportion of detects	Estimated site mean	Site 95% UCL on the mean	Maximum detected value	S-3 95% UCL on the mean	PRG[a]	MCL	Comments[b]
Total Organic Chloride (mg/L)	212/220	0.075	.085	1.07	NAF	NA	NA	None
Total Uranium	70/108	0.002	.002	.06	.003	NA	NA	None
Vinyl acetate (mg/L)	1/82	0.005	0.005	0.002	ND	37*	NA	A,E,F
			Radionuclides					
Gross Beta (pCi/L)	108/108	52.602	70.509	2102	487.631	NA	NA	D
^{137}Cs (pCi/L)	14/14	9.402	34.304	49.4	NAF	NA	NA	None
Gross Alpha (pCi/L)	108/108	3.212	4.494	30	46.880	NA	.015	D,C
^{90}Sr (pCi/L)	14/14	6.627	45.986	124.07	NAF	NA	.008	C
^{99}Tc (pCi/L)	11/11	386.421	3051.73	2040	NAF	NA	NA	F

Nondetects set to 1/2 the reported detection limit. Generated by program gwtab1_2.sas on 06APR94 from validated SEIMS and historical data.
NA = Not available
NAF = Not analyzed for
ND = Nondetect
[a]Ingestion pathway, * noncarcinogenic (HI), ** carcinogenic (10^{-6})
[b]A = Site UCL exceeds S-3 Well UCL, B = Site UCL exceeds PRG, C = Site UCL exceeds MCL, D = Analyte is a COPC in soil, E = Analyte is an outlier (<5% detects), F = Site UCL exceeds maximum value

well, but cannot be compared to PRGs because one is not available. TCE is also determined to be a COPC in soil. The subjective decision was made that this analyte warrants further discussion in the text based on its exceeding the MCL and its common occurrence as a contaminant in groundwater. The nature and extent of TCE is discussed more fully in Sect. 3.2.3.3.

The comparisons described above for antimony and TCE can be found in tabular format for all COPCs at each site in BCV OU 2 in Tables 3.18, 3.19, and 3.20.

Seep Data. The data for the single seep sample at SA-1 are presented in Appendix B. COPCs that were detected in SA-1 above background were antimony, lead, cobalt, vanadium, mercury, and nickel. All exceeded background values, however only mercury exceeded its MCL (2 μg/L) with a concentration in S-1 at 21.2 μg/L. This concentration was the result of analyzing the unfiltered sample and mercury was nondetected in the filtered sample. This suggests that this contamination is the result of sampling particle-bound mercury not dissolved. No VOCs or nitrate were detected in S-1.

3.2.3.3 Nature and extent of contamination

The following is a description of the nature and extent of contamination at the BCV OU 2 site and includes discussion of COPCs detected in groundwater in both historic and current data. Tables 3.18, 3.19, and 3.20 and Table 1, Appendix B, present the statistical contaminant concentration data for all COPCs at each site with the relevant MCL, S-3 plume reference value, and the PRG. This statistical analysis is based on data published in the GWQARs for the relevant years.

Inorganics Metals. In general, concentrations of metals in groundwater have been low over the time period that groundwater at these sites has been monitored. Particular exceptions to this are metals that are usually associated with suspended particles, such as aluminum, iron, and manganese, in unfiltered samples. Although these metals have been detected in the majority of unfiltered groundwater samples taken at the sites in BCV OU 2, and many samples were recorded above MCLs, their significance as contaminants can be discounted when the frequency of their occurrence above MCLs is considered in filtered samples. Aluminum is a major constituent of clay minerals, and iron and manganese are common elements in the red oxide coating of these minerals. In addition, manganese can often be reported in samples with high aluminum due to interference effects on the inductively coupled plasma (ICP). The occurrence of these metals in unfiltered samples is, therefore, the result of dissolution of suspended solids after addition of preservation acids and does not reflect the presence of these metals in groundwater in the dissolved form.

Other trace metals that have been detected in samples at BCV OU 2 and have exceeded their respective MCL or PRG are arsenic, beryllium, chromium, lead, niobium, strontium, and zirconium. With the exception of strontium, none of these metals was detected regularly between 1988 and 1993 in any single well above MCLs and less often above detection limits. The frequency of detection for these metals was also much lower in the filtered samples, such that their values could be considered outliers. With the exception of strontium, these metals are generally found in natural waters in low concentrations due to their propensity to sorb to mineral surfaces. The occurrence of these metals in unfiltered samples is probably the result of dissolution of these chemicals from surface sites on suspended solids after addition of preservation acids and does not reflect the presence of these metals in groundwater in the

dissolved form. Strontium was detected in all groundwater samples in BCV OU 2. The maximum reported value was 3.10 mg/L in GW-312 at RSA in 1988. Strontium has been detected at elevated concentrations in wells near the S-3 Site and is a contaminant usually associated with the S-3 plume in the upper BCV Hydrologic Regime. The values reported in the 1993 GWQAR (HSW 1993) for wells near the S-3 Site were 11 mg/L in GW-256 to 320 mg/L in GW-615. In general, at BCV OU 2 the highest values of strontium were detected in wells with elevated nitrate values, suggesting that the source of strontium in groundwater at RSA is the S-3 Site.

Inorganic Anions. Major anions, chloride, sulphate, and nitrate were detected in nearly all groundwater samples from the sites in BCV OU 2. The distribution of major anions can be divided into two distinct populations in the upper BCV Hydrologic Regime: high total dissolved solid groundwater that characteristically contains elevated concentrations of nitrate and is associated with contamination from the S-3 Site, and lower total dissolved solid groundwater for which the concentration of nitrate is <10 mg/L (the MCL value for nitrate).

Nitrate is the characteristic contaminant of the S-3 Ponds groundwater plume. In the Maynardville Limestone this plume extends along BCV downgradient of the former S-3 Ponds (Fig. 3.16). West of the BCV OU 2 site, nitrate concentrations exceeding 10 mg/L have been recorded downgradient in the Maynardville Limestone past the Burial Grounds.

Historical nitrate concentrations have been elevated above the MCL value of 10 mg/L in wells GW-314 and -315 at SA-1 (Fig. 3.17) and in all wells with the exception of GW-312 at RSA (Fig. 3.18). No historical data are available for the SY-200 Yard. Values for nitrate for the 4th quarter 1993 were generally lower than historical values at SA-1 and RSA with only wells GW-314 and -315 in the SA-1 exceeding the MCL value of 10 mg/L. None of the wells installed in the shallow residuum at the SY-200 Yard detected nitrate.

Figure 3.19 shows the concentrations of nitrate over the past 5 years in wells at SA-1 and the RSA. Figure 3.20 shows the concentrations of nitrate over the past 5 years in the background reference well (GW-317) and the reference well from the S-3 plume (GW-122).

With the exception of GW-311 and -312, concentrations of nitrate in wells at RSA have continuously exceeded 10 mg/L since 1989 and groundwater at this site probably exceeded the MCL in the preceding years. Concentrations have been steadily decreasing over the past 5 years, probably a result of the discontinued use and closure of the S-3 Ponds. A similar declining trend is also seen in the nitrate data from the S-3 Ponds reference well.

At SA-1, nitrate values have fluctuated widely in two of the wells that regularly detected nitrate above MCLs: GW-314 and -315. The reasons for this wide range of values are not clear; however, nitrate concentrations in GW-315 appear to have fluctuated between January 1990 and August 1992 on an annual basis, with the highest values occurring during summer and early fall and the lowest values during winter and spring. GW-314 and -315 also show fluctuations in the concentrations of VOCs; this is discussed in the next section.

Chloride concentrations are elevated in wells that have elevated nitrate concentrations and, therefore, are wells that probably sample the S-3 plume. The only sample that exceeded the groundwater MCL (250 mg/L) was from GW-813 at the SY-200 Yard (487 mg/L). There

were no other analytes that showed elevated concentrations in this well; therefore, the reason for this high chloride concentration is not clear.

VOCs. The relative proportion of organic contaminants in groundwater from upper BCV suggests that there are two, and possibly three, distinct contaminant plumes (Fig. 3.21). Organic contaminants commonly associated with the S-3 Ponds are PCE, acetone, and chloroform, with minor concentrations of TCE and methylene chloride. Wells near the S-3 Ponds show large variability in proportions of these organic contaminants, and this may be an artifact of the original distribution of these contaminants in the former ponds or the temporal changes in discharge of these contaminants into the ponds.

Wells at the RSA show a distinct suite of organic contaminants (Fig. 3.21). These wells have historically recorded TCE and DCE as the main organic contaminants and have recorded only minor PCE and chloroform. This suggests a source of organic contamination in groundwater for RSA different from the S-3 Site. TCE is found in soils at RSA, and it is reasonable to assume a local soil source for TCE contamination in groundwater. The potential for TCE to leach from soils at RSA is discussed in Sect. 3.2.5.

The pattern of organic contaminants at SA-1 is unlike that in the S-3 plume and that at RSA. The suite of organic contaminants is similar to that found at wells near the Fire Training Area located in the upper EFPC Hydrologic Regime. PCE, TCE, DCE, and chloroform have been recorded regularly in bedrock wells GW-313, -314, and -315 at SA-1 (Fig. 3.21). The overburden monitoring well installed during this RI at SA-1, however, contains contamination similar to that at S-3, with acetone dominating (81 μg/L) the suite, and minor amounts of PCE (14 μg/L), DCE (11 μg/L), and TCE (7 μg/L).

VOCs have not been recorded in soils at SA-1 at concentrations suggested by the levels of contamination in groundwater, and SA-1 may not be a source for the VOC contamination at this site. The following is a discussion of the two possible sources of VOC contamination in groundwater at SA-1 that are outside the SA-1 boundaries.

Fire Training Area

In the RI work plan for BCV OU 2, the Fire Training Area in the upper EFPC Hydrologic Regime was assumed to be the source for organic contamination. This was based on recorded organic contamination in GW-619 and -620 at the Fire Training Area, both of which contain a suite of organic contaminants similar to those at SA-1. Based on this evidence alone, the Fire Training Area was assumed to be the source of VOC contamination at SA-1.

One new monitoring well (GW-812) was installed during this investigation to test this hypothesis; however, no organics were detected in this well. The suite of VOC contaminants detected in bedrock wells at SA-1 is different from that in the overburden monitoring well GW-811. Therefore, lack of VOCs in GW-812 does not alone exclude the Fire Training Area as a possible source of these contaminants at SA-1. The Fire Training Area is located in the upper EFPC Hydrologic Regime close to the hydrologic divide separating the BCV Hydrologic Regime and the upper EFPC Hydrologic Regime (Fig. 3.15). Bedrock at both the Fire Training Area and SA-1 is the Maynardville Limestone and karst hydrology may dominate groundwater flow at both sites. The lack of a hydrologic connection between the Fire Training Area and SA-1 cannot be ruled out solely on the basis of the configuration of

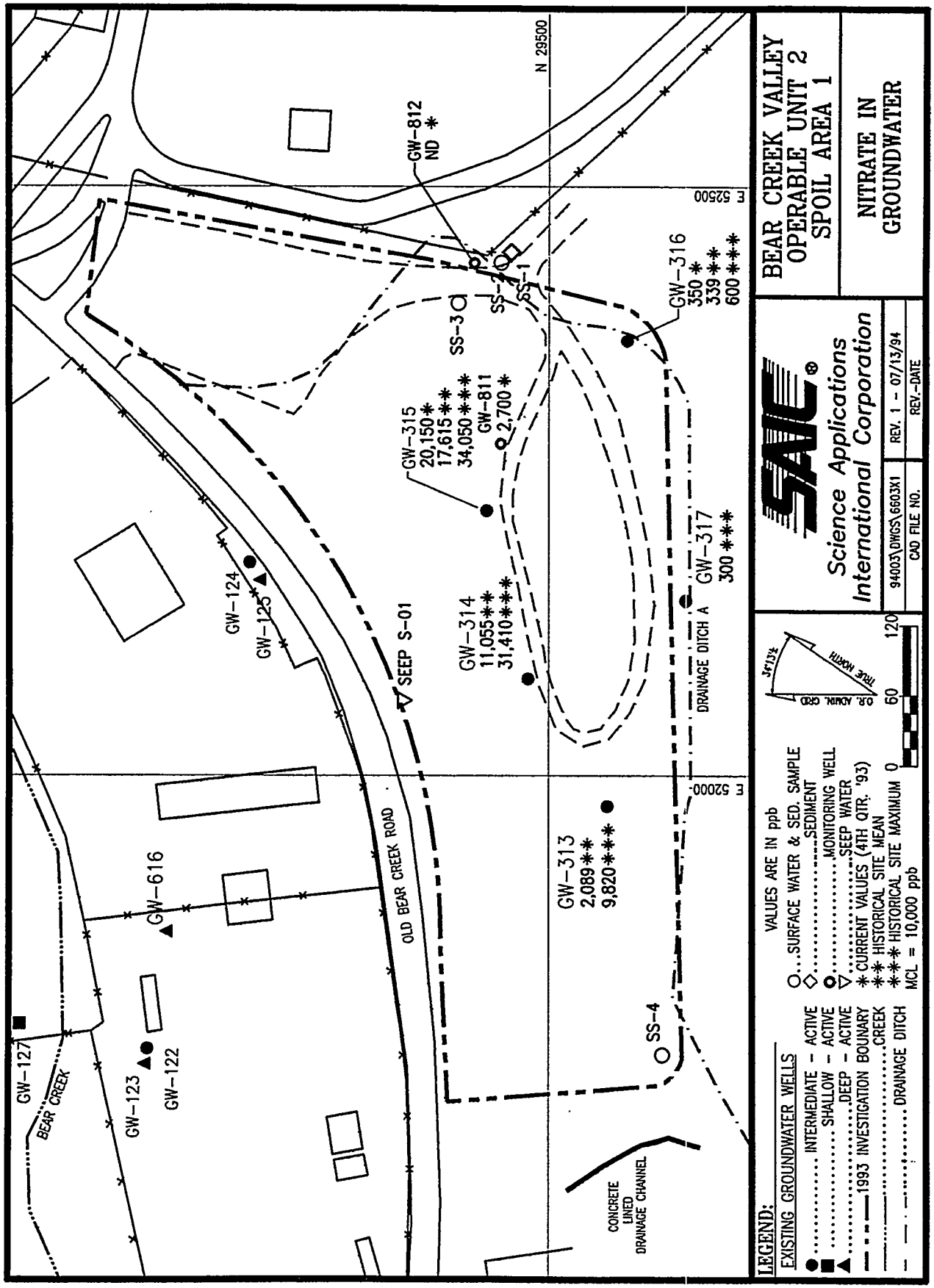


Fig. 3.17. Concentrations of nitrate in groundwater at SA-1.

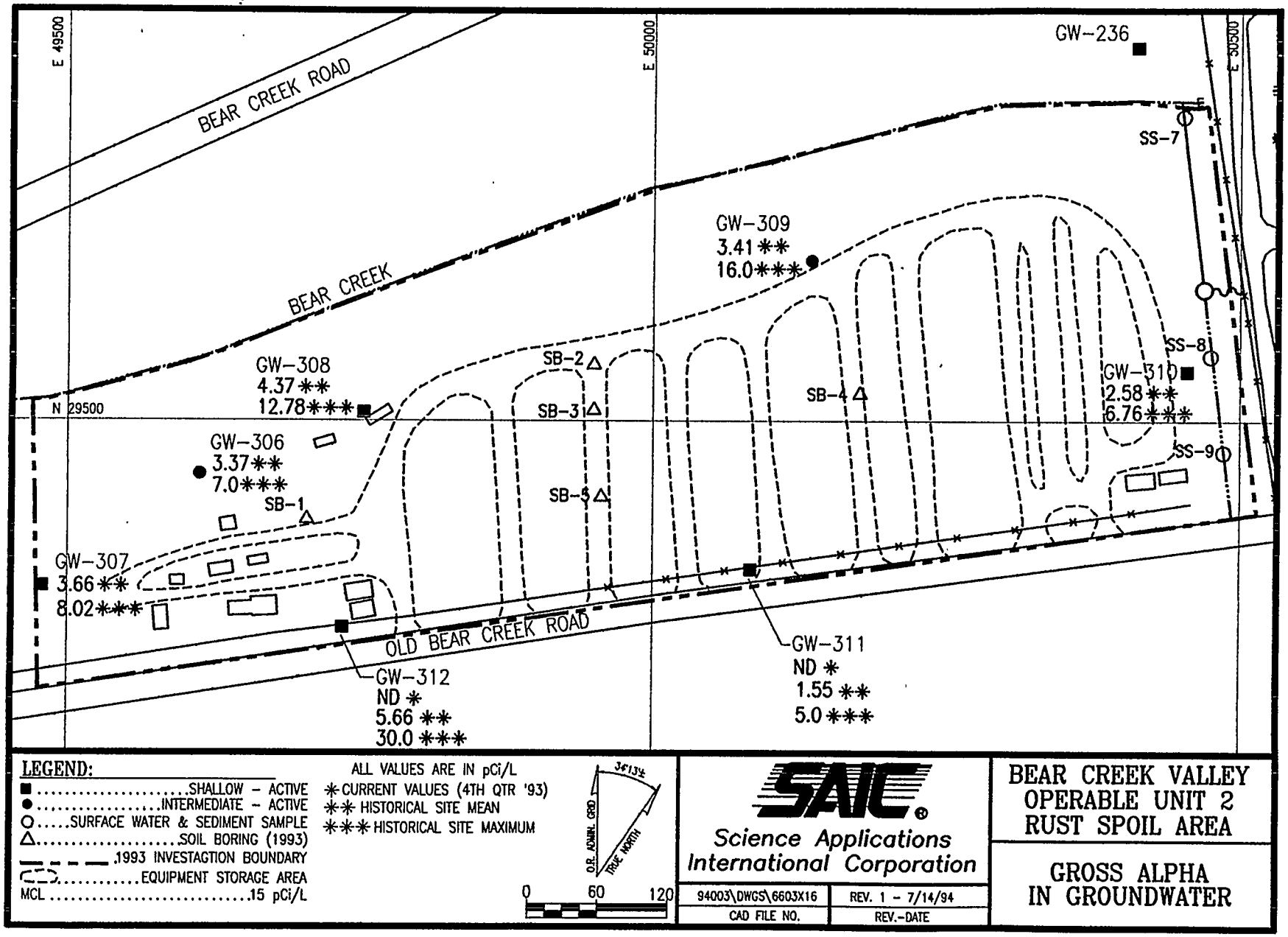


Fig. 3.18. Concentrations of nitrate in groundwater at RSA.

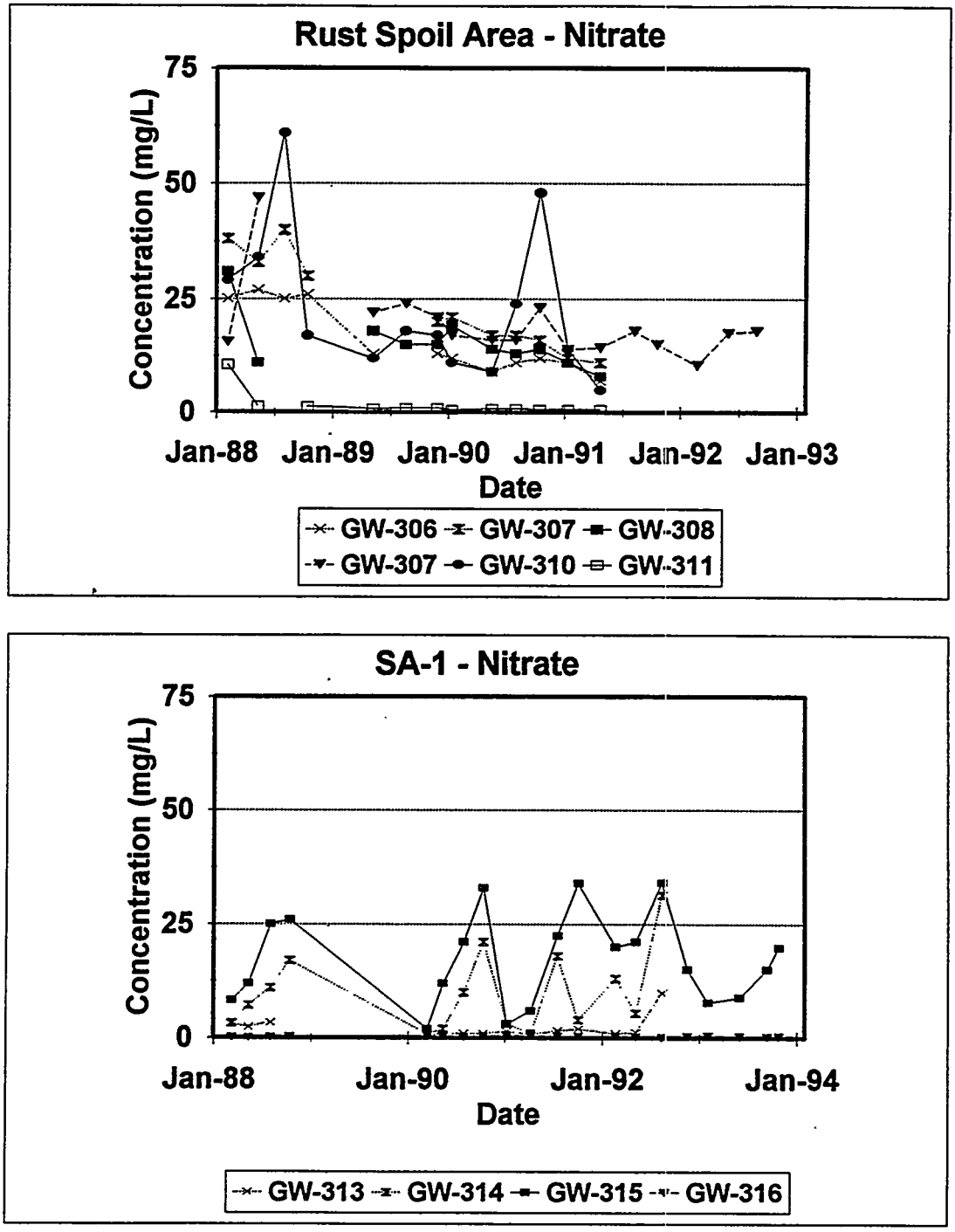
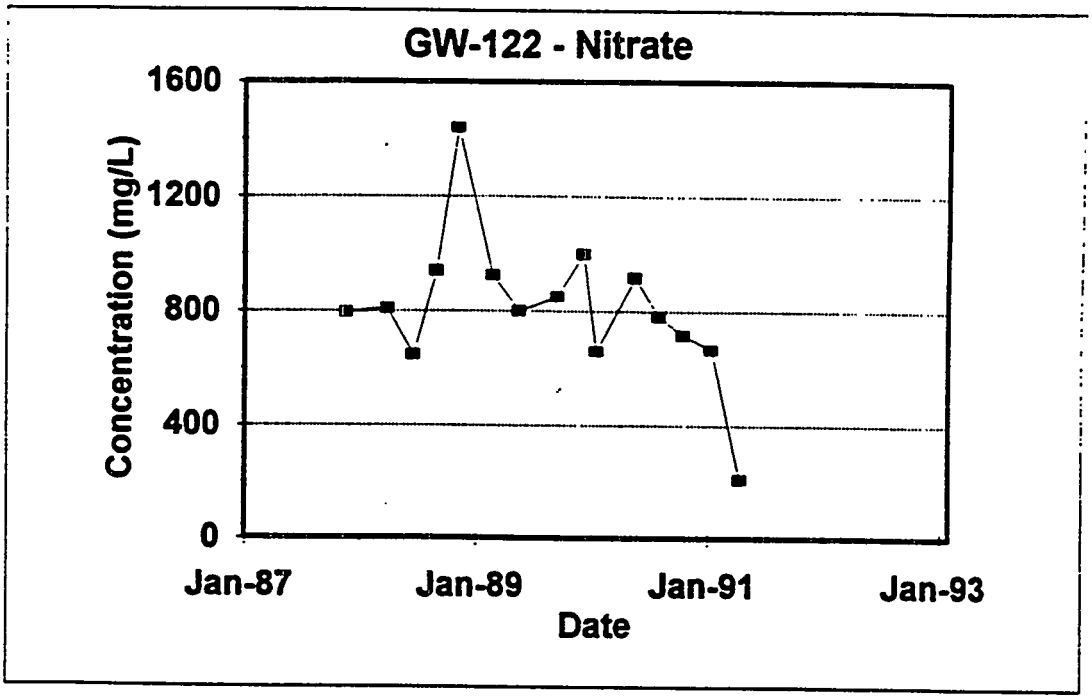


Fig. 3.19. Concentrations of nitrate in groundwater at RSA and SA-1 between 1988 and 1993.



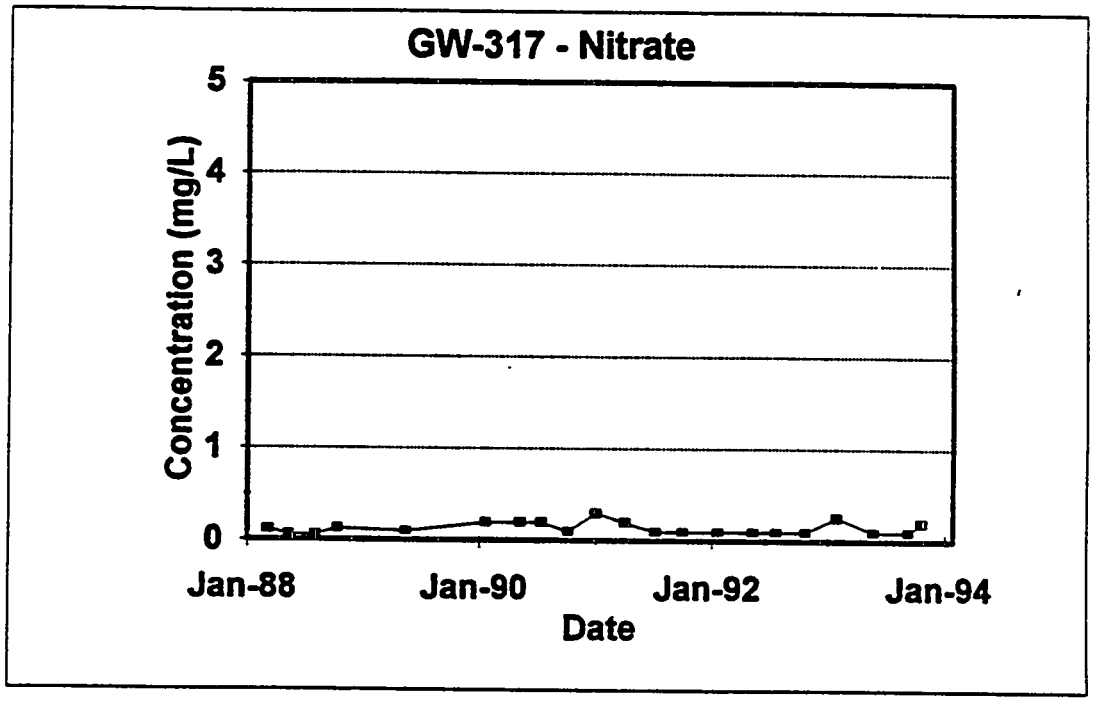


Fig. 3.20. Concentrations of nitrate in groundwater at GW-122 and -317 between 1988 and 1993.

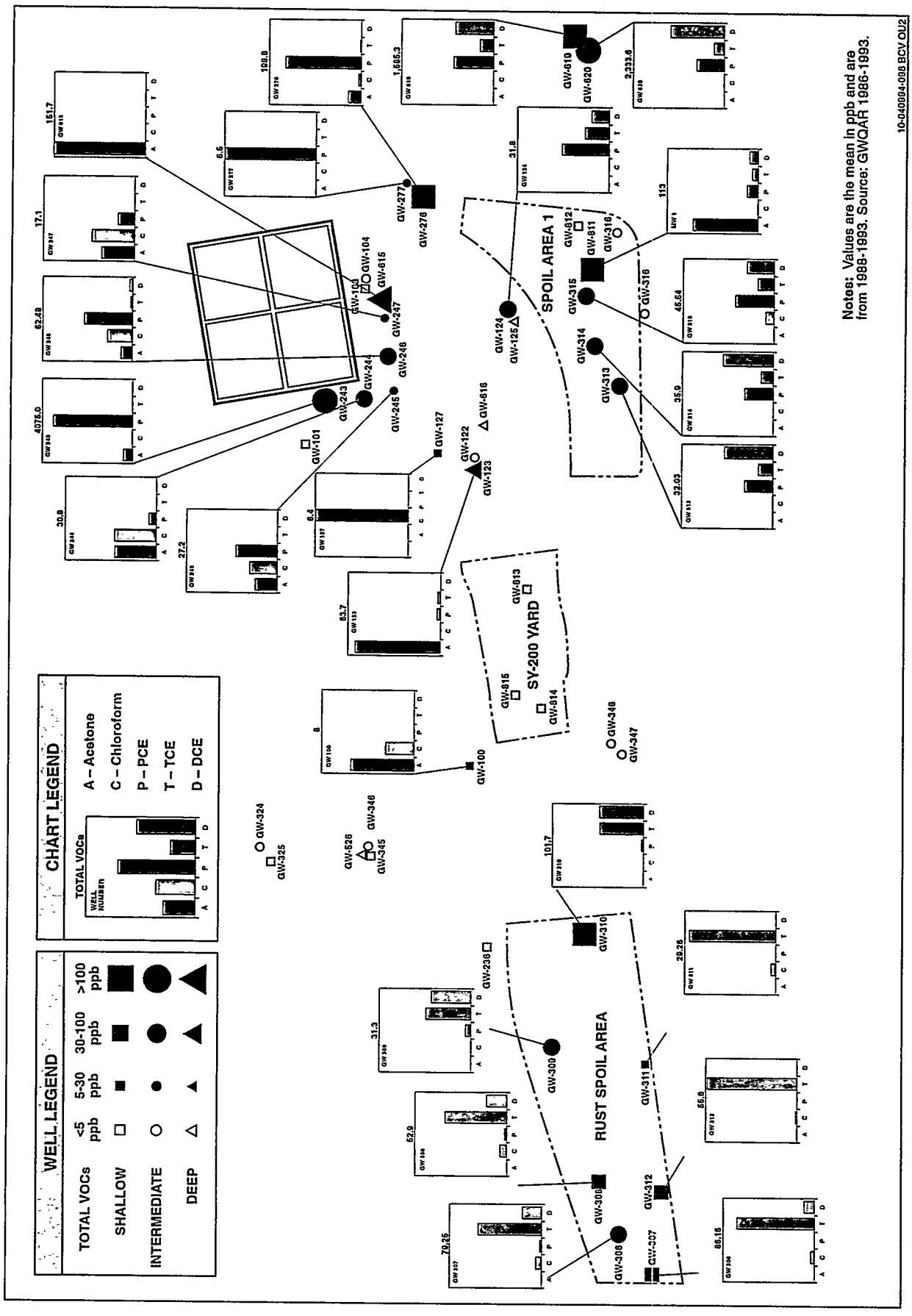


Fig. 3.21. Concentrations of VOCs in groundwater in the upper BCV Hydrologic Regime.

the groundwater table due to its proximity to the divide and the potential karst nature of the hydrologic system. Based on the suite of contaminants, and the uncertainty about hydrologic connections in the karst flow systems, a likely source of contamination to the bedrock wells at SA-1 is the Fire Training Area.

S-3 Site

Organic contamination at SA-1 occurs in GW-313, -314, and -315 which are also wells that are contaminated by the S-3 plume, evidenced by the high nitrate concentrations. Two of the contaminants at SA-1, PCE and chloroform, are characteristic contaminants found in groundwater at the S-3 Site and may have been derived from S-3. However DCE, which is the major VOC contaminant at SA-1, is only occasionally seen in wells close to the S-3 Site, and then only in minor proportions. Biodegradation of PCE, a major contaminant at the S-3 Site, could result in buildup of DCE in groundwater if biodegradation occurred in an anaerobic environment. Aerobic degradation of PCE would result in vinyl chloride as the final breakdown product, and this chemical has not been detected in groundwater in any of the wells in the upper BCV Hydrologic Regime.

Acetone is the main VOC contaminant in GW-811 at SA-1. Wells at the S-3 Site are the only wells in the upper BCV Hydrologic Regime to regularly record acetone in groundwater. The S-3 Site appears to be a possible source for VOC contamination in GW-811; however, the configuration of the water table in upper BCV makes this an unlikely source.

Elevated concentrations of nitrate found in GW-314 and -315 and the similarity of the VOC contaminant suite in these wells to that at the Fire Training Area suggest that VOC and nitrate contamination in bedrock groundwater at SA-1 is the result of commingled plumes from S-3 and the Fire Training Area. These sites are located at the groundwater and surface water divide between the BCV Hydrologic Regime and upper EFPC Hydrologic Regime. Historically, the configuration of the groundwater table and the location of the groundwater divide has changed as closure of the S-3 Ponds has altered infiltration. The position of these sites at the divide makes it possible that gradients, and therefore the direction of groundwater flow, may vary based on the ambient hydrologic conditions and result in temporary reversal of plume migration directions.

Concentration vs time plots for nitrate and VOCs in wells at SA-1 show systematic variations in the concentration of nitrate, PCE, TCE, and DCE with time (Fig. 3.22). For both GW-314 and -315, the concentrations of DCE and PCE peak over the fall of 1990 and winter of 1991. The concentration of nitrate in GW-314 and -315 peaks in the fall of 1990; however, over the winter 1991 period when the VOCs had the highest concentrations in these wells, nitrate levels fell. For the period after spring 1991 to winter 1993, VOC concentrations in both these wells are relatively stable; however, the concentration of nitrate varies widely. These characteristics support the hypothesis that VOC contamination and nitrate contamination in these wells are derived from separate sources. However, the physical processes yielding these observations are not clear from available data.

The suite of VOC contaminants detected in GW-811 cannot be attributed to migration from the Fire Training Area. S-3 has been a source of acetone contamination in BCV; however, the configuration of the water table indicates that the S-3 site is not a likely source

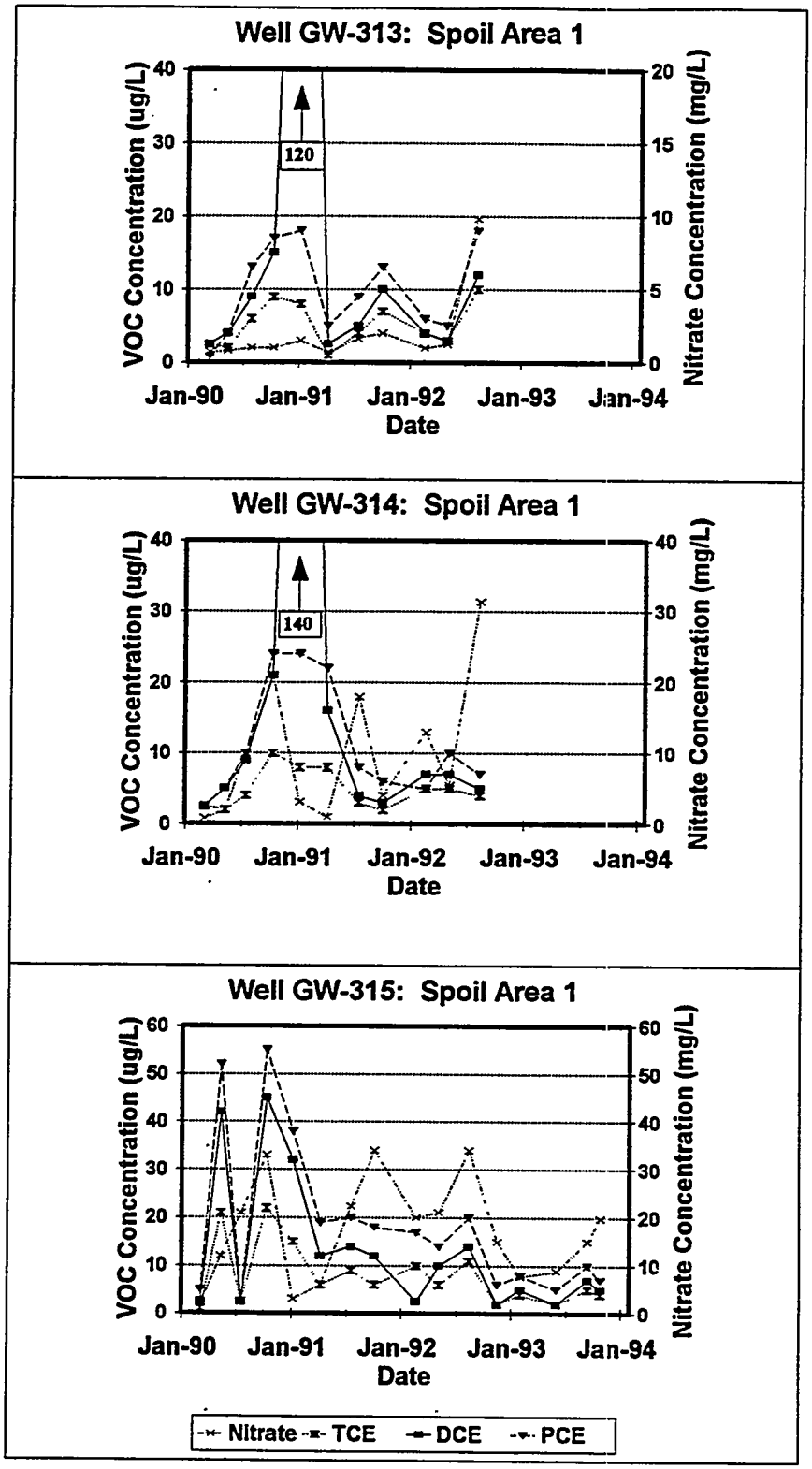


Fig. 3.22. Concentration vs time plots for VOCs and nitrate in wells at SA-1.

(Fig. 3.15). Leaching of acetone and trace chlorinated solvents (TCE, PCE, and 1,2 DCE) from debris in SA-1 is a possible source; however, the absence of acetone in bedrock wells probably indicates that contamination of the shallow aquifer is not extensive.

Radionuclides

The general pattern of gross alpha and gross beta activities in groundwater in BCV OU 2 follows the distribution of nitrate and reflects the common source of these contaminants, the S-3 Site (HSW 1993). Some of the wells at the sites in BCV OU 2 are affected by the S-3 Site contamination as evidenced by the elevated nitrate concentrations, and it is reasonable to assume that the radiological contamination recorded in these wells is derived from the S-3 Site.

Gross alpha and gross beta are COPCs in groundwater at SA-1, the SY-200 Yard, and RSA (Figs. 3.23–3.25). The site UCL value for gross alpha exceeded the MCL value of 15 pCi/L only at the SY-200 Yard; however, maximum values recorded at all three sites exceeded the maximum value detected, indicating that the levels of contamination periodically exceeded the MCL. The maximum value for gross alpha at SA-1 was 63.10 pCi/L in GW-812 during 1993; for the SY-200 Yard it was 38.10 pCi/L in GW-813 during 1993; and for RSA it was 30 pCi/L in GW-312 during 1988.

Strontium-90 , ^{137}Cs, and ^{99}Tc were sporadically detected in wells at the RSA. The maximum value for ^{90}Sr at RSA was 124.07 pCi/L in GW-306 during 1990; the maximum value for ^{137}Cs was 49.4 pCi/L in GW-306 during 1990; and the maximum value for ^{99}Tc was 2040 pCi/L in GW-306 during 1991.

Elevated radiological contamination at SA-1 and RSA can be attributed to contamination in groundwater associated with the S-3 Site. Gross alpha and gross beta contamination at the SY-200 Yard cannot be attributed to the S-3 Site and is probably the result of radionuclides adsorbed to suspended solids that are derived from contaminated soil.

3.2.3.4 Groundwater geochemistry

Most wells in the Maynardville Limestone and Knox aquifer in BCV monitor a calcium-magnesium-bicarbonate type groundwater (Fig. 3.26). The main exceptions to this are wells near the S-3 Ponds where the anion makeup is dominated by elevated concentrations of nitrate and chloride that result from the contamination caused by the S-3 Ponds. All groundwater sampled during this RI in GW-811, -812, -813, -814, and -815 at SA-1 and the SY-200 Yard show major ion geochemistry that is consistent with wells screened in the Maynardville or in its overlying residuum. However, with the exception of the sample from GW-812, charge balance could not be obtained within $\pm 10\%$. This implies that there is some inconsistency in the analytical methods used to analyze for the major ions and that the data for these chemicals may be suspect.

Wells GW-813, -814, and -815 at the SY-200 Yard show some anomalies in major ion geochemistry. GW-813 has an unusually high chloride concentration (487 mg/L), and GW-814 and -815 have anomalously low chloride concentrations. The anomalous concentration in GW-813 is not associated with high nitrate, and so it cannot be considered as being part of the S-3 plume. High chloride is usually indicative of groundwater contamination, however no COPCs were detected in this well at anomalous values, and the source of this high chloride is uncertain. Anomalously low concentrations in GW-814 and -815 could be the result of

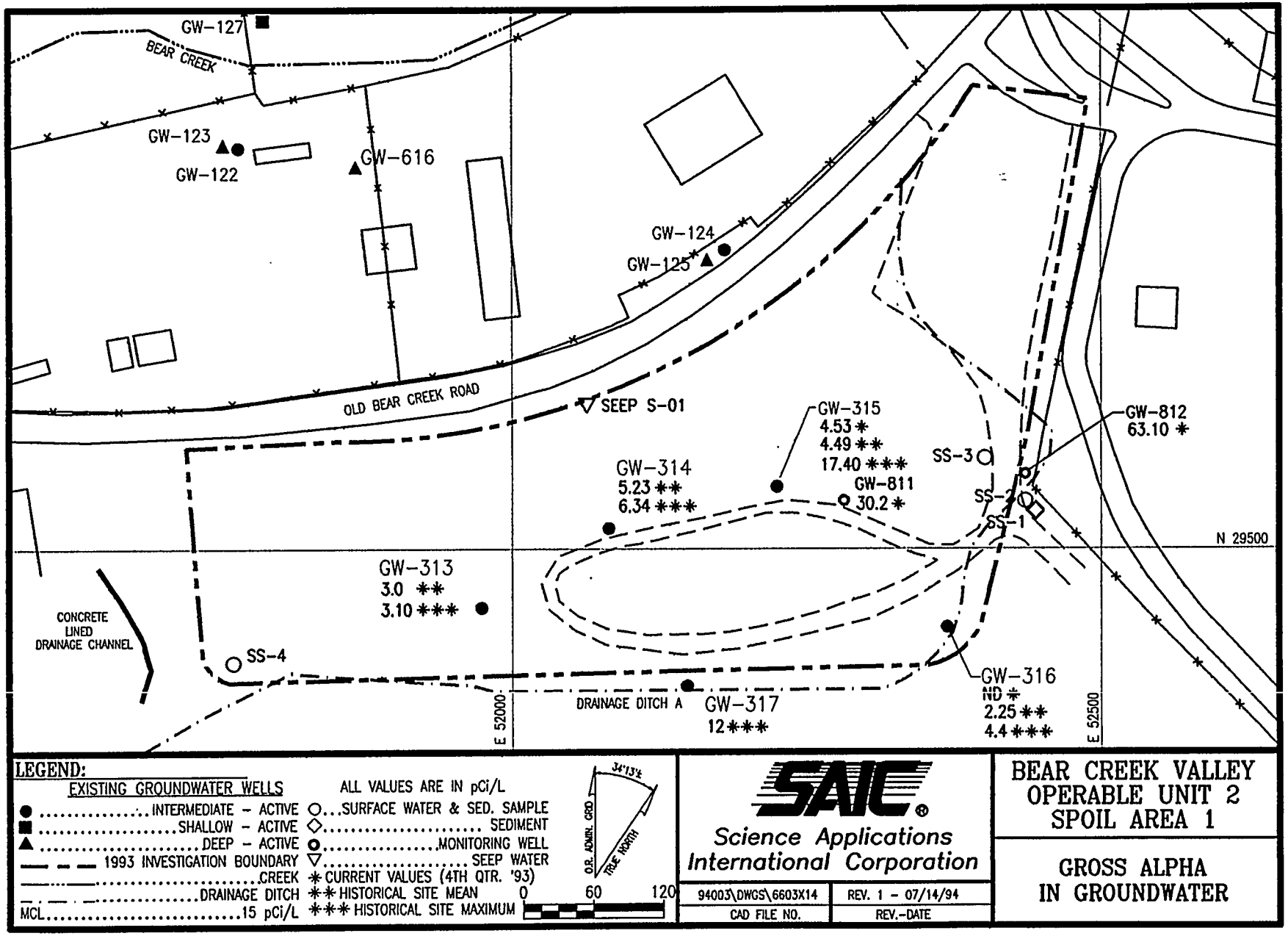


Fig. 3.23. Concentrations of gross alpha in groundwater at SA-1.

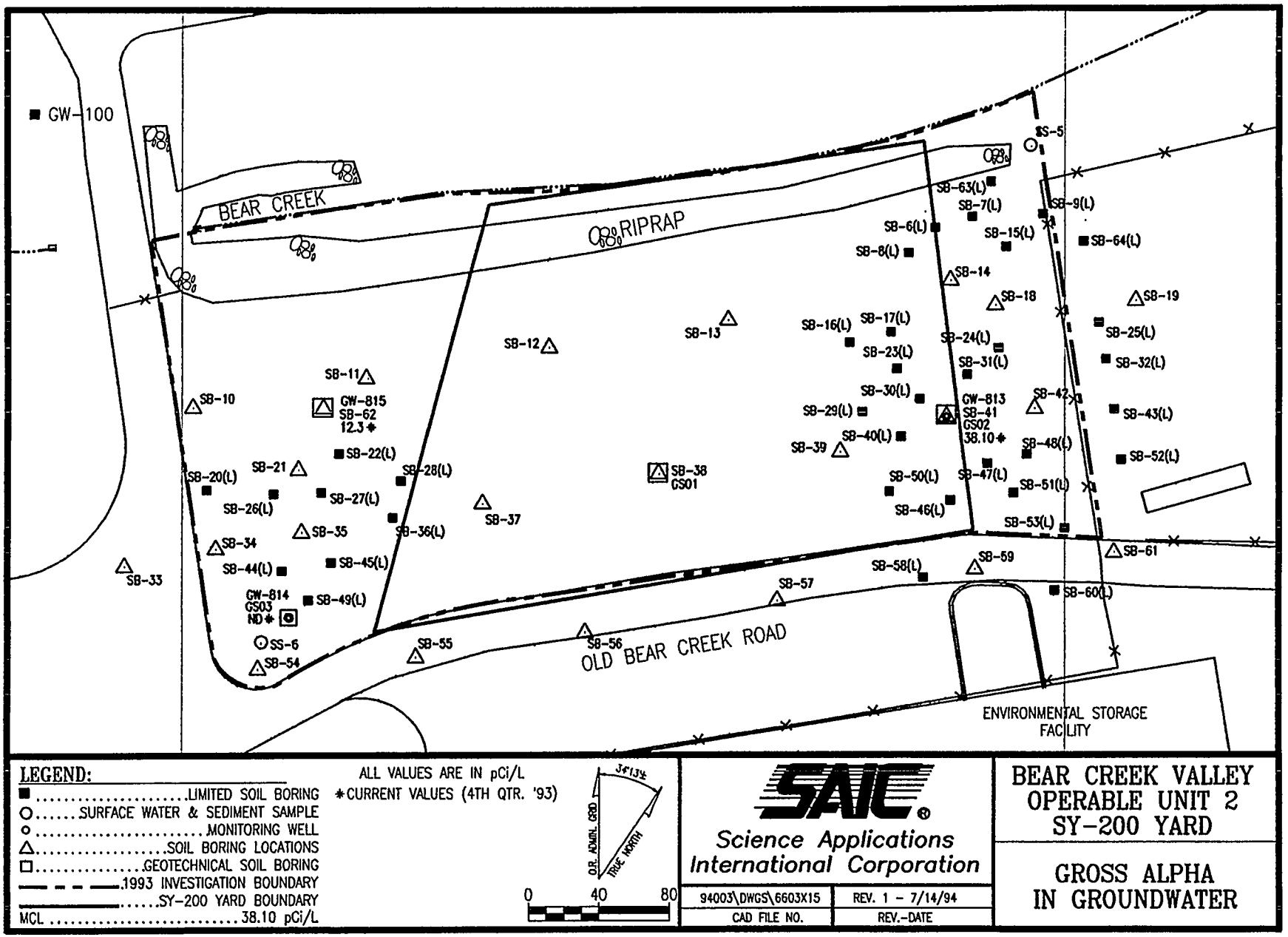


Fig. 3.24. Concentrations of gross alpha in groundwater at the SY-200 Yard.

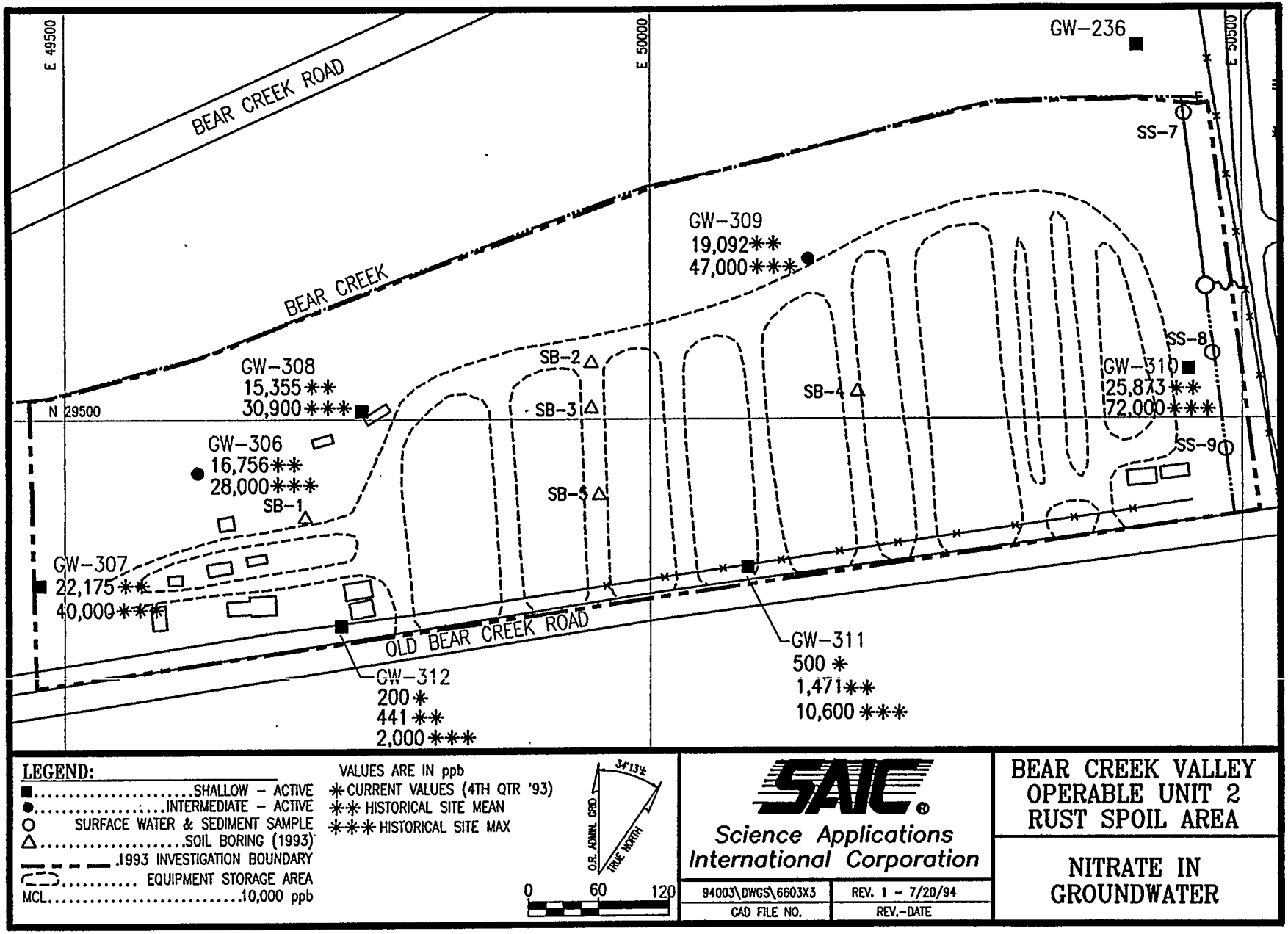


Fig. 3.25. Concentrations of gross alpha in groundwater at RSA.

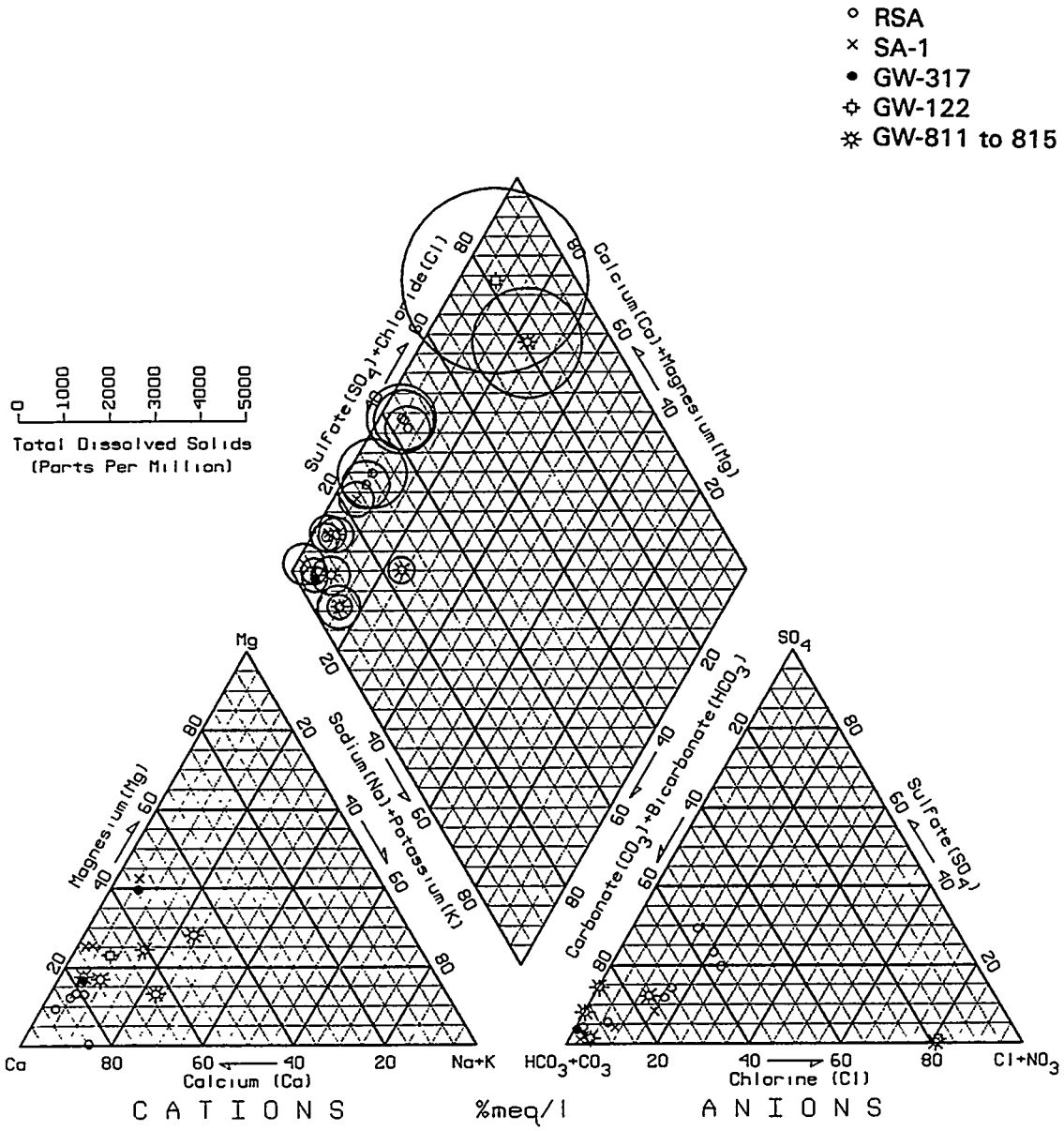


Fig. 3.26. Piper diagram showing representative groundwater compositions from the upper BCV Hydrologic Regime.

rapid infiltration and recharge of rainfall such that these wells are sampling rainwater that is virtually unchanged.

3.2.4 Soil Chemical Data

Soil investigation activities were performed at the RSA and the SY-200 Yard from August to December 1993 to verify and determine the nature and extent of soil contamination at the SY-200 Yard and RSA. A total of 64 locations was sampled in the two areas by split spoon or hand augers to groundwater or refusal. Samples were recovered from five soil borings in the RSA and from 59 soil borings in the SY-200 Yard, including two hand-augured borings. Hand auger samples were taken where the use of a drill rig was not possible. A total of 261 soil samples was analyzed for specific suites of analyses in the two areas.

3.2.4.1 RI sampling methodologies

Before beginning work at the BCV OU 2 site, the drill rig and all drilling support equipment were inspected to ensure that there were no possible sources for external contamination. In addition, the Y-12 Plant HPD screened all equipment for possible radiation contamination before entering or leaving the BCV OU 2 site. A decontamination pad was set up outside the RSA for conducting equipment decontamination during the RI. The drill rig was decontaminated prior to use, between individual sites, between boring locations as necessary, and upon completion of work. The drill rig and all support equipment were decontaminated using a steam cleaner and in accordance with ESP-901, "Equipment Decontamination."

All sampling equipment not precleaned and disposable was decontaminated before use, between uses, and before it left the site in accordance with ESP-900, "Cleaning and Decontaminating Sample Containers and Sampling Devices." All nondisposable sampling equipment was also screened by the Y-12 Site HPD for possible radiation before entering or leaving the BCV OU 2 site.

Before initiating field activities, excavation/penetration permits for each site were obtained. All underground utilities, storm drains, and surface lines were identified and surveyed. A portable phone pass was obtained prior to beginning operations, and construction permits were obtained as necessary to prevent accidental damage or penetration.

All sampling and borehole activities were accomplished using a central mining equipment 550 all-terrain drill rig equipped with continuous hollow stem augers, and in accordance with ESP-303-2, "Soil Sampling with an Auger" and ESP-303-4, "Penetration Test and Split-Barrel Sampling." Samples were recovered using 2- and 3-in. diam, 2-ft stainless-steel split-barrel samplers deployed through 6-1/4 in. outside diam hollow stem augers except for the boreholes that were ultimately converted to monitoring wells. Those borings were drilled with 10-1/4 in. outside diam hollow-stem augers. Split-barrel samplers were pushed with the drill-rig head when possible as approved by a field change order and in accordance with ER/C-P119, "Controlling and Documenting Field Changes to Approved Field Sampling Plans." When the soil was too resistant to push the sampler, the samplers were driven with an hydraulic-driven automatic drop hammer. Blow counts were recorded and are presented on the lithologic logs in Appendix A. All down-hole instrumentation was retrieved with a drill rig-mounted winch.

Upon retrieving each split-spoon sample, the outside of the split spoon was screened for potential radiological contamination using a beta/gamma pancake meter and an alpha scintillation detector in accordance with SAIC Procedure FTP-451, "Operation of Radiation Survey Instruments." The split spoon was then opened and the soil monitored with a Jerome and an organic vapor detector, in accordance with SAIC's FTP-753, "Field Measurement Procedures: Mercury Vapor Analyzer" and FTP-750, "Field Measurement Procedure: Organic Vapor Detector." In addition, the soil was screened for potential radiological contamination using a beta/gamma pancake meter and an alpha scintillation detector in accordance with SAIC Procedure FTP-451. If a VOC sample was to be collected, it was immediately taken from the first of two split-spoon samplers that were to be composited and placed in a laboratory-grade sample jar to prevent volatilization. A lithologic description of a portion of the remaining contents of the first split spoon and a portion of the second split spoon was recorded along with the results of the field screening for potential contamination. A detailed log was completed and maintained for each of the soil borings (Appendix A).

Initially, 2-in. diam split-barrel samplers were exclusively used for sampling but did not provide sample volumes large enough to satisfy sampling needs when <100% recovery was achieved. A field change order (Appendix A) was initiated and approved in accordance with ER/C-P1719 to allow use of both 2- and 3-in. diam samplers for the remainder of the investigation. Care was taken to ensure the same diameter sampler was used for both samples of a composite. In the event different diameter samplers were used for the same composited sample, equal volumes of homogenized sample were used from both samplers. Hand auger sample volumes were dictated by recovery and auger refusal.

After compositing the two 2-ft split spoons, the soil was again scanned for potential radiological contamination using a beta/gamma pancake meter and an alpha scintillation detector in accordance with SAIC Procedure FTP-451. Sample containers specified clean by the manufacturer in accordance with ESP-900, "Cleaning and Decontaminating Sample Containers and Sampling Devices," were filled, packaged, labeled, and shipped to the appropriate laboratory in accordance with ER/C-P2302IAD, "Sampling, Classifying, Packaging, Marking, Labeling, and Shipping for Analysis" through the K-25 and Y-12 Environmental Restoration Program. Sample custody was maintained from time of sampling until the samples were shipped according to ESP-500, "Manual Chain-of Custody Procedures."

Soil borings not converted to monitoring wells were backfilled with soil cuttings from the borehole to a depth of 6 to 2 ft below ground surface. The remaining borehole annulus was backfilled with a grout mixture consisting of Portland Type 1 cement with ~5% powdered bentonite having a bulk density of ~13.5 lb/gal. Soil borings located in Old Bear Creek Road at the SY-200 Yard (SB-55 through SB-61) were abandoned, using only the grout mixture to guard against subsidence in the newly repaved road. Soil cuttings that were not backfilled were spread around the borehole in the area of concern and in accordance with the BCV OU 2 Waste Management Plan.

All sampling locations established in the RI were surveyed by a registered civil surveyor to the nearest 0.01 ft. The data presented are for the final positions of the boreholes made after position adjustment because of drilling difficulties.

3.2.4.2 Soil evaluation methodologies

The COPCs in soil were determined using a method similar to that used for determining COPCs in groundwater (Sect. 3.2.3). The first-tier screen involved comparing the UCB median concentration values for each analyte at each site to the UCB median concentration for that analyte in background soil samples. For comparison of data, both current RI and historical data were used at RSA, only historical data were used at SA-1, and only current RI data were used at the SY-200 Yard.

Background levels for soil contamination comparisons were calculated by using the results of C-Horizon chemical analysis averaged from the Copper Ridge sample points from the ORR Background Soil Characterization Project (DOE 1993). This was based on the assumption that the three waste management areas included in BCV OU 2 are all fill areas. Background data cannot be determined to be completely representative of the fill because the origin of the fill is unknown. It is, however, assumed the fill was excavated from an area within the bounds of the ORR. Any significant excavation would penetrate the C-Horizon of the soil, which occurs on average between 0.6 and 0.8 m below ground surface; C-Horizon soils would constitute the bulk of the borrowed material volume due to the thin nature of Horizons A and B. The waste management areas are also located in the Copper Ridge soil district, and it is known that the top 5 ft of clean fill in the SY-200 Yard was borrowed from a Copper Ridge soil site. If the UCB median value of the analyte at a given site was found to exceed the UCB median value of the background soil samples, that analyte was considered to be a COPC.

Due to the large number of analytes that were identified as soil COPCs by the previously mentioned first-tier screenings, additional data comparisons were performed to limit the number of COPCs discussed in detail in the nature and extent of contamination sections to those that were regularly detected in soil at or above one or more benchmark values. These additional data comparisons include: (1) Because nondetects were set at half the detection limit for statistical purposes, situations occasionally arose in which the UCB median value was greater than the maximum concentration observed. In these cases, the maximum value was used for comparison to background. (2) If the analyte did not exceed the UCB median value of the background soil and the concentrations of the background soil were also below PRGs, then the analyte was dropped from further consideration.

The number of detects out of total samples was noted. If the analyte was detected in <5% of the samples, that analyte may be considered an outlier and dropped from further consideration. The COPC list was further refined by comparing the UCL of the mean value at the site to the PRG values. This comparison was done in tabular format (see Sects. 3.2.4.3–3.2.4.5), with the results of each comparison noted in the comment section. For example, Analyte A was detected in 1 out of 60 samples; it would be considered an outlier, regardless of the concentrations detected, and would be dropped from further discussion. However, analyte B was detected in 50 out of 60 samples. The site UCL was 180 ppm, and the PRG is 150 ppm. Thus, because analyte B occurs in >5% of the samples, it is not an outlier. It is above the PRG, and it was also determined to be a COPC in groundwater. The subjective decision made was that the analyte is of interest and further discussion of this contaminant in soil is therefore warranted.

3.2.4.3 SA-1

Subsurface soil samples were taken at SA-1 during previous investigation activities in August 1990 (SAIC 1993a) to define the nature and extent of soil contamination at SA-1. Samples were collected from six soil borings (Fig. 3.27) and analyzed for VOCs and SVOCs, inorganics (metals and cyanide), and radiological parameters (Table 3.21) by methods and limits presented in Table 3.6. Three of the borings were placed along the southern edge of SA-1, where the fill and debris were <15-ft deep. Two of the borings were placed along a diagonal traversing the center of the site. In these locations, the fill material and debris were 35- to 40-ft deep. The sixth boring was in the northeastern corner of the site, where the fill depth had again decreased to <15 ft.No split-spoon samples were taken at SA-1 during the 1993 RI because previous soil characterization at the site (August 1990) had covered the readily available portions of the site. However, soil cuttings were logged for lithology during the installation of two monitoring wells (GW-811 and -2) at the site (Fig. 3.28).

The cross section (Fig. 3.29) drawn along M-M′ (Fig. 3.30) represents the lithologic descriptions of the soil cuttings. Cuttings logged during the installation of the GW-811 borehole indicate that the main body of SA-1 site is underlain by a brown to reddish-brown clay with weathered chert fragments and contains a variety of fill material including wood fragments, nails, shale fragments, brick, particle board, concrete, metal fragments, and plastic. This fill material was observed to a depth of ~39 ft below ground surface where it graded into a red clay with weathered chert fragments and no evidence of debris. Augering to bedrock was complicated due to fill obstructions. Refusal occurred on Maynardville Limestone bedrock at 63.8 ft below ground surface. The soil/bedrock interface provides the only location of groundwater in the unconsolidated zone and is also associated with the seep that occurs on the bottom slope of SA-1 as described in Sect. 3.2.3. GW-812 was installed on the southeast flank of SA-1. This area is underlain by brown to reddish-brown clay with weathered chert fragments and oolitic chert fragments. No fill debris was encountered during the installation of this monitoring well. Refusal occurred on Maynardville Limestone bedrock at 44.9 ft below ground surface. Again, this interface provided the only groundwater in the unconsolidated section. Appendix A contains additional cross sections (K-K′ and L-L′) showing lithology at SA-1.

A comparison of historical sample data indicated 57 analytes were present in the SA-1 soils at levels above background. Fifteen of these analytes warranted further discussion. The nature and extent of contamination by these 15 COPCs analytes are presented in the following sections.

Metals. A comparison of analytical results of soil samples recovered from the SA-1 to background levels resulted in the identification of 17 metal COPCs. Six of the 17 metals are common constituents found in soil (Table 3.22). Beryllium is the only metal found in concentrations above PRGs. The following section describes the nature and extent of these metals.

Barium was detected in 44 of 44 samples taken in the SA-1 area. Barium was present in detectable concentrations in all borings from 4.5 ft below ground surface to the maximum depth of sampling, the deepest of which was 55.5 ft below ground surface at SA 1.4. The maximum concentration (385 ppm) was detected in the sample recovered from 4.5 to 6.0 ft

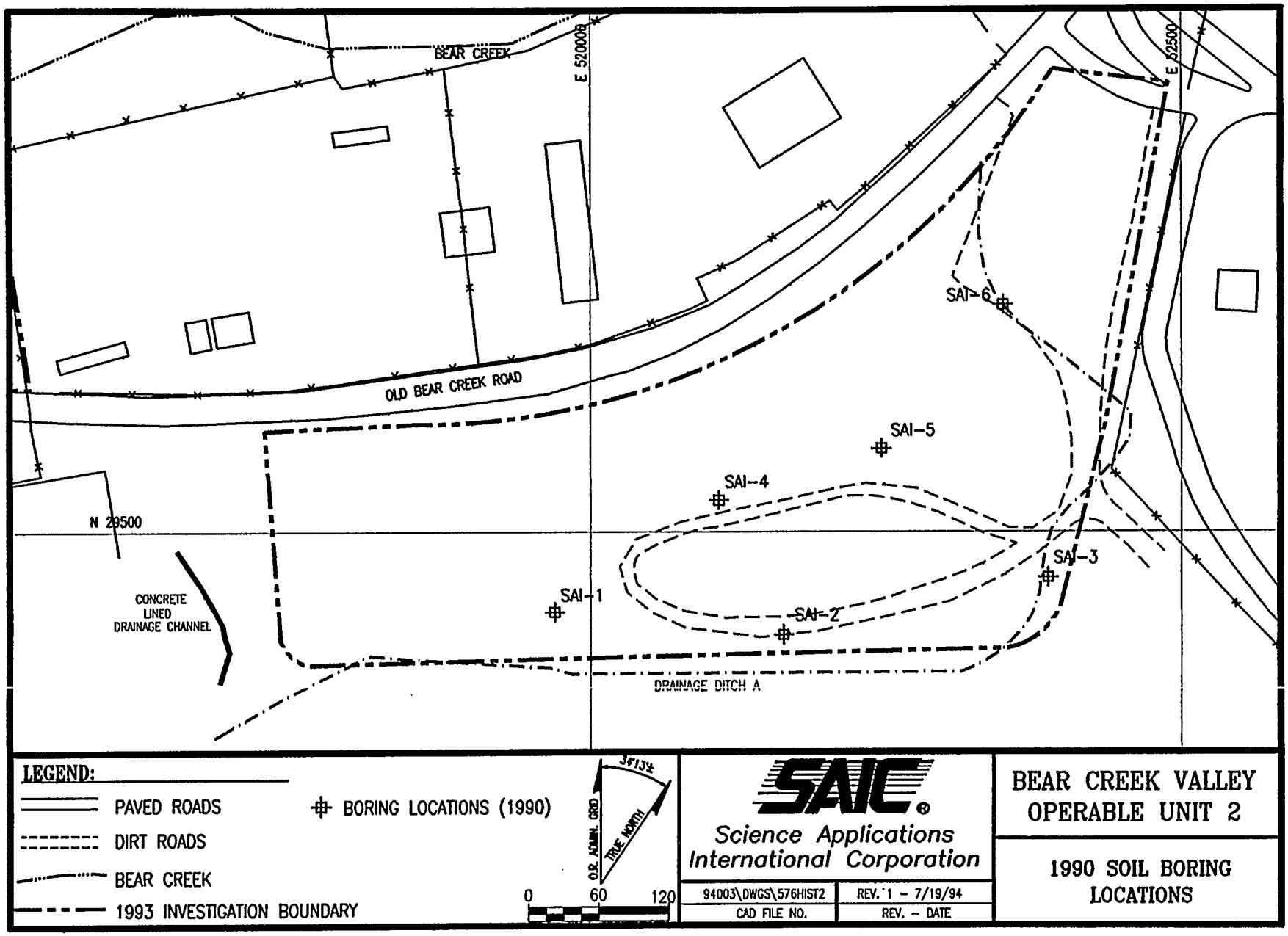


Fig. 3.27. SA-1 1990 soil boring locations at BCV OU 2.

Table 3.21. Analytical parameters for SA-1[a]

Soil boring	Volatile	SVOC; pesticide/PCB	Metals—cyanide	Asbestos	Radionuclides	PCB	Metal
SA1-1	X	X	X		X		
SA1-2	X	X	X		X		
SA1-3	X	X	X		X		
SA1-4	X	X	X		X		
SA1-5	X	X	X		X		
SA1-6	X	X	X		X		

[a] All SA-1 data are historical.

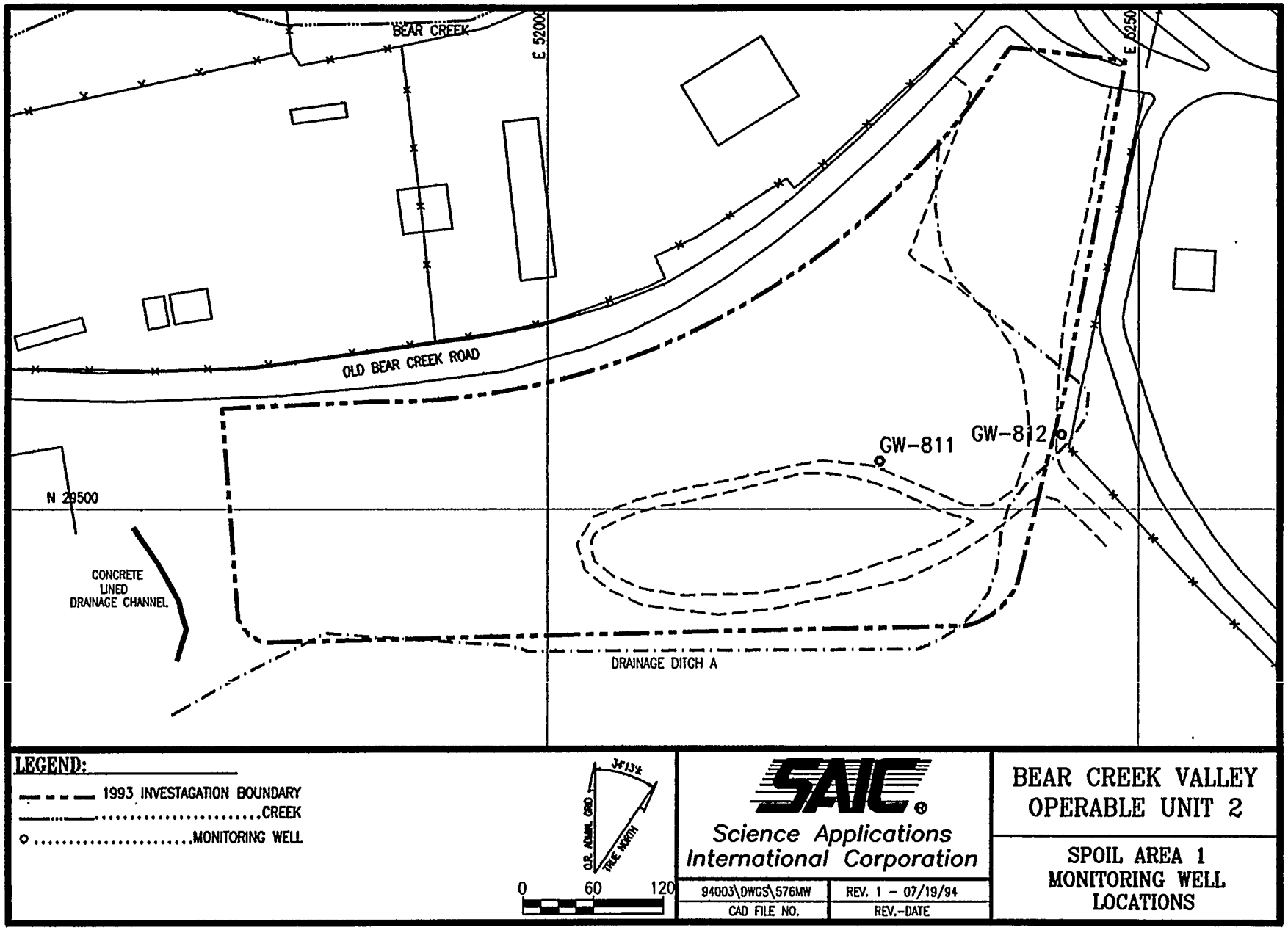


Fig. 3.28. Y-12 Plant BCV OU 2 SA-1.

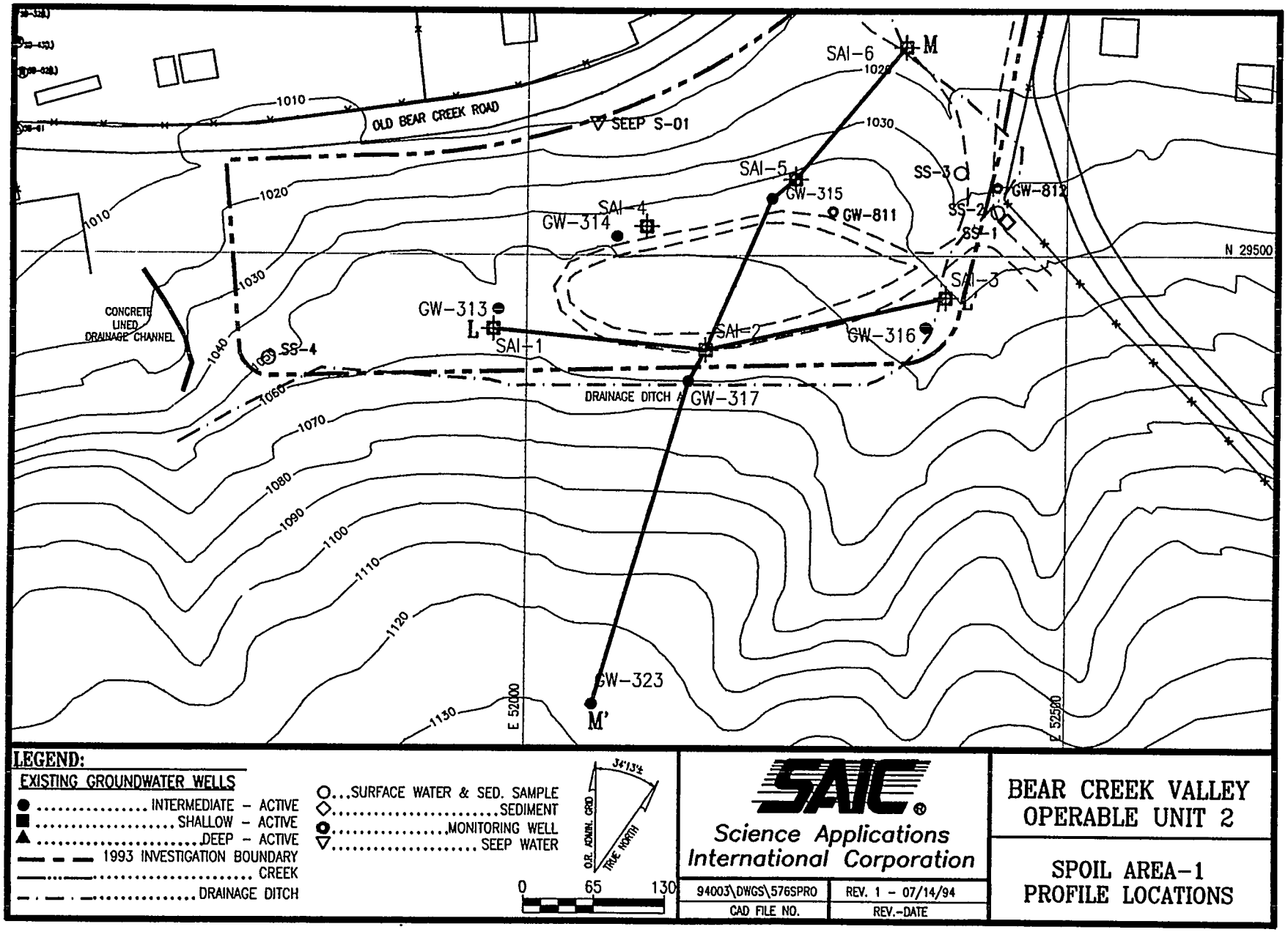


Fig. 3.29. SA-1 profile locations.

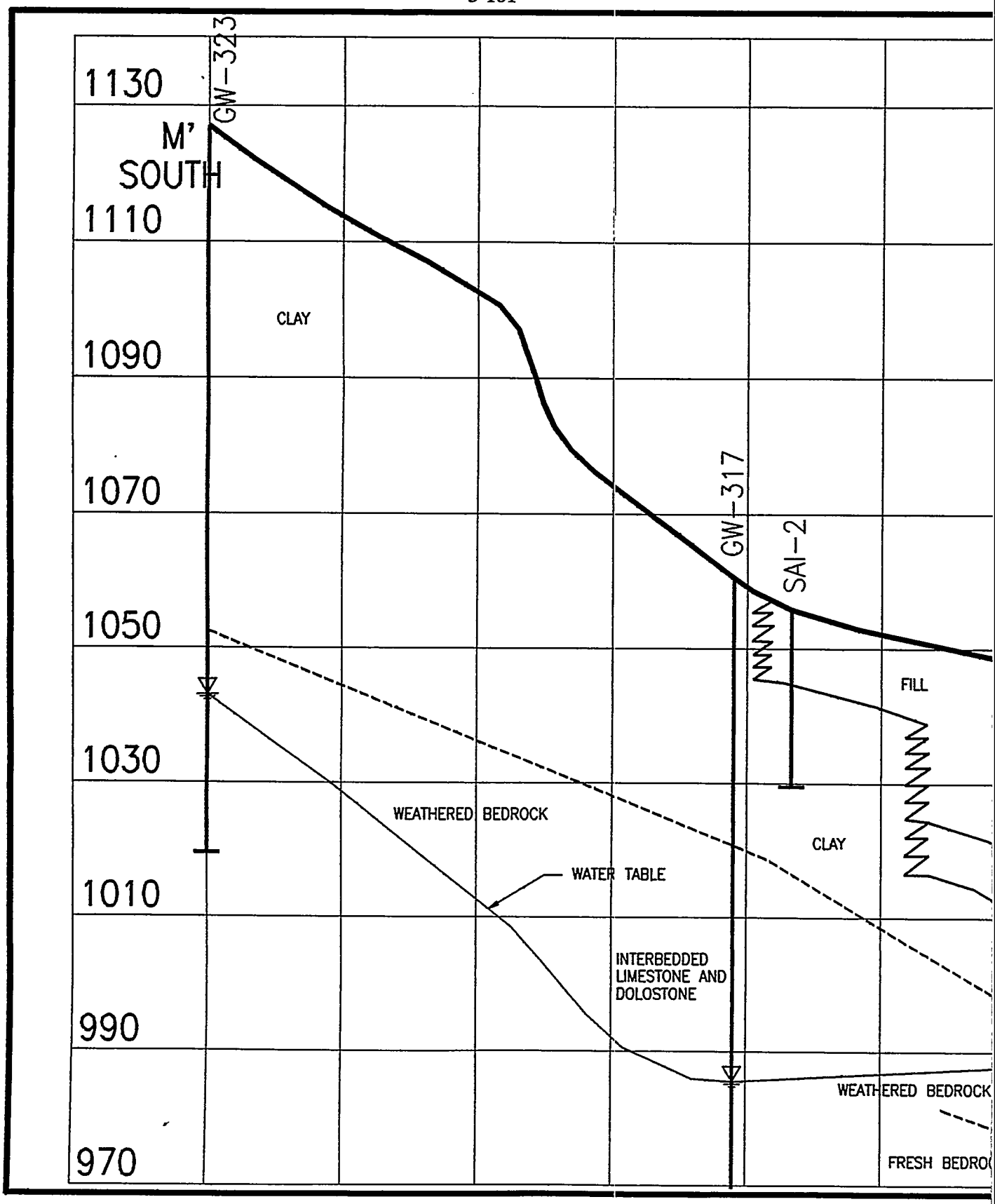
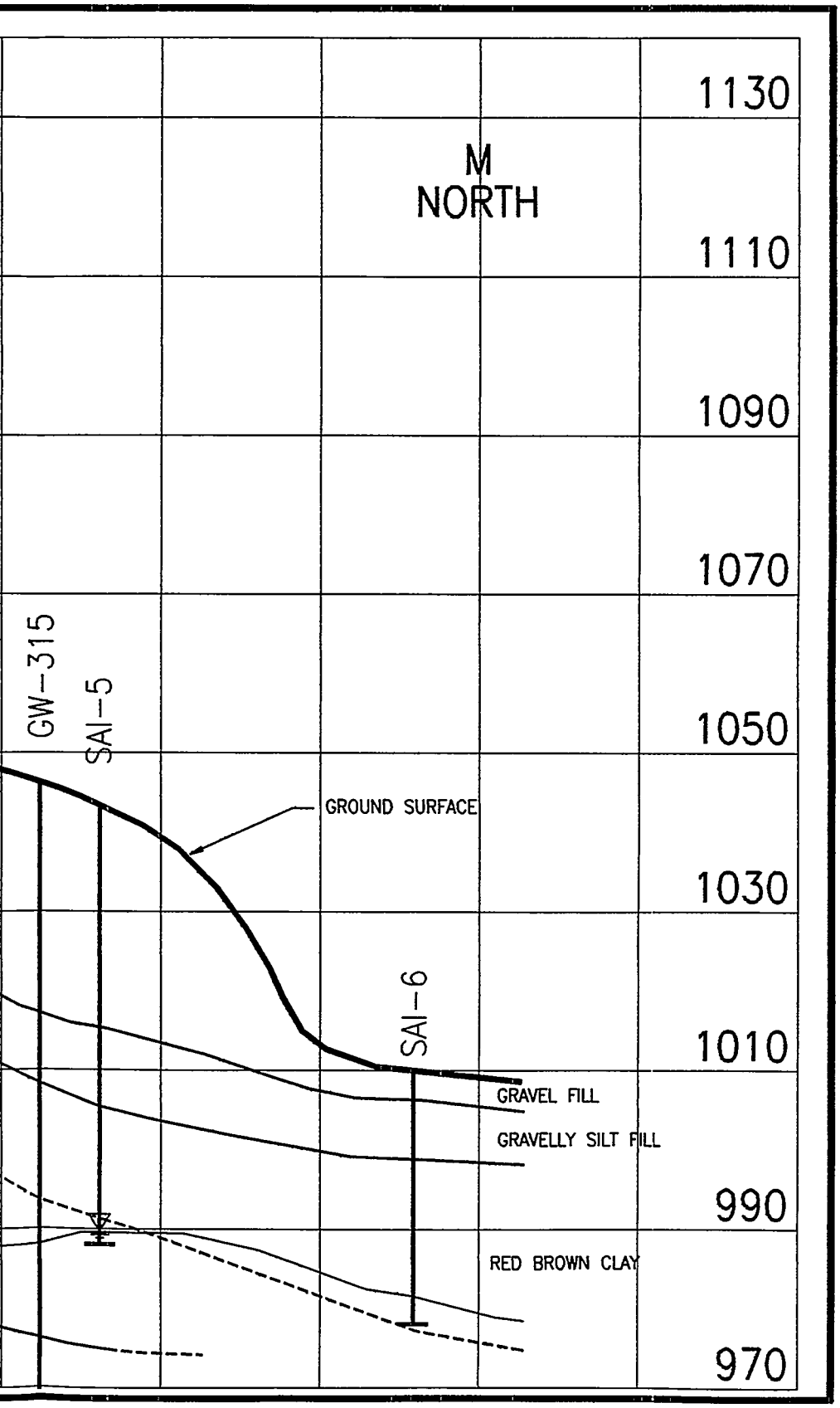


Fig. 3.30. SA-1 prof



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
.....GROUNDWATER TABLE

0 5 10 20 40
VERTICAL SCALE: 1" = 20'

0 40 80 160
HORIZONTAL SCALE: 1" = 80'

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BEAR CREEK VALLEY OU2
SPOIL AREA 1 PROFILE M-M'
SOIL LITHOLOGY

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	RODNEY BEELER	TIM COFFEY	04-14-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
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SHT 1 OF 3	/94003/DWGS/576PR011	N/A
DRAWING #	CAD FILE #	ROT. ANGLE

M-M′ soil lithology.

Table 3.22. Soil data summary for BCV OU 2 sites at SA-1, comparison to PRGs and soil background data[a]

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				Metals (mg/kg)					
Aluminum	1.4E+04	2.3E+04	3.4E+04	3.4E+03	6.2E+04	3.2E+04			E
Barium	9.1E+00	1.4E+01	2.1E+01	1.5E+01	3.9E+02	1.2E+02	1.9E+04 (TI)	0/44	B,F
Beryllium	6.2E-01	9.6E-01	2.0E+00	2.7E-01	1.1E+01	1.9E+00	1.5E-01 (CI)	43/44	A, B, F
Cadmium	ND[d]			1.1E+00	1.1E+01	4.4E+00	2.7E+02 (TI)	0/44	B, F
Calcium	1.5E+02	2.2E+02	4.6E+02	4.3E+01	1.0E+05	7.1E+04			B, E
Chromium	2.2E+01	3.6E+01	4.8E+01	6.4E+00	5.4E+01	3.1E+01	1.4E+03 (TI)	0/44	F
Cobalt	4.2E+00	4.2E+00	6.1E+01	3.4E+00	1.1E+02	3.5E+01			B, E, F
Copper	2.4E+01	3.6E+01	4.4E+01	1.3E+01	1.1E+02	5.1E+01			
Cyanide	ND[d]			1.1E+00	2.6E+00	7.5E-01	5.5E+03 (TI)	0/44	C
Lead	3.1E+01	3.9E+01	4.2E+01	6.5E+00	3.4E+02	1.3E+02			B
Magnesium	3.4E+02	7.2E+02	1.4E+03	5.3E+02	2.5E+04	1.3E+05			D, E
Manganese	8.5E+01	1.1E+02	1.1E+02	1.3E+02	6.9E+03	1.6E+03	3.8E+04 (TI)	0/44	B, F
Mercury	1.5E-01	3.0E-01	7.2E-01	5.0E-02	3.2E+01	1.9E+00	8.2E+01 (TI)	0/44	F
Nickel	1.3E+01	2.1E+01	2.7E+01	4.7E+00	1.7E+02	4.9E+01	5.5E+03 (TI)	0/44	
Niobium	ND[d]			1.8E+00	3.3E+00	1.1E+00			B
Potassium	6.1E+02	1.0E+03	1.5E+03	4.1E+02	5.4E+03	3.0E+03			B, E

Table 3.22 (continued)

Compound	Background Minimum[b]	Background Maximum[b]	Background UCL[c]	Site Minimum[b]	Site Maximum[b]	Site UCL	PRG	No. detects >PRG	Comments
				SVOCs (ppb)					
2-Methylnaphthalene				9.8E+01	9.8E+01	4.4E+02			C
Acenaphthene				7.9E+01	4.1E+02	4.1E+02	1.6E+07 (TI)	0/44	D
Acenaphthylene				1.1E+02	1.1E+02	4.4E+02			C, D
Anthracene				2.0E+02	8.5E+02	3.8E+02	8.2E+07 (TI)	0/44	
Benzo(a)anthracene				2.0E+02	1.7E+03	4.2E+02	8.8E+02 (CI)	2/44	F
Benzo(a)pyrene				1.5E+02	1.3E+03	4.0E+02	8.8E+01 (CI)	10/44	F
Benzo(b)fluoranthene				1.6E+02	1.4E+03	4.1E+02	8.8E+02 (CI)	2/44	
Benzo(ghi)perylene				1.2E+02	8.0E+02	3.8E+02			F
Benzo(k)fluoranthene				2.0E+02	1.4E+03	4.3E+02	8.8E+03 (CI)	0/44	F
Benzoicacid				5.5E+01	5.5E+01	2.5E+03	1.1E+06 (TI	0/44	C, D
Bis(2-ethylhexyl)phthalate				4.6E+02	8.9E+02	5.9E+02	4.6E+04 (CI)	0/44	C, D
Butylbenzylphthalate				6.9E+01	6.9E+01	4.5E+02	5.5E+07 (TI)	0/44	
Chrysene				2.6E+02	1.7E+03	4.2E+02	8.8E+04 (CI)	0/44	B
Dibenzofuran				2.4E+02	2.5E+02	4.3E+02			C, D, F
Diethyl Phthalate				7.7E+01	7.7E+01	4.5E+02	2.2E+08 (TI)	0/44	C, D
Dimethyl Phthalate				6.4E+01	6.4E+01	4.5E+02	2.7E+09 (TI)	0/44	C, D
Fluoranthene				7.0E+01	4.1E+03	6.8E+02	1.1E+07 (TI)	0/44	
Fluorene				1.8E+02	4.5E+02	3.7E+02	1.1E+07 (TI)	0/44	

Table 3.22 (continued)

Compound	Background Minimum[b]	Background Maximum[b]	Background UCL[c]	Site Minimum[b]	Site Maximum[b]	Site UCL	PRG	No. detects >PRG	Comments
Indeno(1,2,3-cd)pyrene				9.9E+01	7.7E+02	3.8E+02			F
Naphthalene				1.2E+02	2.1E+02	4.3E+02			C, D, F
Phenanthrene				5.9E+01	3.6E+03	5.6E+02			F
Pyrene				5.5E+01	3.1E+03	5.8E+02	8.2E+06 (TI)	0/44	
				VOCs (µg/kg)					
1,1-Dichloroethane				7.0E+00	7.0E+00	3.5E+00	2.7E+07 (TI)	0/44	C
1,2-Dichloroethene (total)				2.0E+00	2.0E+00	3.4E+00	2.5E+06 (CI)	0/44	B, C, D
2-Butanone				1.0E+00	1.1E+01	7.9E+00	1.6E+08 (TI)	0/36	
4-Methyl-2-pentanone				2.0E+00	1.2E+01	7.2E+00	1.4E+07 (TI)	0/44	B, C
Acetone				6.0E+00	2.2E+02	1.4E+01	2.7E+07 (TI)	0/44	B
Benzene				2.0E+00	2.0E+00	3.4E+00	2.2E+04 (CI)	0/44	C, D
Carbon disulfide				3.0E+00	3.0E+00	3.4E+00	2.7E+07 (TI)	0/44	B, C, D
Chloroform				1.0E+00	2.0E+00	3.3E+00	1.0E+05 (CI)	0/44	B, D
Methylene chloride				2.0E+00	2.0E+00	4.4E+00	8.5E+04 (CI)	0/44	B, D
Tetrachloroethene				1.0E+00	6.0E+00	3.6E+00	2.7E+06 (TI)	0/44	B
Toluene				1.0E+00	4.0E+00	3.4E+00	5.5E+07 (TI)	0/44	C
Xylene (total)				2.0E+00	8.0E+00	3.6E+00	5.5E+08 (TI)		

Table 3.22 (continued)

Compound	Background Minimum[b]	Background Maximum[b]	Background UCL[c]	Site Minimum[b]	Site Maximum[b]	Site UCL	PRG	No. detects >PRG	Comments
				Other Analyses (mg/kg)					
Phosphorus				4.9E+01	7.2E+02	2.3E+02	5.5E+00	23/44	
Total uranium				2.0E+00	8.0E+01	1.0E+01	8.2E+02	0/44	B
				Radionuclides (pCi/g)					
Gross alpha	NA			2.1E+00	1.2E+01	5.4E+00			B
Gross beta	NA			4.2E+00	3.7E+01	2.0E+01			
Total radium				9.7E-01	7.6E+00	4.0E+00			
^{235}U	1.2E-01	3.5E-01	1.2E+00	9.4E-02	1.1E-01	[e]	1.7E-01	0/2	B
^{235}U (Wt %)	NA			2.9E-01	1.0E+00	8.2E-01			

[a] Generated by program PRGMERG.SAS on 20 Apr 94. Background data are for Copper Ridge Horizon C from the ORR Background Soil Characterization Project, DOE 1993a.
[b] Minima and maxima represent actual detected values.
[c] Upper 95% Confidence Limit (UCL) for the mean, calculated assuming a lognormal distribution unless the data fit a normal distribution.
[d] Not detected in the background soil study.
[e] Insufficient data to calculate UCL.
A = Over PRG
B = Analyte is COPC in groundwater
C = Outlier
D = UCL >maximum
E = Essential nutrient
F = Potential human health concern
PRGs are residential (TI) Toxic Ingestion or (CI) Carcinogenic Ingestion

below ground surface in SA 1.4. All samples were above the background range but no sample had concentrations above the (19,000 ppm) PRG and, therefore, are not considered to be environmentally significant.

Beryllium was found in 43 of 44 samples recovered from the SA-1; all were above the 0.15 ppm PRG. The maximum concentration of beryllium (11 ppm) was detected in borehole SA 1.1 at the sample interval 54 to 55.5 ft below ground surface (Fig. 3.31). Beryllium concentrations are relatively continuous from the ground surface to the maximum penetration depth of all the boreholes. Beryllium levels are roughly background levels with 31 of the 43 detected levels of beryllium within 0.5 ppm of the background range. The higher values were consistently detected in samples recovered from the bottom intervals of the boreholes where fill native material boundary occurs. Higher values are within the native clay.

Beryllium concentration isoline maps indicate a trend of increasing concentrations with depth over the entire site (Appendix A.). This is evidenced by a decrease in area with below background concentrations. Additional cross-sectional views (K-K′ and L-L′) (Appendix A) indicate isolated zones of elevated concentrations.

Cadmium, cobalt and mercury were detected in 43 of 44 samples. These analytes were detected in all soil borings from the surface to the maximum borehole depth. The maximum cadmium concentration (10.9 ppm) was detected in SA-1.4 at 54 to 55.5 ft below ground surface; cobalt (110 ppm) at 39 to 40.5 ft below ground surface in SA1.1; and mercury (31.5 ppm) at 19.5 to 21 ft below ground surface in SA-1.5. Detected levels for cadmium and mercury were not above PRGs. Background levels of cadmium were not available for any soil horizon or location. A PRG was not available for comparison of cobalt though levels were roughly background (Table 3.22) and was not considered significant.

Chromium was detected in every borehole and at every sample interval. The site maximum concentration (54.2 ppm) was detected in the sample recovered from 4.5 to 7.5 ft below ground surface of SA-1.4. The 95% UCL for the site was in the range of the background results and is not present in significant concentrations. All detected levels of chromium were two orders of magnitude below the PRG of 1.4E+03 ppm.

Manganese was also detected in every sample interval in every borehole. The maximum concentration (6930 ppm) was detected from 39 to 40.5 ft below ground surface of SA-1.4 and significantly below the 38,000 ppm PRG. The site UCL for manganese was slightly above the maximum background level (Table 3.22). In addition, manganese is a common constituent found in soils and bedrock throughout the ORR and is not environmentally significant.

SVOCs. Comparison of historical data to background levels resulted in 22 SVOCs being identified as COPCs. Benzo(a)anthracene, benzo(a)pyrene, and benzo(b)fluoranthene, however, were the only SVOCs with concentrations exceeding their respective PRGs.

Benzo(a)pyrene exceeded the PRG in 10 of 44 samples. Vertical and lateral distribution of benzo(a)pyrene contamination shown in cross section (Fig. 3.32) was sporadic in isolated areas of elevated concentrations and considered to be representative of the polyaromatic hydrocarbons. The maximum concentration of benzo(a)pyrene (1300 ppb) was detected in the sample recovered from 34.5 to 37.5 ft below ground surface of SA.1.4. Other polyaromatic hydrocarbons maxima were found in the same interval.

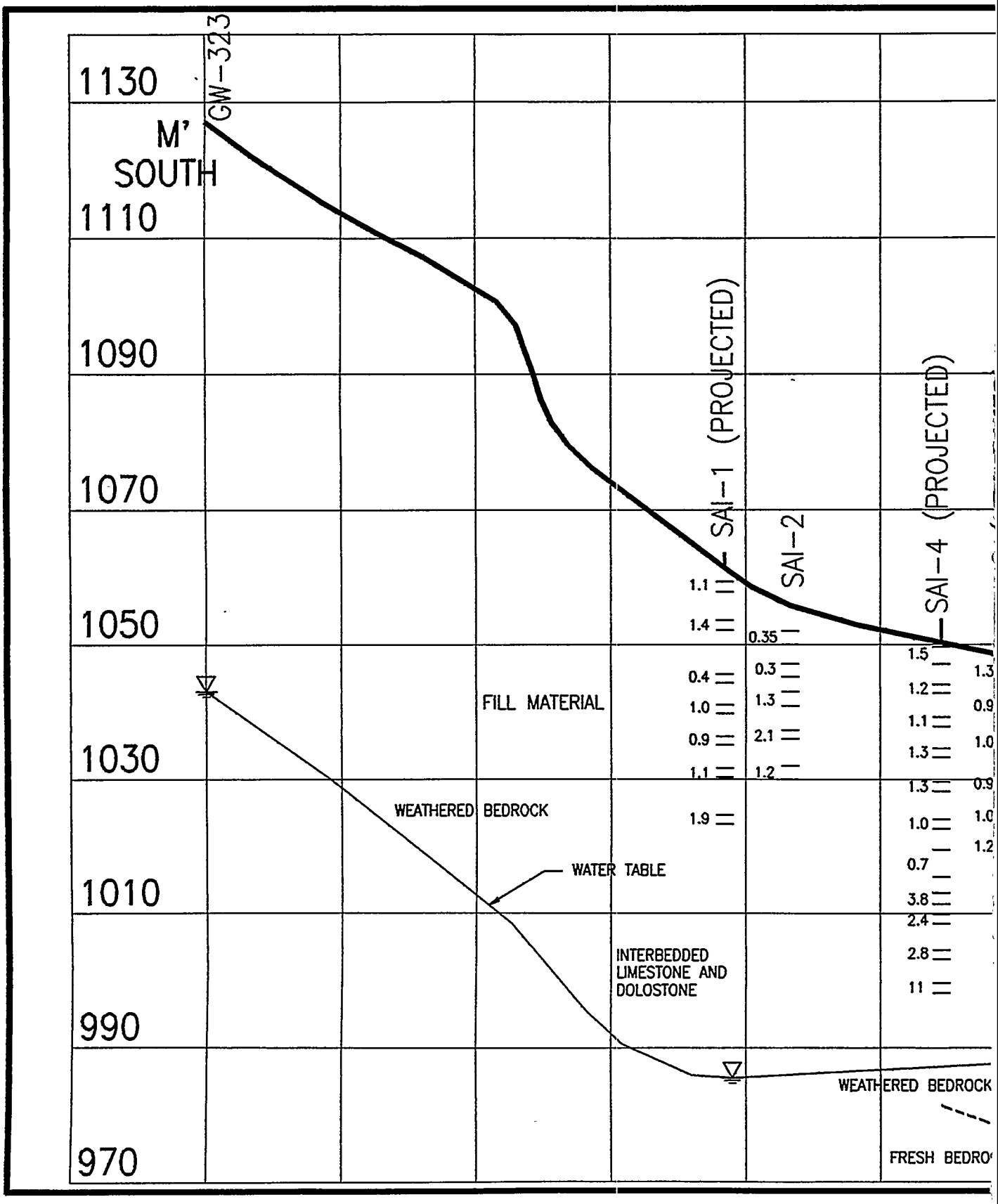
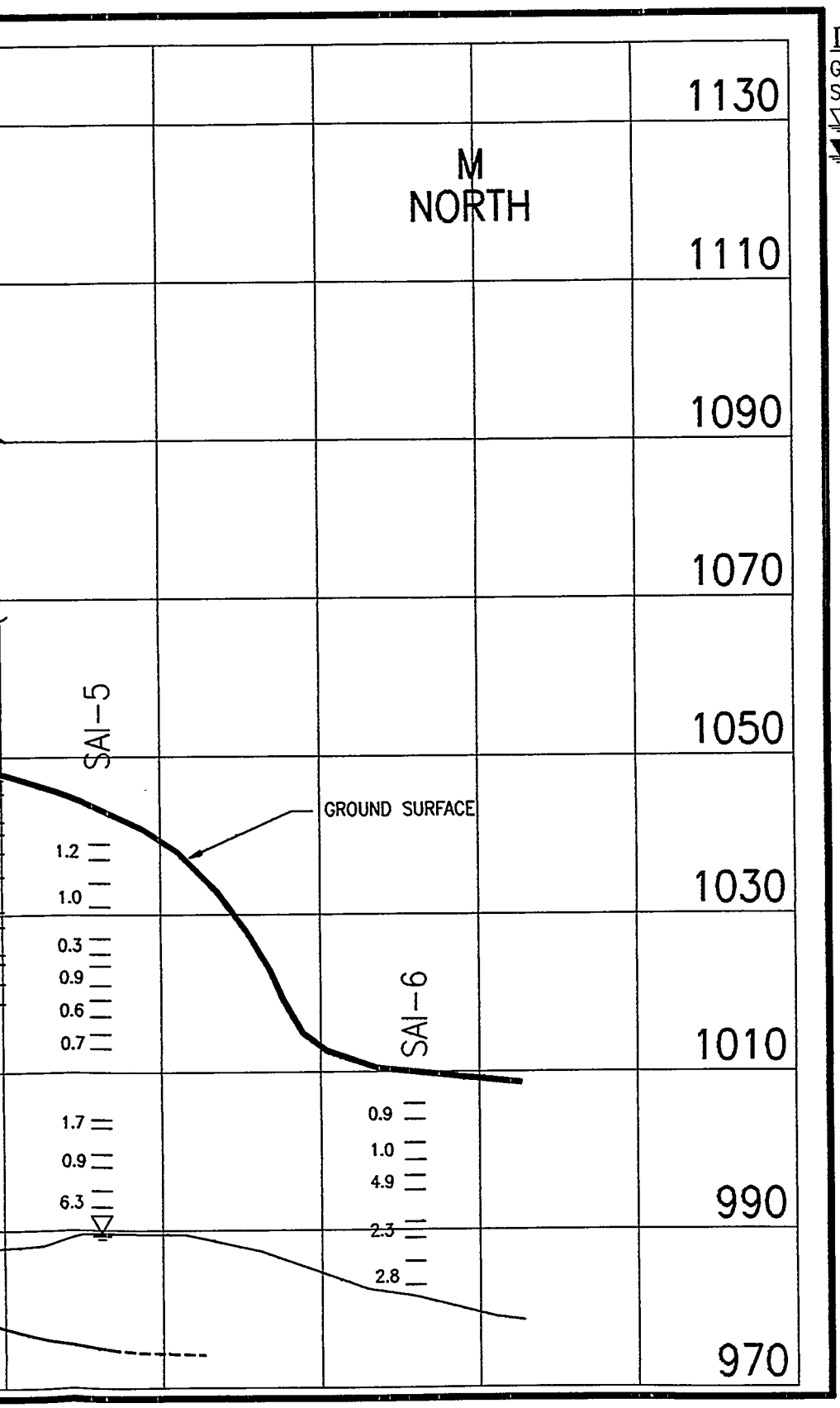


Fig. 3.31. SA-1 profil



LEGEND:

GW.....MONITORING WELL
SB.....SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE
▼.....GROUNDWATER TABLE

0 5 10 20 40
VERTICAL SCALE: 1" = 20'

0 40 80 160
HORIZONTAL SCALE: 1" = 80'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SPOIL AREA 1 PROFILE M-M'
BERYLLIUM (ppm)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	RODNEY BEELER	KEN SWAIN	04-22-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
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SHT 3 OF 4 (DRAWING #) | /94003/DWGS/667PROM (CAD FILE #) | N/A (ROT. ANGLE)

M-M' beryllium (ppm).

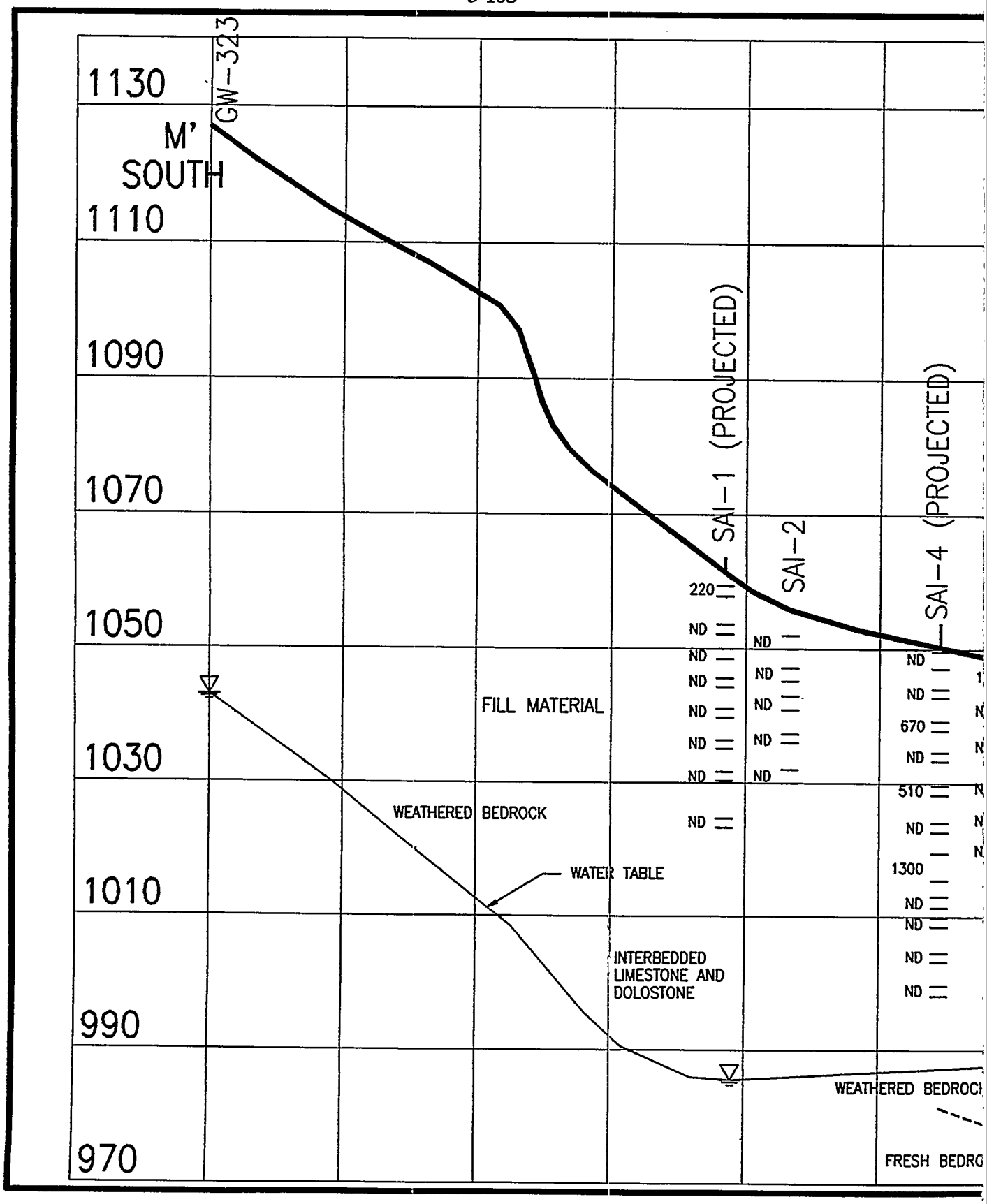
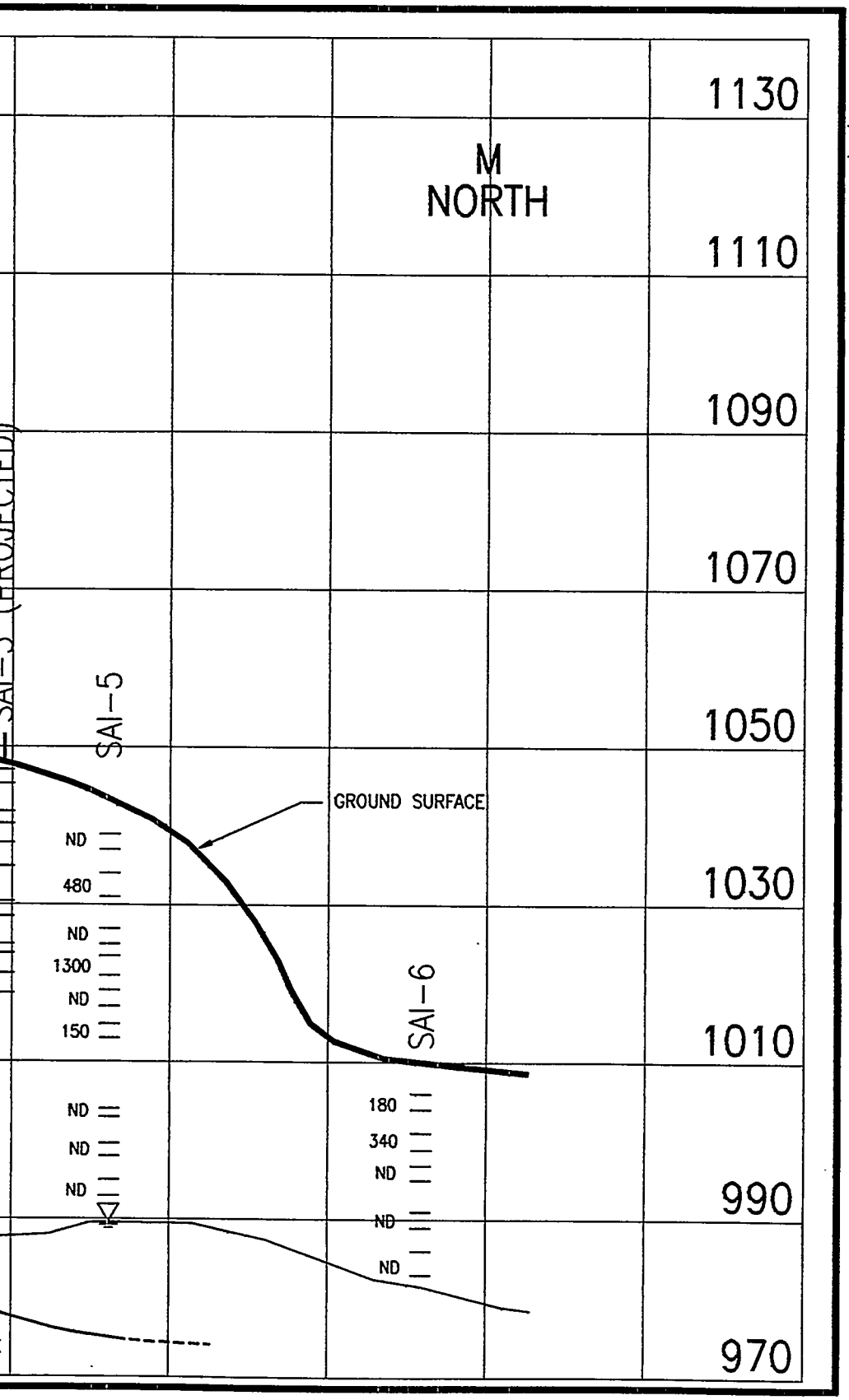


Fig. 3.32. SA-1 profile l



LEGEND:

GW.....MONITORING WELL
SB.....SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE
▼.....GROUNDWATER TABLE

0 5 10 20 40
VERTICAL SCALE: 1" = 20'

0 40 80 160
HORIZONTAL SCALE: 1" = 80'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SPOIL AREA 1 PROFILE M-M'
BENZO (A) PYRENE (ppb)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	RODNEY BEELER	KEN SWAIN	04-22-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
	/94003/PLOT/667PROM1.PLT /94003/PLOT/667PROM2.PLT /94003/PLOT/667PROM3.PLT /94003/PLOT/665PROM4.PLT

SHT 2 OF 4 (DRAWING #) | /94003/DWGS/667PROM (CAD FILE #) | N/A (ROT. ANGLE)

M' benzo(a)pyrene (ppb).

The background concentrations for Copper Ridge ORR Horizon C are not available for benzo(a)pyrene but data do exist for other Copper Ridge sample sites and horizons. The minimum concentration detected in the SA-1 (150 ppb) was significantly higher than the 95% UCB of all Copper Ridge sampling sites (DOE/OR/01-1175/V3; ES/ER/TM-84/V3) of 3.54 ppb.

Radionuclides. Six radionuclides were identified as COPCs by comparing analytical results of historical samples to background levels.

Total radium was detected in all soil borings with boring maximum concentrations ranging from 1.0 to 7.6 pCi/g at depths from 9.0 to 42.5 ft below ground surface. Calculations using isotopic masses suggest a very high percentage of total radium is ^{226}Ra. It is assumed all radium is ^{226}Ra for the purpose of comparison to background concentrations. Contamination isoline maps presented in Appendix A for radium show a shift from highs located in the central area of the SA-1 at depths of 0-12 ft to highs located in the northeast corner of the site in deeper intervals. A cross-sectional view of the area (Fig. 3.33) shows the estimated vertical extent of contamination to surpass the deepest points of sampling. Cross-sectional views of areas greater than the 6.9×10^{-3} pCi/g PRG clearly show high concentrations to maximum borehole depths and the entire subsurface area defined by the sampling points is above the 6.9×10^{-3} pCi/g PRG (Appendix A). The vertical extent of radium concentration is therefore not fully defined.

Background data for radium for Copper Ridge ORR C-Horizon soil do not exist. Ninety-five percent UCB values for ^{226}Ra for other sampling areas of Knox, Chickamauga, and Conasauga group soils for Horizon-C range from 0.860 to 1.44 pCi/g. Maximum radium concentrations for SA-1 are approximately regional background.

Total Uranium. Total uranium was detected in all the boreholes and all intervals above the detection limits. Concentrations were, however, below the PRG for all samples. Total uranium background values do not exist for the Copper Ridge ORR C-Horizon soils but the Conasauga C-Horizon soils, in general, have a 95% UCB of 1.65 pCi/g. Total uranium concentrations for the SA-1 are roughly background except for the isolated detects in SA 1.5 and SA 1.6 which are an order of magnitude higher than background (Fig. 3.34).

3.2.4.4 SY-200 Yard

Previous soil sampling at the SY-200 Yard has consisted of three sampling events: July 1986, January 1988, and January 1989. The first sampling event was initiated to investigate possible surface contamination from the storage of lead shielding plates and transformers at the SY-200 Yard. The subsequent sampling events were conducted to identify possible contaminants in the soil in the area proposed for construction of the ESF building.

Six samples were collected on July 3, 1986 (Energy Systems 1989). Three surface samples (EP-1, -2, and -3) were collected from the lead shielding storage areas and one composite surface sample and two soil samples from depths of 2 to 4 in. were collected from the oil-stained area where the transformers were stored. Sample points are shown on Fig. 3.35. Samples collected from the lead shielding storage areas were analyzed for mercury and EP toxicity metals. Samples from the transformer storage area were analyzed for mercury and PCBs. PCB concentrations detected in these samples ranged from 2.8 to 32 ppm. Mercury concentrations in these samples ranged from 3.8 ppm in the composite surface sample to 17,000 ppm in EP-3.

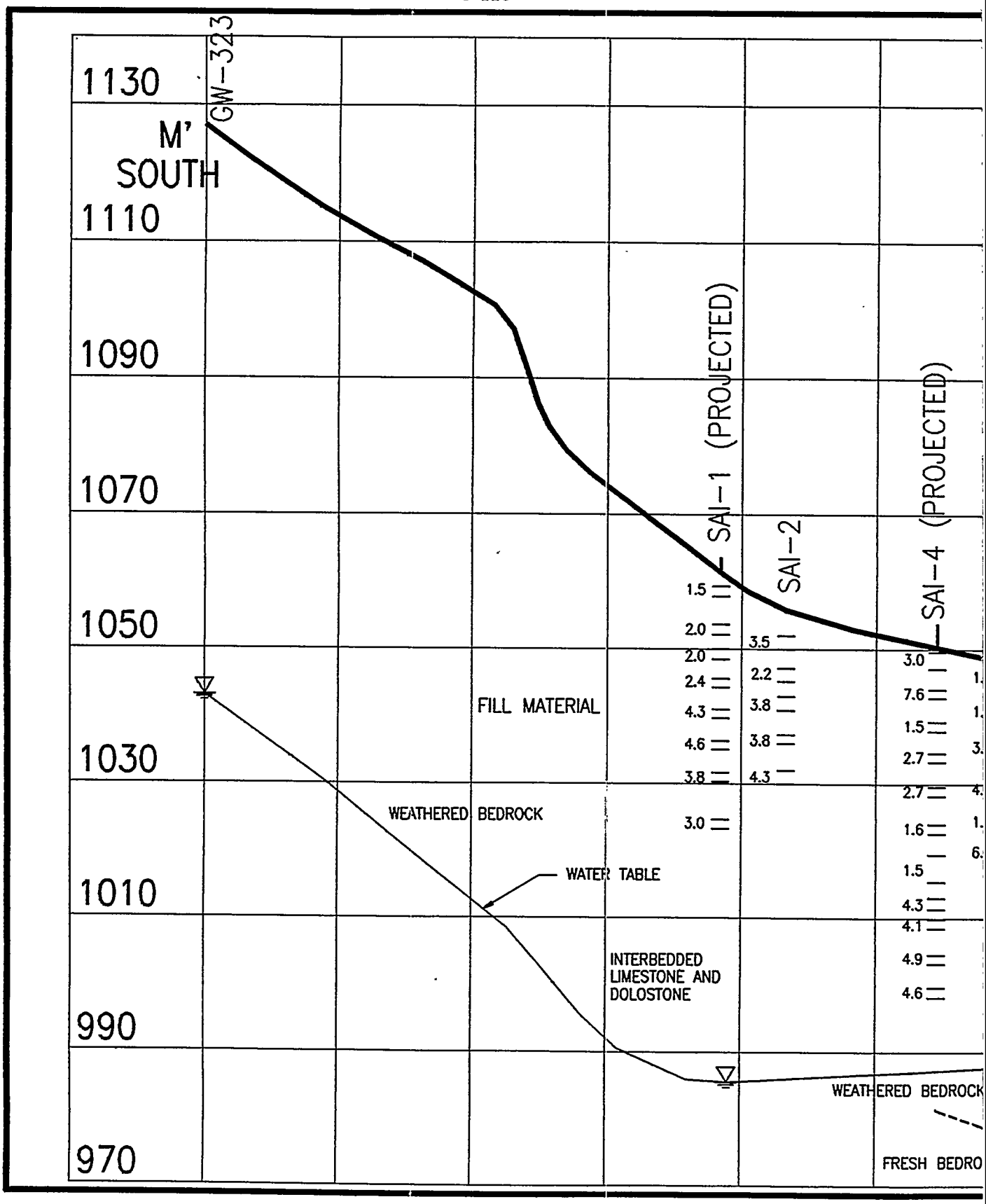
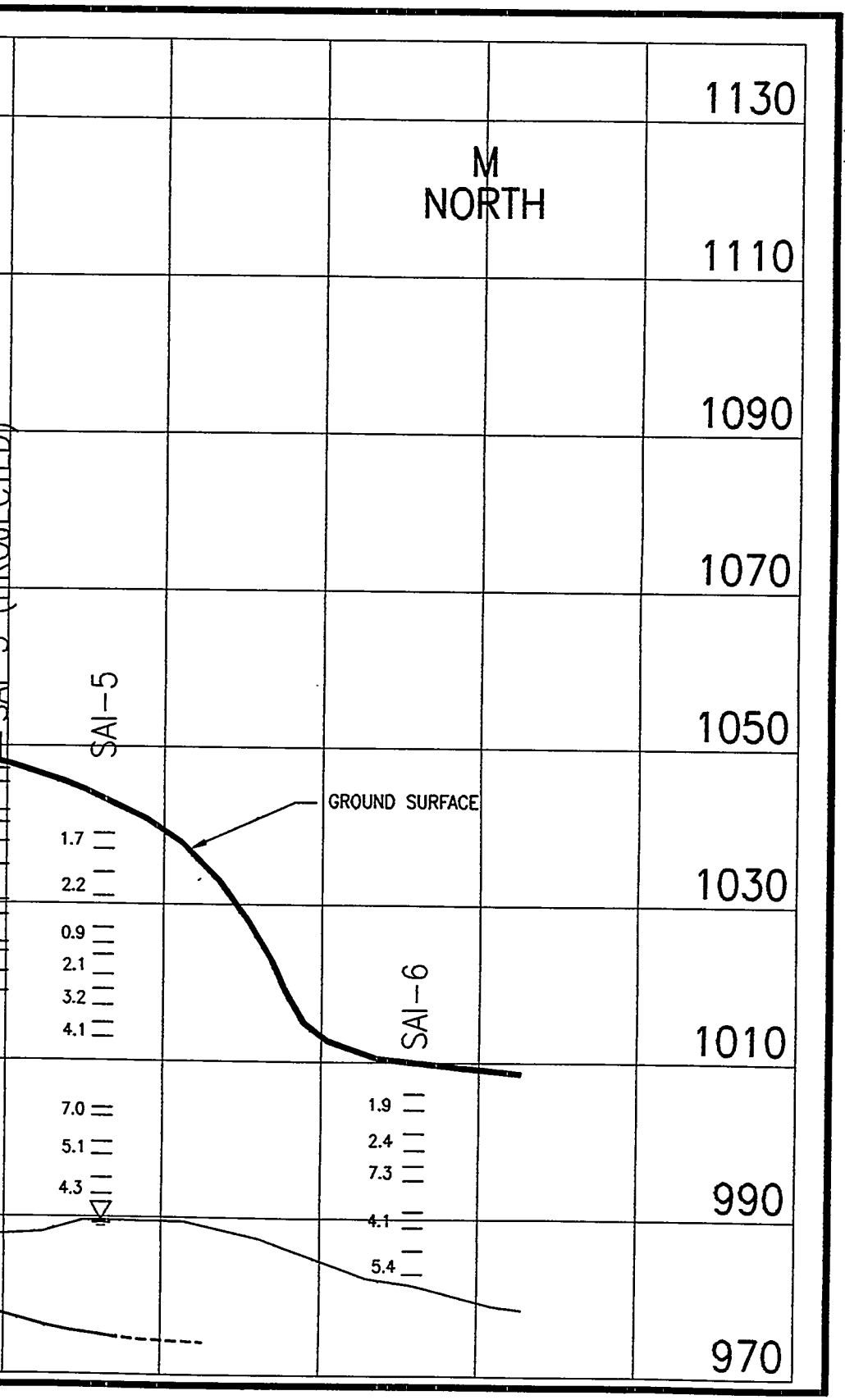


Fig. 3.33. SA-1 prof



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
.....GROUNDWATER TABLE

0 5 10 20 40
VERTICAL SCALE: 1" = 20'

0 40 80 160
HORIZONTAL SCALE: 1" = 80'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SPOIL AREA 1 PROFILE M-M'
RADIUM (pCi/g)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	RODNEY BEELER	KEN SWAIN	04-22-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
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SHT 4 OF 4 DRAWING # | /94003/DWGS/667PROM CAD FILE # | N/A ROT. ANGLE

M-M′ radium (pCi/g).

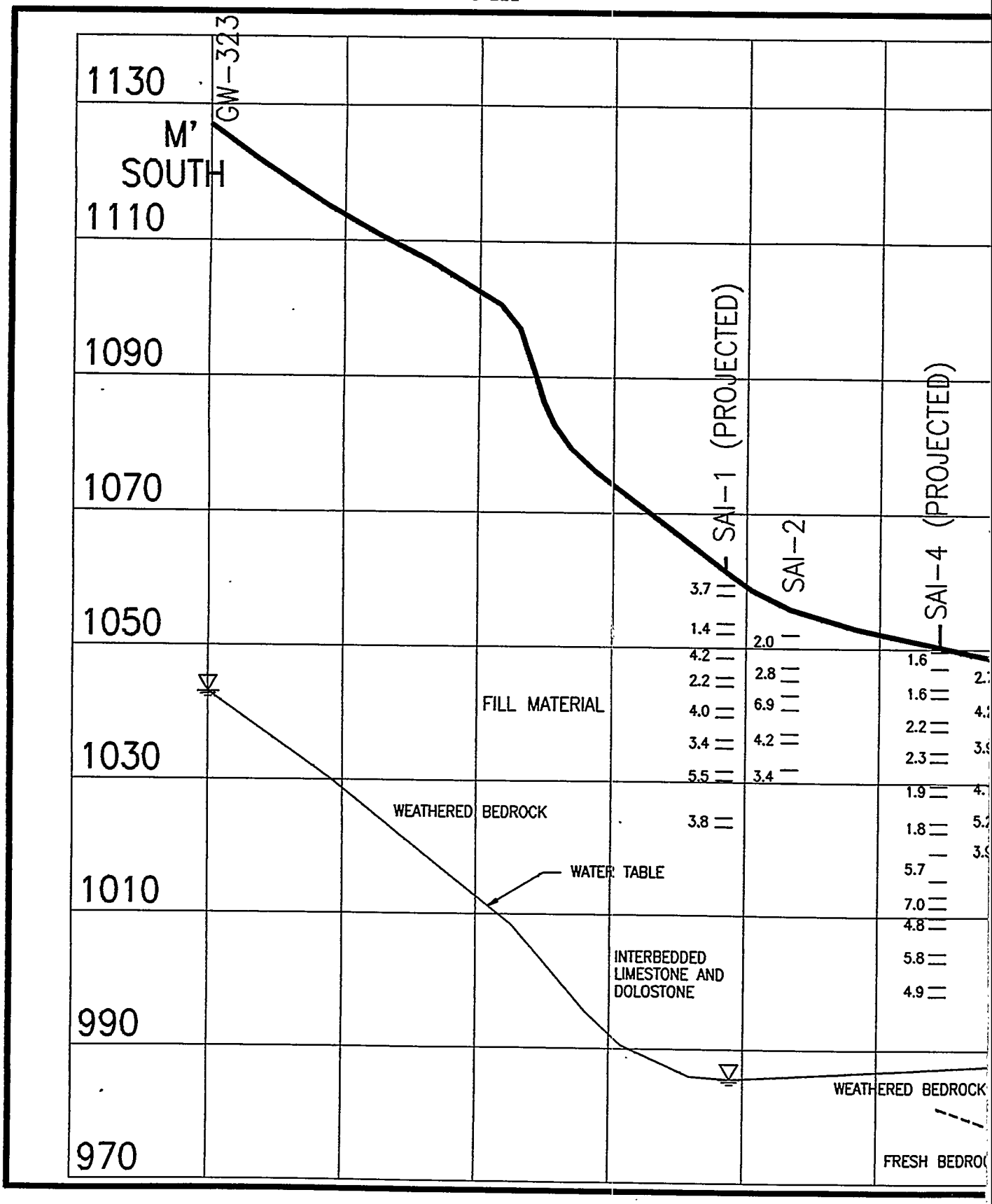
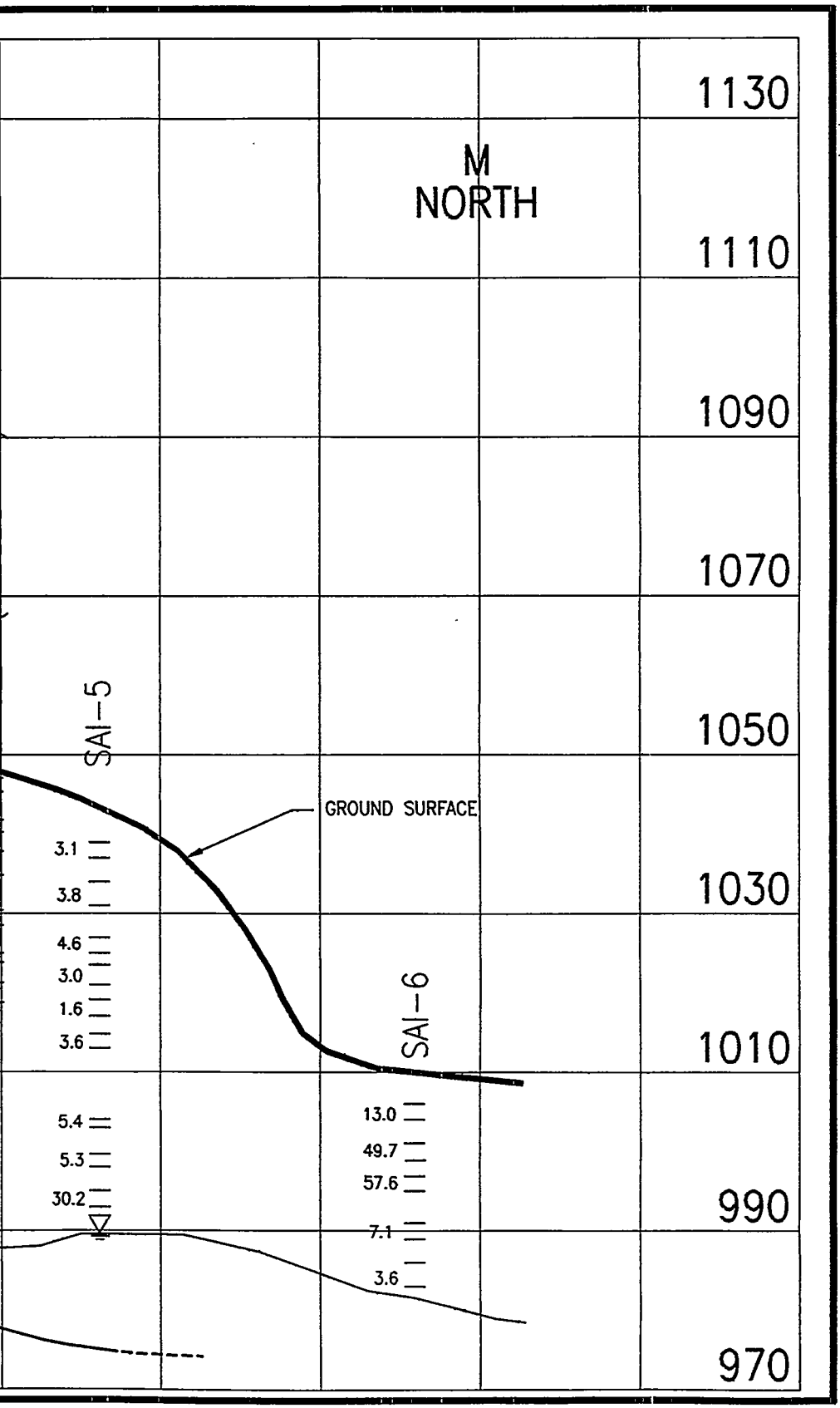


Fig. 3.34. SA-1 profile M



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
.....GROUNDWATER TABLE

0 5 10 20 40
VERTICAL SCALE: 1" = 20'

0 40 80 160
HORIZONTAL SCALE: 1" = 80'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SPOIL AREA 1 PROFILE M-M'
TOTAL URANIUM (pCi/g)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	ROONEY BEELER	KEN SWAIN	04-22-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
	*/94003/PLOT/667PROM1.PLT /94003/PLOT/667PROM2.PLT /94003/PLOT/667PROM3.PLT /94003/PLOT/665PROM4.PLT

SHT 1 OF 4 (DRAWING #) | /94003/DWGS/667PROM (CAD FILE #) | N/A (ROT. ANGLE)

M' total uranium (pCi/g).

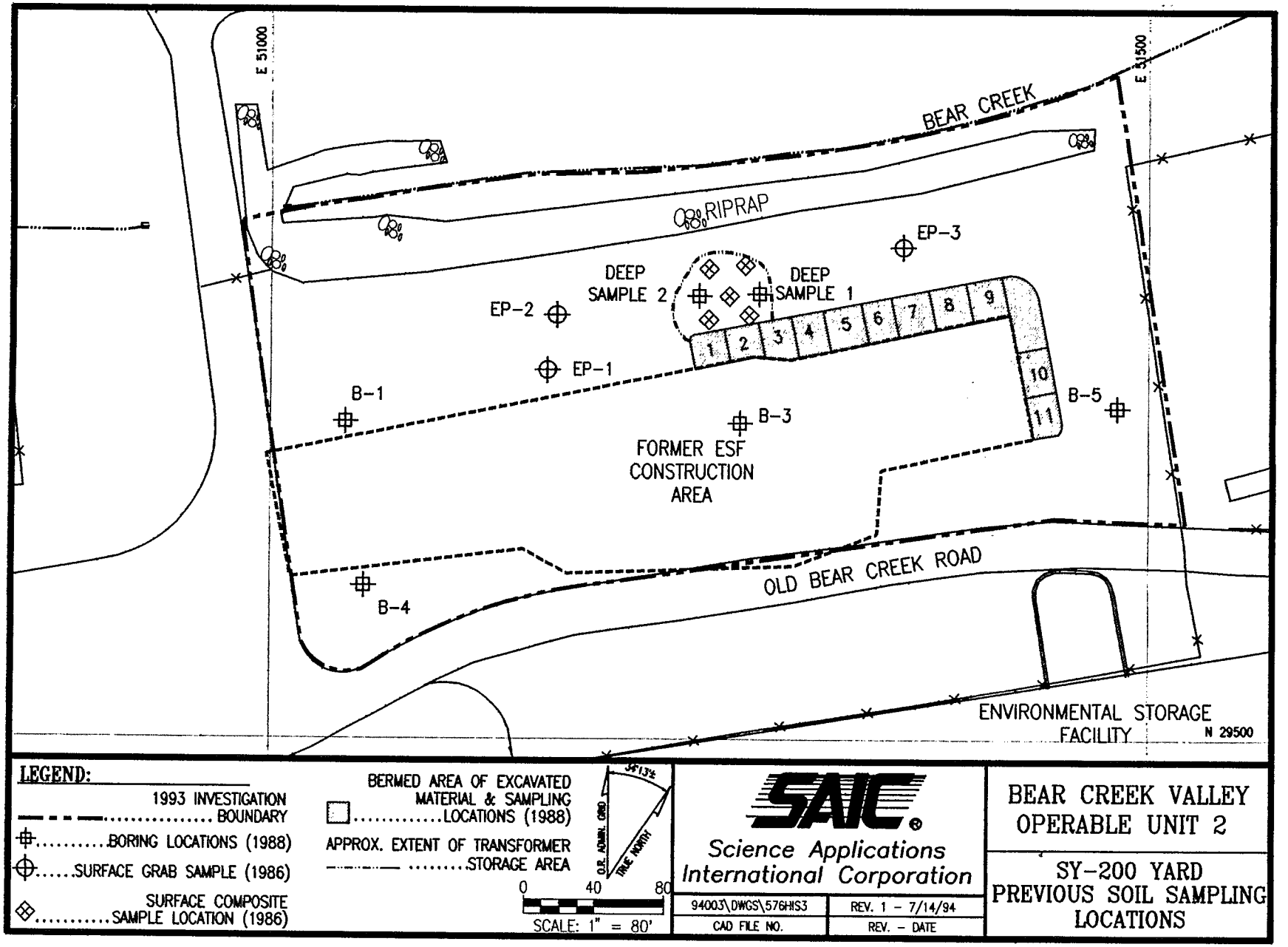


Fig. 3.35. Previous soil sampling locations in the vicinity of the SY-200 Yard.

The next sampling event took place in January 1988 in an effort to identify contaminated soils on the site where the ESF building was to be located (Energy Systems 1989). Fifteen samples were collected from boreholes B-1, -3, -4, and -5 (Fig. 3.35). The samples were collected at 2-ft intervals from the ground surface to a maximum depth of 10 ft. These samples were analyzed for alpha activity, beta activity, gamma activity, PCBs, EPA primary drinking water metals, and the EP toxicity metals.

The analytical results indicate that samples collected in B-5 had the highest radiological reading of 420 pCi/g for gamma activity, in addition to the highest concentration of mercury of 200 ppm. Trace levels of PCBs were detected in the top 4 ft of B-4 and in the top 2 ft of B-3. PCB concentrations were $\leq$0.3 ppm. The highest concentrations of lead, barium, and chromium were detected in B-1, -4, and -3, respectively. All samples passed the EP toxicity test. In addition, no measurable amounts of arsenic, cadmium, or silver were detected in any of the samples analyzed.

The third sampling event took place in January 1989 to characterize fill material which had been excavated from about 8 ft in the SY-200 Yard as part of the former ESF construction (Energy Systems 1989). This fill material had been bermed along the northeast corner of the excavation to ~20-ft high, 20-ft wide, and 180-ft long. Twenty-two composite samples from 1 to 2 ft and 3 to 5 ft in depth were collected from the excavated material. The bermed area was divided into 11 sections, and four hand auger holes were augered into each section to obtain the samples (Fig. 3.35). Each sample was analyzed for total thorium, total uranium, percent ^{235}U, and mercury.

Results of the historical soil sampling events at the SY-200 Yard indicated that the fill materials are contaminated with mercury. It is believed that the mercury detected in fill materials originated from contaminated fill and not as a result of operations at the SY-200 Yard (Sect. 3.1.3.3 and Fig. 3.8). Lead contamination was indicated in the northwest corner of the site (B-1) where lead shielding plates were stored, and PCB contamination of surface soils was indicated in the north-central portion of the site where transformers were stored. Therefore, this soil contamination was probably derived from operations at the site. In addition, radiological contamination was also indicated, although the highest levels of radioactivity were detected east of the SY-200 Yard.

Observation at the SY-200 Yard site during earlier construction activities of ESF suggested there were areas of particular concern that warranted focused sampling at the site. Subsequent construction activities redistributed soils at the site, making the horizontal and vertical distribution of contamination unpredictable. Therefore, the sampling plan for the RI activities at the SY-200 Yard was based on a 100-ft triangular grid system, and within historical areas of concern, the sampling grid was reduced to 25 ft. The locations for boring on the grids at the site were selected by a computerized random number generator.

Environmental samples collected from 23 borings were analyzed for the complete suite of analytes and are represented by triangles on Fig. 3.36. Samples from 36 borings were submitted for a limited suite of analytes and are represented by squares on Fig. 3.36. Limited analysis consisted of PCBs, metals, and gross alpha, beta, and isotopic uranium; full analysis consisted of volatiles, SVOCs, pesticides and PCBs, metals-cyanide, asbestos, and gross alpha, beta, and isotopic uranium (Table 3.23.)

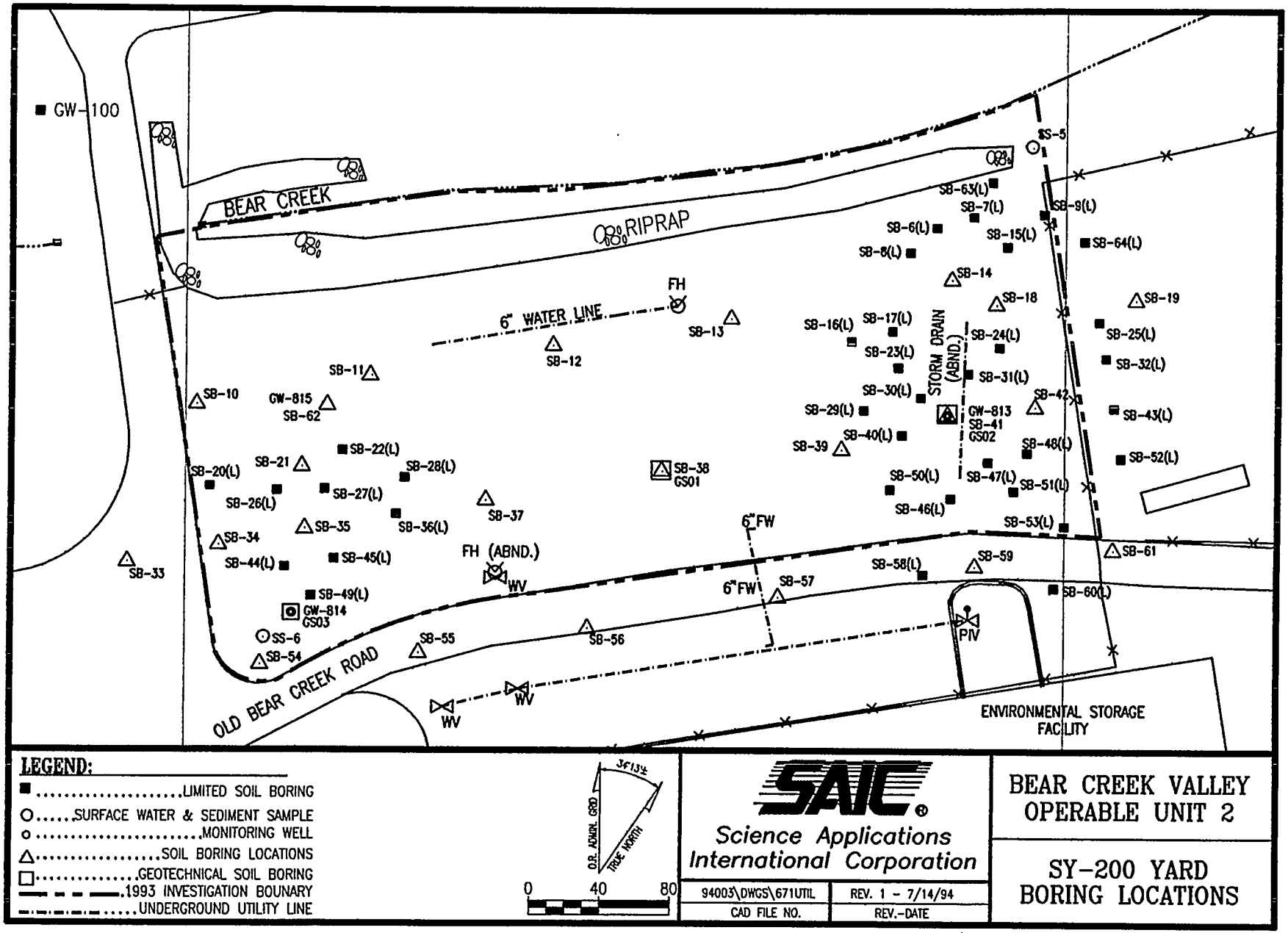


Fig. 3.36. The SY-200 Yard boring locations.

Table 3.23. Analytical parameters for the SY-200 Yard and RSA[a]

Soil boring	Full analysis				Gross alpha, beta, isotopic uranium[a]	Limited analysis	
	VOC	SVOC; pesticide/PCB	Metals—cyanide	Asbestos		PCB	Metal
			RSA				
SB-01	X	X	X		X		
SB-02	X	X	X		X		
SB-03	X	X	X		X		
SB-04	X	X	X		X		
SB-05	X	X	X		X		
Historical							
RSA-1	X		X	X	X		
RSA-2	X		X	X	X		
RSA-3	X		X	X	X		
RSA-4	X		X	X	X		
RSA-5	X		X	X	X		
RSA-6	X		X	X	X		
RSA-7	X		X	X	X		
			SY-200 Yard				
SB-06					X	X	X
SB-07					X	X	X
SB-08					X	X	X
SB-09					X	X	X

Table 3.23 (continued)

Soil boring	Full analysis					Limited analysis	
	VOC	SVOC; pesticide/PCB	Metals—cyanide	Asbestos	Gross alpha, beta, isotopic uranium[a]	PCB	Metal
SB-10	X	X	X	X	X		
SB-11	X	X	X	X	X		
SB-12	X	X	X	X	X		
SB-13	X	X	X	X	X		
SB-14	X	X	X	X	X		
SB-15					X	X	X
SB-16					X	X	X
SB-17					X	X	X
SB-18	X	X	X	X	X		
SB-19	X	X	X	X	X		
SB-20					X	X	X
SB-21	X	X	X	X	X		
SB-22					X	X	X
SB-23					X	X	X
SB-24					X	X	X
SB-25					X	X	X
SB-26	X	X	X	X	X		
SB-27					X	X	X
SB-28					X	X	X

Table 3.23 (continued)

Soil boring	Full analysis					Limited analysis	
	VOC	SVOC; pesticide/PCB	Metals—cyanide	Asbestos	Gross alpha, beta, isotopic uranium[a]	PCB	Metal
SB-29					X	X	X
SB-30					X	X	X
SB-31					X	X	X
SB-32					X	X	X
SB-33	X	X	X	X	X		
SB-34	X	X	X	X	X		
SB-35	X	X	X	X	X		
SB-36					X	X	X
SB-37	X	X	X	X	X		
SB-38	X	X	X	X	X		
SB-39	X	X	X	X	X		
SB-40					X	X	X
SB-41	X	X	X	X	X		
SB-42	X	X	X	X	X		
SB-43					X	X	X
SB-44					X	X	X
SB-45	X	X	X	X	X		
SB-46					X	X	X
SB-47					X	X	X

Table 3.23 (continued)

Soil boring	Full analysis					Limited analysis	
	VOC	SVOC; pesticide/PCB	Metals—cyanide	Asbestos	Gross alpha, beta, isotopic uranium[a]	PCB	Metal
SB-48					X	X	X
SB-49					X	X	X
SB-50					X	X	X
SB-51					X	X	X
SB-52					X	X	X
SB-53					X	X	X
SB-54	X	X	X	X	X		
SB-55	X	X	X	X	X		
SB-56	X	X	X	X	X		
SB-57	X	X	X	X	X		
SB-58					X	X	X
SB-59	X	X	X	X	X		
SB-60					X	X	X
SB-61	X	X	X	X	X		
SB-62	X	X	X	X	X		
SB-63					X	X	X
SB-64	X	X	X	X	X		

[a] Gross alpha, beta, and isotopic uranium are included in both full and limited analyses.

Originally 56 borings were to be sampled with 22 of the borings to be submitted for a complete suite of analytes and 34 borings from the 25-ft grid to be analyzed for a limited suite of analytes. However, due to field observations of elemental mercury and apparent large data gaps created by the randomly generated sample location three additional borings (SB-62, -63, and -64) were installed for a total of 59 locations (Fig. 3.36). Borehole locations were often adjusted slightly due to construction debris, shallow refusal, and overhead obstructions. Furthermore, samples from SB-9 and -64 were collected using a hand auger because the use of a drill rig was not possible due to overhead powerlines.

Historical data indicated at least 3 ft of clean fill was added to the entire SY-200 Yard; herefore environmental samples were recovered from 3 ft below ground surface to refusal or groundwater, whichever was encountered first.

Lithologic descriptions were made from 59 boring locations in which subsurface soil samples were collected at the SY-200 Yard site. A detailed log was completed and maintained for each soil boring (Appendix A).

Figure 3.37 shows the locations of cross sections at the SY-200 Yard. Cross section F-F′ (Fig. 3.38) shows that the top 4 to 10 ft of fill at the SY-200 Yard consists of yellowish-red to yellowish-brown stiff clay with stained chert fragments. This upper fill layer overlies 0–16 ft of shale fill material consisting of shale fragments, plant detritus, limestone fragments, asphalt, gravel, nails, and general fill material. This lower fill is underlain by a native yellowish-red to brown stiff clay with weathered chert fragments. The borings placed at the far east end of the site and the ones placed in Old Bear Creek Road encountered less shale fill material than was encountered in the former ESF construction site. This can be explained by repeated excavation that has occurred in this area of the site. Bedrock was not encountered in any of the soil borings at the SY-200 Yard. The maximum sample depth of 35 ft below ground surface was reached in borehole SB-57. Appendix A contains additional cross sections (G-G′ and H-H′) showing lithology at the SY-200 Yard.

Of the 65 individual analytes identified as COPCs at the SY-200 Yard site only 7 (beryllium, cobalt, lead, mercury, aroclor-1254, aroclor-1260, and benzo(a)pyrene) (Table 3.24), warranted further discussion of nature and extent based on the criteria discussed in Sect. 3.2.4.2.

Beryllium. Beryllium concentrations above the PRG of 0.15 ppm were detected in 230 of 232 samples and in all 59 boreholes and the surface sample SS-6 at the SY-200 Yard site. Furthermore, 128 of the 232 samples had concentrations above background levels as given in the ORR Background Soil Characterization Project (DOE 1993). A maximum concentration of 17.4 ppm was detected in SB-59 at a depth of 23-27 ft. However, this concentration is considerably higher than the others and is an outlier. Of the remaining sample, a maximum value of 4.5 ppm was detected in boring 58 at a depth of 19–23 ft.

The horizontal and vertical extent of beryllium at the site was mapped at a concentration of 1.007 ppm which is the 95% UCB of background. This was done because all the borings exhibited concentrations above PRG (0.15 ppm) at depths ranging from 2 to 31 ft below ground surface. Furthermore, the PRG of 0.15 ppm is below the quantitation limit goal of 0.5 ppm (Table 3.6). The value of 1.007 ppm was a calculated background concentration. However, analytical methods are accurate to this degree of certainty. Beryllium concentrations are reported above 1.007 ppm for the east end, south side, and some locations of the west

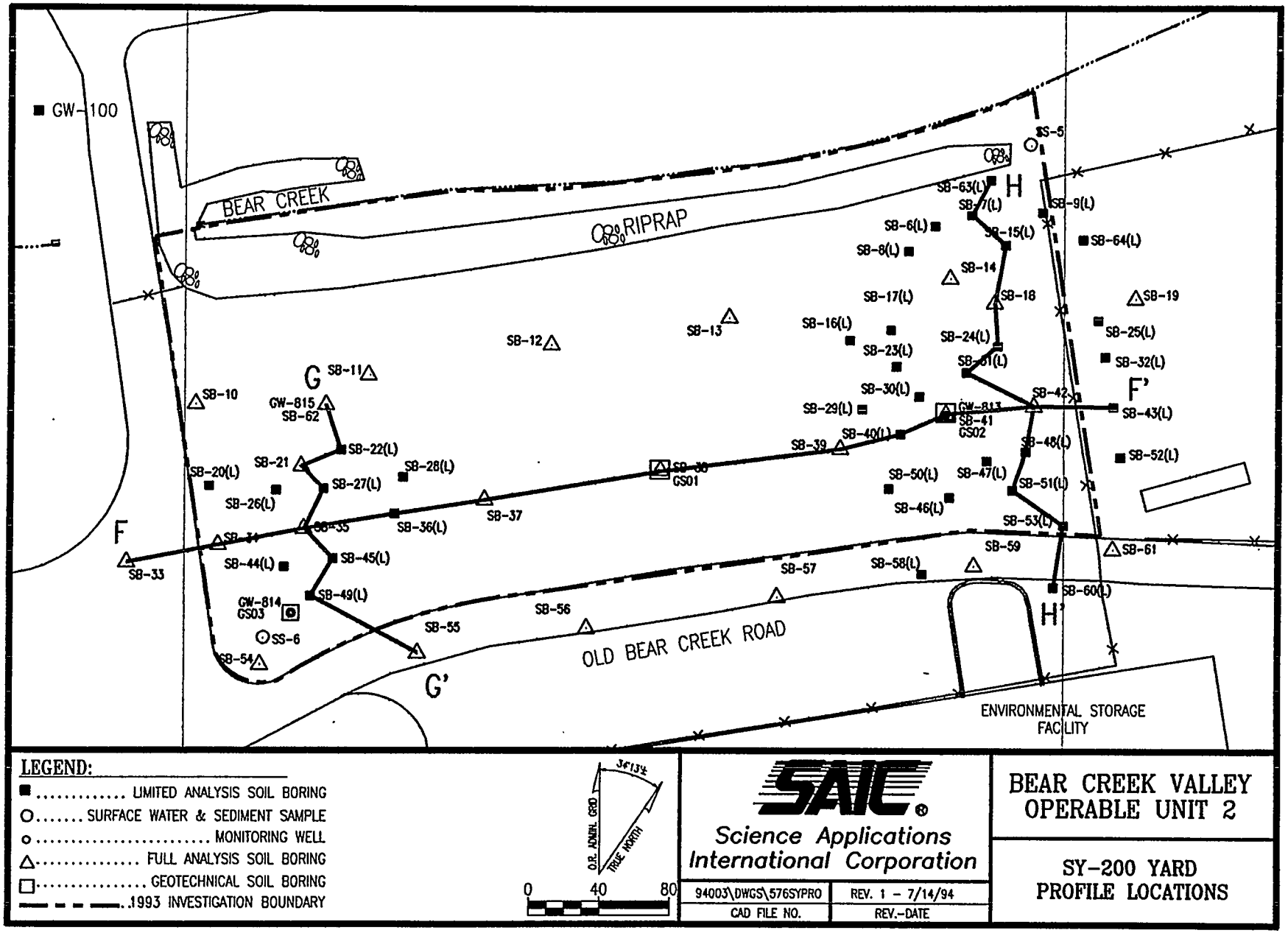


Fig. 3.37. The SY-200 Yard profile locations.

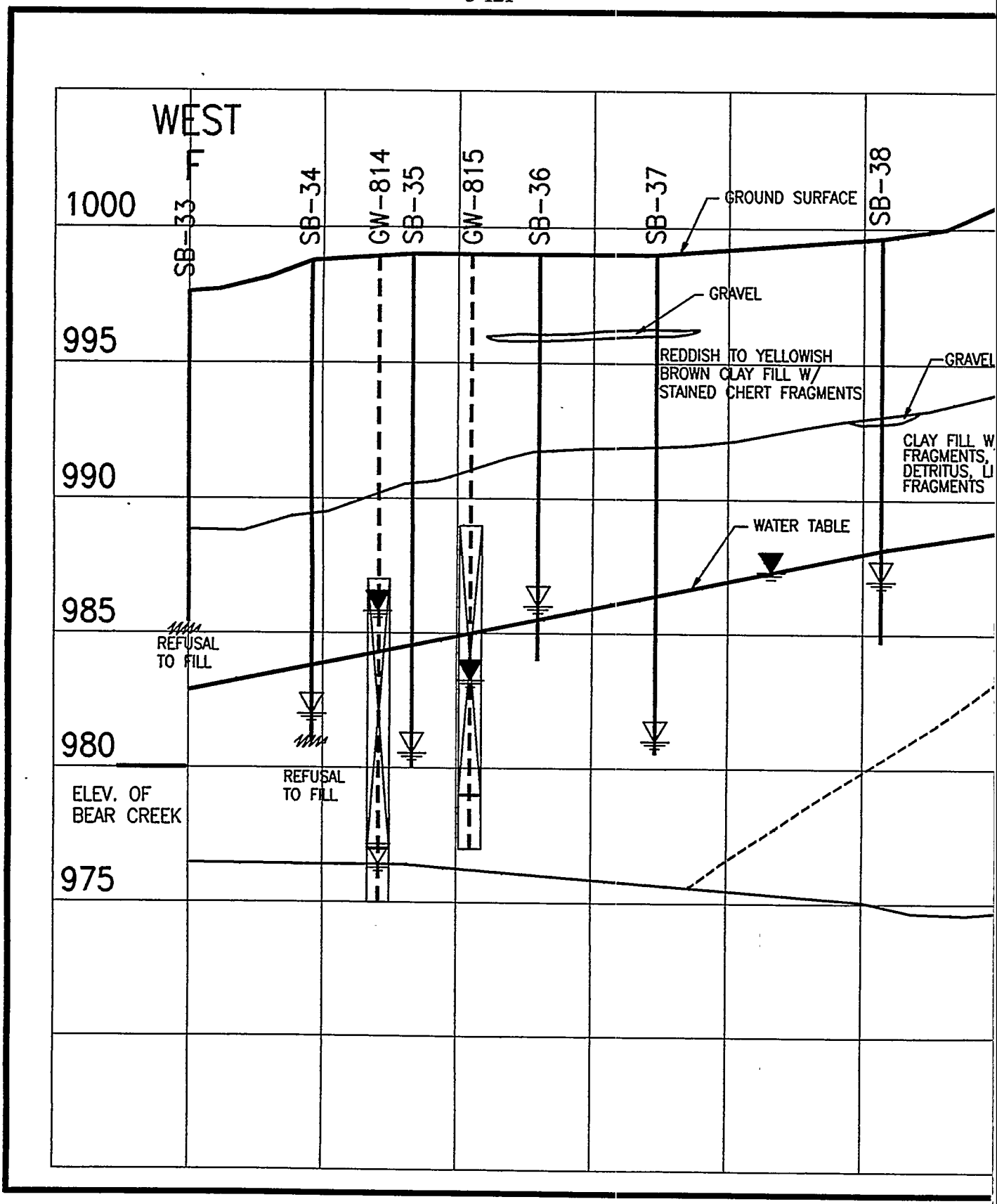
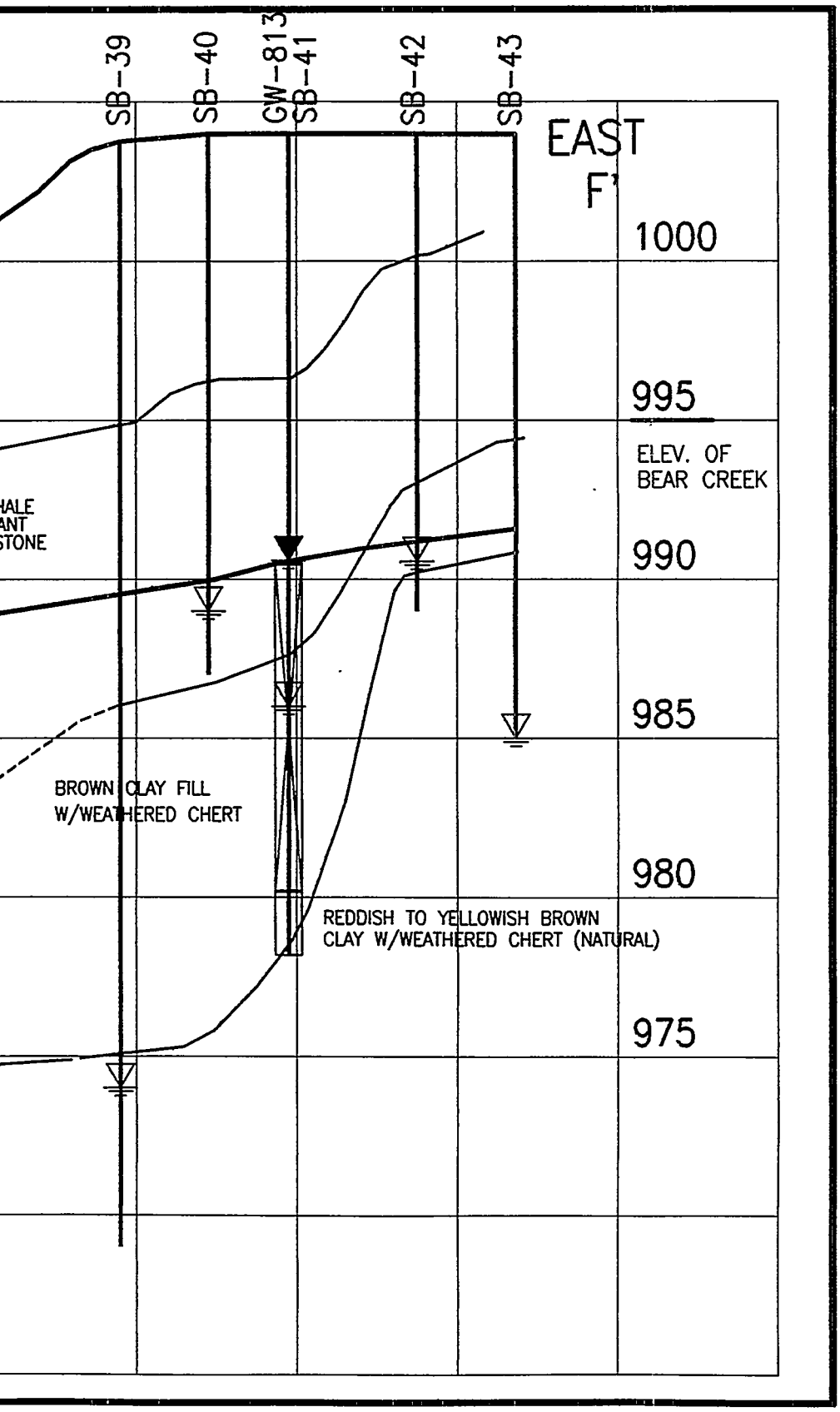


Fig. 3.38. The SY-200 Yard



LEGEND:

GW.....MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
.....GROUNDWATER TABLE
.....PROJECTED WELLS
.....SCREENED INTERVAL

0 1 2 3 4 5 10
VERTICAL SCALE: 1" = 5'

0 30 60 120
HORIZONTAL SCALE: 1" = 60'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SY-200 SITE PROFILE F-F'
SOIL LITHOLOGY

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	04-27-94
1	J. HOY	S. REID	07-19-94

XREFERENCES	PLOT FILES
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SHT. 1 OF 5 (DRAWING #) | /94003/DWGS/576PR02 (CAD FILE #) | N/A (ROT. ANGLE)

te profile F-F' soil lithology.

Table 3.24. Soil data summary for BCV OU 2 sites at the SY-200 Yard, comparison to PRGs and soil background data[a]

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				Metals (ppm)					
Antimony	ND[d]			2.0E-01	9.2E-01	3.9E-01	1.1E+02 (TI)	0/109	B
Barium	9.1E+00	1.4E+01	2.1E+01	8.5E+00	3.2E+02	9.0E+01	1.9E+04 (TI)	0/233	B
Beryllium	6.2E-01	9.6E-01	2.0E+00	8.0E-02	1.7E+01	1.2E+00	1.5E-01 (CI)	231/233	A
Cadmium	ND[d]			1.2E-01	3.1E+00	1.2E-01	2.7E+02 (TI)	0/215	F
Calcium	1.5E+02	2.2E+02	4.6E+02	5.3E+01	1.2E+05	2.5E+04			B, C
Cobalt	4.2E+00	4.2E+00	6.1E+01	2.7E+00	3.4E+02	2.2E+01			B, F
Cyanide	ND[d]			6.0E-01	1.6E+00	3.3E-01	5.5E+03 (TI)	0/98	B, C
Lead	3.1E+01	3.9E+01	4.2E+01	2.6E+00	4.4E+02	5.6E+01			B
Magnesium	3.4E+02	7.2E+02	1.4E+03	2.3E+02	1.7E+04	3.2E+03			B, E
Manganese	8.5E+01	1.1E+02	1.1E+02	8.9E+01	5.1E+03	8.2E+02	3.8E+04 (TI)	0/233	B, F
Mercury	1.5E-01	3.0E-01	7.2E-01	5.0E-02	8.2E+02	3.6E+01	8.2E+01 (TI)	14/232	B, F
Nickel	1.3E+01	2.1E+01	2.7E+01	4.1E+00	1.2E+02	2.7E+01	5.5E+03 (TI)	0/233	B
Potassium	6.1E+02	1.0E+03	1.5E+03	3.0E+02	4.9E+03	1.7E+03			B
Silver	ND[d]			3.5E-01	3.3E+00	1.1E+00	1.4E+03 (TI)	0/233	
Thallium	ND[d]			1.5E-01	1.4E+00	3.3E-01			F
				Pesticide/PCB compounds (ppb)					
4,4'-DDE				4.1E+00	4.1E+00	5.1E+00	1.9E+03 (CI)	0/99	C, D
Aroclor-1254				4.3E+01	2.4E+03	6.7E+01	8.3E+01 (CI)	17/232	F
Aroclor-1260				2.0E+01	1.0E+04	4.2E+02	8.3E+01 (CI)	53/232	A, F

Table 3.24 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
Endrin				1.2E+00	1.9E+00	5.0E+00	8.2E+04 (TI)	0/99	C, D
p,p'-Methoxychlor				9.2E+00	4.1E+01	2.7E+01	1.4E+06 (TI)	0/99	C
				SVOCs (µg/kg)					
1,2,4-Trichlorobenzene				4.7E+01	9.6E+01	2.4E+02	2.7E+06 (TI)	0/99	D
1,4-Dichlorobenzene				4.6E+01	9.8E+01	2.4E+02	2.7E+04 (TI)	0/99	D
2,4-Dinitrotoluene				4.3E+01	9.1E+01	2.4E+02	9.4E+02 (CI)	0/99	C, D
2-Chlorophenol				5.3E+01	1.4E+02	2.4E+02	1.4E+06 (TI)	0/98	D
2-Methylnaphthalene				3.6E+02	3.7E+03	2.4E+02			C
4-Chloro-3-methylphenol				4.5E+01	1.8E+02	2.4E+02			C, D, F
4-Nitrophenol				4.6E+01	2.4E+02	6.1E+02			C, D, F
Acenaphthene				4.9E+01	6.1E+03	2.5E+02	1.6E+07 (TI)	0/99	
Acenaphthylene				5.8E+01	8.7E+02	2.2E+02			C
Anthracene				4.3E+01	9.6E+03	2.7E+02	8.2E+07 (TI)	0/99	
Benzo(a)anthracene				5.8E+01	1.2E+04	3.2E+02	8.8E+02 (CI)	5/99	F
Benzo(a)pyrene				4.4E+01	1.0E+04	3.0E+02	8.8E+01 (CI)	13/99	A, F
Benzo(b)fluoranthene				4.5E+01	1.4E+04	3.5E+02	8.8E+02 (CI)	7/99	F
Benzo(g,h,i)perylene				5.5E+01	5.1E+03	2.6E+02			F
Benzo(k)fluoranthene				4.1E+01	4.7E+03	2.7E+02	8.8E+03 (CI)	0/99	
Bis(2-ethylhexyl)phthalate				4.1E+01	5.9E+02	2.4E+02	4.6E+04 (CI)	0/99	B
Butylbenzylphthalate				6.5E+01	6.5E+01	2.4E+02	5.5E+07 (TI)	0/99	B, C, D

Table 3.24 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
Carbazole				7.1E+01	6.7E+03	2.5E+02	3.2E+04 (CI)	0/99	
Chrysene				4.6E+01	1.1E+04	3.1E+02	8.8E+04 (CI)	0/99	
Di-n-butylphthalate				4.3E+02	4.3E+02	2.6E+02	2.7E+07 (TI)	0/99	B, C
Dibenzo(a,h)anthracene				5.0E+01	1.2E+03	2.3E+02	8.8E+01 (CI)	7/99	A, F
Dibenzofuran				4.8E+01	3.7E+03	2.4E+02			
Diethylphthalate				4.3E+01	4.3E+01	2.4E+02			F
Dimethylphthalate				4.8E+01	4.8E+01	2.4E+02			C, D
Fluoranthene				4.1E+01	2.4E+04	3.9E+02	1.1E+07 (TI)	0/99	
Fluorene				5.8E+01	8.0E+03	2.5E+02	1.1E+07 (TI)	0/99	
Indeno(1,2,3-c,d)pyrene				4.7E+01	5.7E+03	2.7E+02	8.8E+02 (CI)	1/99	
N-Nitroso-di-n-propylamine				5.6E+01	8.5E+01	2.4E+02	9.1E+01	0/99	C, D
Naphthalene				4.5E+01	1.4E+04	2.8E+02			F
Pentachlorophenol				6.2E+01	3.0E+02	6.0E+02	5.3E+03 (CI)	0/98	D
Phenanthrene				4.8E+01	3.0E+04	3.7E+02			F
Phenol				5.8E+01	6.2E+01	2.4E+02	1.6E+08 (TI)	0/98	D
Pyrene				4.4E+01	2.2E+04	3.8E+02	8.2E+06 (TI)	0/99	
				VOCs (ppb)					
1,1,2-Trichloro-1,2,2-trifluoroethane				1.0E+00	1.8E+02	8.4E+00	8.2E+09 (TI)	0/99	
2-Butanone				5.0E+00	2.8E+01	8.9E+00	1.6E+08 (TI)	0/99	C

Table 3.24 (continued)

Compound	Background Minimum[b]	Background Maximum[b]	Background UCL[c]	Site Minimum[b]	Site Maximum[b]	Site UCL	PRG	No. detects >PRG	Comments
4-Methyl-2-pentanone				3.0E+00	2.5E+01	8.9E+00	1.4E+07 (TI)	0/99	
Acetone				1.4E+01	2.1E+03	2.2E+02	2.7E+07 (TI)	0/99	
Benzene				1.0E+00	6.0E+00	4.5E+00	2.2E+04 (CI)	0/99	C
Carbon disulfide				2.0E+00	2.0E+00	4.5E+00	2.7E+07 (TI)	0/99	C, D
Ethylbenzene				4.0E+00	1.1E+01	4.6E+00	2.7E+07 (TI)	0/99	C
Methylene chloride				6.0E+00	4.7E+02	4.0E+01	8.5E+04 (CI)	0/99	
Toluene				1.0E+00	2.0E+00	4.5E+00	5.5E+07 (TI)	0/99	C, D
Xylene, total				2.3E+01	2.7E+01	4.9E+00			C
				Radionuclides (pCi/g)					
Gross alpha	NA			5.5E+00	5.5E+01	1.8E+01			B
Gross beta	NA			8.7E+00	9.1E+01	3.0E+01			B

[a] Generated by program PRGMERG.SAS on 20 Apr 94. Background data are for Copper Ridge Horizon C from the ORR Background Soil Characterization Project, DOE 1993a.
[b] Minima and maxima represent actual detected values.
[c] Upper 95% Confidence Limit (UCL) for the mean, calculated assuming a lognormal distribution unless the data fit a normal distribution.
[d] Not detected in the background soil study.
A = Over PRG
B = Analyte is COPC in groundwater
C = Outlier
D = UCL >maximum
E = Essential nutrient
F = Potential human health concern
PRGs are residential (TI) Toxic Ingestion or (CI) Carcinogenic Ingestion

end of the site as indicated by Fig. 3.39. Appendix A contains figures showing the concentrations of beryllium by borehole for each 4-ft sample interval, cross sections showing the extent of vertical contamination. Beryllium levels above the 95% UCB background value appear to concentrate on the 25-ft grid on the east end of the site and on the 25-ft grid on the west end of the site to a depth of 19 ft below ground surface. At 19 ft below ground surface there is gradation of high concentrations to the south of the site along Old Bear Creek Road. Higher concentrations of beryllium (>2 ppm) were associated with the deeper native yellowish-red stiff clay and appear to represent natural site background values. This relationship is further demonstrated by cross section H-H′ of the site (Fig. 3.40). Furthermore, beryllium is not considered to be environmentally significant due to this association with native materials. Additional cross sections showing vertical extent of beryllium are included in Appendix A.

Cobalt. Concentrations of cobalt were detected in 229 of 233 samples at levels ranging from 2.7 ppm to 336.0 ppm at the SY-200 Yard site. A PRG is not available for cobalt; however, it was detected above background concentrations in 217 of 233 samples and is also a COPC in groundwater.

All borings displayed detects of cobalt at depths ranging from 3 to 31 ft below ground surface. A maximum concentration of 366.0 ppm was detected in SB-58 at a depth of 19–23 ft below ground surface. The higher concentrations (>100 ppm) of cobalt, like beryllium, were associated with the deeper native yellowish-red stiff clay to the south of the site, along Old Bear Creek Road.

Lead. Lead was detected in all 233 samples with concentrations ranging from 2.6 to 440 ppm at the SY-200 Yard site. A PRG for lead is not available, however, 90 of the 233 samples had concentrations above maximum background concentrations and lead is a COPC in groundwater; therefore, lead is a COPC in soil at the SY-200 Yard.

Elevated concentrations of lead (>100 ppm) were detected at a depth of 3-7 ft in an isolated area of SB-39, -40, and -41. Like beryllium and cobalt, all other elevated concentrations were associated with the deeper native yellowish-red stiff clay to the south of the site, along Old Bear Creek Road. Cross section H-H′ (Fig. 3.41) further demonstrates this relationship.

Mercury. Concentrations of mercury were detected above the PRG of 82 ppm in 14 of 232 samples at the SY-200 Yard site. Furthermore, 135 of 232 samples had concentrations of mercury above background levels. A maximum concentration of 816 ppm was detected in SB-14 at a depth of 3-7 ft.

Historical soil analyses and data acquired from this RI indicate mercury is not present over the entire SY-200 Yard but is confined to isolated areas of elevated concentrations. Figure 3.42 shows the lateral distribution of mercury at all depth intervals and indicates clustered sample detects around SB-17, -14, -41, -39, -45, -33, and -35. This figure also depicts the locations where elemental mercury was observed in the samples retrieved from the split spoon.

Delineation of mercury contamination by analytical sampling is difficult to accomplish and has a large degree of uncertainty due to the characteristics of elemental mercury. Often analysis of samples with visible mercury in small portions of the composite was negative for mercury. This is partly attributable to the "nugget effect," where observed distribution of the

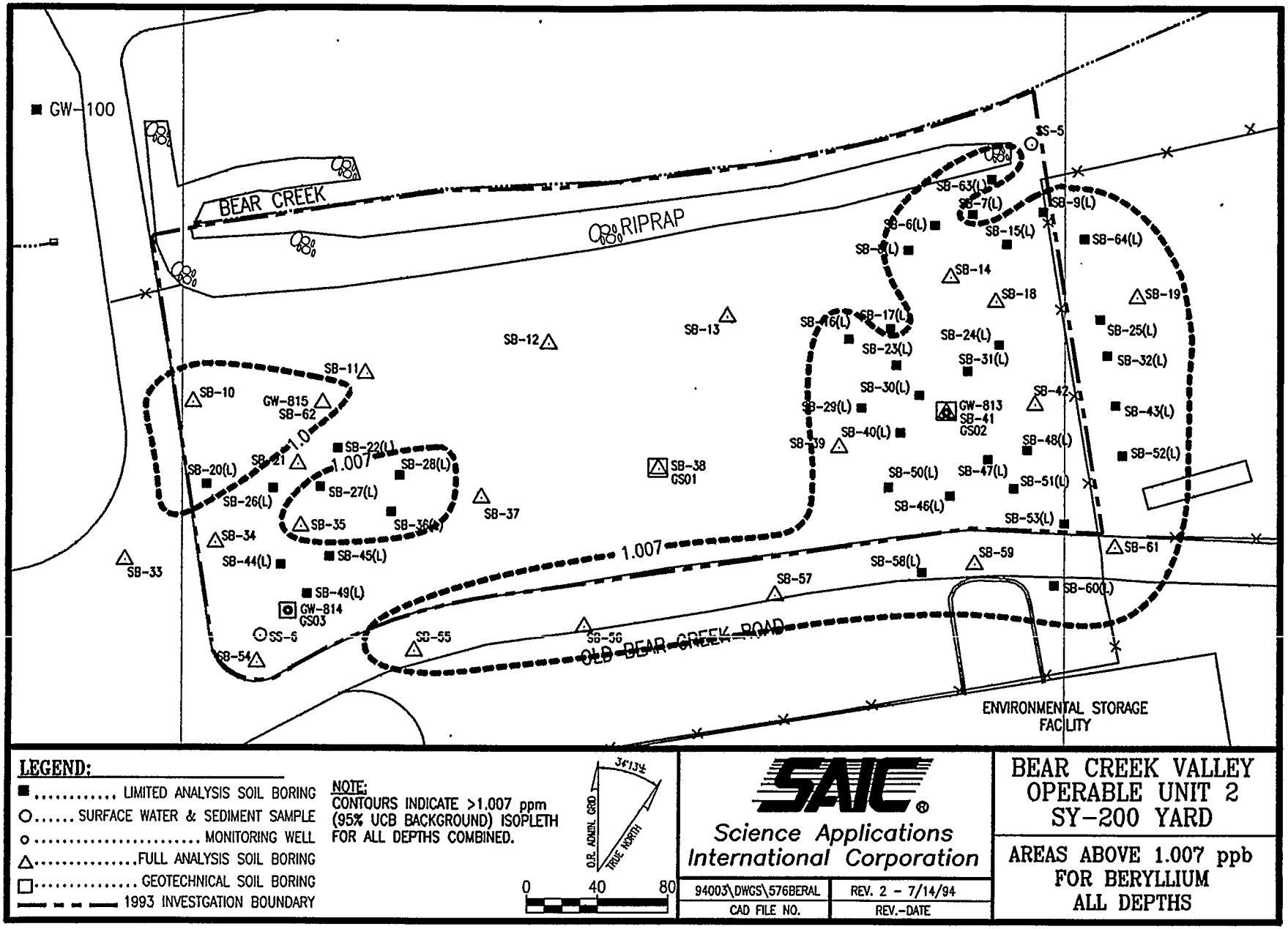


Fig. 3.39. Areas above 1.007 ppb for all depths of beryllium.

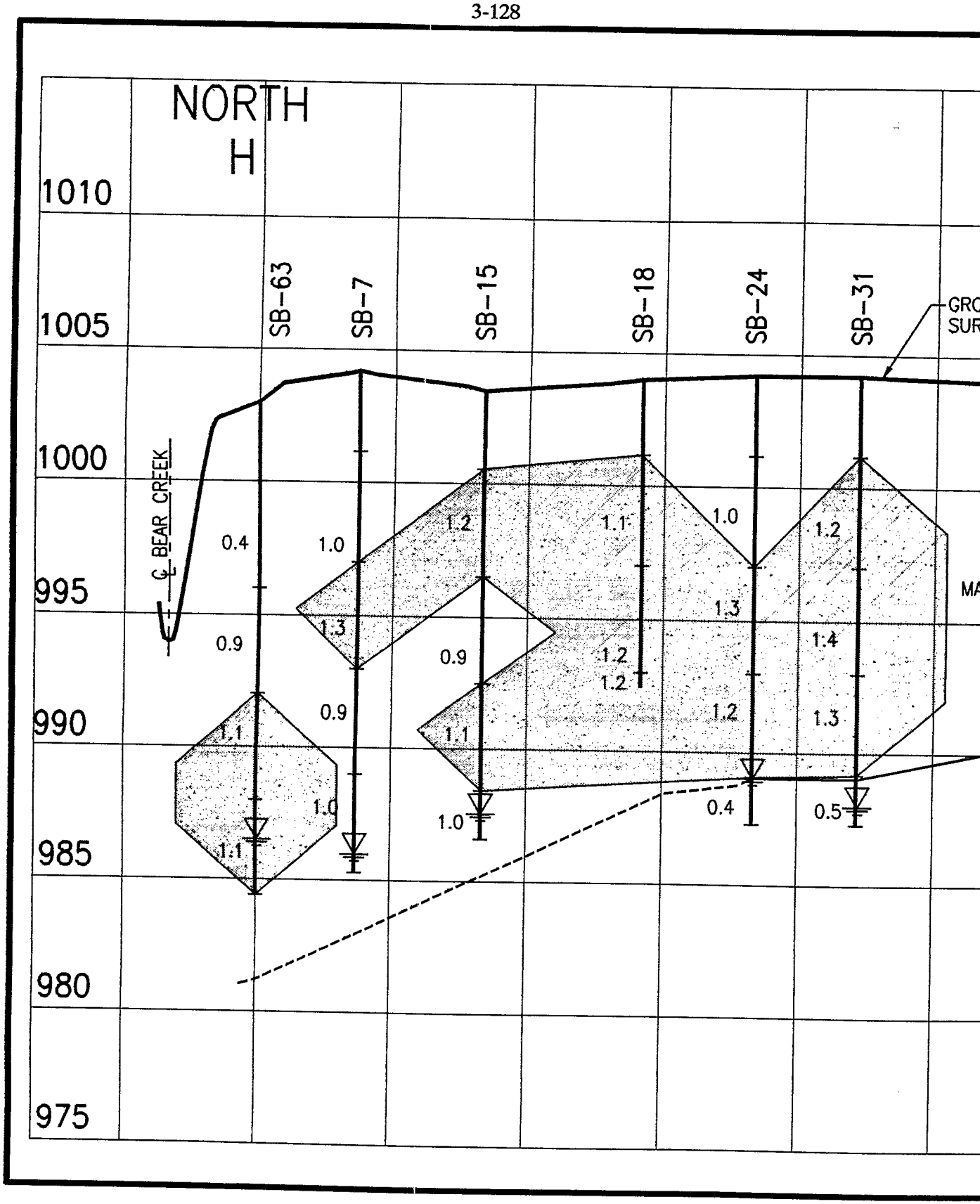
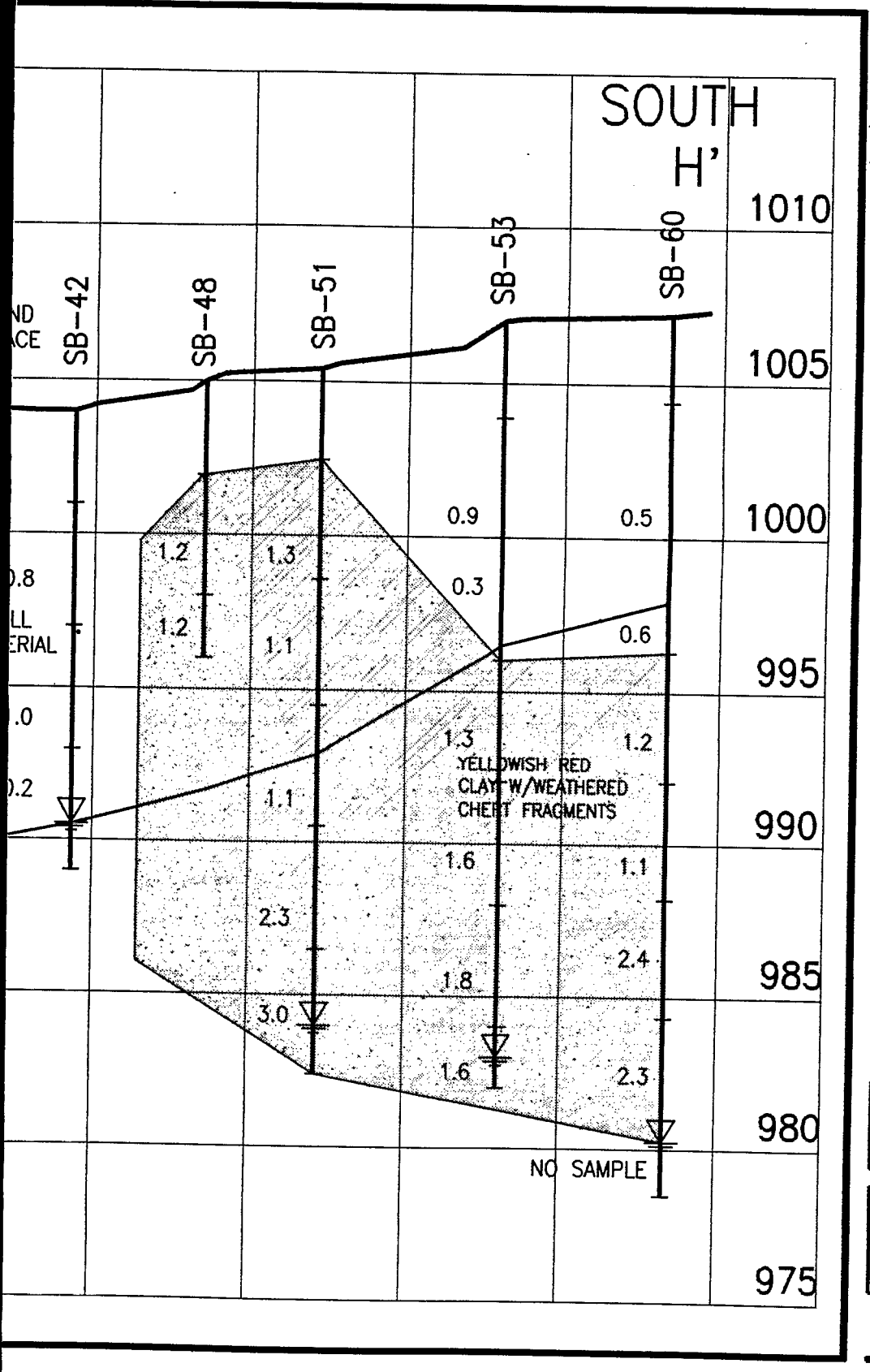


Fig. 3.40. The SY-200 Yard prof



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
>1.007 PPM BERYLLIUM
.....(95% UCB BACKGROUND)

0 1 2 3 4 5 10
VERTICAL SCALE: 1" = 5'

0 10 20 30 60
HORIZONTAL SCALE: 1" = 30'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
SY-200 YARD, PROFILE H-H'
BERYLLIUM CONCENTRATIONS

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	04-27-94
1	J. HOY	S. REID	07-18-94

XREFERENCES	PLOT FILES
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SHT. 2 OF 6 DRAWING # | /94003/DWGS/576PR06 CAD FILE # | N/A ROT. ANGLE

le H-H′ for beryllium concentrations.

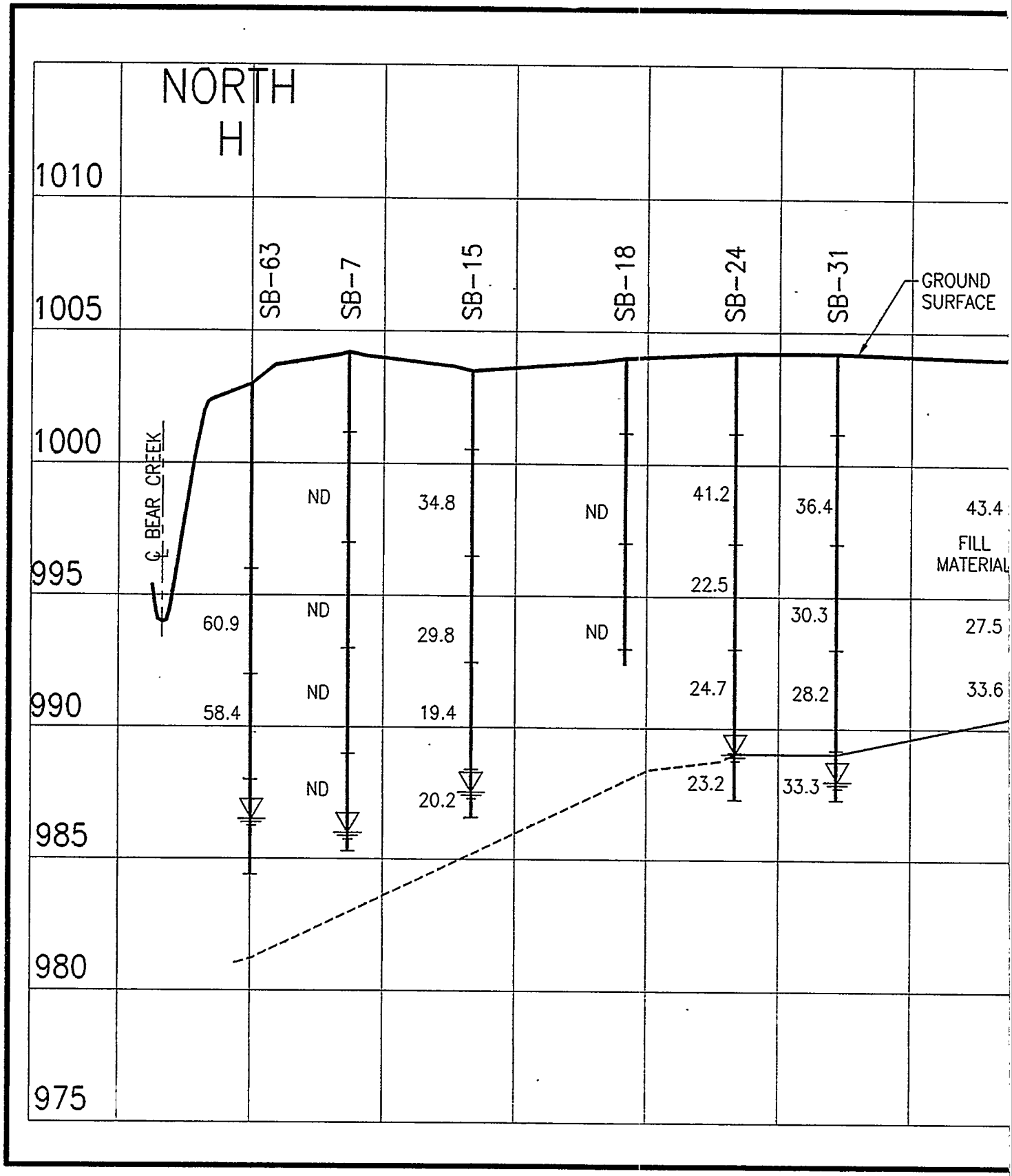
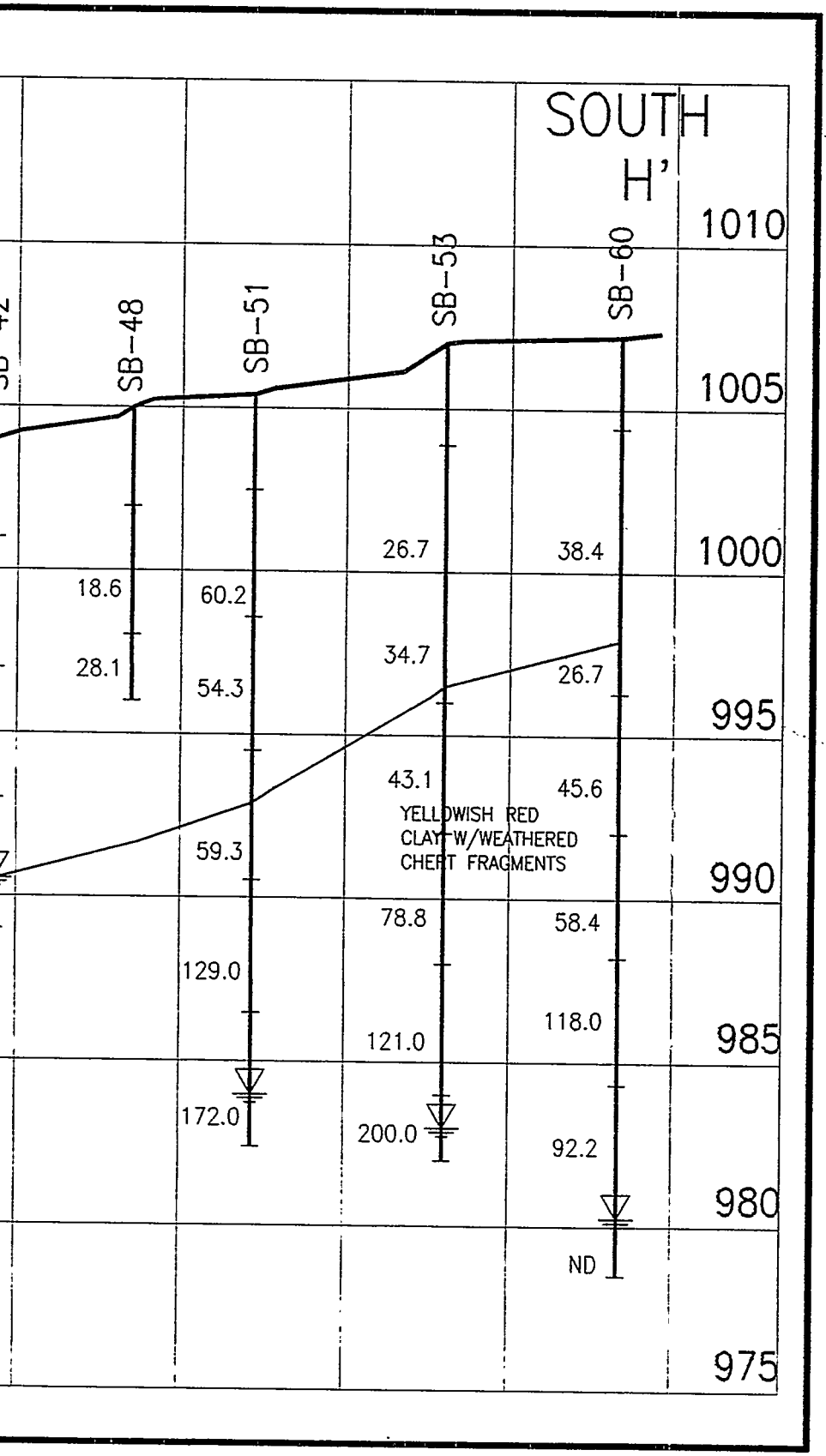


Fig. 3.41. The SY-200 Yard profile H-H' lo



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE
ND..... NOT DETECTED
NA..... NOT ANALYZED
26.7.....ppm LEAD

0 1 2 3 4 5 10
VERTICAL SCALE: 1" = 5'

0 10 20 30 60
HORIZONTAL SCALE: 1" = 30'

SAIC®
Science Applications International Corporation

BEAR CREEK VALLEY OU2
SY-200 YARD, PROFILE H-H'
LEAD CONCENTRATIONS (ppm)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	04-27-94
1	J. HOY	S. REID	07-18-94

XREFERENCES	PLOT FILES
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SHT. 6 OF 6 DRAWING # | /94003/DWGS/576PR06 CAD FILE # | N/A ROT. ANGLE

concentrations (ppm).

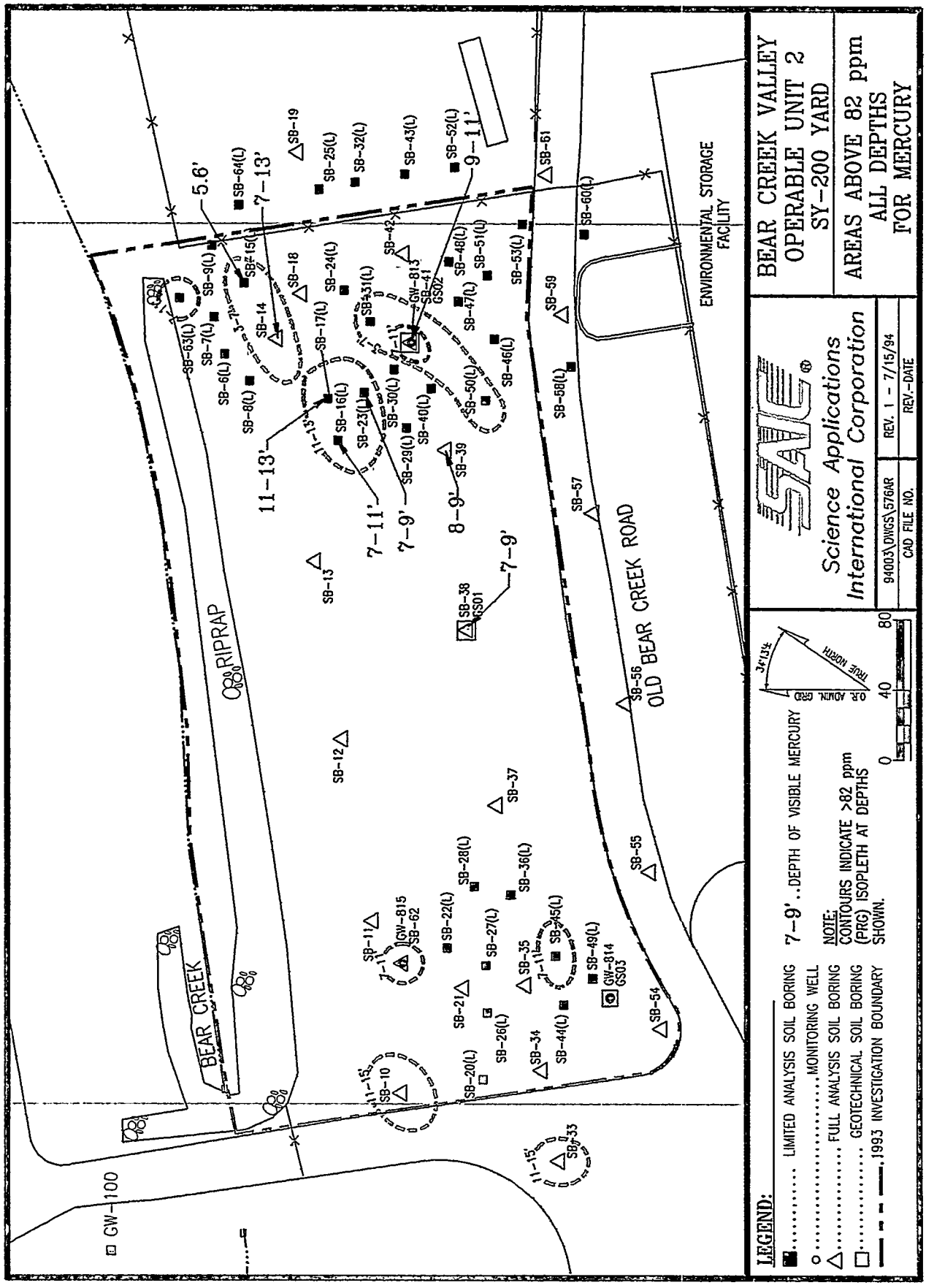


Fig. 3.42. Areas above 82 ppm all depths for mercury.

visible mercury in small spheres and its dilution by large volumes of mercury-free soil in the compositing of a 4-ft interval results in low concentrations being reported where mercury was observed. Interpolation between points of known levels can introduce an even larger degree of uncertainty.

Concentrations of mercury by boring and 4-ft sample interval are shown on contour maps located in Appendix A. These concentrations are contoured based on an 83 ppm PRG and at 200 and 500 ppm intervals. The highest concentrations of mercury are associated with the 3–11 ft below ground surface interval. This can also be seen on the three cross sections located in Appendix A. Furthermore, two trends of vertical contamination are identifiable from contamination profiles for the SY-200 Yard: (1) an overall decrease in concentration with depth from ground surface and (2) an increase in concentration with depth from ground surface to a maximum level in the sample interval from 7 to 11 ft below ground surface with a relatively uniform decrease with depth below this interval. The latter distribution is characteristic of the borings taken within the confines of the excavated and refilled area of the former ESF foundation. Sixteen of 18 borings sampled from inside the former ESF excavation exhibited this characteristic profile (Fig. 3.43). Contamination profiles of borings adjacent to but outside the excavation area have no identifiable trend, however, contamination levels generally decrease with depth (Fig. 3.44).

The maximum concentration levels within the former ESF foundation correspond with the maximum depth of excavation of the foundation (Fig. 3.43). Historical sampling of the bermed excavation material indicated that very high levels of mercury (as great as 2100 ppm) existed in the former ESF area. The excavated material was placed back in the foundation excavation after termination of the ESF construction. The two possible explanations for the characteristic profiles arethe following:

- The high concentrations of mercury in the excavated soils and the disturbed nature of the excavated soil allowed for rapid vertical migration of mercury through the reintroduced foundation fill. High concentrations of mercury in the interval from 7 to 11 ft below ground surface are believed to be due to the less permeable nature of the undisturbed fill below the 8-ft excavation depth which acts as a migration barrier that is conducive to pooling of mercury.
- The profile of undisturbed soil in the former ESF foundation area may have indicated a decrease in contamination from ground surface with depth. Excavation and storage of the excavated material may have resulted in contamination reduction of the material by volatilization of mercury or removal by leaching of the bermed material by rainwater. Placement of this cleaner soil back into the excavation would result in a profile indicating a low level of contamination in the 3- to 7-ft sample interval, increasing to a maximum level of contamination in the 7- to 11-ft sample interval and decreasing with depth below 11 ft below ground surface. The profile below 11 ft below ground surface would represent the undisturbed soil levels.

Aroclor-1254 and aroclor-1260. Aroclor-1254 concentrations were above the PRG of 83 ppb in 17 of 232 samples at the SY-200 Yard site. Aroclor-1260 concentrations were above the PRG of 83 ppb in 53 of 232 samples at the site. Aroclor-1254 was combined with aroclor-1260 for the discussion of the levels of contaminants of PCBs. A maximum concentration of 11,000 ppb was detected in SB-34 at a depth of 7-11 ft.

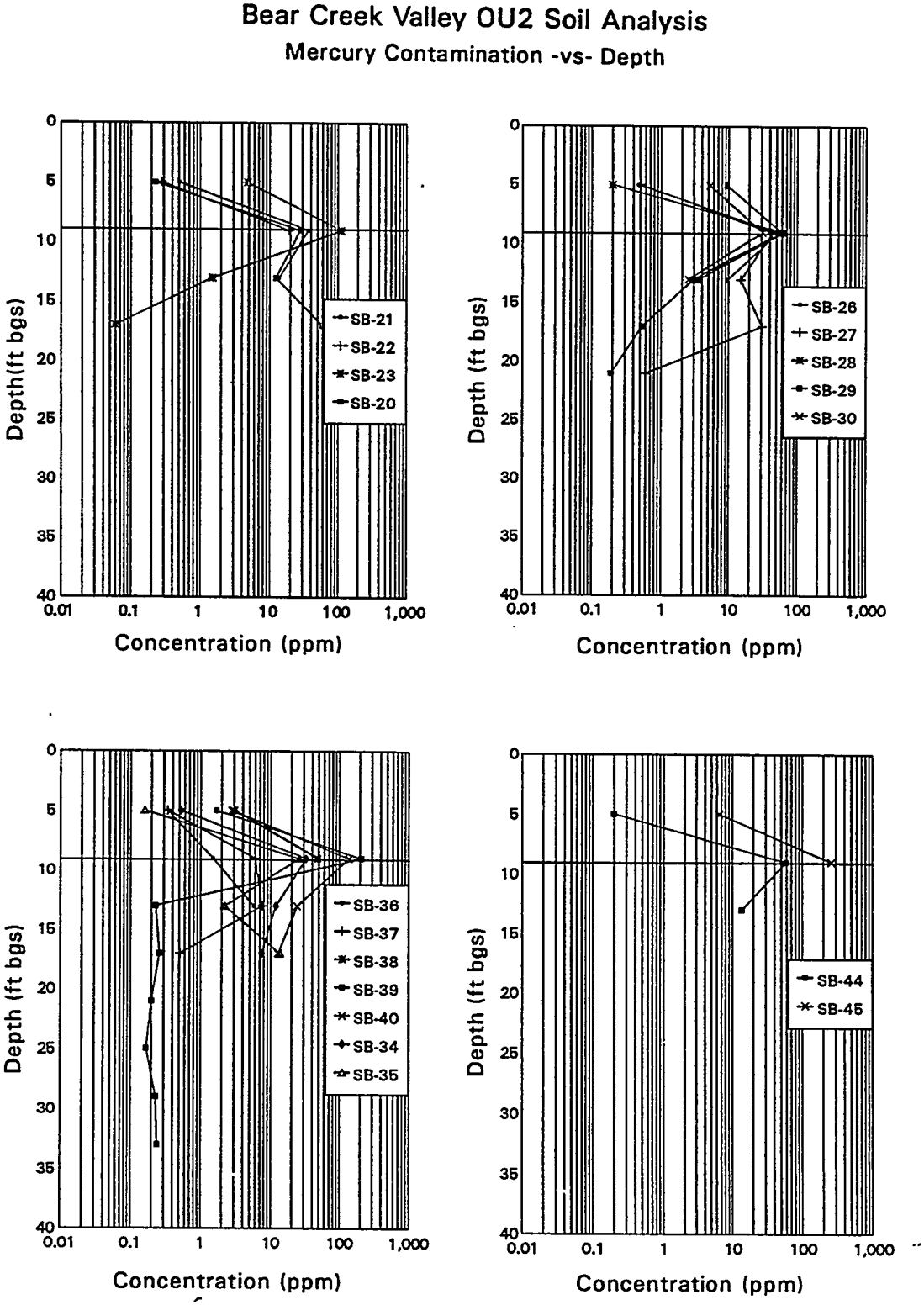


Fig. 3.43. Boreholes adjacent to filled ESF foundation.

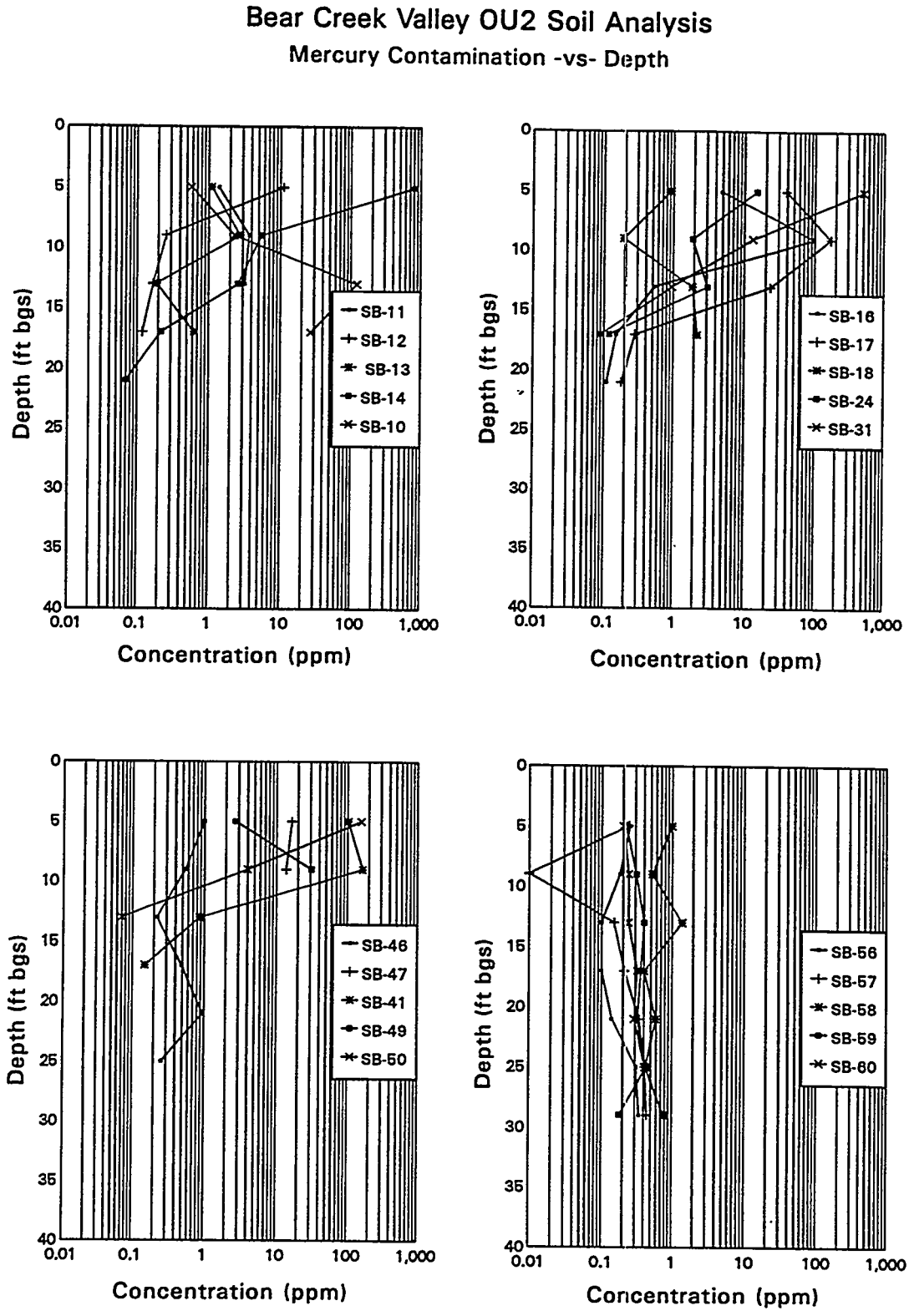


Fig. 3.44. Boreholes within filled ESF foundation.

The horizontal and vertical extent of combined aroclor-1254 and -1260 were mapped at the PRG concentration of 83 ppb. Aroclor concentrations are reported above 83 ppb across the site as can be seen in Fig. 3.45. Included in Appendix A are figures showing the concentrations of combined aroclor by sample intervals and indicate that isolated areas of elevated concentrations originate at the east end of the site at shallow depths and gradually move to the west with increasing depth. No aroclor was detected below 19 ft below ground surface. The cross sections indicate that the concentrations above the PRG are within the fill area of the site and are not detected in the naturally occurring yellowish-red stiff clay with weathered chert fragments. Cross section F-F' shows transects west to east across the middle of the site and displays the gradual migration of the aroclor across the site from east to west and down through the section.

SVOCs. Several polyaromatic hydrocarbons exhibit concentrations above PRGs. Comparison of data from all detects of these compounds reveals similarities in detections. For example, the analytes have maximum concentrations in SB-34 at a depth of 15-19 ft below ground surface. In addition, benzo(a)pyrene has representative detects at each boring location and depth where the other analytes have detections. The only exceptions to the latter were two detections of 4-chloro-3-methylphenol of 180.0 ppb in SB-61 at 3-7 and 19-23 ft below ground surface respectively, one detection of dibenzo(a,h)anthracene of 50.0 ppb in SB-31 at a depth of 11-12.5 ft below ground surface, and one detection of 120.0 ppb in SB-42 at a depth of 7-11 ft below ground surface. Benzo(a)pyrene was also shown to have the most hits above PRGs with 13 of 98. Benzo(a)pyrene was selected to represent the SVOCs because of the frequency of detection.

Benzo(a)pyrene results were contoured for the PRG of 88 ppb at each 4-ft sample interval and are on figures in Appendix A. These figures indicate a general increase in mean concentrations and a shift to the west with increase in depth. Figure 3.46 exhibits all areas and their depths that have concentrations over 88 ppb. However, it should be noted that benzo(a)pyrene's PRG of 88 ppb is below its quantitation limit goal of 330 ppb (Table 3.6). Only eight samples had concentrations above 330 ppb. The east end of the site had no borings with concentration of benzo(a)pyrene above PRGs and only four samples from four borings and three sample depths above detection limits. Cross sections reinforce the plan view observations (Appendix A). The elevated levels of PAHs are believed to be attributed to the past and present industrial nature of the site. In addition, during the RI sampling effort, resurfacing was being carried out on Old Bear Creek Road. Asphalt was used to resurface the road. This operation, in close proximity to the sampling, may have contributed SVOCs to the soil.

3.2.4.5 RSA

Subsurface soil samples were previously taken at the RSA in early 1990 to characterize the nature and extent of soil contamination. Samples were collected from seven borings around the perimeter of the site (Fig. 3.47). Soil samples were collected for each location at 5-ft intervals until refusal was reached. The depth to refusal at the sampling points ranged from a minimum of 5 ft in RSA-6 and -7 up to a maximum of 25 ft in RSA-3 and -4. The shallow and variable depth to refusal across the site is believed to be caused by variable depths to bedrock. The entire thickness of fill was penetrated by these borings. A total of 24 subsurface soil samples was collected at the RSA and analyzed for metals, VOCs, asbestos, cyanide, and radiologicals (see Table 3.23).

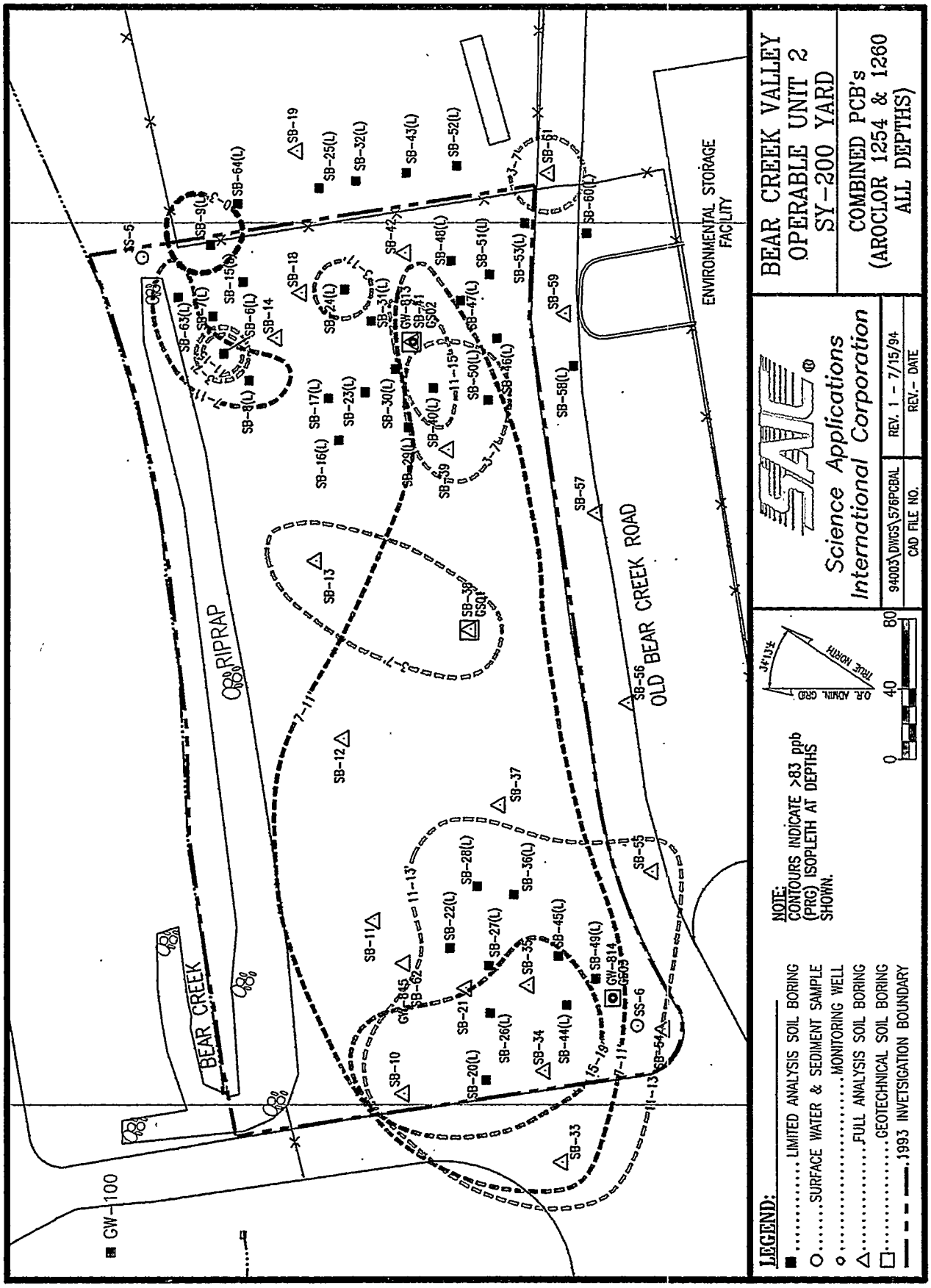


Fig. 3.45. Combined PCBs (aroclor 1254 and 1260 all depths).

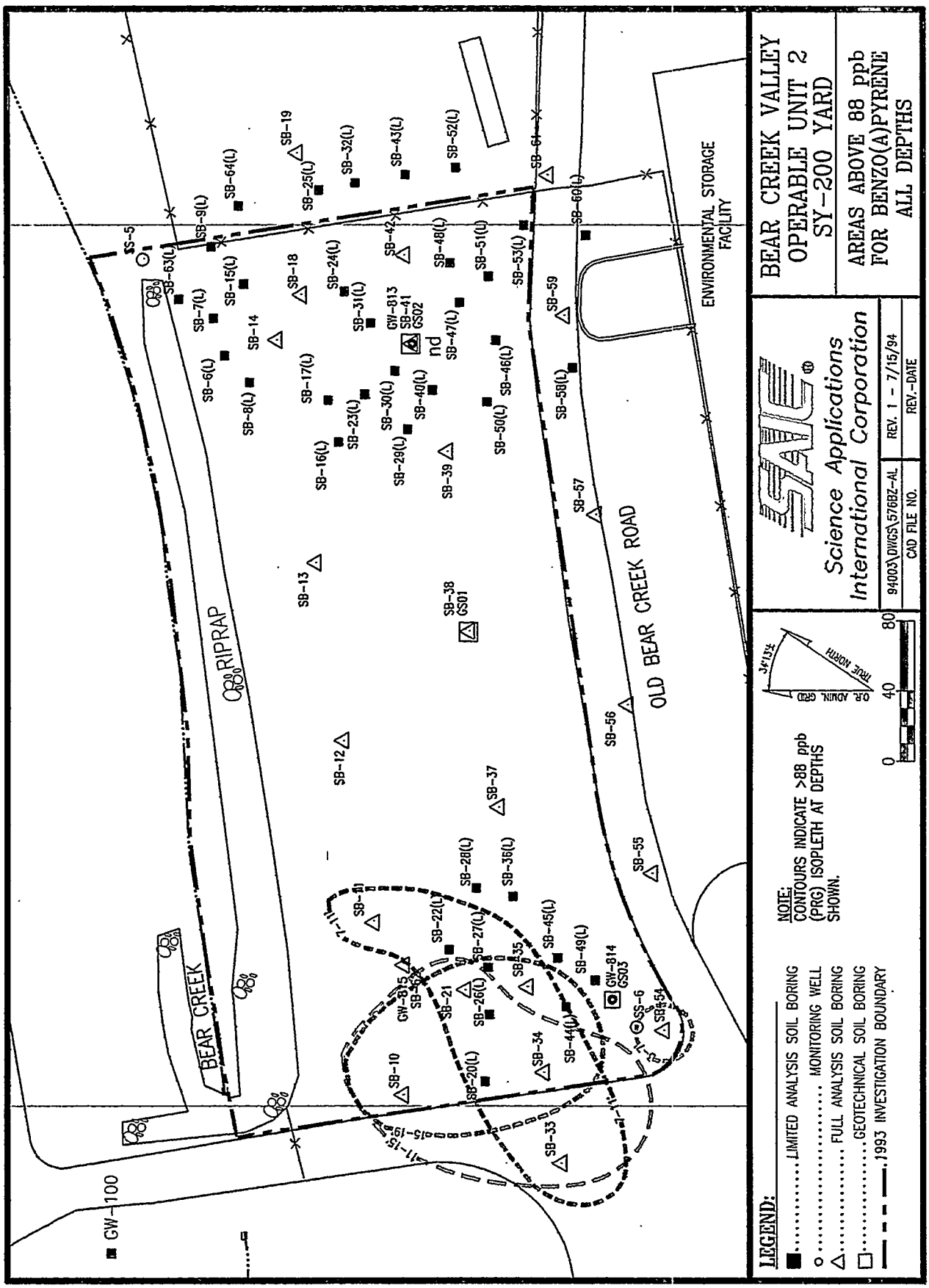


Fig. 3.46. Areas above 88 ppb for benzo(a)pyrene at all depths.

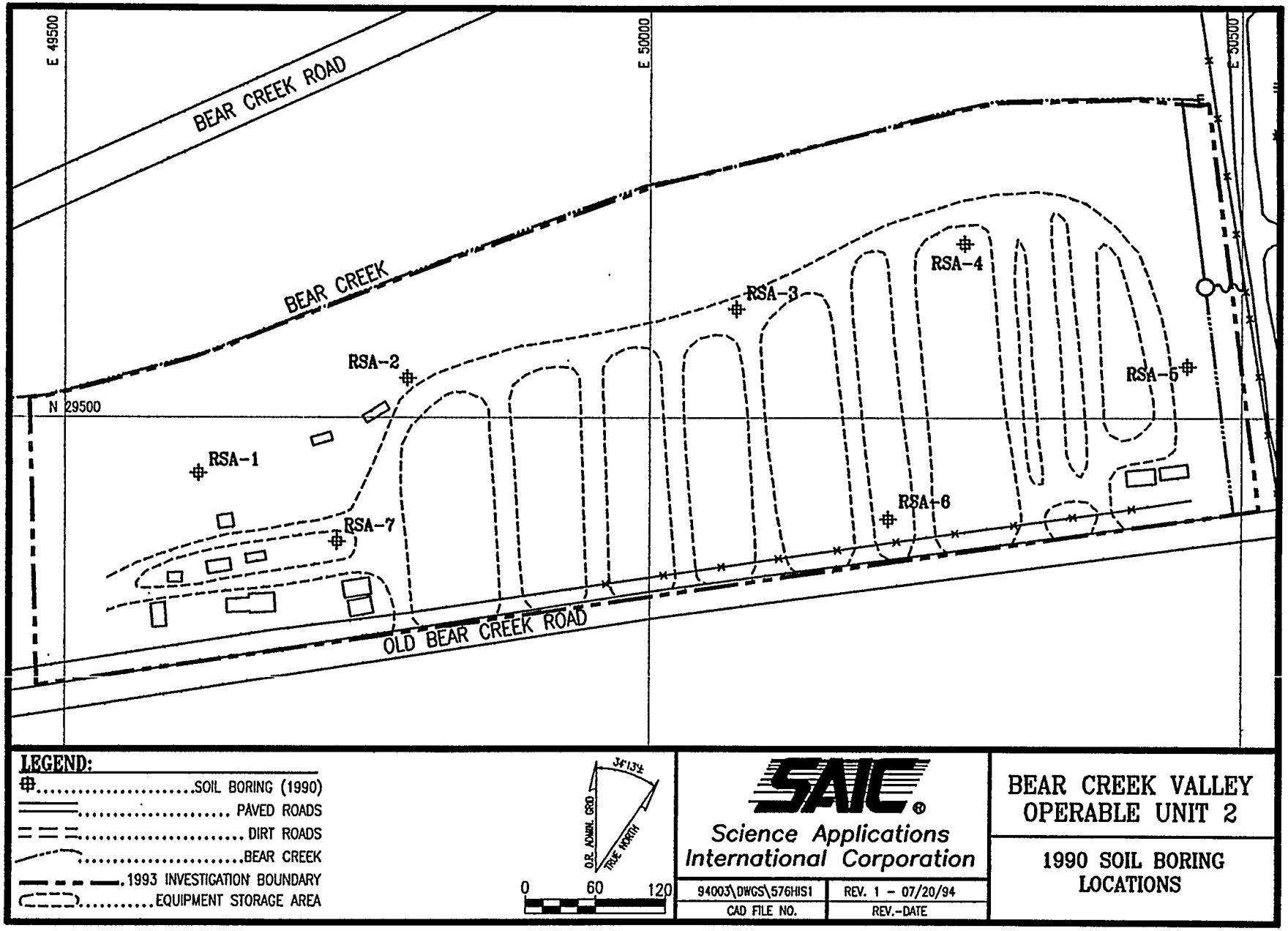


Fig. 3.47. 1990 soil boring locations.

Subsurface soil samples were recovered from five sites along two perpendicular transects across the center of the site during this RI (Fig. 3.48). The intent of this sampling effort was to verify the nature and extent of contamination revealed by previous sampling at the site boundaries. Environmental samples were recovered from the ground surface to refusal or groundwater, whichever was encountered first, and were analyzed for VOCs, SVOCs, pesticides and PCBs, metals-cyanide, and gross alpha, beta, and isotopic uranium (see Table 3.23).

The lithology of the soil was described from subsurface soil samples recovered from five sites. A detailed log was completed and maintained for each of the soil borings (Appendix A). Maximum sample depth of 36.9 ft below ground surface was reached in SB-03.

Figure 3.49 shows the cross sections of the RSA. Cross section A-A′ (Fig. 3.50) shows that the site is underlain by brown clay with chert fragments and pockets of yellowish-red to brown fill material containing limestone fragments, large wood fragments, plant detritus, chert fragments, electrical wire, sand-filled wood fragments, concrete fragments, organic debris, bricks, mortar, and rounded quartz pebbles. Additional cross sections support this and are presented in Appendix A. These pockets of "dirty fill" occur throughout the site and to depths of 30 ft below ground surface. SB-03 and -02 are believed to have refused on the weathered bedrock.

Historic soil samples were taken from 5-ft intervals from the surface in the RSA. To compare the historical data to the RI-derived data, the historical data were converted to values for 4-ft intervals from the surface. The reported concentrations were assumed to be representative of the entire sample interval. Weighted averages were calculated for 4-ft intervals from the historic data.

A comparison of historical and BCV OU 2 RI sample data indicated 89 analytes were present in the RSA soils at levels above background. Twenty-six of these analytes warranted further discussion based on criteria presented in Sect. 3.2.4.2. The nature and extent of contamination by these COPCs are presented in the following sections.

Metals. A comparison of BCV OU 2 RI and historical sample data to background data resulted in the identification of 17 metals as COPCs. Beryllium was the only metal COPC to be detected at concentrations above PRGs.

Beryllium was detected in all 47 samples recovered from the RSA with 46 above the PRGs (Table 3.25). The maximum level of beryllium contamination (3 ppm) was detected in SB-03 at the sample interval 32–36 ft below ground surface.

Beryllium was detected throughout the lateral and vertical extent of the RSA sampling area at concentrations above the 0.15 ppm PRG (Fig. 3.51). Only small isolated areas in the RSA were below the PRG. Comparison of the site UCL to the range of background concentrations indicates levels were less than an order of magnitude greater than background maximum. Plan view maps indicate only small areas above background levels exist across the site (Appendix A).

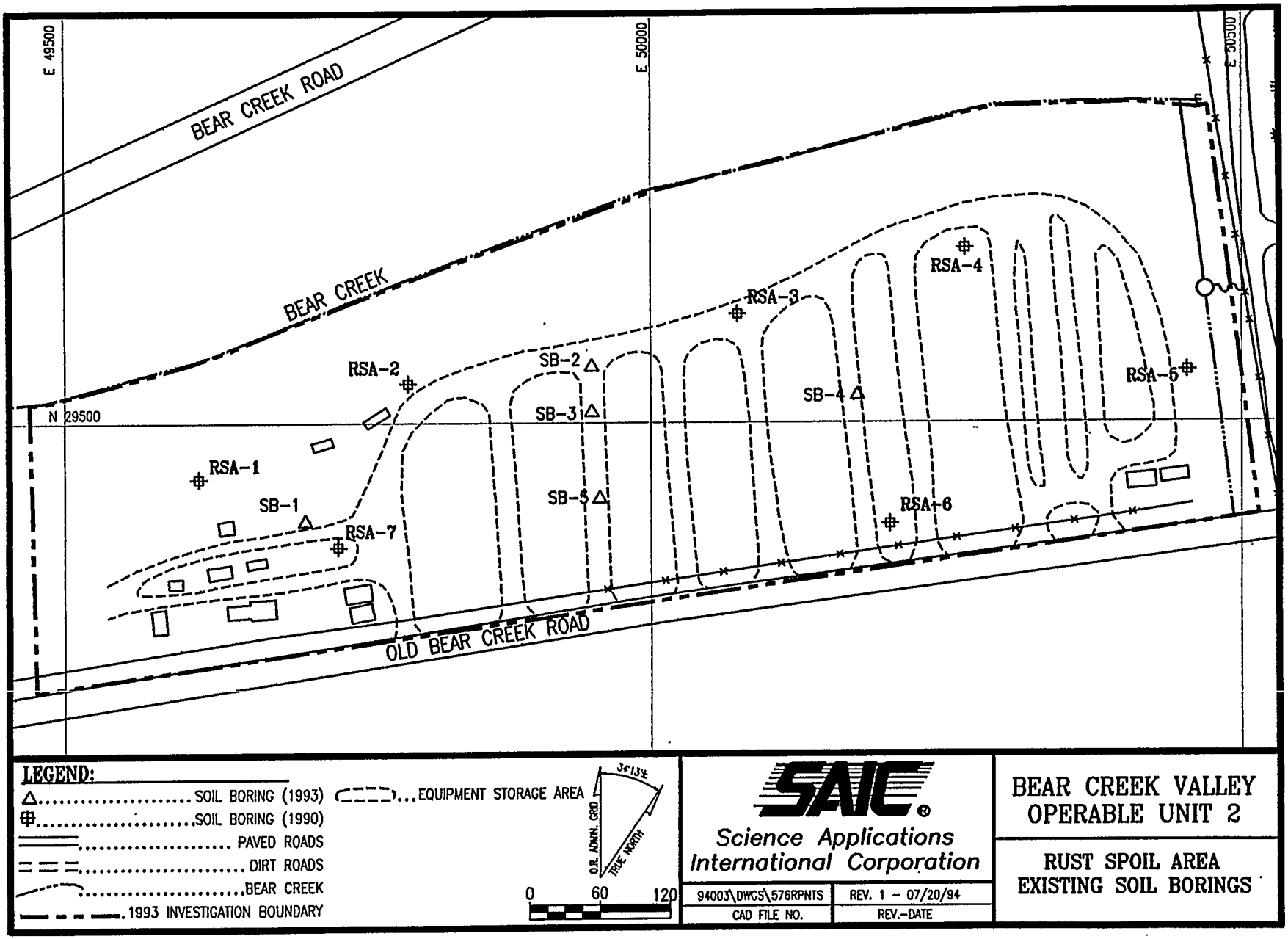


Fig. 3.48. RSA existing soil borings.

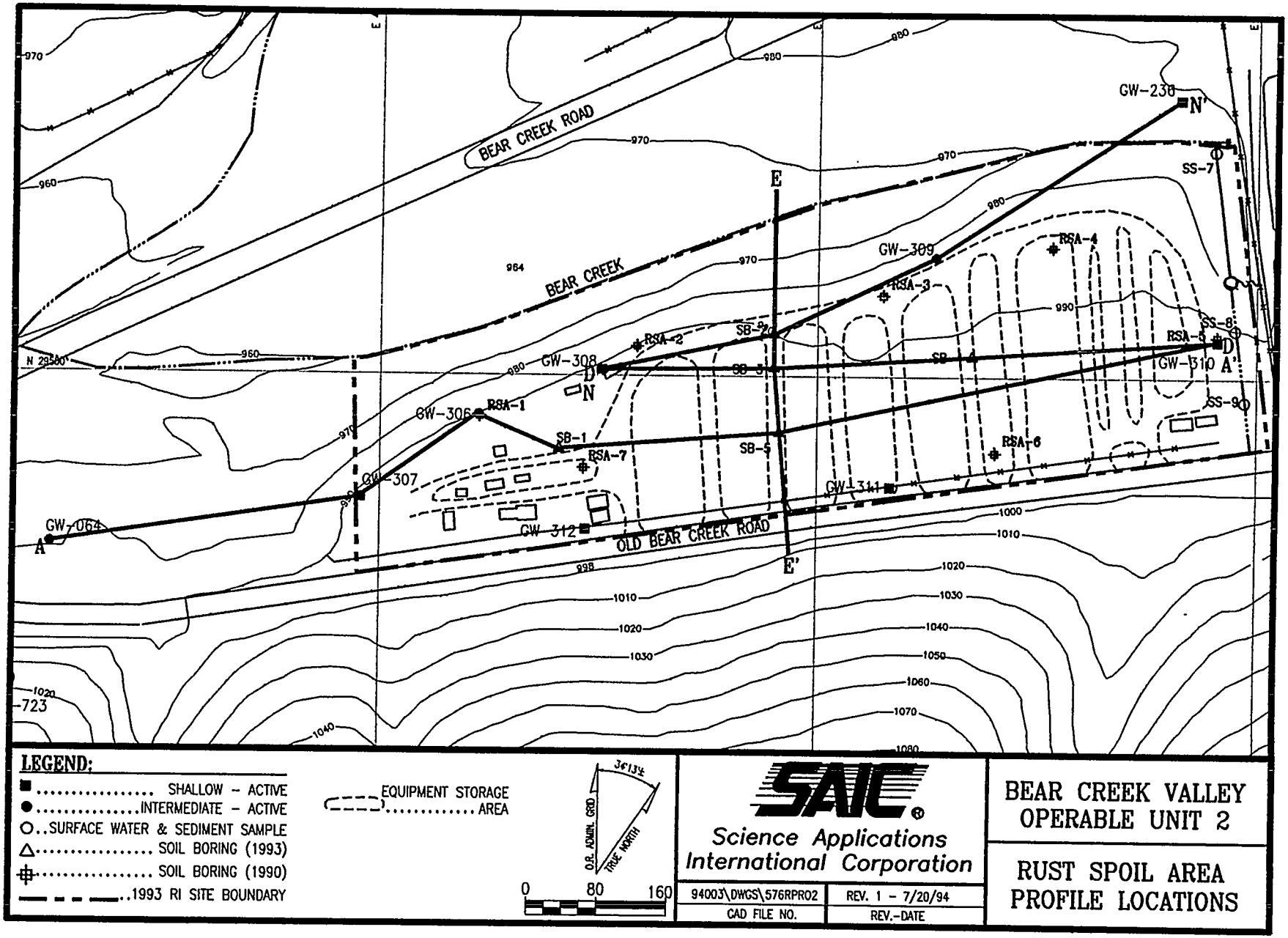


Fig. 3.49. RSA profile locations.

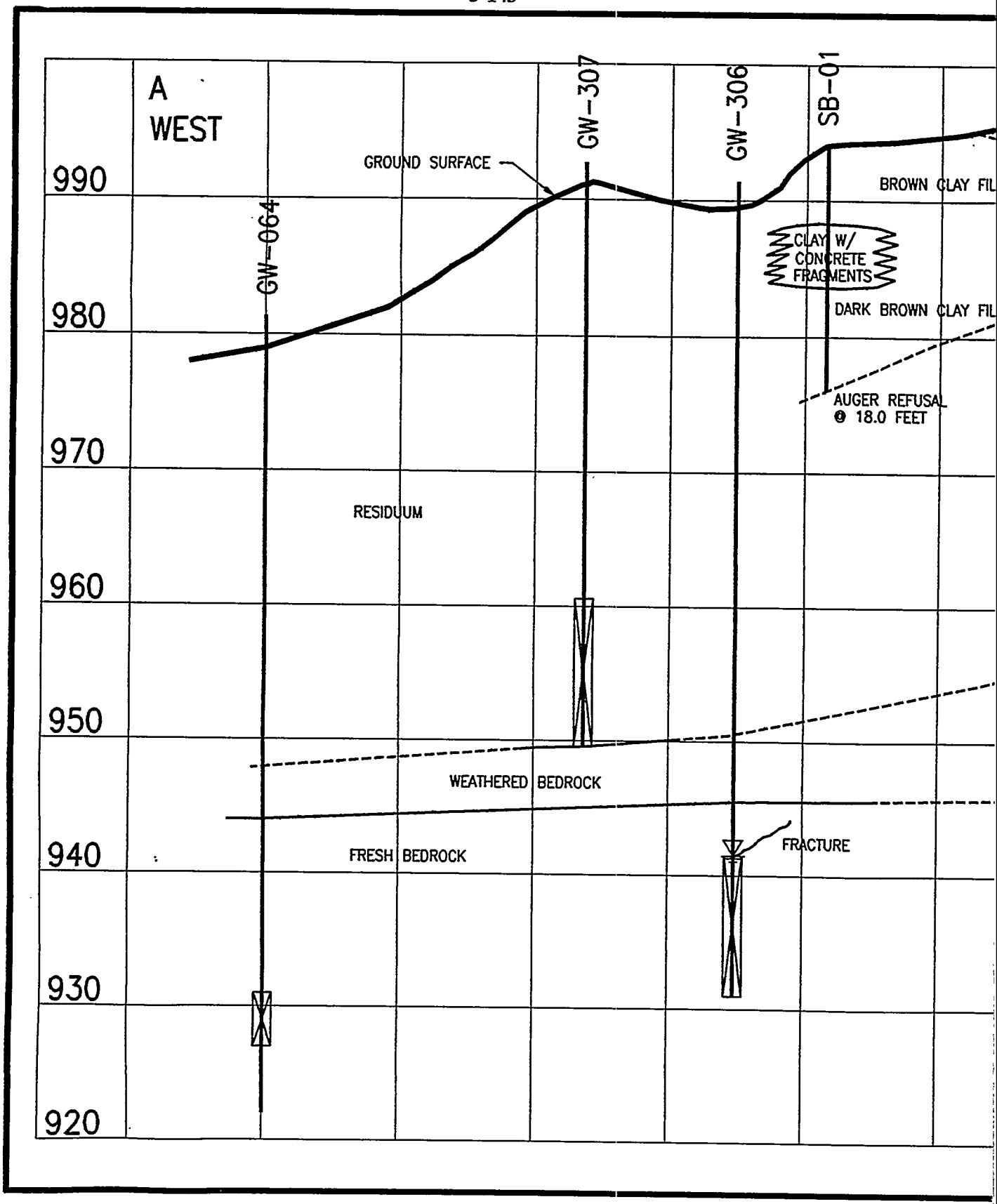
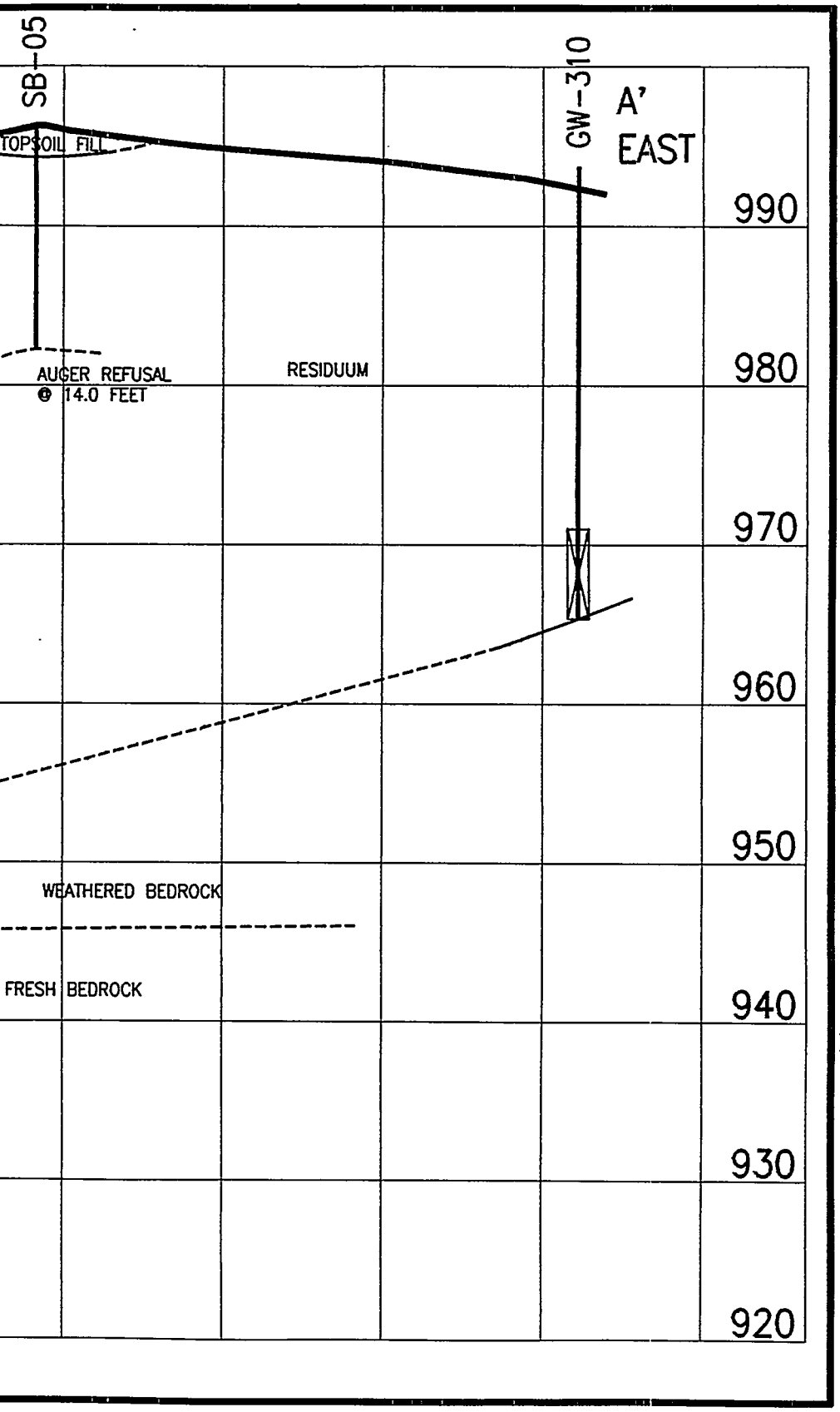


Fig. 3.50. RSA prof



LEGEND:

GW.....MONITORING WELL
SB.....SOILBORING
GROUNDWATER ENCOUNTERED IN BOREHOLE
.....SCREENED INTERVAL
.....TOTAL DEPTH OF HOLE

0 2 4 6 8 10 20
VERTICAL SCALE: 1" = 10'

0 50 100 150 300
HORIZONTAL SCALE: 1" = 150'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
RUST SPOIL AREA PROFILE A-A'
SOIL LITHOLOGY

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	03-13-94
1	B. HADDEN	S. REID	07-15-94

XREFERENCES	PLOT FILES
	/94003/PLOT/576PR09.PLT

SHT 1 OF 1 (DRAWING #) | /94003/DWGS/576PR09 (CAD FILE #) | N/A (ROT. ANGLE)

A-A' soil lithology.

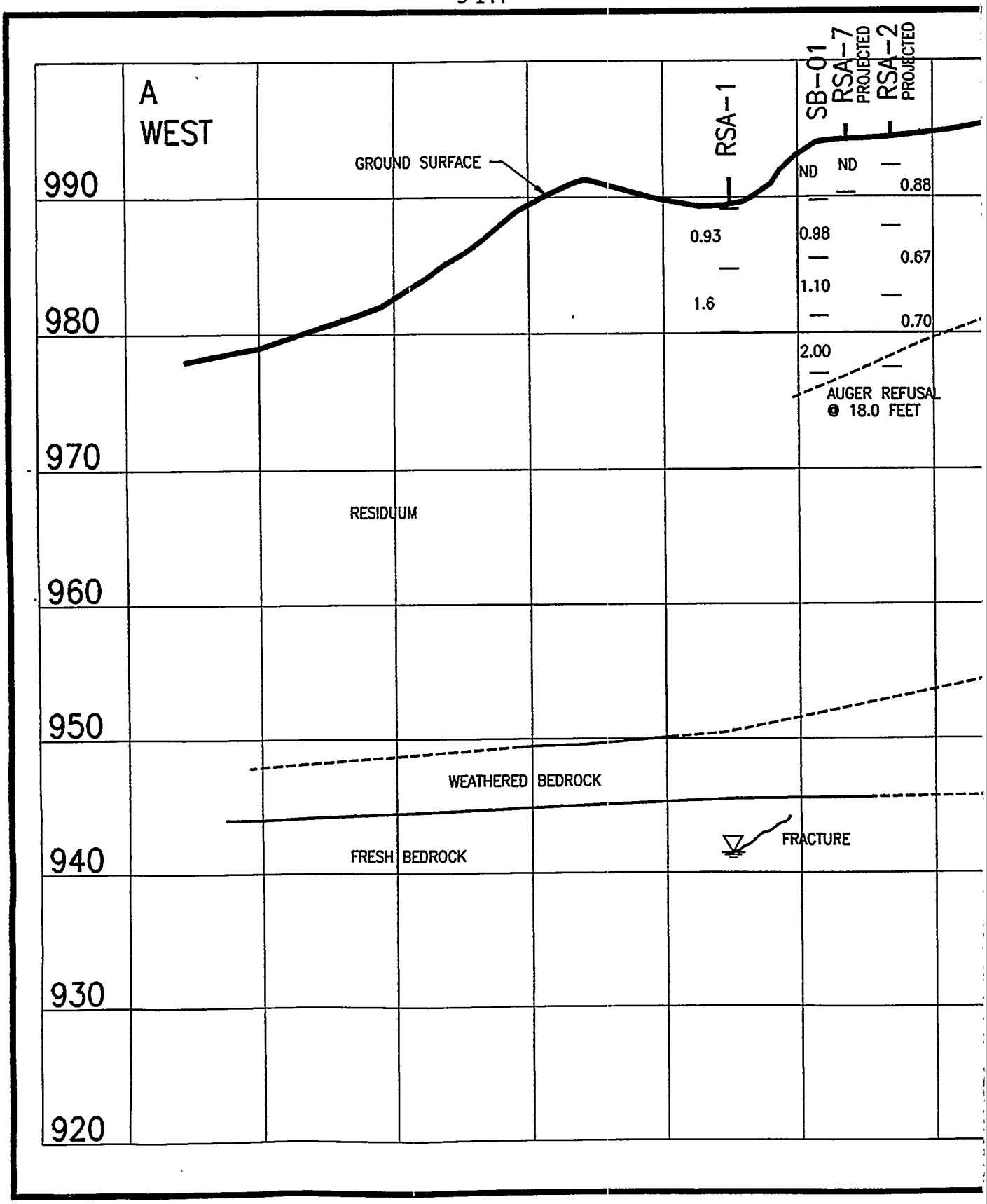
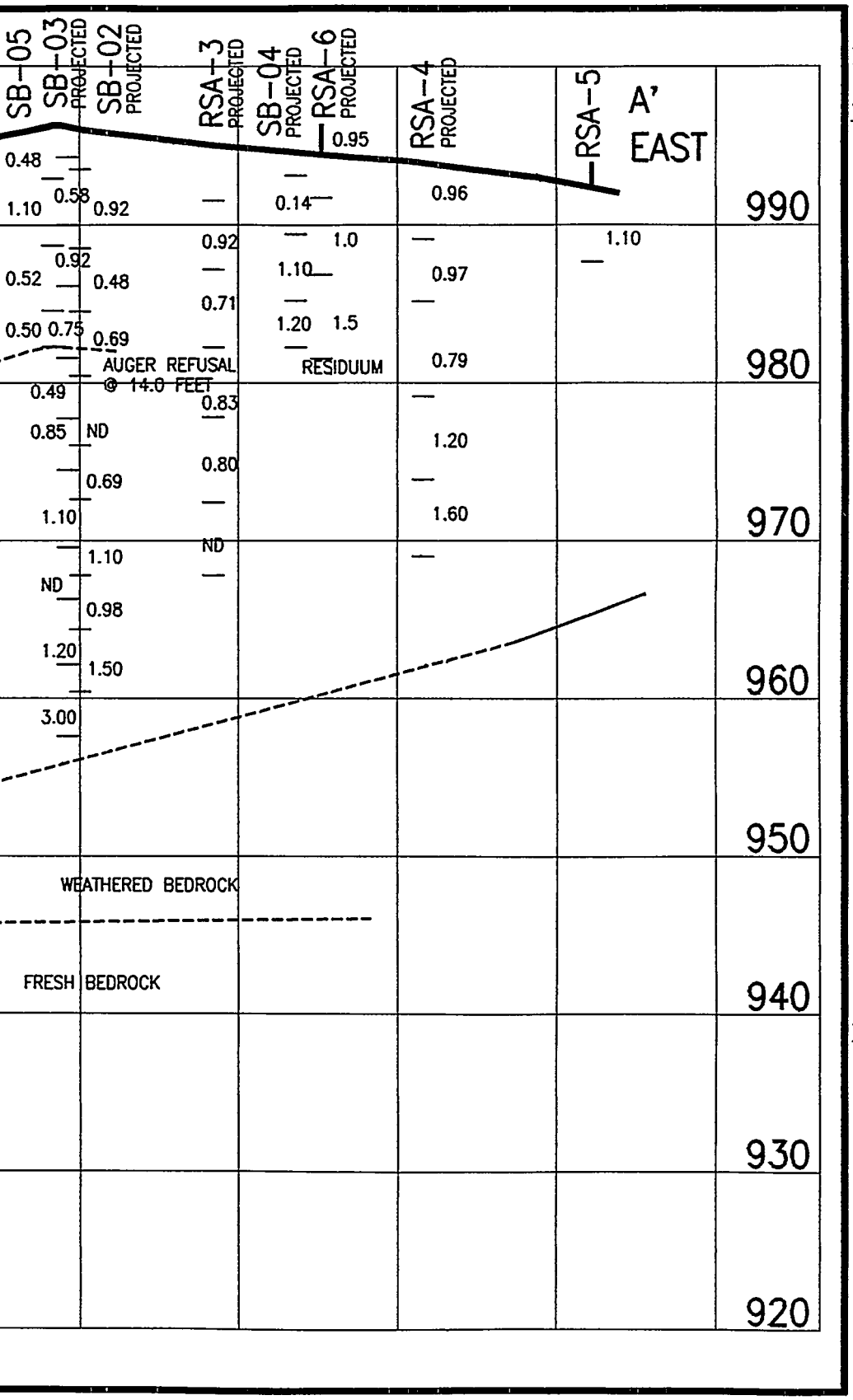


Fig. 3.51. RSA pro



LEGEND:

GW..... MONITORING WELL
SB..... SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE

0 2 4 6 8 10 20
VERTICAL SCALE: 1" = 10'

0 50 100 150 300
HORIZONTAL SCALE: 1" = 150'

SAIC®
Science Applications International Corporation

BEAR CREEK VALLEY OU2
RUST SPOIL AREA PROFILE A-A'
BERYLLIUM (ppm)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	05-05-94
1	J. HOY	S. REID	07-20-94

XREFERENCES	PLOT FILES
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SHT 2 OF 5 DRAWING # | /94003/DWGS/667PROA CAD FILE # | N/A ROT. ANGLE

e A-A′ beryllium (ppm).

Table 3.25. Soil data summary for BCV OU 2 sites at RSA, comparison to PRGs and soil background data[a]

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				Metals (ppm)					
Antimony	ND[d]			2.3E-01	4.3E-01	2.1E-01	1.1E+02 (TI)	0/18	B
Barium	9.1E+00	1.4E+01	2.1E+01	1.9E+01	1.1E+03	1.7E+02	1.9E+04 (TI)	0/47	B, F
Beryllium	6.2E-01	9.6E-01	2.0E+00	1.4E-01	3.4E+00	1.2E+00	1.5E-01 (CI)	46/47	A, F
Cadmium	ND[d]			3.6E-01	3.4E+01	1.7E+01	2.7E+02 (TI)	0/47	B, F
Calcium	1.5E+02	2.2E+02	4.6E+02	7.2E+01	1.6E+05	1.4E+05			B, E
Cobalt	4.2E+00	4.2E+00	6.1E+01	4.6E+00	6.6E+01	2.1E+01			B, F
Cyanide	ND[d]			1.0E-01	2.5E+01	1.2E+00	5.5E+03 (TI)	0/39	
Lead	3.1E+01	3.9E+01	4.2E+01	9.1E+00	5.6E+02	5.5E+01			
Magnesium	3.4E+02	7.2E+02	1.4E+03	5.5E+02	3.4E+04	8.0E+03			E
Manganese	8.5E+01	1.1E+02	1.1E+02	1.5E+02	7.6E+03	1.3E+03	3.8E+04 (TI)	0/47	B, F
Mercury	1.5E-01	3.0E-01	7.2E-01	6.0E-02	3.1E+01	5.1E+00	8.2E+01 (TI)	0/47	F
Nickel	1.3E+01	2.1E+01	2.7E+01	7.8E+00	3.1E+02	3.6E+01	5.5E+03 (TI)	0/47	F
Niobium	ND[d]			7.3E-01	7.9E+01	3.7E+00			B
Potassium	6.1E+02	1.0E+03	1.5E+03	5.9E+02	6.8E+03	2.3E+03			B, E
Silver	ND			5.1E-01	6.8E+01	2.0E+00	1.4E+03 (TI)	0/47	
Thallium	ND			1.2E-01	4.4E-01	1.9E-01			F
Thorium	ND			2.1E+01	2.3E+03	1.1E+02			F

Table 3.25 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				Pesticide/PCB compounds (ppb)[e]					
Aroclor-1254				3.5E+01	8.9E+03	3.6E+02	8.3E+01 (CI)	4/21	F
Aroclor-1260				5.0E+01	5.0E+01	6.1E+01	8.3E+01 (CI)	0/20	D
Endosulfan I				6.5E-01	6.5E-01	2.9E+00	1.6E+06	0/20	D, F
Heptachlor				6.3E-01	9.8E-01	2.6E+00	1.4E+02	0/22	D
p,p′-Methoxychlor				1.5E+00	1.5E+00	3.4E+01	1.4E+06 (TI)	0/20	D
				SVOCs (ppb)					
1,2,4-Trichlorobenzene				4.3E+04	4.3E+04	7.6E+02	2.7E+06 (TI)	0/27	C, F
1,2-Dichlorobenzene				3.6E+02	3.6E+02	2.2E+02	2.5E+07 (TI)	0/27	C, F
2,4-Dimethylphenol				3.4E+02	3.4E+02	2.2E+02	5.5E+03 (TI)	0/27	C
2-Methylnaphthalene				6.4E+01	2.7E+02	2.2E+02			F
4-Methylphenol				5.2E+02	5.2E+02	2.3E+02	1.4E+06	0/27	C
4-Nitrophenol				1.2E+02	1.2E+02	5.6E+02			C, D
Acenaphthene				4.6E+01	2.9E+02	2.4E+02	1.6E+07 (TI)	0/27	
Acenaphthylene				5.3E+01	1.0E+02	2.3E+02			D, F
Anthracene				5.7E+01	6.5E+02	2.5E+02	8.2E+07 (TI)	0/26	
Benzo(a)anthracene				4.2E+01	2.5E+03	5.3E+02	8.8E+02 (CI)	3/26	A, F
Benzo(a)pyrene				5.8E+01	1.9E+03	4.5E+02	8.8E+01 (CI)	7/27	A, F
Benzo(b)fluoranthene				5.5E+01	1.9E+03	4.4E+02	8.8E+02(CI)	2/27	A, F
Benzo(g,h,i)perylene				5.6E+01	1.7E+03	4.5E+02			F

Table 3.25 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
Benzo(k)fluoranthene				5.9E+01	1.3E+03	3.8E+02	8.8E+03 (CI)	0/27	
bis(2-Ethylhexyl)phthalate				4.3E+01	4.1E+04	7.5E+02	4.6E+04 (CI)	0/27	F
Butylbenzylphthalate				7.3E+01	7.3E+01	2.1E+02	5.5E+07 (TI)	0/26	C, D
Carbazole				5.1E+01	3.0E+02	2.3E+02	3.2E+04 (CI)	0/26	
Chrysene				5.6E+01	2.4E+03	4.8E+02	8.8E+04 (CI)	0/26	
Di-n-butylphthalate				8.3E+02	2.8E+03	9.7E+02	2.7E+07 (TI)	0/27	
Di-n-octylphthalate				8.0E+02	8.0E+02	2.4E+02	5.5E+06 (TI)	0/27	C
Dibenzo(a,h)anthracene				9.5E+01	8.8E+02	2.8E+02	8.8E+01 (CI)	7/27	A, F
Dibenzofuran				3.8E+01	1.6E+02	2.3E+02			D, F
Dimethylphthalate				8.0E+01	1.8E+02	2.0E+02			D
Fluoranthene				4.5E+01	3.3E+03	8.4E+02	1.1E+07 (TI)	0/26	
Fluorene				5.5E+01	2.9E+02	2.3E+02	1.1E+07 (TI)	0/27	
Indeno(1,2,3-c,d)pyrene				4.5E+01	2.0E+03	4.7E+02	8.8E+02 (CI)	2/27	
Naphthalene				7.2E+01	2.1E+02	2.1E+02			F
Pentachlorophenol				4.7E+01	4.7E+01	6.0E+02	5.3E+03 (CI)	0/26	C, D
Phenanthrene				4.4E+01	1.9E+03	5.3E+02			F
Phenol				2.5E+03	2.5E+03	3.0E+02	1.6E+08 (TI)	0/27	C
Pyrene				3.9E+01	4.6E+03	1.1E+03	8.2E+06 (TI)	0/26	

Table 3.25 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				VOCs (ppb)					
1,1,1-Trichloroethane				1.2E+01	1.7E+02	2.3E+01			B, F
1,1,2,2-Tetrachloroethane				1.2E+01	3.7E+01	1.9E+01			
1,1,2-Trichloro-1,2,2-trifluoroethane				2.7E+01	3.2E+04	6.2E+02	8.2E+09 (TI)	0/28	
1,1,2-Trichloroethane				1.2E+01	3.7E+01	1.8E+01			
1,1-Dichloroethane				1.0E+01	6.4E+02	2.7E+01	2.7E+07 (TI)	0/48	B
1,1-Dichloroethene				1.2E+01	5.1E+01	2.0E+01	1.1E+03 (CI)	0/48	
1,2-Dichloroethane				3.0E+00	3.7E+01	1.8E+01	7.0E+03 (CI)	0/48	
1,2-Dichloroethene(total)				4.0E+00	1.1E+05	1.7E+02	2.5E+06 (TI)	0/48	B
1,2-Dichloropropane				1.2E+01	3.7E+01	1.8E+01			
2-Butanone				5.0E+00	2.7E+02	4.6E+01	1.6E+08 (TI)	0/48	
2-Hexanone				1.1E+01	7.6E+01	3.2E+01			
4-Methyl-2-pentanone				5.0E+00	2.1E+02	4.0E+01	1.4E+07 (TI)	0/47	B
Acetone				1.4E+01	2.6E+03	1.1E+03	2.7E+07 (TI)	0/48	B
Benzene				1.0E+01	3.7E+01	1.8E+01	2.2E+04 (CI)	0/48	
Bromodichloromethane				1.2E+01	3.7E+01	1.8E+01			B
Bromoform				1.2E+01	3.7E+01	1.8E+01			
Bromomethane				2.4E+01	7.6E+01	3.1E+01			
Carbon disulfide				2.0E+00	3.7E+01	2.0E+01	2.7E+07 (TI)	0/48	
Carbon tetrachloride				1.2E+01	3.7E+01	1.8E+01			B

Table 3.25 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
Chlorobenzene				7.0E+00	3.7E+01	1.9E+01	5.5E+06 (TI)	0/46	
Chloroethane				2.1E+01	7.6E+01	3.2E+01			
Chloroform				1.2E+01	7.9E+01	2.1E+01	1.0E+05 (CI)	0/48	B
Chloromethane				2.4E+01	7.6E+01	3.1E+01			
cis-1,3-Dichloropropene				1.2E+01	3.7E+01	1.8E+01			
Dibromochloromethane				1.2E+01	3.7E+01	1.8E+01			
Ethylbenzene				5.0E+00	2.8E+02	2.2E+01	2.7E+07 (TI)	0/47	
Methylene chloride				8.0E+00	5.8E+04	1.3E+02	8.5E+04 (CI)	0/48	
Styrene				1.2E+01	3.7E+01	1.9E+01			
Tetrachloroethene				3.0E+00	4.0E+05	1.3E+03	2.7E+06 (TI)	0/48	F
Toluene				1.0E+00	7.5E+02	2.9E+01	5.5E+07 (TI)	0/48	
Trans-1,3-dichloropropene				1.2E+01	3.7E+01	1.8E+01			
Trichloroethene				4.0E+00	1.0E+05	1.3E+02	5.8E+04	1/48	B, F
Vinyl acetate				2.4E+01	7.6E+01	3.3E+01			B
Vinyl chloride				2.4E+01	7.6E+01	3.1E+01			
Xylene, total				9.0E+00	4.6E+02	2.8E+01			
				Other analyses (ppm)					
Phosphorus				2.4E+02	2.3E+03	1.3E+03	5.5E+00	20/20	E
Total uranium				2.0E+00	1.2E+01	6.6E+00	8.2E+02	0/20	B

Table 3.25 (continued)

Compound	Background			Site			PRG	No. detects >PRG	Comments
	Minimum[b]	Maximum[b]	UCL[c]	Minimum[b]	Maximum[b]	UCL			
				Radionuclides (pCi/g)					
Gross alpha	NA			1.5E+00	1.8E+01	1.0E+01			B
Gross beta	NA			1.9E+00	5.6E+01	3.3E+01			B
^{234}U	1.7E+00	2.6E+00	2.8E+00	9.6E-01	7.9E+00	2.9E+00	4.8E+01	0/27	

[a] Generated by program PRGMERG.SAS on 20 Apr 94. Background data are for Copper Ridge Horizon C from the ORR Background Soil Characterization Project, DOE 1993a.
[b] Minima and maxima represent actual detected values.
[c] Upper 95% Confidence Limit (UCL) for the mean, calculated assuming a lognormal distribution unless the data fit a normal distribution.
[d] Not detected in the background soil study.
[e] Background data not used for organic compounds.
A = Over PRG
B = Analyte is COPC in groundwater
C = Outlier
D = UCL >maximum
E = Essential nutrient
F = Potential human health concern
PRGs are residential (TI) Toxic Ingestion or (CI) Carcinogic Ingestion

The extent of vertical contamination was not well defined due to refusal within the sampling zone. Beryllium concentrations increase with depth in seven of nine boreholes in the RSA. Data were unavailable for characterization of contamination below sampler refusal and consequently borehole contamination maxima for most sample sites are not available. Contamination levels at sampler refusal depths were above PRGs. SB-03 had increased concentrations from the first appearance to a maximum of 3 ppm in the sample interval 32–36 ft below ground surface. It is unlikely that contamination terminates at the maximum borehole penetration and therefore the extent of vertical contamination for beryllium was not completely characterized. It is likely, however, that native soils have higher beryllium concentrations as determined for the SA-1 and the SY-200 Yard sites.

Barium, cobalt, manganese, and nickel were detected in all 74 samples recovered from the RSA. Cobalt, manganese, and nickel were detected in samples from all historic investigations and this RI. Nickel was detected in all borings except RSA-1, -2, and -7. These four analytes were generally detected from ground surface to a maximum depth of 36 ft in SB-03. Maximum concentrations of barium, cobalt, and manganese were recovered from the 24–28 ft below ground surface interval of SB-02 at concentrations of 1090, 55.2, and 7600 ppm, respectively. Maximum nickel concentrations (57.1 ppm) for the site were detected in the sample from the 32–36 ft below ground surface interval of SB-03. Maximum barium concentrations were two orders of magnitude below the PRG while manganese and nickel maxima were one order of magnitude less than their respective PRGs. A PRG for cobalt was not available but concentrations were roughly background.

Cadmium was detected in 28 of 74 samples distributed among all boreholes excluding RSA-2 and SB-02 to a maximum depth of 25 ft below ground surface in RSA-4. The site maximum concentration of 7.3 ppm was detected in the 20- to 25-ft below ground surface interval of RSA-4. Background concentrations were not available for comparison, but the site maximum was an order of magnitude below the PRG of 270 ppm.

Mercury was detected in all RI soil borings, RSA-3, and -4. Detectable concentrations were generally restricted to the top 5-12 ft of each borehole but was found at a maximum depth of 20 ft below ground surface in RSA-4. The maximum concentration of 30.9 ppm was detected in the sample from 20 to 24 ft below ground surface in SB-02. The site UCL is within one order of magnitude of the background UCL (Table 3.25) and below the 82 ppm PRG.

Thallium concentrations were restricted to SB-02, -03, -04, and -05 with a maximum concentration of 0.63 ppm detected in the sample collected from the 32- to 36-ft below ground surface interval. This interval was also the maximum depth at which thallium was detected. Background concentrations (95% UCB) for surrounding soils ranged from 0.410 to 0.563 ppm. The site maximum is therefore approximately background.

Thorium was detected in all 20 samples with 19 reported as below detection limits. A concentration of 31 ppm was detected in RSA-6 from 10 to 15 ft below ground surface. A background concentration and PRG were not available for comparison. However, because the concentrations are below detection limits, it is not considered environmentally significant.

PCB contamination was confined to the top 12 ft of soil in four of the five boreholes sampled for this RI (Fig. 3.52). SB-03, however, had an anomalous PCB contamination distribution as contamination was not detected at depths of <32 ft below ground surface but was detected in soil from 32 to 36 ft below ground surface but at a concentration less than the PRG. Areas of elevated concentrations were isolated vertically and laterally. Only small areas were above the PRG for each interval sampled. Contour maps showing the PRG isopleth and cross sections are presented in Appendix A.

Organics

Aroclor-1254 was greater than background in 6 of 21 samples recovered during this RI (historic data were not available). Historic samples were not analyzed for PCB contamination and are not discussed. Of the six detects, four surpassed the PRG of 83 ppb. The highest concentration (8900 ppb) was recorded for the sample taken from the 0- to 4-ft interval below ground surface from SB-05 (Fig. 3.52). Isolated detects were identified from 4 ft to 8 ft below ground surface. The other samples that exceeded PRGs were recovered from SB-01 and -02.

Phosphorus was detected in samples collected during previously implemented projects at the RSA. Table 3.25 indicates concentrations ranged from 240 to 2300 ppm and all detects were above the 5.5 ppm PRG. The 5.5 ppm PRG was calculated for elemental phosphorus (white metal). It is unlikely the phosphorus detected in the historical sampling is the result of pure white-metal phosphorus; it is more likely a result of phosphatic compounds and, therefore, the PRG does not apply. Phosphates are essential nutrients in the soil and, therefore, the phosphorus detects are not environmentally significant. Background data for comparison do not exist.

SVOCs. Comparison of BCV OU 2 RI and historic sample data indicated 31 SVOCs were present in concentrations above background. Five PAHs were present in concentrations above the PRGs. Eight other analytes were of special interest due to human health risks. The nature and extent of these analytes are discussed in the following sections. Thirteen of these analytes were identified as COPCs that warranted further evaluation based on the criteria discussed in Sect. 3.2.4.2.

PAHs detected at concentrations above the respective PRGs were benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(b)fluoranthene, indeno(1,2,3-c,d)pyrene, and benzo(a)-anthracene and are discussed in the following text.

Benzo(a)pyrene was detected in 10 of 27 samples of which 7 were above the PRG. Concentrations above the PRG were restricted to boreholes SB-02 and -03 (Fig. 3.52).

Benzo(a)pyrene was detected at a maximum depth of 28 ft below ground surface in SB-02 and at a maximum concentration of 1900 ppb in SB-03 from 12 to 16 ft below ground surface. Vertical distribution is in isolated zones. Small isolated areas of elevated concentrations exist in the SB-02 and -03 area. Cross sections showing areas above the PRG are presented in Appendix A.

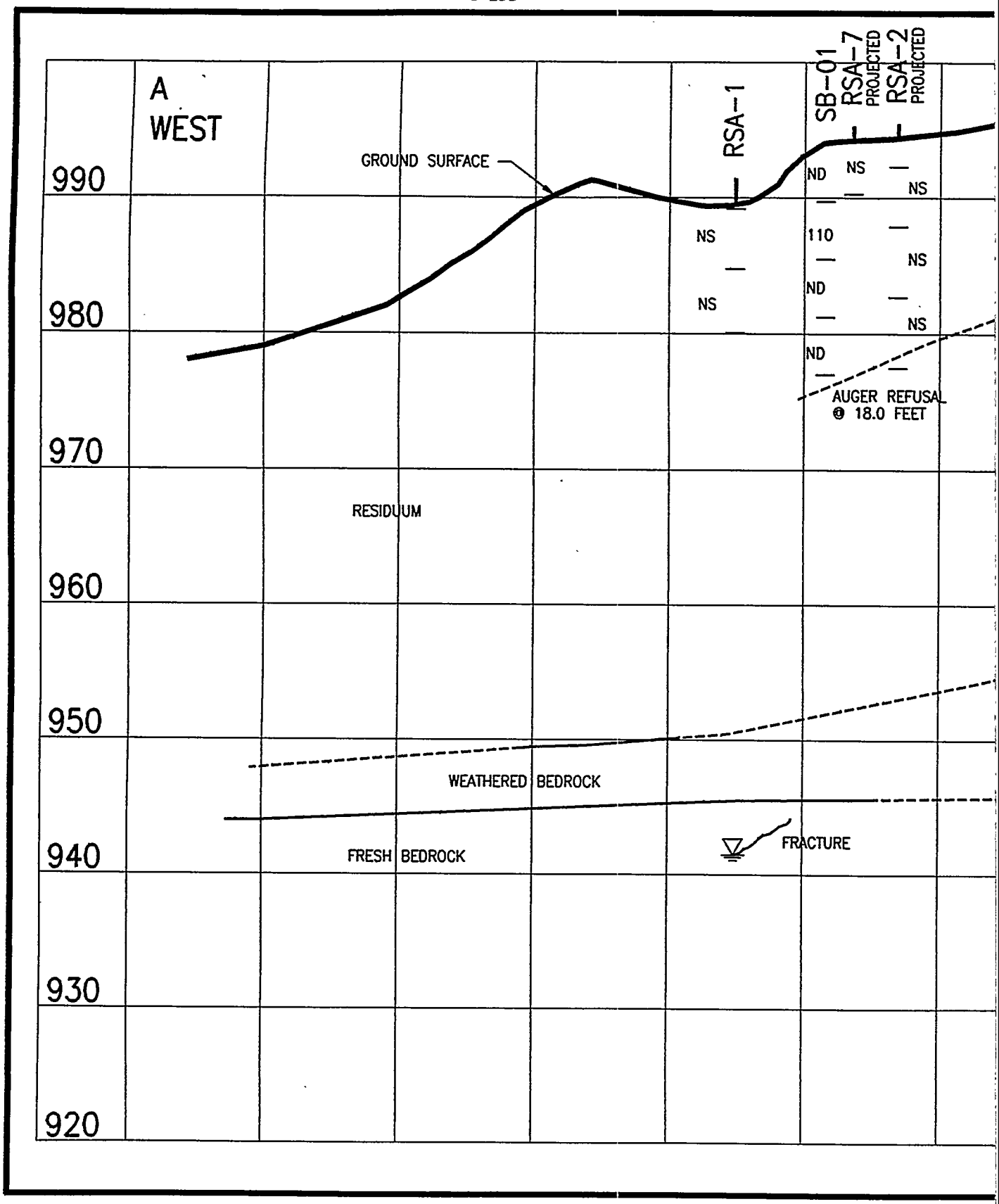
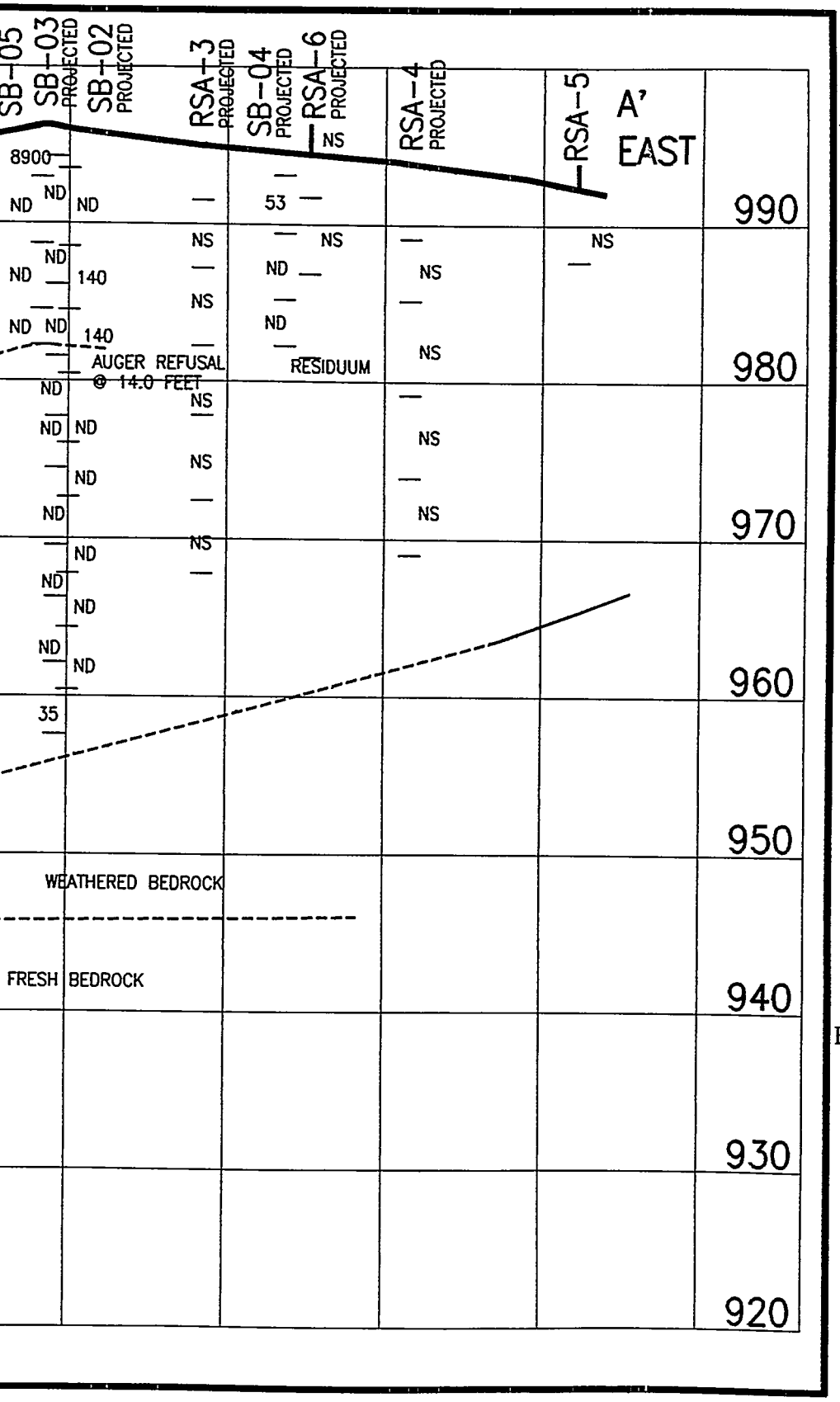


Fig. 3.52. RSA prof



LEGEND:

GW..... MONITORING WELL
SB.....SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE

0 2 4 6 8 10 20

VERTICAL SCALE: 1" = 10'

0 50 100 150 300

HORIZONTAL SCALE: 1" = 150'

Science Applications International Corporation

BEAR CREEK VALLEY OU2
RUST SPOIL AREA PROFILE A-A'
TOTAL AROCLOR

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	05-05-94
1	J. HOY	S. REID	07-20-94

XREFERENCES	PLOT FILES
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SHT 3 OF 5 (DRAWING #) | /94003/DWGS/667PR0A (CAD FILE #) | N/A (ROT. ANGLE)

A-A′ total aroclor.

Dibenzo(a,h)anthracene was detected above the PRGs in 7 of 27 samples. Concentrations above PRGs were restricted to SB-02 and -03 for dibenzo(a,h)anthracene. Dibenzo(a,h)-anthracene was detected at a maximum depth of 24 ft below ground surface in SB-02 and at a maximum concentration of 880 ppb in SB-03.

Benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene concentrations were greater than background in 11 of the 27 samples recovered from the RSA during the RI. Samples from the 8- to 12-ft and 12- to 16-ft below ground surface intervals in SB-03 had concentrations of both compounds greater than the PRGs. Site maxima for benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene were identified in SB-03 from 12 to 16 ft below ground surface at 1900 and 2000 ppb, respectively. Concentrations above background but less than PRGs were identified in SB-01, -02, -03, and -04 for each analyte. Detects of one of these analytes were always associated with a detect of the other within the same sample interval. In addition, concentrations of the two analytes in a discrete sample were identical or varied <100 ppb with the exception of the 4- to 8-ft below ground surface interval in SB-02.

Benzo(a)anthracene was detected in 13 of 26 samples at concentrations above background. However, the PRG was only exceeded in 3 of the 26 samples. The maximum detect was identified in the 12- to 16-ft below ground surface interval of SB-03 corresponding to the maxima for benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene. The other two concentrations above the PRG were also from SB-03 and correlate to highs of benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene. All other detects also correlate to detects of benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene with the addition of the 32- to 36-ft below ground surface interval for SB-03 and the 4- to 8-ft below ground surface interval for SB-04. PAHs in concentrations less than PRGs were found in isolated areas of elevated concentrations in the central area of the RSA site centered around SB-03. All site maxima for individual PAH concentrations not listed above were detected in soils recovered from the 16–20 ft below ground surface interval of SB-03 or the 0- to 4-ft interval of SB-05. All were detected at concentrations from 2 to 5 orders of magnitude less than the respective PRGs.

Bis(2-ethylhexyl)phthalate was detected in 18 of 54 samples with 9 exceeding background levels. These detects were distributed about SB-01, -02 and -05 at depths ranging from 0 to 28 ft below ground surface. The maximum concentration (41,000) was detected in the top 4 ft of SB-05.

Dibenzofuran was detected in 6 of 54 samples of which 3 were above background levels. Contamination was restricted to SB-02 and SB-03 and ranged in depth from 4 to 20 ft below ground surface. The maximum level (160 ppb) was detected in the sample taken from 12 to 16 ft of SB-03, but is below the detection limit of 330 ppb (Table 3.6) and is therefore suspect.

VOCs. Thirty-five VOCs were identified as COPCs. Three of these were identified as COPCs that warranted further evaluation based on criteria listed in Table 3.25. The following sections discuss the nature and extent of contamination for these analytes.

Trichloroethene was detected in 22 of 76 samples recovered from the RSA. Samples from SB-01, -04, and -05, and all historic borings had detects; however, all historical data were validated as less than detection limits and therefore not discussed. The maximum (100,000 ppb) and only concentration above the PRG was detected in the sample from SB-05

from 0 to 4 ft below ground surface. SB-05 appears to be in an isolated area of elevated concentration (Fig. 3.53). Volatile samples were taken from the top 2 ft of each sample interval and therefore the 100,000 ppb detect in SB-05 was for soil from 0-2 ft below ground surface. This would have come from the 2-ft thick clean soil cap covering the RSA and suggests a more recent spill event. Trichloroethene was identified as a COPC in groundwater and is a key COPC.

Tetrachloroethene was detected in 36 of 76 samples recovered from the RSA. SB-01, -04, and -05 were again the only RI borings with detected concentrations. All historical samples were below detection limits. Detected concentrations were found in depths that ranged from 0 to 14 ft below ground surface with the maximum concentration (19,000 ppb) at 0 to 4 ft below ground surface (SB-05). This was much lower than the PRG (2.7E+06 ppb).

1,1,1-trichloroethene was detected in 22 of 76 samples. However, only one was a validated detect above detection limits. The sample recovered from 0 to 4 ft below ground surface from SB-05 had a concentration of 170 ppb.

3.2.4.6 Geotechnical sampling

Geotechnical samples were taken using shelby tubes from three sample locations in the SY-200 Yard (see Fig. 3.36) in accordance with ESP-303-5, "Subsurface Soil Sampling with a Shelby Tube," and analyzed for grain-size parameters and hydraulic conductivity. After augering to the desired top depth of the geotechnical sample, the shelby tube was pushed through the hollow stem auger using down pressure from the drill rig boom. Ends of the tube were sealed with paraffin and plastic end caps were placed and secured on each end with duct tape. The geotechnical samples were tagged and labeled in accordance with ER/C-P2302IAD, and custody was maintained from time of recovery until delivery to the laboratory. The samples were stored and shipped in an upright position. Upon receipt of the samples, the laboratory analyzed the samples for grain size distribution and hydraulic conductivity in accordance with ASTM D2217 and SW-846 9100.

A geotechnical investigation was designed and implemented to provide data to support the FS. Geotechnical samples were recovered exclusively from the SY-200 Yard during the implementation of this RI. Samples were collected from three locations within the SY-200 Yard (Fig. 3.54) with 2-ft stainless-steel shelby tubes on a transect oriented roughly northeast-southwest. Sample intervals were 15–17 ft below ground surface, 11–13 ft below ground surface, and 5–7 ft below ground surface.

Results of the geotechnical investigation are shown on Fig. 3.54 and indicate some variation in soil geotechnical parameters. Hydraulic conductivity decreased from 5.5×10^{-8} to 3.7×10^{-9} cm/s across the site from the northeast to the southwest and/or with depth (Fig. 3.54).

The laboratory performed total size fraction analysis on all geotechnical samples. Particle sizes were quantitatively determined by wet sieve analysis and hydrometer studies to delineate the particle-size distribution by weight percent for each of the three geotechnical samples recovered. The following grain-size classification was used:

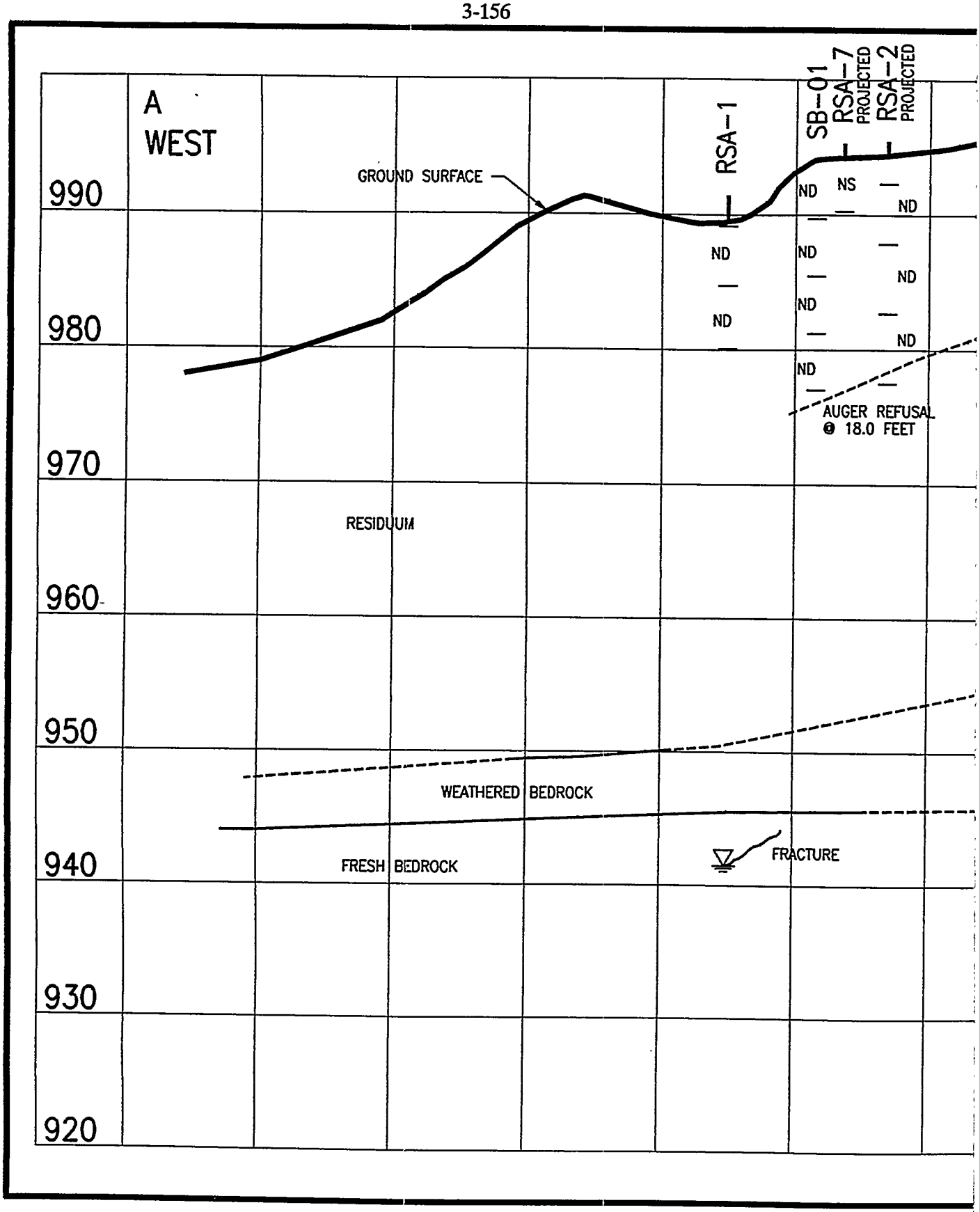
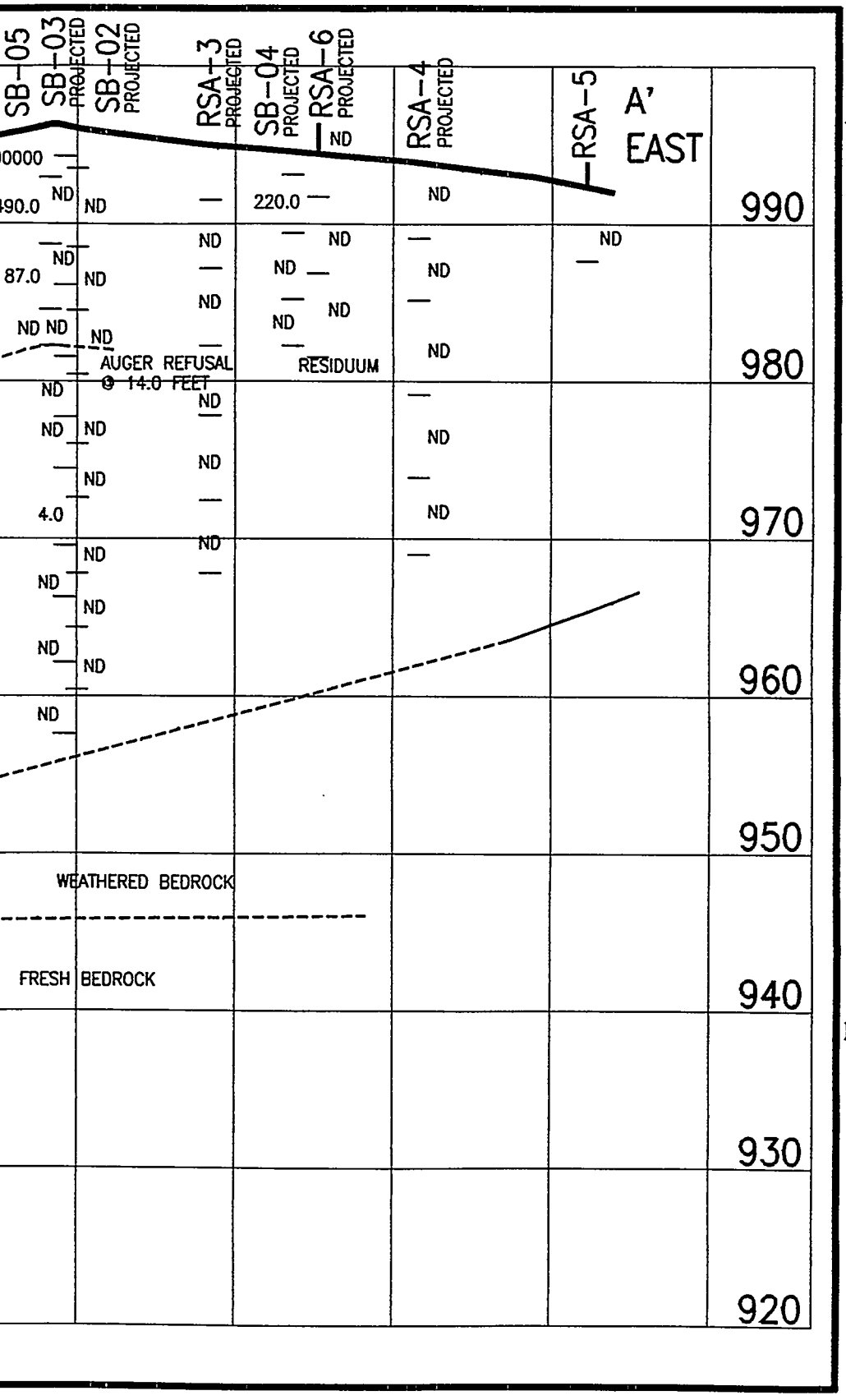


Fig. 3.53. RSA profile



LEGEND:

GW.....MONITORING WELL
SB.....SOILBORING
▽ GROUNDWATER ENCOUNTERED IN BOREHOLE

0 2 4 6 8 10 20
VERTICAL SCALE: 1" = 10'

0 50 100 150 300
HORIZONTAL SCALE: 1" = 150'

SAIC®
Science Applications International Corporation

BEAR CREEK VALLEY OU2
RUST SPOIL AREA PROFILE A-A'
TRICHLOROETHENE (ppb)

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. ABSTON	05-05-94
1	J. HOY	S. REID	07-20-94

XREFERENCES	PLOT FILES
	/94003/PLOT/667PR0A1.PLT /94003/PLOT/667PR0A2.PLT /94003/PLOT/667PR0A3.PLT /94003/PLOT/667PR0A4.PLT */94003/PLOT/667PR0A5.PLT

SHT 5 OF 5 (DRAWING #) | /94003/DWGS/667PR0A (CAD FILE #) | N/A (ROT. ANGLE)

A-A′ trichlorethene (ppb).

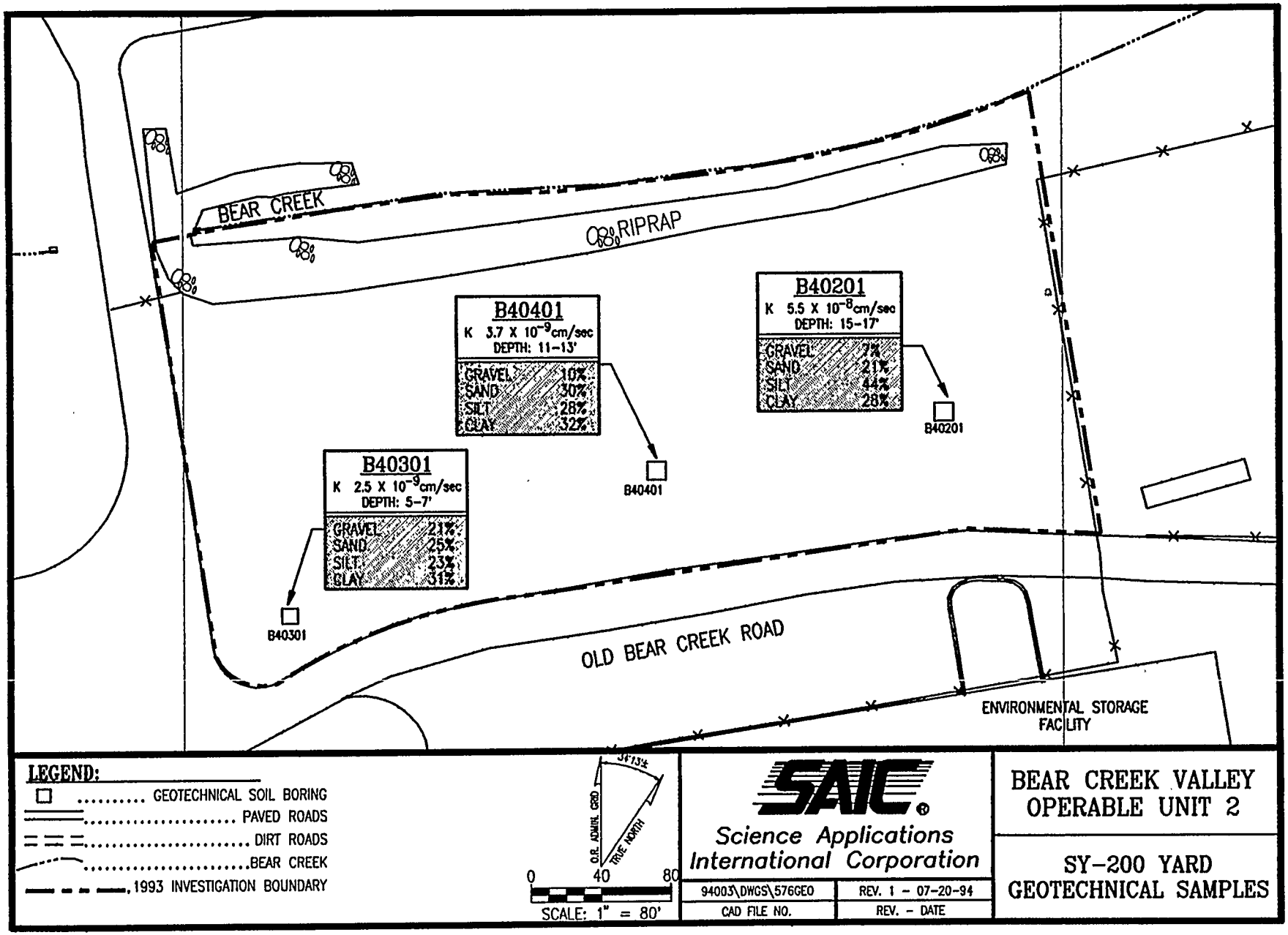


Fig. 3.54. Locations of geotechnical samples taken from the SY-200 Yard.

Gravel	>2 mm
Sand	2 mm - 0.0625 mm
Silt	0.0625-0.002 mm
Clay	<0.002 mm

Results indicate the soils in the SY-200 Yard are predominantly silt-sized (0.0625-0.002 mm) or smaller (Fig. 3.54). Percent gravel increased from 7% to a maximum of 21% from northeast to southwest and/or with depth. Percent sand followed no discernible trend. Percent silt decreased from a maximum of 44% to 23% from northeast to southwest and/or with depth. Percent clay remained relatively stable at 28–32%.

3.2.4.7 Summary of soil results

Soils at the three sites in BCV OU 2 have common characteristics that are important in understanding the nature and extent of contamination. The concentration ranges of some metals present at concentrations above PRGs were detected at BCV OU 2 generally in higher concentrations in the native soils encountered at the bottom of most borings than in fill material. For example, although beryllium concentrations were higher than the PRG (0.15 ppm) in all sites, the higher concentrations were associated with native soils and not with fill material. The background UCB (1.007 ppm) is also above the PRG, and most of the fill material soils showed concentrations of beryllium within ± 0.5 ppm of this concentration. When the analytical detection limit (0.5 ppm) is taken into account, this range of concentrations for beryllium seen at the sites in BCV OU 2 cannot be considered as contamination.

SVOCs were detected in all three sites in isolated areas of elevated concentrations. SVOCs were present at concentrations above PRGs, but the detection limits were again greater than the calculated PRGs. For example, benzo(a)pyrene had a quantification limit goal of 330 ppb while the calculated PRG was 88 ppb. The fact that the PRG is lower than the analytical quantitation limit goal should be taken into account when reviewing the data.

Total PCBs were detected at concentrations well above the PRG (0.083 ppm) in RSA and the SY-200 Yard in isolated areas of elevated concentrations. It should be noted, however, that EPA guidance on PRGs is 1 ppm for residential land use and 10 to 25 ppm for industrial land use (EPA 1990a). The extent of PCB concentrations above the 1 ppm action limit is reduced from that above the PRG; if the industrial action limit of 10 ppm is used, then elevated concentrations are sporadic at all sites.

Mercury at the SY-200 Yard presented its own problem of defining the nature and extent of contamination. As described in Sect. 3.2.4.4, samples with visible mercury often had not detected analytical results. Historical observations of mercury on extracted fence posts and observations of mercury spheres in the soil samples taken during this RI suggest that the observations of visible mercury at the SY-200 Yard may be more significant than analytical results.

3.2.5 Contaminant Fate and Transport

The primary purpose of the RI is to determine either the nature and extent of releases of hazardous or radioactive substances or the potential for such releases, and to gather the

necessary data to support evaluation of remedial alternatives in the FS. Therefore, the focus of the RI report is to present data identifying the current and potential contributing sources of contamination and to define the vertical and lateral extent of contamination within the boundaries of the site of interest. In the previous sections, sources of potential radiological and chemical contamination at BCV OU 2 were identified and characterized, and the nature and extent of waste-related radiological and chemical substances found in soils, sediments, surface water, and groundwater were determined. The nature of contamination at the site was determined by evaluating the activities and processes that took place at the site combined with evaluation of the analytical data collected during the RI.

Having characterized the nature and extent of contamination, the next step in the RI is to identify the potential migration pathways and mechanisms for transport of radiological and chemical substances found in soils, sediments, surface water, and groundwater. Based on this information, contaminant fate and transport analyses can be performed to predict the rate of contaminant migration and project contaminant concentrations to receptor locations via various media. Computer-based fate and transport models were used to predict contaminant movement from source areas to receptor locations. Used in conjunction with data derived from monitoring of the source area, these models calculate contaminant concentrations at potential exposure locations when measured contaminant concentrations are not available, such as at off-site locations or in future exposure scenarios.

A brief summary of the principles of contaminant fate and transport modeling are presented here along with the results of modeling activities. Section 3.2.5.1 discusses the persistence of the contaminants in the environment and the physical and chemical properties of the radionuclides and chemicals of potential concern for BCV OU 2. Section 3.2.5.2 presents a conceptual model for potential contaminant migration pathways and describes site topography, geology, and hydrology. Contaminant release mechanisms and transport media are also described in this section. Section 3.2.5.3 presents contaminant modeling procedures and the computational results for the principal transport media at BCV OU 2. Section 3.2.5.4 discusses uncertainties associated with the modeling results and summarizes the conclusions drawn from the modeling results. Fate and transport models are used to simulate the vertical transport of contaminants from the waste source down through the vadose zone to the saturated zone. Horizontal transport through the aquifer to receptor locations is not considered in the scope of this RI but will be included in the BCV OU 4 RI. Modeling approaches for both groundwater and surface water are presented in this section.

3.2.5.1 Persistence of contaminants

The COPCs presented in Sect. 3.2.4 (Tables 3.22, 3.24, and 3.25) for BCV OU 2 include radionuclides and organic and inorganic chemical species. The fate and transport of these contaminants are functions of both site characteristics and the physical/chemical properties of the contaminants. Such properties include solubility in water, tendency to transform or degrade (usually described by a half-life or an environmental half-life in a given media), and chemical affinity for solids or organic matter (usually described by a partitioning coefficient K_d, K_{OC} or K_{OW}). These properties and how they affect radioactive, inorganic, and organic contaminant behavior are described below.

Inorganics. Inorganic COPCs for BCV OU 2 include metals and cyanide. Metals do not degrade in the environment, but they may change chemical form, or speciation. They may also react with soils or other solid surfaces by ion exchange, adsorption, precipitation, or

complexation. Such reactions are affected by pH, oxidation-reduction conditions, and the type and amount of organic matter, clay, and hydrous oxides present. In general, these reactions are reversible and cause an element's mobility to be retarded. The retardation factor (R_d) describes numerically the extent to which the velocity of the contaminant is slowed and is largely derived from the partitioning coefficient (K_d).

Inorganic chemical form has a large impact on solubility and therefore mobility in the environment. Chemical speciation, however, is very complex and difficult to distinguish in routine laboratory analysis. In general, the only distinction made in sampling and analysis for inorganics is between total and filtrable inorganics in water. The filtrable inorganics represent the dissolved fraction, which is the more mobile and bioavailable fraction. Table 3.26 presents the K_d and R_d. Of the compounds that are most likely to form, usually the chlorides, nitrates, and nitrites are the most soluble. Sulfates, carbonates, and hydroxides have low to moderate solubility. Soluble compounds are transported in aqueous form subject to retardation whereas an insoluble compound remains as a precipitate and limits the overall dissolution of the metal.

Radionuclides. Radionuclides comprise a special case of inorganic species. Radioactive nuclides undergo spontaneous transformations that involve the emission of particles (most important for BCV OU 2 are alpha and beta particles) and radiant energy (most important for BCV OU 2 is gamma energy). The resulting daughters (i.e., product nuclides) may be either radioactive themselves, in which case they too will undergo spontaneous decay, or they may be stable nuclides. The decay process can occur by various spontaneous mechanisms. Two of the more important decay modes are alpha decay and beta decay, with the latter differentiated into negatron and positron decay.

The radionuclides present at the BCV OU 2 sites belong to two decay chain series: the ^{238}U series and the ^{235}U series. The half-lives of most of the radionuclides of concern at these sites are long (thousands to billions of years; see Table 3.27) when compared to the life of the sites. Like inorganic and organic chemical species which do not undergo nuclear transformations, the persistence of radionuclide contaminants on the BCV OU 2 sites is related largely to their geochemical mobility in the environment. Table 3.27 presents the half-lives ($t_{1/2}$), radioactive decay constants (λ), K_ds, and R_ds for the radionuclides of potential concern at the BCV OU 2 sites.

Organics. The organic COPCs at the three sites in BCV OU 2 include VOCs, SVOCs, and PCBs. These contaminants may be degraded in the environment by various processes, including hydrolysis, oxidation/reduction, photolysis, or biodegradation. Half-lives of organic compounds in various media can vary from minutes to years, depending on the chemical and on environmental conditions. Degradation may either enhance or reduce the toxicity of a chemical. For the organic COPCs in BCV OU 2, one example of a degradation process may be biodegradation of trichloroethanes and dichloroethanes via dechlorination to lower chlorinated compounds. Environmental half-lives for organic COPCs are presented in Table 3.28.

Table 3.26. Adsorption coefficients (K_d) and retardation factors (R_d) for the BCV OU 2 inorganic COPCs

Constituents	K_d[a] (l/Kg)	R_d[b]
Aluminum	1.5E+03[c]	5.85E+03
Antimony	2.5E+02	9.77E+02
Barium	6.0E+01[c]	2.35E+02
Beryllium	1.3E+03	5.06E+03
Cadmium	5.6E+02	2.19E+03
Calcium	5.0E+01	1.96E+02
Chromium	1.5E+03	5.84E+03
Cobalt	5.5E+02	2.15E+03
Copper	3.5E+01[c]	1.38E+02
Cyanide	1.4E-02[d]	1.05E+00
Lead	5.5E+02	2.14E+03
Magnesium	4.5E+00	1.86E+01
Manganese	1.8E+02	7.03E+02
Mercury	8.8E+04[e]	3.43E+05
Nickel	6.5E+02	2.53E+03
Niobium	9.0E+02	3.51E+03
Phosphorus	3.5E+01	1.38E+02
Potassium	7.5E+01	2.94E+02
Radium	9.1E+03	3.54E+04
Silver	1.8E+02	7.03E+02
Strontium	1.1E+02	4.28E+02
Thallium	1.5E+03[c]	5.84E+03
Thorium	5.8E+03	2.26E+04
Uranium	1.6E+03	6.23E+03

[a] K_d values taken from Sheppard and Thibault 1990 unless otherwise noted

[b] $R_d = 1 + \frac{K_d \cdot \rho_b}{\theta}$ ρ_b = bulk density, θ = soil moisture content

[c] Baes et. al 1984

[d] EPA 1993 (RREL)

[e] Burns 1994

Table 3.27. Radioactive half lives, decay rates, K_ds, and R_ds for BCV OU 2 radionuclide COPCs

Radionuclide	Half life (year)	Decay Constant (day^{-1})	K_d (l/Kg)	R_d
^{137}Cs	3.02E+01	6.28E-05	1.9E+03	7.39E+03
^{226}Ra	1.60E+03	1.19E-06	9.10E+03	3.54E+04
^{90}Sr	2.86E+01	6.64E-05	1.10E+02	4.28E+02
^{232}Th	1.41E+10	1.35E-13	5.80E+03	2.26E+05
^{234}U	2.45E+05	7.77E-09	1.60E+03	6.23E+03
^{235}U	7.04E+08	2.70E-12	1.60E+03	6.23E+03
^{238}U	4.47E+09	4.25E-13	1.60E+03	6.23E+03
^{99}Tc	2.13E+05	8.92E-09	1.18E-01	1.46E+00

Table 3.28. Solubility in water, biodegradation/decay rates, Henry's Law constant, and air diffusion coefficients for the BCV OU 2 organic COPCs

Compound	Solubility (mg/L)	Henry's Law constant ($atm.m^3/mol$)	Air diffusion coefficient (cm^2/s)	Biodegradation (day^{-1})
		Organics		
1,1 Dichloroethane	5.50E+03	5.45E-03	9.10E-02	1.13E-03
1,1 Dichloroethene	2.10E+02	1.49E-02	1.14E-01	3.85E-03
1,1,1 Trichloroethane	4.40E+03	4.08E-03	1.94E-02	6.35E-04
1,1,2 Trichloroethane	4.50E+03	2.94E-05	7.90E-02	1.90E-03
1,1,2-Trichloro-1,2,2-trifluoroethane	1.70E+02	3.94E-01	7.80E-02	4.81E-04
1,1,2,2 Tetrachloroethane	2.90E+03	3.80E-04	7.30E-02	6.19E-03
1,2 Dichloroethane	8.69E+03	1.10E-03	9.10E-02	9.63E-04
1,2 Dichloroethene	8.00E+02	4.08E-03	1.14E-01	2.41E-04
1,2-Dichlorobenzene	1.45E+02	1.94E-03	6.30E-02	9.63E-04
1,2 Dichloropropane	2.70E+03	2.82E-03	8.00E-02	2.69E-04
1,2,4-Trichlorobenzene	1.90E+01	1.42E-03	5.70E-02	9.63E-04
1,4-Dichlorobenzene	7.90E+01	2.72E-03	6.30E-02	9.63E-04
2-Butanone	2.75E+05	6.61E-07	9.20E-02	2.48E-02
2-Chlorophenol	2.85E+04	1.03E-05	7.20E-02	NA
2-Hexanone	3.50E+04	7.53E-06	7.80E-02	NA
2-Methylnaphthalene	2.60E+01	2.20E-02	5.60E-02	NA
2,4-Dimethylphenol	5.90E-02	1.70E-05	7.40E-02	2.48E-02
2,4-Dinitrotoluene	2.70E+02	2.12E-08	5.50E-02	1.93E-03
4-Chloro-3-methylphenol	3.85E+03	2.50E-06	5.60E-02	NA
4-Methyl-2-pentanone	1.91E+04	1.03E-06	7.80E-02	2.48E-02
4-Methylphenol	2.40E+04	5.87E-09	7.50E-02	2.48E-02
4-Nitrophenol	1.60E+04	7.34E-06	6.70E-02	7.08E-02
4,4'-DDE	4.00E-02	5.72E-07	4.10E-02	6.16E-05
Acenaphthene	3.42E+00	2.41E-04	6.20E-02	1.70E-03

Table 3.28 (continued)

Compound	Solubility (mg/L)	Henry's Law constant ($atm.m^3/mol$)	Air diffusion coefficient (cm^2/s)	Biodegradation (day^{-1})
Acenaphthylene	3.93E+00	1.14E-04	6.20E-02	8.66E-02
Acetic acid ethyl ester	7.90E+04	4.40E+02	7.23E-02	2.48E-02
Acetone	1.00E+06	5.14E-07	1.24E-01	2.48E-02
Acrylic acid	1.00E+06	7.83E-09	9.80E-02	3.85E-03
Anthracene	1.29E+00	8.60E-05	4.21E-02	3.77E-04
Aroclor-1254	5.70E-02	8.37E-03	5.30E-02	4.72E-03
Aroclor-1260	8.00E-02	3.36E-04	5.30E-02	NA
Benzene	1.78E+03	5.55E-03	9.32E-02	9.63E-04
Benzo(a)anthracene	1.00E-02	2.94E-08	5.10E-02	2.55E-04
Benzo(a)pyrene	3.80E-03	4.90E-07	4.30E-02	3.27E-04
Benzo(b)fluoranthene	1.00E-03	2.94E-07	4.40E-02	2.84E-04
Benzo(g,h,i)perylene	2.60E-04	1.40E-07	4.20E-02	2.67E-04
Benzo(k)fluoranthene	3.00E-04	2.54E-05	4.40E-02	8.10E-05
Benzoic acid	2.90E+03	5.54E-04	7.40E-02	NA
bis-(2-ethylhexyl)phthalate	3.50E-01	3.00E-07	3.51E-02	1.78E-03
Bromodichloromethane	4.50E+03	2.12E-03	6.10E-02	NA
Bromoform	3.20E+03	5.32E-04	1.00E-01	1.93E-03
Bromomethane (methyl bromide)	1.75E+04	1.53E-04	1.10E-01	6.19E-03
Butylbenzylphthalate	2.90E+00	3.18E-08	4.00E-02	3.85E-03
Carbon disulfide	2.90E+03	2.94E-04	1.05E-01	NA
Carbon tetrachloride	8.00E+02	2.93E-02	7.80E-02	1.93E-03
Chlorobenzene	4.88E+02	3.93E-03	7.30E-02	1.16E-03
Chloroethane	5.74E+03	1.11E-02	2.71E-01	6.19E-03
Chloroform	9.30E+03	3.39E-03	1.04E-01	3.85E-04
Chloromethane (methyl chloride)	6.36E+03	8.82E-03	1.10E-01	6.19E-03
Chrysene	6.00E-03	1.05E-06	4.60E-02	1.73E-04
cis-1,3-dichloropropene	2.70E+03	2.32E-03	1.00E-01	6.20E-03

Table 3.28 (continued)

Compound	Solubility (mg/L)	Henry's Law constant ($atm.m^3/mol$)	Air diffusion coefficient (cm^2/s)	Biodegradation (day^{-1})
Cyclohexane	1.00E+02	6.12E-03	8.40E-02	1.03E-03
Dibenzofuran	1.00E+01		6.80E-02	6.19E-03
Dibenzo(a,h)anthracene	5.00E-04	7.30E-08	4.20E-02	1.84E-04
Dibromochloromethane	4.50E+03	7.83E-04	5.40E-02	3.85E-03
Dieldrin	1.86E-01	5.84E-05	5.30E-02	3.21E-04
Diethylphthalate	2.10E-02	1.17E-08	5.30E-02	3.09E-03
Dimethylphthalate	5.00E+03	2.69E-09	5.68E-02	2.48E-02
Di-n-butylphthalate	4.00E+02	2.80E-07	4.20E-02	3.01E-02
Di-n-octyphthalate	3.00E+00	3.45E-14	3.50E-02	1.90E-03
Endosulfan I	3.20E-01	2.67E-02	5.10E-02	1.24E-02
Endrin	2.60E-01	4.00E-07	5.30E-02	1.51E-03
Ethylbenzene	1.52E+02	6.44E-03	7.50E-02	3.04E-03
Fluoranthene	2.65E-01	6.50E-06	4.90E-02	3.94E-04
Fluorene	1.90E+00	1.17E-04	5.50E-02	2.89E-03
Heptachlor	5.60E-02	1.48E-03	3.70E-02	2.65E-03
Hydrogen cyanide	1.00E+06	2.98E-06	1.73E-01	1.03E-03
Ideno(1,2,3-c,d)pyrene	1.40E-04	6.95E-08	4.40E-02	2.37E-04
Methylene chloride	1.67E+04	3.19E-03	1.04E-01	6.19E-03
Naphthalene	3.00E+01	4.83E-04	5.90E-02	2.69E-03
n-Nitro-di-n-propylamine	9.90E+03	1.69E-07	7.40E-02	9.63E-04
Pentachlorophenol	1.40E+01	2.80E-06	5.20E-02	4.56E-04
Phenanthrene	8.16E-01	3.93E-05	5.40E-02	8.66E-04
Phenol	8.00E+04	1.30E-06	8.20E-02	2.48E-02
Phthalic anhydride	6.20E+03	1.52E-10	7.10E-02	2.48E-02
Pyrene	1.60E-01	5.10E-06	5.10E-02	9.12E-05
p,p'-methoxychlor	4.00E-02	6.12E-10	3.90E-02	1.90E-03
Styrene	3.00E+02	2.28E-03	7.10E-02	3.30E-03
Tetrachloroethene	1.50E+02	2.87E-02	7.20E-02	4.19E-04

Table 3.28 (continued)

Compound	Solubility (mg/L)	Henry's Law constant ($atm.m^3/mol$)	Air diffusion coefficient (cm^2/s)	Biodegradation (day^{-1})
Toluene	5.15E+02	5.92E-03	8.49E-02	3.30E-03
Trans-1,3-dichloropropene	2.80E+03	1.80E-03	8.00E-02	6.20E-03
Trichloroethene	1.10E+03	1.17E-02	8.75E-02	4.19E-04
Trichlorofluoromethane	1.10E+03	5.83E-02	8.70E-02	4.81E-04
Vinyl acetate	2.00E+04	5.66E-04	8.50E-02	NA
Vinyl chloride	1.10E+00	2.78E-02	1.06E-01	2.41E-04
Xylene	1.89E+00	5.25E-03	7.00E-02	1.93E-03

The mobility of an organic compound is affected by its volatility, its partitioning behavior between solids and water, water solubility, and concentration. Water solubility and the tendency to adsorb to particles or organic matter can correlate with retardation in groundwater transport. The adsorption coefficient/distribution coefficient (K_d) of an organic compound is related to the organic carbon based water partition coefficient (K_{oc}) by

$$K_d = f_{oc} \cdot K_{oc}$$

where f_{oc} = soil organic carbon content as mass fraction.

Chemicals with relatively high water solubilities and low adsorption coefficients (acetone, methylene chloride, etc.) are expected to remain primarily as dissolved phases and be transported at the same rate as the groundwater flow. Chemicals with lower water solubilities and higher adsorption coefficients (PCBs, PAHs observed in BCV OU 2) are expected to remain primarily adsorbed to the surface of the soils and their transportation with the groundwater would be very limited and at a much slower rate. Table 3.28 presents the solubility, Henry's Law constant (K_H), air diffusion coefficients, and biodegradation rate constants for the organic compounds that are of potential concern at the three sites in BCV OU 2. K_{oc}, K_d, and R_d for these compounds are presented in Table 3.29.

3.2.5.2 Conceptual model

A site conceptual model is a statement of *expected* site conditions that serves as a paradigm against which observations can be compared and within which predictions can be made. The predictive function of the site conceptual model, of primary importance to contaminant fate and transport modeling, relies on known information and informed assumptions about the site. The better the information and the greater the accuracy of the assumptions, the more accurately the site conceptual model describes the site resulting in more reliable predictions.

Expected Site Conditions. The expected site conditions at BCV OU 2 are described here and illustrated in Fig. 3.55 using the RSA as a model. The components of the conceptual model follow.

Infiltration and Surface Runoff. The potential for contaminant transport begins with precipitation. Moore (1988) estimated that on the ORR nearly all precipitation infiltrates into the subsurface. The actual amount of infiltration is probably highly variable and it is expected that in areas that are capped, such as the RSA and SA-1, the amount of infiltration will be small and, therefore, the amount of surface runoff will be large.

Evapotranspiration. All infiltrated water does not recharge to groundwater; much of it is lost from the subsurface via evapotranspiration. The amount lost is variable ORR-wide, depending largely on the extent and type of vegetative cover. According to the data in Moore (1988), ~57% of the average annual precipitation is consumed by evapotranspiration over the ORR. The bulk of the evapotranspiration, ~75%, occurs during the growing season, April through September.

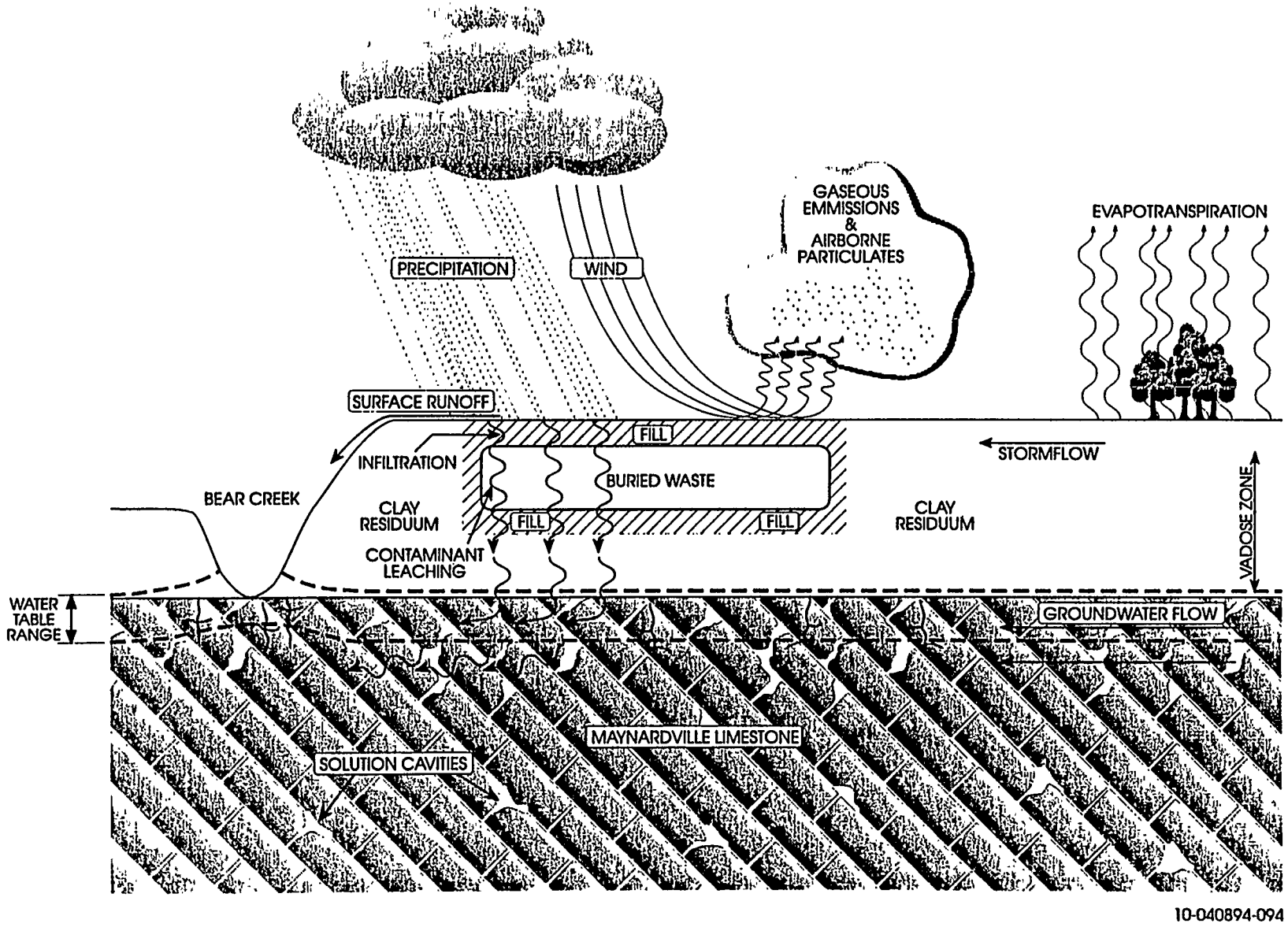


Fig. 3.55. Conceptual model of RSA expected site conditions.

Table 3.29. Adsorption coefficients and retardation factors for the BCV OU 2 organic COPCs

	Kow (mL/mL)	Koc[a] (L/Ks)	K_d[b] (L/Kg)	R_d[c]
1,1 Dichloroethane	6.17E+01	3.88E+01	3.88E-01	2.66E+00
1,1 Dichloroethene	3.02E+01	1.90E+01	1.90E-01	1.81E+00
1,1,1 Trichloroethane	2.95E+02	1.86E+02	1.86E+00	8.94E+00
1,1,2 Trichloroethane	1.48E+02	9.32E+01	9.32E-01	4.98E+00
1,1,2-Trichloro-1,2,2-trifluoroethane	1.48E+02	9.32E+01	9.32E-01	4.98E+00
1,1,2,2 Tetrachloroethane	2.46E+02	1.55E+02	1.55E+00	7.62E+00
1,2 Dichloroethane	2.82E+01	1.78E+01	1.78E-01	1.76E+00
1,2 Dichloroethene	1.23E+02	7.75E+01	7.75E-01	4.31E+00
1,2-Dichlorobenzene	2.40E+03	1.51E+03	1.51E+01	6.56E+01
1,2 Dichloropropane	1.91E+02	1.20E+02	1.20E+00	6.13E+00
1,2,4-Trichlorobenzene	9.55E+03	6.02E+03	6.02E+01	2.58E+02
1,4-Dichlorobenzene	2.45E+03	1.55E+03	1.55E+01	6.71E+01
2-Butanone	1.82E+00	1.15E+00	1.15E-02	1.05E+00
2-Chlorophenol	1.41E+02	8.90E+01	8.90E-01	4.80E+00
2-Hexanone	2.40E+01	1.51E+01	1.51E-01	1.65E+00
2-Methylnaphthalene	7.24E+03	4.56E+03	4.56E+01	1.96E+02
2,4-Dimethylphenol	2.63E+02	1.66E+02	1.66E+00	8.08E+00
2,4-Dinitrotoluene	1.02E+02	6.45E+01	6.45E-01	3.75E+00
4-Chloro-3-methylphenol	1.26E+03	7.93E+02	7.93E+00	3.49E+01
4-Methyl-2-pentanone	5.25E+00	3.31E+00	3.31E-02	1.14E+00
4-Methylphenol	8.51E+01	5.36E+01	5.36E-01	3.29E+00
4-Nitrophenol	8.13E+01	5.12E+01	5.12E-01	3.19E+00
4,4'-DDE	4.90E+05	3.09E+05	3.09E+03	1.32E+04
Acenaphthene	8.32E+03	5.24E+03	5.24E+01	2.25E+02
Acenaphthylene	1.17E+04	7.40E+03	7.40E+01	3.17E+02
Acetic acid ethyl ester	5.37E+00	3.38E+00	3.38E-02	1.14E+00
Acetone	5.75E-01	3.63E-01	3.63E-03	1.02E+00
Acrylic acid	2.04E+00	1.29E+00	1.29E-02	1.05E+00
Anthracene	2.82E+04	1.78E+04	1.78E+02	7.59E+02
Aroclor-1254	1.07E+06	6.75E+05	6.75E+03	2.88E+04
Aroclor-1260	1.29E+06	8.13E+05	8.13E+03	3.47E+04

Table 3.29 (continued)

	Kow (mL/mL)	Koc[a] (L/Ks)	K_d[b] (L/Kg)	R_d[c]
Benzene	1.35E+02	8.50E+01	8.50E-01	4.63E+00
Benzo(a)anthracene	4.07E+05	2.57E+05	2.57E+03	1.10E+04
Benzo(a)pyrene	9.55E+05	6.02E+05	6.02E+03	2.57E+04
Benzo(b)fluoranthene	3.72E+06	2.34E+06	2.34E+04	1.00E+05
Benzo(g,h,i)perylene	1.70E+07	1.07E+07	1.07E+05	4.57E+05
Benzo(k)fluoranthene	6.92E+06	4.36E+06	4.36E+04	1.86E+05
Benzoic acid	7.41E+01	4.67E+01	4.67E-01	3.00E+00
bis-(2-Ethylhexyl)phthalate	2.00E+05	1.26E+05	1.26E+03	5.37E+03
Bromodichloromethane	7.59E+01	4.78E+01	4.78E-01	3.04E+00
Bromoform	2.00E+02	1.26E+02	1.26E+00	6.37E+00
Bromomethane (methyl bromide)	1.26E+01	7.93E+00	7.93E-02	1.34E+00
Butylbenzylphthalate	6.03E+04	3.80E+04	3.80E+02	1.62E+03
Carbazole	3.24E+03	2.04E+03	2.04E+01	8.82E+01
Carbon disulfide	1.45E+02	9.11E+01	9.11E-01	4.89E+00
Carbon tetrachloride	5.37E+02	3.38E+02	3.38E+00	1.55E+01
Chlorobenzene	6.92E+02	4.36E+02	4.36E+00	1.96E+01
Chloroethane	2.69E+01	1.70E+01	1.70E-01	1.72E+00
Chloroform	9.33E+01	5.88E+01	5.88E-01	3.51E+00
Chloromethane (methyl chloride)	8.13E+00	5.12E+00	5.12E-02	1.22E+00
Chrysene	4.07E+05	2.57E+05	2.57E+03	1.10E+04
cis-1,3-dichloropropene	1.15E+02	7.23E+01	7.23E-01	4.09E+00
Cyclohexane	2.82E+03	1.78E+03	1.78E+01	7.68E+01
Dibenzofuran	1.32E+04	8.31E+03	8.31E+01	3.56E+02
Dibenzo(a,h)anthracene	9.33E+05	5.88E+05	5.88E+03	2.51E+04
Dibromochloromethane	1.23E+02	7.75E+01	7.75E-01	4.31E+00
Dieldrin	1.23E+04	7.75E+03	7.75E+01	3.32E+02
Diethylphthalate	9.12E+02	5.75E+02	5.75E+00	2.55E+01
Dimethylphthalate	7.41E+01	4.67E+01	4.67E-01	3.00E+00
Di-n-butylphthalate	1.58E+05	9.98E+04	9.98E+02	4.27E+03
Di-n-octyphthalate	1.58E+09	9.98E+08	9.98E+06	4.27E+07
Endosulfan I	3.55E+03	2.24E+03	2.24E+01	9.65E+01

Table 3.29 (continued)

	Kow (mL/mL)	Koc[a] (L/Ks)	K_d[b] (L/Kg)	R_d[c]
Endrin	3.98E+05	2.51E+05	2.51E+03	1.07E+04
Ethylbenzene	1.41E+03	8.90E+02	8.90E+00	3.90E+01
Fluoranthene	2.14E+05	1.35E+05	1.35E+03	5.75E+03
Fluorene	1.51E+04	9.54E+03	9.54E+01	4.08E+02
Heptachlor	2.51E+04	1.58E+04	1.58E+02	6.77E+02
Hydrogen cyanide	2.24E+00	1.41E+00	1.41E-02	1.06E+00
Ideno(1,2,3-c,d)pyrene	4.57E+07	2.88E+07	2.88E+05	1.23E+06
Methylene chloride	1.78E+01	1.12E+01	1.12E-01	1.48E+00
Naphthalene	2.34E+03	1.48E+03	1.48E+01	6.41E+01
n-Nitro-di-n-propylamine	2.04E+01	1.29E+01	1.29E-01	1.55E+00
Pentachlorophenol	1.02E+05	6.45E+04	6.45E+02	2.75E+03
Phenanthrene	2.88E+04	1.82E+04	1.82E+02	7.77E+02
Phenol	2.88E+01	1.82E+01	1.82E-01	1.78E+00
Phthalic anhydride	1.00E+00	6.30E-01	6.30E-03	1.03E+00
Pyrene	1.51E+05	9.54E+04	9.54E+02	4.07E+03
p,p′-methoxychlor	4.79E+04	3.02E+04	3.02E+02	1.29E+03
Styrene	1.45E+03	9.11E+02	9.11E+00	3.99E+01
Tetrachloroethene	3.39E+02	2.13E+02	2.13E+00	1.01E+01
Toluene	4.90E+02	3.09E+02	3.09E+00	1.42E+01
Trans-1,3-dichloropropene	1.12E+02	7.07E+01	7.07E-01	4.02E+00
Trichloroethene	3.39E+02	2.13E+02	2.13E+00	1.01E+01
Trichlorofluoromethane	3.39E+02	2.13E+02	2.13E+00	1.01E+01
Vinyl acetate	4.30E-01	2.71E-01	2.71E-03	1.01E+00
Vinyl chloride	3.98E+00	2.51E+00	2.51E-02	1.11E+00
Xylene	1.41E+03	8.90E+02	8.90E+00	3.90E+01

[a] Koc = 0.63 Kow
[b] K_d = Koc * foc
[c] $R_d = {}_1 + \frac{(K_d \cdot P_b)}{\Theta}$

Subsurface Flow System. The infiltrated water that is not lost to evapotranspiration makes it into the subsurface flow system. This system has been described in detail by Moore (1988), Solomon et al. (1992), and Moore and Toran (1992) from which the following discussion is derived. The subsurface flow system can be divided as follows: the stormflow zone; the vadose zone; the groundwater zone, which is subdivided into the water table interval, the intermediate interval, and the deep interval; and the aquiclude. Although many factors influence groundwater flow on the ORR, topography, surface cover, geologic structure, and lithology exhibit strong influence on the hydrogeology. Variations in these features result in water flux variations.

Release Mechanisms. The primary release mechanisms at the BCV OU 2 sites are infiltration with leaching to groundwater, gaseous and airborne particulate emission, and surface runoff.

Infiltration with leaching to groundwater. Precipitation that does not leave the site as surface runoff infiltrates into the subsurface. Some of this infiltrating water leaves the subsurface environment via evapotranspiration after little or no subsurface flow. The remainder of the water percolates into the subsurface flow system as described above and illustrated in Fig. 3.55. The rate of percolation is controlled by soil cover, ground slope, saturated conductivity of the soil, and meteorological conditions.

Water infiltrating through contaminated surface and subsurface soils may leach contaminants into the groundwater. The factors that affect leaching rate include a contaminant's solubility and distribution coefficient (K_d) and the amount of percolation. Whether it is the contaminant's partition coefficient or solubility that controls leaching depends on whether leaching is solubility-controlled or sorption-controlled. Insoluble compounds will precipitate out of solution in the subsurface or remain in their insoluble form with little leaching. However, the COPCs at the BCV OU 2 generally do not form insoluble compounds in the natural environment so sorption processes, and the K_d, will have the greatest effect on leaching. Those contaminants with small K_ds will be leached more effectively than those with larger K_ds.

Another factor that affects whether a contaminant will reach the water table is the contaminant's rate of decay. Radioactive isotopes and certain organic compounds decay or breakdown at characteristic rates that are described by the substance's half-life. For a given percolation rate, those contaminants with long half-lives have a greater potential for contaminating groundwater than do those contaminants with shorter half-lives.

Surface runoff. Contaminants that are sorbed onto surface soils can be released by desorption in surface runoff or captured with particulate matter by sheet erosion during a rainstorm (Fig. 3.55). Sheet erosion may be an important factor at the RSA and the SY-200 Yard because of the lack of vegetative cover. In both cases, the surface runoff at the three BCV OU 2 sites flows primarily as sheet flow into Bear Creek. Channelized flow, other than Bear Creek, is important mainly in man-made ditches and culverts. These, and the few naturally-occurring, topographically-controlled surface channels, empty into Bear Creek. Figure 3.56 illustrates the major drainage pathways for BCV OU 2.

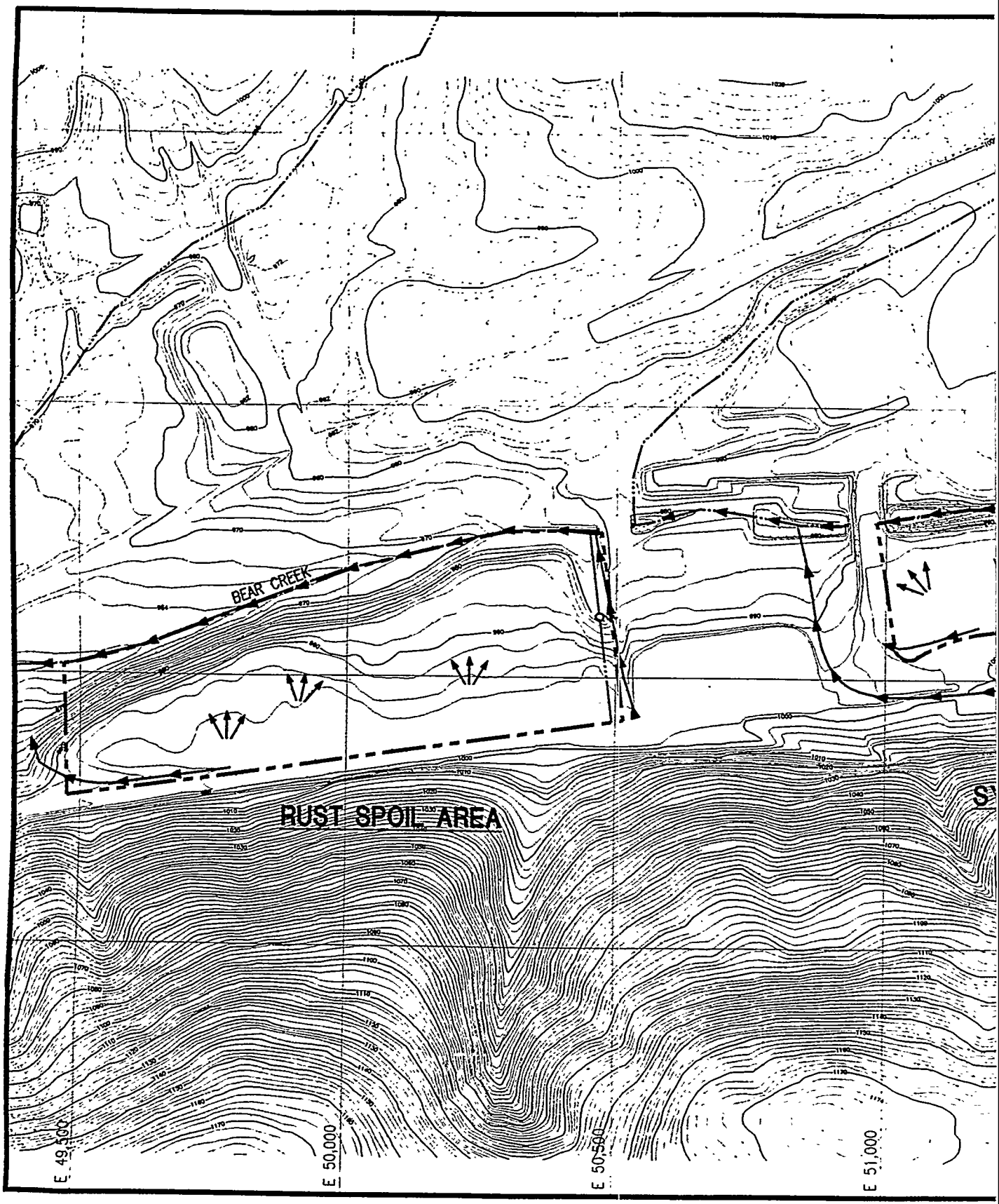
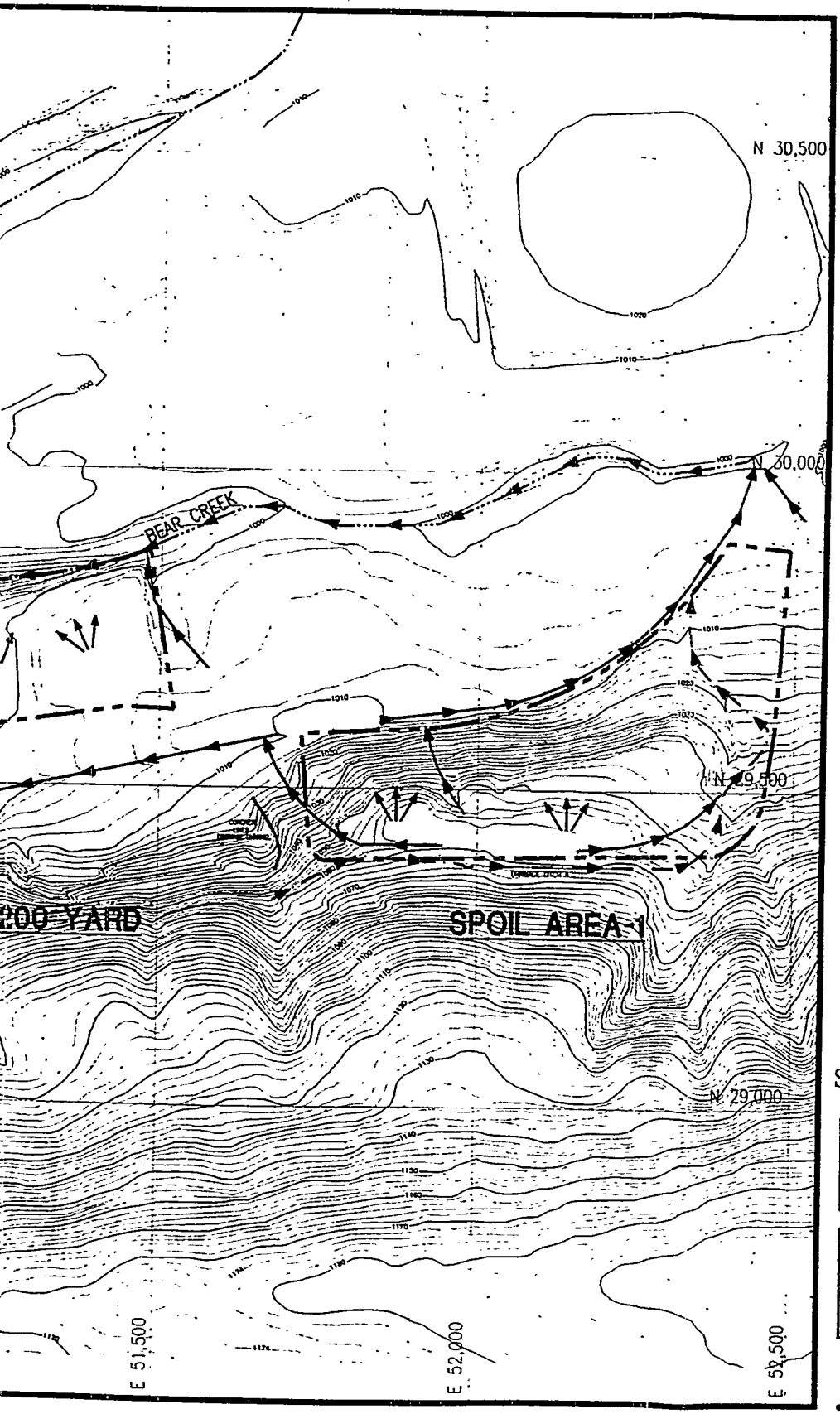


Fig. 3.56. Surfac



LEGEND:

- CREEK
- 1993 RI SITE BOUNDARY
- SHEET FLOW
- CHANNELIZED FLOW

34°13'±

O.R. ADMIN. GRID

TRUE NORTH

0 125 250 500

SCALE: 1" = 250'

SAIC®

Science Applications International Corporation

BEAR CREEK VALLEY
OPERABLE UNIT 2
SURFACE WATER FLOW PATHS

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	P. HOLM	P. SALPAS	4/6/94

XREFERENCES	PLOT FILES
94003/XREF/BASE2	94003/PLOT/576FLOW

94003 DRAWING # | DWGS\576FLOW CAD FILE # | N/A ROT. ANGLE

ater flow paths.

Gaseous emission and airborne particulates. VOCs in surface soil are emitted to air via vaporization (Fig. 3.55). The rate of emission is controlled by the vapor pressure of the organic compounds and decreases rapidly over a short period of time as the volatiles are depleted by release to the atmosphere. VOCs in the subsurface soils are emitted to the atmosphere via vertical diffusion through soil pores. Depending on how extensively diffusion has occurred, gaseous emissions from subsurface soils may be significant. Because the three sites at BCV OU 2 have been covered with relatively low porosity fill and clay, gaseous emissions probably pose little problem.

Particulate matter from contaminated surface soil can become airborne as a result of wind erosion (Fig. 3.55). This process is controlled by vegetative cover, wind speed, and moisture in the surface soils. Wind erosion can be significant at the RSA and the SY-200 Yard because the ground surface is largely bare. However, the wastes disposed of at these sites are covered with clean fill or clay, therefore wind erosion poses little problem for contaminant transport.

3.2.5.3 Contaminant fate and transport modeling procedures

Contaminant fate and transport modeling is based on the conceptual model for BCV OU 2 discussed in Sect. 3.2.5.2. Air is not considered an important pathway at the BCV OU 2 sites, therefore, air modeling was not performed. Soils and groundwater as well as surface water and sediments are important media for contaminant migration at these sites. Modeling for these media are presented below.

Soils and Groundwater. The models selected to evaluate flow in the vadose zone are ODAST (Javandel, Doughty, and Tsang 1984) and SESOIL. ODAST, a one-dimensional analytical solution, was used for the initial screening of constituents for mobility in the unsaturated zone. The ODAST code can account for retardation of contaminants, source changes, and decay. Analyses were performed for all the COPCs for each of the sites in BCV OU 2 to identify the contaminants that will migrate from the source to the water table within 100 years. Although analytical soil data evaluation based on current conditions warranted further discussion only on selected constituents from the list of COPCs, fate and transport analysis included all the COPCs with a frequency of detection greater than 5%. Based on current conditions a contaminant present in soil may not produce significant risk for human health, but due to leaching of this contaminant to groundwater may provide a threat to human health in future exposure scenarios. This analysis used 100 years as the future scenario based on human life span of 70 years and a period of 30 years that has already passed from the time contamination began. The contaminants that do not reach the water table in 100 years were eliminated from further analyses. The remaining contaminants for SESOIL modeling are listed in Table 3.30.

SESOIL was used to model the fate and transport of remaining constituents. SESOIL is an acronym for Seasonal Soil compartment model and is a one-dimensional, vertical transport code for the unsaturated soil zone. It is an integrated soil compartment model and is designed to simultaneously model water transport, sediment transport, and pollutant fate. The program was developed for the EPA's Office of Water and the Office of Toxic Substances in 1981 by Arthur D. Little, Inc. (ADL). ADL updated the SESOIL model in 1984 to include a fourth soil compartment (the original model included up to three layers) and the soil erosion algorithms (Bonazountas, Wagner, and Goodwin 1982; Bonazountas and

Table 3.30. List of constituents for the three sites remaining for SESOIL modeling based on screening runs using ODAST

RSA	*SA-1*
1,1 Dichloroethane	2-Butanone
1,1 Dichloroethene	Acetone
1,1,1 Trichloroethane	Chloroform
1,1,2 Trichloroethane	Methylene chloride
1,1,2-Trichloro-1,2,2-trifluoroethane	Tetrachloroethene
1,2 Dichloroethane	Toluene
1,2 Dichloroethene (Total)	*SY-200 Yard*
1,2 Dichloropropane	1,1,2-Trichloro-1,2,2-trifluoroethane
1,1,2,2-Tetrachloroethane	1,4-Dichlorobenzene
2-Butanone	2-Chlorophenol
2-Hexanone	4-Methyl-2-pentanone
4-Methyl-2-pentanone	Acetone
Acetone	Carbazole
Benzene	Methylene chloride
Bromodichloromethane	
Bromoform	
Bromomethane	
Carbon disulfide	
Carbon tetrachloride	
Chlorobenzene	
Chloroethane	
Chloromethane	
Chloroform	
cis-1,3-dichloropropene	
Cyanide	
Dibromochloromethane	
Dimethylphthalate	
Methylene chloride	
Tetrachloroethene	
Toluene	
Trans-1,3-dichloropropene	
Trichloroethene	

Table 3.30 (continued)

	RSA
Vinyl Acetate	
Vinyl Chloride	
Xylene	

Wagner 1984). A comprehensive evaluation of SESOIL, performed by Watson and Brown (1985), uncovered numerous deficiencies in the model and, subsequently, SESOIL was extensively modified to enhance its capabilities (Hetrick et al. 1989, Hetrick et al. 1986, and Hetrick and Travis 1988). This model was designed to perform "long-term" simulations of chemical transport and transformations in soil.

The SESOIL model estimates pollutant concentrations in the soil profile following introduction via direct application and/or interaction with other media, e.g., deposition from air. The model defines the soil compartment as a soil column extending from the ground surface through the unsaturated zone and to the upper level of the saturated soil zone. Processes simulated in SESOIL are categorized in three cycles: the hydrologic cycle, sediment cycle, and pollutant cycle. Each of the three cycles is separate submodules in the SESOIL code. The hydrologic cycle includes rainfall, surface runoff, infiltration, soil water content, evapotranspiration, and groundwater recharge. The sediment cycle includes sediment washload as a result of rainstorms, i.e., soil erosion that results from surface runoff. The pollutant cycle includes convective transport, volatilization, adsorption/desorption, and degradation/decay. A contaminant in SESOIL can partition in up to four phases (liquid, adsorbed, air, and pure).

Data requirements for SESOIL are not extensive, utilizing a minimum of soil and chemical parameters and monthly or seasonal meteorological values as input. Output of the SESOIL model includes pollutant concentrations at various soil depths and pollutant loss from the unsaturated soil zone in terms of surface runoff, percolation to groundwater, volatilization, and degradation.

Selection of the Model. SESOIL is well recognized and accepted by the scientific community utilizing soil-chemical fate models. It has been extensively validated and shown to work under a number of scenarios. Output of the SESOIL model includes pollutant concentrations at various soil depths and pollutant loss from the unsaturated soil zone in terms of percolation to groundwater, volatilization, and degradation. This information will be used to obtain contaminant concentrations in the soil which may be used to serve as guidelines for deep soil remediation. SESOIL has the advantage of fewer input requirements and faster computer run times than more complex unsaturated zone models, while still maintaining considerable resolution of the pollutant front in terms of both time and space.

Some of the attributes of SESOIL which make it particularly attractive and suitable for the vadose zone soil leaching study at BCV OU 2 are iterated below:

- SESOIL has been extensively validated and shown to work under a number of scenarios. It has also been used for similar applications in other parts of the country and is capable of providing the information required from this study (Bonazountas, Wagner, and Goodwin 1982; Wagner et al. 1986; Hetrick 1984; Watson and Brown 1985; Hetrick et al. 1986; Melancol, Pollard, and Hern 1986; Hetrick and Travis 1988; Hetrick et al. 1989; Hetrick, Luxmoore, and Tharp 1993).
- SESOIL has the advantage of fewer input requirements and faster run times than more complex unsaturated zone models, while still maintaining considerable resolution of the pollutant front in both time and space.
- Documentation of SESOIL is readily available including numerous publications on the subject and a user's guide recently developed by Hetrick and Scott (1993).

- The model can be divided into as few as two layers and as many as four layers. This compartmental nature of the model allows for user-specified tailoring to suit a particular site.
- SESOIL is a one-dimensional soil compartment model that takes adsorption, volatilization, degradation/decay, convective transport, and metal complexation processes into account. At the same time, the input data requirements are not extensive, making it simpler than more complex models.

Input Parameters. Selection of input parameters for a specific site is a critical factor in evaluating the exposure assessment relating to any modeling effort. The following sections present discussions on data collection, sensitivity analysis, and development of site-specific parameters.

The input data for SESOIL can be grouped into four types: climatic data, soil data, chemical data, and application data. There are a total of 61 separate parameters contained in these four data groups as presented in Table 3.31.

The climatic data file of SESOIL consists of an array of mean monthly temperature, mean monthly cloud cover fraction, average monthly relative humidity, average monthly shortwave albedo, average daily evapotranspiration, monthly precipitation, mean number of storm events per month, mean duration of rainfall, and mean length of rainy season. These data were taken from ATDL at Oak Ridge. Mean values for the last 50 years were used for mean monthly temperature and precipitation. Evapotranspiration values were based on Moore (1988).

The soil data file of SESOIL contains input parameters describing the physical characteristics of the subsurface soil. The parameters include soil bulk density, intrinsic permeability, soil disconnectedness index, soil porosity, organic carbon content, and cation exchange capacity. Most of these data were not collected during the RI sampling at the site and default values were used. There is, however, no measurement method for the soil disconnectedness index or a measured value of the Freundlich exponent. Soil disconnectedness index is a parameter that relates the soil permeability to the moisture content. Thus, SESOIL default values were used for these two parameters.

The intrinsic permeability for the vadose zone was calibrated using the groundwater recharge as the calibration target. The soil porosity was set to default values for clay (0.42). The calibrated intrinsic permeability for the unsaturated zone was 8E-10 cm^2 (7.8E-05 cm/s) which lies within the range of values observed at ORR shallow soil zone and corresponds to silty clay (Freeze and Cherry 1979). This value, however, is greater than the mean value (3.7E-05 cm/s) for near the base of storm flow zone determined by G. Moore (1989). This calibrated intrinsic permeability of 8E-10 cm^2 produced a recharge rate of 12.8 cm (5.0 in.) which compares favorably with the 13.7 cm (5.4 in.) determined by SAIC (1993).

Soil disconnectedness index replaces the moisture retention curves (or characteristic curves) used by other unsaturated zone leaching models. SESOIL User's Guide (Hetrick and Scott 1993) defines this parameter to be the exponent relating the "wetting" and "drying" time-dependent permeability of soil to its saturated permeability. The two permeabilities are related as:

Table 3.31. Input data accepted by SESOIL

Climate data	*Soil data*
Average Monthly Temperature	Description of Soil Type
Average Monthly Fraction of Cloud Cover	Soil Bulk Density
Average Monthly Relative Humidity	Soil Intrinsic Permeability (Unsaturated Zone)
Average Monthly Shortwave Albedo	Soil Disconnectedness Index
Average Daily Evapotranspiration	Effective Soil Porosity
Monthly Precipitation Depth	Saturated Hydraulic Conductivity (Saturated Zone)
Mean Time of Rainfall	Hydraulic Gradient (Saturated Zone)
Mean Number of Storm Events/Month	Organic Carbon Content of the Soil
Mean Length of Rainy Season	Cation Exchange Capacity of the Soil
	Freundlich Exponent
	Aquifer thickness
Chemical data	*Application data*
Description of the Compound	Number of Soil Layers
Solubility in Water	Number of Years of Data included in the Data Set
Diffusion Coefficient in Air	Surface Area of the Compartment
Henry's Law Constant	Depth of Each Layer (Unsaturated Zone)
Adsorption Coefficient on Organic Carbon	pH of Each Layer
Adsorption Coefficient of the Soil	Intrinsic Permeability of Each Layer
Molecular Weight of the Compound	Layer Ratios for Biodegradation in the Liquid Phase
Valence of the Compound	Layer Ratios for Biodegradation in the Solid Phase
Neutral Hydrolysis Constant	Layer Ratios for Organic Carbon Content of the Soil
Base Catalyzed Hydrolysis Constant	Layer Ratios for Cation Exchange Capacity in the Soil
Acid Catalyzed Hydrolysis Constant	Layer Ratios for Freundlich Exponent
Biodegradation Rate in the Liquid Phase	Layer Ratios for Adsorption Coefficient
Biodegradation Rate in the Solid Phase	Monthly Pollutant Load (Mass/Unit Area) entering Each Zone
Stability Constant of the Ligand Complex	Monthly Mass of Pollutant Transformed in Each Sublayer by Some Other Process
Moles of Ligand/Mole Complexed	Monthly Mass of Pollutant Removed from Each Sublayer by Some Other Process
Molecular Weight of Ligand	Monthly Ligand Mass Input to Each Sublayer
	Index of Volatilization/Diffusion Occurrence from Each Soil
	Index of Surface Pollutant Runoff

$$K(S) = K(1)S^c$$

where:

K(S)	=	hydraulic conductivity at S (cm/s),
S	=	percent saturation,
K(1)	=	saturated hydraulic conductivity (cm/s), and
c	=	soil disconnectedness index.

This "one" variable approach of using soil disconnectedness index in SESOIL simplifies the data estimation process and reduces computational time. In addition, this parameter was calibrated for four different soil types ranging from sandy loam to sharkey clay (Hetrick et al. 1986) and the calibrated values fell within the default range specified in the SESOIL User's Guide.

The pollutant fate cycle of SESOIL focuses on the various chemical transport and transformation processes that may occur in the soil zone. These processes include volatilization/diffusion, adsorption/desorption, and cation exchange, biodegradation and hydrolysis, and metal complexation. The chemical data file of SESOIL requires the following parameters for each of the pollutants to be modeled:

- solubility in water,
- air diffusion coefficient,
- Henry's law constant,
- organic carbon partition coefficient,
- soil adsorption coefficient,
- Freundlich exponent,
- molecular weight,
- valence of the pollutant compound,
- biodegradation rate in the liquid and solid phase, and
- hydrolysis rate constants (neutral, basic, and acidic).

Solubility in water, air diffusion coefficient, Henry's law constant, and organic carbon partition coefficient are chemical-specific parameters and were obtained from literature (EPA 1987a; EPA 1988a; EPA 1991d; EPA 1993a; Shen, Schmidt, and Card 1993; Perry, Chilton, and Kirkpatrick 1969). The remaining input parameters listed above are both chemical and site-specific (e.g., soil adsorption coefficient, biodegradation rates, etc.). Values found for these parameters in literature were carefully screened to select those values that were derived under conditions that approximate those at ORR. Literature values for K_d were used for all focused inorganic COPCs and were taken from Sheppard and Thibault (1990) or Baes et al. (1984). K_d values for organics were estimated using organic carbon content. An empirical formula (Mills et al. 1982) was used to correlate the octanol-water partitioning coefficient

(K_{ow}) to the octanol-carbon partitioning coefficient (K_{oc}). The K_{ow}s for the organic compounds were taken from EPA Risk Reduction Engineering Laboratory Treatability Database (EPA 1993a) and EPA Soil Transport and Fate Database (EPA 1991d).

The process of hydrolysis was ignored in this study because of the large uncertainty in the hydrolysis rates. For example, the rates of hydrolysis for various organic chemicals vary over more than 14 orders of magnitude. Due to this large uncertainty, SESOIL model results are considered only as approximations at best. Hydrolysis estimations require the acidic, basic, and neutral hydrolysis rate constants for different chemicals. Hence, these parameters were not needed and were set to zero for this analysis.

The biodegradation rates for the organic compounds were taken from the Handbook of Environmental Degradation Rates (Howard et al. 1991). A range of values is presented in this book, only the lowest biodegradation rates (highest half-life) were taken for this analysis. This approach was adopted to ensure conservatism in estimating contaminant loss through degradation/decay. The biodegradation rate was set to zero if none could be found in literature.

The Air Diffusion Coefficient is required to calculate losses of the pollutant due to the volatilization/diffusion process. Further, to determine the concentration of pollutant in the soil air (gaseous phase), Henry's Constant is required in the chemical input file. These parameters have already been summarized in Table 3.28 in Sect. 3.2.5.1. For a compound for which the air diffusion coefficient cannot be found directly from literature, a reasonable estimate was made from a known compound using the following relationship:

$$D^* = D\,(M/M^*)^{1/2}$$ (Shen, Schmidt, and Card 1993)

where:

D^* = air diffusion coefficient for the unknown compound,
D = air diffusion coefficient for the known compound,
M = molecular weight of the known compound,
M^* = molecular weight of the unknown compound.

"Known" compound refers to the chemical for which the air diffusion coefficient is known from the literature. "Unknown" compound refers to the chemical for which the air diffusion coefficient is sought. This equation can be applied only to an unknown compound having a molecular weight and a molecular structure close to that of the known compound (i.e., furan to dibenzofuran, etc.).

The application data file of SESOIL contains the general information describing the specifics of the chemical releases or application to the soil column. This information includes the dimensions of the soil column, the definition of soil layers (e.g., depths), and several additional soil properties.

Results. The SESOIL model was used to perform long-term predictive simulations of the contaminant transport and transformation processes occurring in the vadose zone at BCV OU 2. The model was run for each of the remaining COPCs listed in Table 3.30 using the initial concentrations at different depth intervals obtained from the RI sampling.

The simulations were continued until the maximum concentration (less than the solubility limit) in groundwater was attained. However, due to the voluminous amount of output per run and the computing time it takes to complete a long-term simulation, the SESOIL model was run for only 100 years for this analysis. The result of this analysis is presented in Tables 3.32, 3.33, and 3.34 for SA-1, SY-200 Yard, and RSA respectively. These tables present the soil exposure concentration (i.e., the 95% UCL of the mean at the site for the entire depth of contamination or the maximum if the UCL was greater than the maximum); the time of arrival (i.e., the time required by the contaminant to migrate to the water table with the percolating water); the time required to reach the maximum concentration at the water table vadose zone interface; and the maximum concentration within 100 years. The groundwater PRGs (MCL values if available; otherwise risk-based values) are also presented in these tables for a comparison with the maximum loading concentration. Based on the simulation results, it can be seen from Table 3.32 that none of the contaminants from SA-1 is expected to reach the water table with a concentration greater than the groundwater PRG within the simulation time of 100 years. From SY-200 (Table 3.33), only methylene chloride and 2-chlorophenol are expected to reach the water table with maximum concentrations above their respective groundwater PRGs. From the RSA (Table 3.34), the contaminants that are projected to be reaching the water table with concentrations above the PRGs are 1,2 dichloroethene, 1,2 dichloropropane, 2-hexanone, bromodichloromethane, cyanide, methylene chloride, tetrachloroethene, trichloroethene, vinyl acetate, and vinyl chloride. Biodegradation rates for bromodichloromethane, vinyl acetate, 2-chlorophenol, and 2-hexanone could not be found during the literature search and were set to zero; therefore, the predicted concentrations for these constituents were high. In reality, the concentrations could be orders of magnitude lower than the predicted values and could be lower than the respective groundwater PRGs.

These concentrations will be further diluted as the contaminant front moves through the saturated zone. Therefore, the output from SESOIL can be used for generating input values for various groundwater transport models to predict the contaminant concentration in groundwater, or simple dilution calculation can be performed using the Summers model (Summers, Gherini, and Chen 1980). The computed maximum groundwater concentration can be used to calculate the soil PRG based on contaminant leaching to groundwater. Since the Freundlich exponent was set to 1.0, SESOIL uses linear equilibrium partitioning and the PRGs can be back calculated from the maximum predicted groundwater concentration using the following linear relationship:

$$PRG = (MCL/C_{max}) \times PLC$$

where:

PRG = Preliminary Remediation Goal (μg/mL),
MCL = Maximum Contaminant Level or risk-based groundwater concentration (μg/mL),
C_{max} = Maximum predicted concentration in groundwater beneath the site under consideration (μg/mL),
PLC = Maximum Pollutant Loading Concentration in soil (μg/mL).

Surface Water and Sediment. Contaminants in surface soils can be released from source areas and transported to surface water via precipitation runoff. When it rains, some amount of the rainwater may stay in the soil, some may infiltrate through the soil column, and some

Table 3.32. Summary of COPCs that are projected to reach the aquifer in 100 years from SA-1

Constituent	Soil concentration[a] (ppm)	Time of arrival (year)	Time of maximum concentration (year)	Maximum loading concentration[b] (mg/L)	Groundwater PRG[c] (mg/L)
2-Butanone	7.7E-03	4	6	1.4E-05	1.1 R
Acetone	1.4E-02	3	8	1.5E-03	3.7 R
Chloroform	2.0E-03	0	30	2.0E-02	0.014 R
Methylene chloride	2.0E-03	13	20	1.4E-07	0.005 M
Tetrachloroethene	3.5E-03	85	100	7.0E-05	0.005 M
Toluene	3.4E-03	0	3	1.3E-03	1.0 M

[a]Soil concentration represents 95% UCL of the mean or the maximum at the site if the UCL is greater than the maximum.
[b]Maximum loading concentration is the maximum concentration of the leachate at the vadose zone aquifer interface.
[c]The basis for establishing groundwater PRG is indicated next to the value; M-MCL, and R-risk based concentration.

Table 3.33. Summary of COPCs that are projected to reach the aquifer in 100 years from the SY-200 Yard

Constituent	Soil concentration[a] (ppm)	Time of arrival (year)	Time of maximum concentration (year)	Maximum loading concentration[b] (mg/L)	Groundwater PRG[c] (mg/L)	
1,1,2-Trichloro-1,2,2-trifluoroethane	8.4E-03	30	45	4.0E-03	78	R
1,4-Dichlorobenzene	9.8E-02	65	75	4.0E-04	0.0035	R
2-Chlorophenol	1.4E-01	5	100	3.0E+00	0.18	R
4-Methyl-2-pentanone	8.9E-03	2	3	4.0E-03	2.9	R
Acetone	2.2E-01	1	3	1.4E-02	3.7	R
Carbazole	2.5E-01	>100	NA	0	—	
Methylene chloride	4.0E-02	0	2	1.7E-01	0.005	M

[a]Soil concentration represents 95% UCL of the mean or the maximum at the site if the UCL is greater than the maximum.
[b]Maximum loading concentration is the maximum concentration of the leachate at the vadose zone aquifer interface.
[c]The basis for establishing groundwater PRG is indicated next to the value; M-MCL, and R-risk based concentration.

Table 3.34. Summary of COPCs that are projected to reach the aquifer in 100 years from RSA

Constituent	Soil concentration[a] (ppm)	Time of arrival (year)	Time of maximum concentration (year)	Maximum loading concentration[b] (mg/L)	Groundwater PRG[c] (mg/L)
1,1 Dichloroethane	2.7E-02	10	15	1.0E-02	3.7 R
1,1 Dichloroethene	2.0E-02	5	10	1.5E-03	0.007 M
1,1,1 Trichloroethane	2.3E-02	37	50	6.2E-04	0.20 M
1,1,2 Trichloroethane	1.8E-02	18	25	1.6E-04	0.005 M
1,1,2-Trichloro-1,2,2-trifluoroethane	6.2E-01	0	90	1.4E+00	78 R
1,1,2,2 Tetrachloroethane	1.9E-02	21	25	2.7E-07	0.003 R
1,2 Dichloroethane	1.8E-02	8	20	4.9E-02	0.0002 R
1,2 Dichloroethene (total)	1.5E-02	18	50	8.1E-02	0.33 R
1,2-Dichloropropane	1.8E-02	25	70	3.8E-02	0.0013 R
2-Butanone	4.6E-02	1	5	7.0E-05	1.1 R
2-Hexanone	3.2E-02	6	30	4.5E+00	—
4-Methyl-2-pentanone	4.0E-02	4	7	1.5E-06	2.9 R
Acetone	1.1E+00	2	5	4.3E-03	3.7 R
Benzene	1.8-02	12	23	4.5E-03	0.005 M
Bromodichloromethane	1.8E-02	12	100	2.1E+00	0.1 M
Bromoform	1.8E-02	25	35	2.0E-05	0.011 R
Bromomethane (methyl bromide)	3.1E-02	5	10	4.0E-04	0.011 R
Carbon disulfide	2.0E-02	15	100	2.1E+00	3.7 R
Carbon tetrachloride	1.8E-02	68	75	2.7E-07	0.005 M
Chlorobenzene	1.8E-02	85	100	1.0E-06	0.73 R
Chloroethane	3.1E-02	8	10	1.2E-04	—

Table 3.34 (continued)

Constituent	Soil concentration[a] (ppm)	Time of arrival (year)	Time of maximum concentration (year)	Maximum loading concentration[b] (mg/L)	Groundwater PRG[c] (mg/L)
Chloroform	2.1E-02	15	40	9.0E-02	0.1 M
Chloromethane (methyl chloride)	3.1E-02	5	10	6.5E-04	0.0036 R
cis-1,3-dichloropropene	1.8E-02	15	20	7.0E-07	0.00019[d] R
Cyanide	1.2E+00	2	10	1.3E+01	0.2 M
Dibromochloromethane	1.8E-02	18	25	5.3E-060	
Dimethylphthalate	2.0E-01	0	2	2.8E-02	0.037 R
Ethylbenzene	2.2E-02	>100	NA	0.0	0.7 M
Methylene chloride	1.3E-01	2	5	7.0E-03	0.005 M
Tetrachloroethene	1.3E+00	32	50	1.6E+00	0.005 M
Toluene	2.8E-02	60	75	1.4E-03	1.0 M
Trans-1,3-dichloropropene	1.8E-02	15	20	7.0E-07	0.00019[d] R
Trichloroethene	1.3E-01	30	50	6.0E-02	0.005 M
Vinyl acetate	3.3E-02	3	20	3.1E+00	0.56 R
Vinyl chloride	3.1E-02	5	25	5.5E-01	0.002 M
Xylene	2.8E-02	>100	NA	0	10 M

[a] Soil concentration represents 95% upper confidence limit (UCL) of the mean at the site for the entire depth of contamination, if the UCL is greater than the maximum
then the maximum value is used.
[b] Maximum loading concentration is the maximum concentration of the leachate at the vadose zone aquifer interface.
[c] The basis for establishing groundwater PRG is indicated next to the value; M-MCL, and R-risk based concentration.
[d] Risk-based PRGs taken from STF database (EPA 1993).

may move as runoff. The proportions of these depend on soil type, soil cover, the amount of moisture already present in the soil, the intensity and duration of rainfall, and slope length and steepness.

Contaminants in the surface soil can be transported via runoff either in the dissolved phase or adsorbed to soil particles. The less soluble a contaminant is in water, the more likely it will be adsorbed to soil particles. Because the water solubility of different types of contaminants (see Table 3.28) vary widely, transport in runoff in both phases should be taken into account.

Natural drainage from the RSA and the SY-200 Yard flows primarily to Bear Creek. The surface runoff at these BCV OU 2 sites flows primarily as sheet flow into Bear Creek. Channelized flow, other than Bear Creek, is important mainly in man-made ditches and culverts. These, and the few naturally-occurring, topographically-controlled surface channels, empty into Bear Creek.

Modeling the transport of soil by runoff requires characterization of the contaminants in the initial soil or waste source term. Two models are used to quantify the migration of contaminated soil to stream sediment from erosion by surface water runoff. The two soil loss models, obtained from the EPA *Superfund Exposure Assessment Manual* (EPA 1988a), are the Universal Soil Loss Equation (USLE) and the Modified Universal Soil Loss Equation (MUSLE). These models calculate the total mass of soil transported for a single rainfall event (MUSLE) or annually (USLE). The USLE model takes the same form as MUSLE, except that USLE uses an area-dependent method to determine runoff, while MUSLE employs event-specific runoff volume and flow-rate variables. Additional contaminant partitioning and loading models are used to describe contaminant partitioning between soil and water in the runoff flow. These partitioning models provide an estimate of the contaminant concentration dissolved in runoff water and adsorbed to the soil that is carried with the runoff and deposited in the sediments of receiving surface water bodies (Haith 1980, Mills et al. 1982). The volume of runoff is also estimated in order to determine both the amount that stream flow may be increased by a runoff event, and to estimate dissolved contaminant loading. The depth of runoff is calculated as a function of the depth of rainfall and a soil water retention factor. The dissolved contaminant concentration in the receiving stream is estimated by a simple dilution model with runoff concentration, runoff volume, and stream flow.

All three sites (SA-1, the SY-200 Yard, and RSA) were selected as source terms for modeling. Surface water and sediment concentrations were modeled on an event-specific basis using MUSLE. Because event-specific concentrations should yield more conservative results of episodal contamination than an average calculated for one or several years. Both low and high flow values for Bear Creek were used in the model to represent flows in Bear Creek. Surface water concentrations were estimated based on both high and low flow rates in the receiving stream. Soil concentrations for the source areas used in the model are presented in Tables 3.35 through 3.37. The results of surface water modeling (i.e, projected total annual contaminant loading to the receiving stream, projected maximum sediment and surface water concentrations) are also presented in these tables. Model parameters and references for these source term areas are presented in Table 3.38.

Table 3.35. Contaminant loading to surface water from RSA

Constituents	Chemical data		Results		
	Partition coefficient Kd (mL/g)	Solid conc. in site source Ci (mg/kg)	Total annual loading to stream Tl (g)	Event surface water conc. Cw (mg/L)	Sediment conc. Cs (mg/kg)
	Organics				
1,1 Dichloroethane	3.88E-01	2.13E-02	1.5E+01	1.5E-04	1.7E-02
1,1 Dichloroethene	1.90E-01	1.66E-02	1.9E+01	2.0E-04	1.1E-02
1,1,1 Trichloroethane	1.86E+00	1.83E-02	4.3E+00	3.3E-05	1.7E-02
1,1,2 Trichloroethane	9.32E-01	1.47E-02	5.6E+00	4.9E-05	1.3E-02
1,1,2-Trichloro-1,2,2-trifluorethane	6.30E-03	1.60E-01	4.5E+02	4.9E-03	8.9E-03
1,1,2,2 Tetrachloroethane	6.91E+00	1.47E-02	1.8E+00	7.3E-06	1.4E-02
1,2 Dichloroethane	1.78E-01	1.48E-02	1.7E+01	1.8E-04	9.2E-03
1,2 Dichloroethene	7.75E-01	1.57E-01	6.8E+01	6.2E-04	1.4E-01
1,2-Dichlorobenzene	1.51E+01	2.22E-01	2.2E+01	5.1E-05	2.2E-01
1,2 Dichloropropane	1.20E+00	1.47E-02	4.7E+00	3.9E-05	1.4E-02
1,2,4-Trichlorobenzene	6.02E+01	7.52E-01	6.3E+01	4.4E-05	7.5E-01
2-Butanone	1.15E-02	3.83E-02	1.0E+02	1.1E-03	3.7E-03
2-Hexanone	1.51E-01	2.74E-02	3.5E+01	3.7E-04	1.6E-02
2-Methylnaphthalene	4.56E+01	2.07E-01	1.8E+01	1.6E-05	2.1E-01
2,4-Dimethylphenol	1.66E+00	2.25E-01	5.7E+01	4.5E-04	2.1E-01
4-Methyl-2-pentanone	3.31E-02	1.12E-01	2.6E+02	2.8E-03	2.7E-02
4-Methylphenol	5.36E-01	2.65E-01	1.5E+02	1.4E-03	2.2E-01
Acenaphthene	5.24E+01	6.60E-02	5.6E+00	4.4E-06	6.6E-02
Acenaphthylene	7.40E+01	5.60E-02	4.6E+00	2.6E-06	5.6E-02
Acetone	3.63E-03	1.78E+00	5.2E+03	5.6E-02	5.9E-02
Anthracene	1.78E+02	1.40E-01	1.1E+01	2.7E-06	1.4E-01
Aroclor-1254	6.75E+03	8.90E+00	7.0E+02	4.6E-06	8.9E+00
Benzene	8.50E-01	3.70E-02	1.5E+01	1.3E-04	3.3E-02
Benzo(a)anthracene	2.57E+03	2.48E-01	1.9E+01	3.4E-07	2.5E-01
Benzo(a)pyrene	6.02E+03	3.61E-01	2.8E+01	2.1E-07	3.6E-01
Benzo(b)fluoranthene	2.34E+04	3.60E-01	2.8E+01	5.4E-08	3.6E-01
Benzo(g,h,i)perylene	1.07E+05	4.00E-01	3.1E+01	1.3E-08	4.0E-01
Benzo(k)fluoranthene	4.36E+04	3.08E-01	2.4E+01	2.5E-08	3.1E-01
Bromodichloromethane	4.78E-01	3.70E-02	2.3E+01	2.2E-04	3.0E-02
Bromoform	1.26E+00	3.70E-02	1.1E+01	9.5E-05	3.4E-02
Bromomethane (methyl bromide)	7.93E-02	7.53E-02	1.3E+02	1.4E-03	3.2E-02
bis-(2-ethylhexyl)phthalate	1.26E+03	2.29E+01	1.8E+03	6.3E-05	2.3E+01
Butylbenzylphthalate	3.80E+02	7.30E-02	5.8E+00	6.7E-07	7.3E-02
Carbazole	2.04E+01	1.00E-01	9.4E+00	1.7E-05	9.9E-02
Carbon disulfide	9.11E-01	3.70E-02	1.4E+01	1.3E-04	3.3E-02
Carbon tetrachloride	3.38E+00	3.70E-02	6.2E+00	3.7E-05	3.6E-02
Chlorobenzene	4.36E+00	3.70E-02	5.5E+00	2.9E-05	3.6E-02
Chloroethane	1.70E-01	7.53E-02	9.1E+01	9.5E-04	4.6E-02
Chloroform	5.88E-01	6.59E-02	3.5E+01	3.3E-04	5.6E-02
Chloromethane (methyl chloride)	5.12E-02	7.53E-02	1.5E+02	1.7E-03	2.4E-02
Chrysene	2.57E+03	2.95E-01	2.3E+01	4.0E-07	2.9E-01
cis-1,3-dichloropropene	7.25E-01	3.70E-02	1.7E+01	1.6E-04	3.2E-02

Table 3.35 (continued)

Constituents	Chemical data: Partition coefficient Kd (mL/g)	Chemical data: Solid conc. in site source Ci (mg/kg)	Results: Total annual loading to stream Tl (g)	Results: Event surface water conc. Cw (mg/L)	Results: Sediment conc. Cs (mg/kg)
Dibenzofuran	8.31E+01	3.80E-02	3.1E+00	1.6E-06	3.8E-02
Dibenzo(a,h)anthracene	5.88E+03	2.45E-01	1.9E+01	1.5E-07	2.4E-01
Dibromochloromethane	7.75E-01	3.70E-02	1.6E+01	1.5E-04	3.3E-02
Dimethylphthalate	4.67E-01	1.50E-01	9.3E+01	9.1E-04	1.2E-01
Di-N-butylphthalate	9.98E+02	1.30E+00	1.0E+02	4.5E-06	1.3E+00
Di-N-octyphthalate	9.98E+06	3.21E-01	2.5E+01	1.1E-10	3.2E-01
Endosulfan I	2.51E+01	6.50E-04	5.9E-02	9.0E-08	6.5E-04
Ethylbenzene	8.90E+00	6.21E-02	7.0E+00	2.4E-05	6.1E-02
Fluoranthene	1.35E+03	4.61E-01	3.6E+01	1.2E-06	4.6E-01
Fluorene	9.54E+01	8.30E-02	6.8E+00	3.0E-06	8.3E-02
Heptachlor	1.58E+02	8.80E-04	7.1E-02	1.9E-08	8.8E-04
Ideno(1,2,3-c,d)pyrene	2.88E+05	4.08E-01	3.2E+01	4.9E-09	4.1E-01
Methylene chloride	1.12E-01	1.10E+00	1.6E+03	1.8E-02	5.6E-01
Naphthalene	1.48E+01	9.00E-02	8.9E+00	2.1E-05	8.9E-02
Pentachlorophenol	6.45E+02	4.70E-02	3.7E+00	2.5E-07	4.7E-02
Phenanthrene	1.82E+02	5.99E-01	4.8E+01	1.1E-05	6.0E-01
Phenol	1.82E-01	6.30E-01	7.3E+02	7.6E-03	4.0E-01
Pyrene	9.54E+02	8.46E-01	6.7E+01	3.1E-06	8.5E-01
p,p′-methoxychlor	3.02E+02	1.50E-03	1.2E-01	1.7E-08	1.5E-03
Styrene	9.11E+00	3.70E-02	4.2E+00	1.4E-05	3.7E-02
Tetrachloroethene	2.13E+00	3.29E+02	7.1E+04	5.1E-01	3.1E+02
Toluene	3.09E+00	9.09E-02	1.6E+01	9.9E-05	8.8E-02
Trans-1,3-dichloropropane	7.06E-01	3.70E-02	1.7E+01	1.6E-04	3.2E-02
Trichloroethene	2.13E+00	2.90E+00	6.3E+02	4.5E-03	2.8E+00
Vinyl acetate	2.71E-03	3.81E-02	1.1E+02	1.2E-03	9.4E-04
Vinyl chloride	2.51E-02	7.53E-02	1.8E+02	2.0E-03	1.4E-02
Xylene	8.90E+00	1.04E-01	1.2E+01	4.0E-05	1.0E-01
Metals					
Antimony	2.50E+02	3.60E-01	2.9E+01	5.0E-06	3.6E-01
Barium	6.00E+01	1.15E+02	9.6E+03	6.7E-03	1.2E+02
Cadmium	5.60E+02	5.70E+00	4.5E+02	3.6-05	5.7E+00
Cobalt	5.50E+02	1.62E+01	1.3E+03	1.0E-04	1.6E+01
Manganese	1.80E+02	9.54E+02	7.6E+04	1.8E-02	9.5E+02
Mercury	8.80E+04	4.28E+00	3.4E+02	1.7E-07	4.3E+00
Nickel	6.50E+02	4.73E+01	3.7E+03	2.5E-04	4.7E+01
Silver	1.80E+02	1.10E+00	8.8E+01	2.1E-05	1.1E+00
Thallium	1.50E+03	1.50E-01	1.2E+01	3.5E-07	1.5E-01
Uranium (total)	4.60E+01	7.81E+00	6.7E+02	5.9E-04	7.8E+00
Radionuclides					
^{234}U	4.60E+01	7.03E-05	6.0E-03	5.3E-09	7.0E-05
^{238}U	4.60E+01	1.00E+01	8.5E+02	7.6E-04	1.0E+01

Table 3.36. Contaminant loading to surface water from SA-1

Constituents	Chemical data		Results		
	Partition coefficient Kd (mL/g)	Solid conc. in site source Ci (mg/kg)	Total annual loading to stream Tl (g)	Event surface water conc. Cw (mg/L)	Sediment conc. Cs (mg/kg)
		Organics			
Acetone	3.63E-03	2.20E-01	3.5E+02	3.8E-03	7.2E-03
Benzo(a)anthracene	2.57E+03	2.30E-01	3.2E+00	1.7E-07	2.3E-01
Benzo(a)pyrene	6.02E+03	2.20E-01	3.1E+00	7.0E-08	2.2E-01
Benzo(b)fluoranthene	2.34E+04	3.10E-01	4.3E+00	2.5E-08	3.1E-01
Benzo(g,h,i)perylene	1.07E+05	1.20E-01	1.7E+00	2.2E-09	1.2E-01
Benzo(k)fluoranthene	4.36E+04	3.10E-01	4.3E+00	1.4E-08	3.1E-01
Chrysene	2.57E+03	2.90E-01	4.1E+00	2.2E-07	2.9E-01
Fluoranthene	1.35E+03	5.60E-01	7.9E+00	8.0E-07	5.6E-01
Ideno(1,2,3-c,d)pyrene	2.88E+05	9.90E-02	1.4E+00	6.6E-10	9.9E-02
Methylene chloride	1.12E-01	2.00E-03	1.6E+00	1.8E-05	1.0E-03
Phenanthrene	1.82E+02	4.30E-01	6.4E+00	4.5E-06	4.3E-01
Pyrene	9.54E+02	4.90E-01	6.9E+00	9.9E-07	4.9E-01
		Metals			
Aluminum	1.50E+03	2.93E+04	4.1E+05	3.8E-02	2.9E+04
Barium	6.00E+01	1.48E+03	2.5E+04	4.7E-02	1.5E+03
Beryllium	1.30E+03	1.29E+00	1.8E+01	1.9E-06	1.3E+00
Cadmium	5.60E+02	3.63E+00	5.2E+01	1.2E-05	3.6E+00
Cobalt	5.50E+02	2.23E+01	3.2E+02	7.8E-05	2.2E+01
Copper	3.50E+01	2.82E+01	5.3E+02	1.5E-03	2.8E+01
Lead	5.50E+02	1.10E+02	1.6E+03	3.8E-04	1.1E+02
Nickel	6.50E+02	5.10E+01	7.3E+02	1.5E-04	5.1E+01
Phosphorus	3.50E+01	4.47E+02	8.5E+03	2.4E-02	4.5E+02
		Radionuclides			
Radium (total)	9.10E+03	3.40E-06	4.8E-05	7.2E-13	3.4E-06
Uranium (total)	4.60E+01	1.80E+01	3.2E+02	7.5E-04	1.8E+01
^{235}U	4.60E+01	5.20E-02	9.2E-01	2.2E-06	5.2E-02

Table 3.37. Contaminant loading to surface water from the SY-200 Yard

Constituents	Chemical data		Results		
	Partition coefficient Kd (mL/g)	Solid conc. in site source Ci (mg/kg)	Total annual loading to stream Tl (g)	Event surface water conc. Cw (mg/L)	Sediment conc. Cs (mg/kg)
		Organics			
1,1,2-Trichloro-1,2,2-trifluoroethane	9.32E-01	1.44E-02	4.2E+00	2.4E-05	1.3E-02
1,2,4-Trichlorobenzene	6.02E+01	9.60E-02	1.5E+01	2.8E-06	9.6E-02
1,4-Dichlorobenzene	1.55E+01	9.80E-02	9.0E+01	8.2E-04	9.7E-02
2-Chlorophenol	8.90E-01	1.40E-01	2.2E+01	3.7E-05	1.3E-01
2,4-Dinitrotoluene	6.45E-01	9.10E-02	1.6E+01	4.3E-05	7.8E-02
4-Chloro-3-methylphenol	7.93E+00	1.80E-01	4.8E+01	2.3E-04	1.8E-01
4-Methyl-2-pentanone	3.31E-02	2.50E-02	3.5E+00	2.9E-05	5.9E-03
4-Nitrophenol	5.12E-01	2.40E-01	3.1E+01	1.3E-05	2.0E-01
4,4'-DDE	3.09E+03	3.94E-03	3.7E+05	4.1E+00	3.9E-03
Acenaphthene	5.24E+01	1.20E-01	2.3E+02	2.3E-03	1.2E-01
Acetone	3.63E-03	2.08E-01	1.3E+00	2.7E-06	6.8E-03
Anthracene	1.78E+02	1.80E-01	5.0E+02	5.1E-03	1.8E-01
Aroclor-1254	6.75E+03	6.20E-02	5.2E+04	5.6E-01	6.2E-02
Aroclor-1260	5.12E+04	4.04E-01	6.0E+04	6.6E-01	4.0E-01
Benzo(a)anthracene	2.57E+03	2.60E-01	4.7E+03	5.1E-02	2.6E-01
Benzo(a)pyrene	6.02E+03	2.65E-01	1.1E+04	1.2E-01	2.7E-01
Benzo(b)fluoranthene	2.34E+04	3.17E-01	3.5E+04	3.8E-01	3.2E-01
Benzo(g,h,i)perylene	1.07E+05	2.31E-01	2.2E+05	2.4E+00	2.3E-01
Benzo(k)fluoranthene	4.36E+04	2.59E-01	8.0E+04	8.7E-01	2.6E-01
bis-(2-ethylhexyl)phthalate	1.26E+03	7.20E-02	8.3E+03	9.0E-02	7.2E-02
Carbazole	2.04E+01	1.70E-01	8.3E+01	6.2E-04	1.7E-01
Chrysene	2.57E+03	2.77E-01	4.4E+03	4.8E-02	2.8E-01
Dibenzofuran	8.31E+01	5.00E-02	8.0E+02	8.6E-03	5.0E-02
Dibenzo(a,h)anthracene	5.88E+03	1.00E-01	2.8E+04	3.0E-01	1.0E-01
Dimethylphthalate	4.67E-01	4.80E-02	1.2E+01	6.2E-05	3.9E-02
Ethylbenzene	8.90E+00	1.10E-02	3.9E+02	4.2E-03	1.1E-02
Fluoranthene	1.35E+03	3.00E-01	2.2E+03	2.3E-02	3.0E-01
Fluorene	9.54E+01	9.60E-02	4.9E+02	5.1E-03	9.6E-02
Ideno(1,2,3-c,d)pyrene	2.88E+05	2.38E-01	5.7E+05	6.3E+00	2.4E-01
Methylene chloride	1.12E-01	5.09E-02	6.0E+00	2.2E-05	2.6E-02
N-Nitro-di-N-propylamine	1.29E-01	8.50E-02	8.3E+00	1.4E-05	4.6E-02
Pentachlorophenol	6.45E+02	3.00E-01	1.1E+03	1.1E-02	3.0E-01
Phenanthrene	1.82E+02	2.92E-01	3.4E+02	3.2E-03	2.9E-01

Table 3.37 (continued)

Constituents	Chemical data: Partition coefficient Kd (mL/g)	Chemical data: Solid conc. in site source Ci (mg/kg)	Results: Total annual loading to stream Tl (g)	Results: Event surface water conc. Cw (mg/L)	Results: Sediment conc. Cs (mg/kg)
Pyrene	9.54E+02	3.10E-01	1.5E+03	1.6E-02	3.1E-01
Toluene	3.09E+00	1.00E-03	1.5E+03	1.7E-02	9.7E-04
Xylene	8.90E+00	1.86E-02	2.3E+02	2.5E-03	1.8E-02
		Metals			
Antimony	2.5E+02	4.60E-01	3.3E+02	2.8E-03	4.6E-01
Barium	6.0E+01	8.76E+01	1.3E+04	3.6E-06	8.7E+01
Beryllium	1.3E+03	9.60E-01	7.9E+02	7.0E-03	9.6E-01
Cadmium	5.6E+02	1.20E-01	2.2E+03	2.4E-02	1.2E-01
Cobalt	5.5E+02	1.98E+01	3.0E+03	1.4E-04	2.0E+01
Lead	5.5E+02	5.88E+01	8.9E+03	4.8E-05	5.9E+01
Manganese	1.8E+02	7.29E+02	1.1E+05	1.3E-06	7.3E+02
Mercury	8.8E+04	6.98E+01	1.1E+04	6.5E-03	7.0E+01
Nickel	6.5E+02	2.71E+01	4.1E+03	1.2E-04	2.7E+01
Silver	1.8E+02	1.51E+00	2.8E+02	6.2E-04	1.5E+00
Thallium	1.5E+03	3.00E-01	2.4E+03	2.6E-02	3.0E-01

Table 3.38. Variables used in the surface water runoff model

Variables	Units	RSA	SA-1	SY-200 Yard
LS, slope length and steepness factor[a]	unitless	2.0	2.2	0.8
C, cover factor[a]	unitless	0.042	0.013	0.45
A, contaminated area[b]	ha	3.04	1.99	1.15
CN, SCS runoff curve No.[a]	unitless	78	71	92
Oc, available water capacity[b]	unitless	0.16	0.16	0.16
ρ, soil bulk density[b]	g/cm^3	1.5	1.5	1.5
Rr, rainfall and runoff factor[c]	unitless	190	190	190
K, soil erodibility factor[d]	ton/ha	0.43	0.43	0.43
Rt, total storm rainfall[e]	cm	19.0	19.0	19.0
Tr, storm duration[e]	h	24	24	24

[a]EPA 1988b (Fig. 2-6 and site-specific information).
[b]Calculated from site-specific information.
[c]Ramsey 1994.
[d]USDA 1981.
[e]NOAA 1993.

3.2.5.4 Summary and results

Groundwater. The major uncertainty in the transport analysis is the estimation of organic decay constants and K_ds for metals and radionuclides. Based upon the data available, a conservative approach was used which may usually overestimate the contaminant concentration in the leachate. Listed below are important assumptions used in this analysis:

- The use of K_d and R_d to describe the reaction term of the transport equation assumes that an equilibrium relationship exists between the solid- and solution-phase concentrations and that the relationship is linear.
- With the exception of mercury, it was necessary to use published or calculated K_d values.
- Lowest biodegradation rates for the organic compounds were taken from literature.
- Migration of contaminants in the vadose zone is only in the vertical direction.
- Initial condition is disregarded in the vadose zone modeling.

The inherent problems associated with using these assumptions must be recognized. K_d values are highly sensitive to changes in the major chemistry of the solution phase. It is, therefore, important that the values be measured or estimated under conditions that will represent as closely as possible those of the contaminant plume. It is also important to note that the major geochemistry of the plume will change over time and be affected by multiple solutes that are present in any waste disposal facility. Projected organic and cyanide concentrations in the aquifer are highly uncertain because of the lack of site-specific data on constituent decay in the vadose zone. Use of literature values may produce either over- or underestimation of constituents' concentrations in the aquifer. In general, conservative values were used, therefore, most of the results are expected to be overly conservative overestimating contaminant concentrations in groundwater.

Based on modeling using ODAST, a majority of the organic compounds (retardation factor >50) that have been identified as the constituents of potential concern in the BCV OU 2 sites do not reach the aquifer within 100 years. In general, organic compounds that are highly soluble (low retardation factors) are projected to reach the aquifer, but because of biodegradation, the concentrations of these compounds are significantly reduced. It should be noted here that the actual retardation factors and especially the organic decay rates at these sites may not closely follow the assumed literature values particularly over the long term. Deviations from assumed literature values may significantly affect contaminant fate predictions. The following paragraphs present a brief discussion on sensitivity of model prediction to uncertainties in model input parameters.

TCE from RSA was used as the representative organic contaminant in the sensitivity analysis since it was found at elevated concentrations in both soil and groundwater. From the modeling results it was observed that the maximum concentration of TCE in the leachate before reaching the water table is expected to be 60 ppb, but analytical results of groundwater sampling indicate otherwise. This discrepancy was investigated by performing sensitivity analysis on the two model input parameters that have the most influence on the model predictions. These parameters are: K_d and biodegradation rate constant. Simulations were performed by varying K_d by one order of magnitude (0.213 to 2.13 L/kg) and by varying biodegradation rate constant from 0 to 0.004 (these values were chosen based on literature

search). The predicted maximum TCE concentration in the leachate before reaching the aquifer ranged from 0.00089 to 310 ppb with mean of 130 ppb.

The mean value estimated based on sensitivity analysis is close to the maximum TCE concentrations observed in the groundwater (120 ppb). This suggests that sensitivity analysis may be necessary for the most important contaminants at the three sites that may pose a threat to human health before using the model predictions for FS (developing the cleanup goals based on contaminant leaching to groundwater). It also indicates that the biodegradation rate used in the initial model, although representative of the most conservative value found in literature, was not conservative for this site. The biodegradation rate that produced 130 ppb TCE concentration is approximately two orders of magnitude less than the literature value used; however, this may be reasonable based on site conditions.

The products of TCE biodegradation (mainly vinyl chloride) are present in soils at RSA and this indicates that biodegradation has occurred in soil at this site. However, vinyl chloride is absent in groundwater at RSA, and its concentration in soil is generally low (30 ppb). This indicates that although biodegradation of TCE and other chlorinated volatiles present in soils at RSA (primarily PCE and DCE) may have occurred, the extent of breakdown is small. These observations are consistent with using a lower biodegradation rate for TCE that results in groundwater concentrations comparable to those seen in groundwater.

Surface Water. Surface water fate and transport calculations were performed for the COPCs at each of the three sites in BCV OU 2. The results of the surface water modeling show that, in general, contaminant loading into Bear Creek from the three sites will be small to negligible (Tables 3.35 through 3.37). The major contributing factor to these results is the magnitude of the K_ds for the COPCs. All of these are greater than unity which indicates that the COPCs will tend to remain in the soil and not partition into the surface water. The loading of a particular element or compound is different at each of the three sites. For example, the modeled loading of barium into Bear Creek ranges from 3.6×10^{-6} mg/L at the SY-200 Yard to 0.012 mg/L at SA-1, and pyrene concentrations range from 9.2 × 10-7 mg/L at SA-1 to 0.016 mg/L at the SY-200 Yard. This variability reflects a number of factors that are variable from site to site including the initial concentration of the element or compound in the soil, erodability of the site (i.e., grass cover), surface slope, and areal extent of contamination.

As a measure of contamination potential, the loading of each COPC from each site was compared to available MCL or PRG values. The concentration of cadmium at the SY-200 Yard (0.024 mg/L) substantially exceeded the MCL/PRG value (0.005 mg/L). The beryllium loading concentration (0.007 mg/L) from the same site was elevated relative to the MCL/PRG value (0.004 mg/L). Predicted concentrations of all constituents from SA-1 were below MCLs and PRGs. The projected concentrations of methylene chloride (0.018 mg/L) and tetrachloroethene (0.51 mg/L) in the RSA were higher than the MCL/PRGs of 0.011 mg/L and 0.005 mg/L, respectively. When compared to analyzed surface water compositions from this report, all contaminant loading values except one are substantially less than the water compositions. This is to be expected because the water samples were collected for analysis directly on the sites and the loading concentrations were calculated to include a dilution factor for water present in Bear Creek.

Contaminant fate and transport by surface water at the three sites in BCV OU 2 were modeled using MUSLE. The modeling was performed to forecast potential contaminant releases to Bear Creek along the boundary of BCV OU 2. The accuracy of the predictions made by the model relies heavily on the accuracy of the assumptions that serve as input parameters to the model calculations. Following is a description of the uncertainties in the model results that may arise due to uncertainties in model input parameters:

Modeling uncertainties can be grouped into five types:

TYPE 1 Soil Compositions. This type of uncertainty arises from the manner in which soil compositions were calculated for input to the model. The composition used in the calculation for each of the three waste units in OU 2 is a composite of analyzed soil compositions for the upper 10 ft of that unit. Type 1 uncertainties are rooted in the inherent vertical and lateral heterogeneities in actual soil compositions that create inaccuracies in the composition of the source term.

TYPE 2 Precipitation. Model results are event-specific. That is, the modeling was conducted to reflect the effects after a single storm event. To make conservative model predictions, the amount of rainfall that was used in the calculations was the maximum rainfall to have occurred in a 24-h period over the last 50 years (19 cm in 24-h period; NOAA 1993).

TYPE 3 Soil Organic Content. One of the most sensitive parameters in fate and transport modeling is the soil/water K_d. As described above, the K_d is calculated by multiplying the K_{oc} by the fraction of organic carbon (f_{oc}) in the soil. Measured values for either K_ds or f_{oc} for these sites were not available, therefore, for f_{oc} a default value of 0.01 for clay soil was used for determining the K_ds for the organic compounds. This value may over represent the fraction of organic carbon in most other types of soils and therefore produce a K_d that is too large.

TYPE 4 Biodegradation. Most of the organic contaminants at the three sites will degrade over time, diminishing their concentrations and risk to potential receptors. The conservative approach used in the surface water modeling was to assume no biodegradation of organic compounds.

TYPE 5 Grass Cover. An input parameter to the surface water model is the amount of grass cover at the site being modeled. The impact of grass cover is that the larger its extent the less erosion will take place. It was assumed for the model that SA-1 was 80% covered, RSA was 60% covered, and the SY-200 Yard had no cover. However, the actual proportion of grass cover can be highly variable depending on such factors as weather conditions or season.

3.2.6 Biomonitoring Data

Numerous biomonitoring studies have been conducted in Bear Creek and the Bear Creek floodplain, including Van Winkle et al. (1984), TVA (1985), Southworth et al. (1992), and the ongoing Biomonitoring and Abatement Program. In general, contaminant concentrations were lower in the downstream reaches of the creek, with increased distance from source units such as the S-3 Ponds and the Bear Creek Burial Grounds. There was no specific sampling done in the vicinity of the BCV OU 2 sites, however, and all of the sampling in these historical investigations was performed in areas covered by the integrator unit (BCV OU 4). It is not likely that any determinations can be made about the contribution from BCV OU 2

sites to ecological risk from the historical investigations, and biomonitoring data were not collected as part of the current RI. Surface runoff from BCV OU 2 may contribute to ecorisks in Bear Creek, but that will be evaluated in BCV OU 4.

3.2.7 Air Data

Background information on air quality is provided with the intent to show that the Y-12 Plant has not affected the air quality of the BCV OU 2 sites. The Y-12 Plant operates 12 ambient air monitoring stations around the plant perimeter for routine measurement of suspended uranium particulate matter. Monitors for total suspended particulate (TSP) and respirable particulate (PM 10) in the ambient air are located at the east and west ends of the site (Fig. 3.57). The west end TSP and PM 10 monitor is located in the immediate vicinity of the BCV OU 2 sites. Air monitoring has been performed on the ORR and around the Y-12 Plant for some time. A source of information on airborne emissions from the Y-12 Plant is the ORR Environmental Report for 1992 (Energy Systems 1993a). This report summarizes the results of air monitoring on the ORR and provides a basis for estimating source and background values relative to BCV. Air has been eliminated from consideration as a migration pathway for contaminants from the BCV OU 2 soil as a result of these studies. This section presents a summary of the results of historical air monitoring activities on ORR and at BCV OU 2 (Sect. 3.2.8.1).

3.2.7.1 Historical data

According to the ORR Environmental Report for 1992 (Energy Systems 1993a), 5800 Ci of radionuclides were released to the atmosphere from Oak Ridge installations during 1992. The contribution of airborne radionuclides from the K-25 Site was 0.0822 Ci, and from the Y-12 Plant (primarily uranium), 0.060 Ci. The remainder was released from ORNL. This represents a reduction in radioactive airborne emissions at ORNL from about 25,000 Ci in 1991, due largely to the cessation of ^{85}Kr and ^{3}H processing operations. The variations in release amounts from year to year can be accounted for almost totally by two inert gases, xenon and krypton. These gases have little or no interaction with the terrestrial biosphere, including humans.

Uranium is the primary radioactive element released from the Y-12 Plant. Uranium emissions have shown a gradual decrease in recent years at the plant. The lowest discharge from the Y-12 Plant in the past 5 years was recorded in 1992. This decrease reflects a reduction in Y-12 Plant process activities, continued improvements in administrative controls of the process activities still operating, and recent improvements in contamination control throughout the Y-12 Plant. With the Y-12 Plant ceasing active production in late 1992, uranium emissions should be less in subsequent years, although this data is not currently available.

Atmospheric radionuclide concentrations occurring in the environment around the ORR and the surrounding region are monitored or sampled continuously by an air-monitoring network. Air concentration measurements are taken for 15 radioactivity parameters: gross alpha, gross beta, ^{137}Cs, ^{237}Np, ^{234}Pa, ^{238}Pu, ^{239}Pu, ^{99}Tc, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}Th, ^{234}U, ^{235}U, and ^{238}U. Analysis of the ORR perimeter air-sampling data shows that operations on the ORR are very slightly increasing local concentrations of radionuclides. These range from <0.01 to 0.16% of the derived concentration guides (DCGs) for the network averages. Therefore, ORR operations have slight impact on local air quality and do not measurably impact the regional air quality. The local impact is well below the DCG (Energy Systems 1993a).

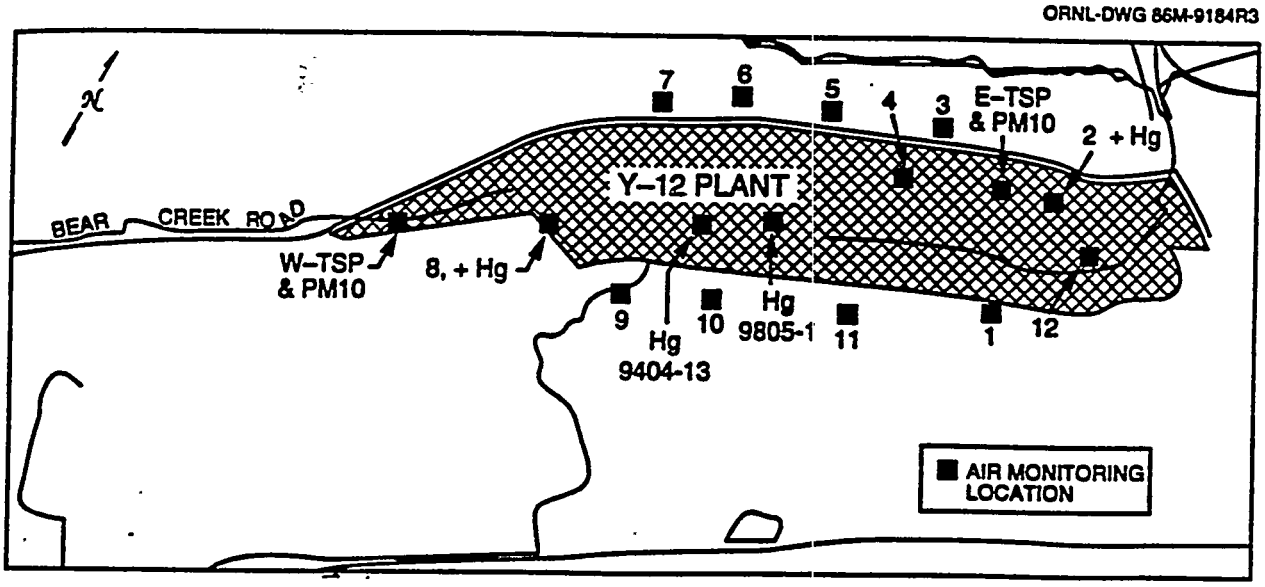


Fig. 3.57. Ambient air monitoring stations at the Y-12 Plant.

Also monitored were ambient fluoride concentration, TSPs, and mercury concentrations. Ambient air concentrations of fluorides measured during 1992 at each of the Y-12 Plant perimeter air-monitoring fluoride stations were well below TDEC standards. TSP samples collected at the Y-12 Plant were not in excess of state primary or secondary standards in 1992 (Energy Systems 1993a).

Data for mercury in ambient air at five monitoring stations at the Y-12 Plant suggest that the environment and human health are not impacted by releases of mercury to the atmosphere. The highest observed 7-d concentrations have, with one exception, been <50% of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) criterion (1.0 $\mu g/m^3$) and <1% of the workplace standard of 50 $\mu g/m^3$. The data do show that ambient air mercury concentrations in the Y-12 Plant area are, in general, slightly elevated above natural background and may reach significantly elevated concentrations for short periods in localized areas. Disturbances, such as excavation of soil in contaminated areas, appear to elevate ambient air concentrations of mercury. Ambient air concentrations exhibited a seasonal pattern, with the highest values typically occurring in the warmer months.

3.2.8 Radiation Survey Data

The distribution of radiological contamination over the ORR and surrounding area has been assessed by airborne radiation surveys. These surveys have been flown since 1959, and a review of the aerial monitoring program is presented in Sect. 3.2.8.1.

3.2.8.1 Historical data

Historically, most of the radiation survey information on the ORR and surrounding area has been provided by the Aerial Measuring System (AMS), an aerial radiological surveillance capability maintained by DOE. The AMS is presently operated and maintained by EG&G Energy Measurements, Inc. (EG&G/EM) under contract to DOE.

The first aerial radiological survey of the ORR and surrounding area was conducted during the spring of 1959 by the USGS using a fixed-wing aircraft flying at a 152-m (500-ft) altitude and 1.6-km (1-mile) line spacing. Its primary purpose was to characterize the radiogeology of the area. In 1973, EG&G/EM conducted a survey using a fixed-wing aircraft flying at an altitude of 152 m (500 ft) and speed of 170 knots. Sites identified as having anomalous radiation levels were re-surveyed with a helicopter-mounted AMS flying at an altitude of 76 m (250 ft) and speed of 70 knots. The increased sensitivity provided detailed coverage of radiological activity at the anomalous radiation sites.

In 1980, an aerial radiological survey of the entire ORR and nearby surrounding area, encompassing 440 km^2 (170 m^2), was conducted. The survey consisted of parallel flight lines 152 m (500 ft) apart at an altitude of 91 m (300 ft). During September 12–29, 1989, an aerial radiological survey of the ORR, city of Oak Ridge, and the surrounding area was conducted using parameters identical to those used during the 1980 survey (Maurer 1992).

Most recently, an aerial radiological survey of the ORR and surrounding area in Oak Ridge, which encompasses BCV, was conducted during the period March 30 to April 14, 1992 (Maurer 1993). The survey consisted of a series of parallel flight lines 76 m (250 ft) apart at an altitude of 46 m (150 ft). The survey was conducted by a helicopter flying at a speed of 70 knots. In support of aerial measurements, ground-based exposure rates and soil samples

were obtained from seven "benchmark" sites located within the survey area. The ground-based measurements were used to verify the integrity of the aerial measurements. Radionuclide assays of representative soil samples were also performed to determine corresponding radioisotopic concentrations. In addition, high-altitude aerial photographs were obtained for use as base maps for the aerial contour data, and oblique aerial photographs were obtained for site documentation.

Two methods were used to analyze the aerial radiation data. The first was the gross count rate method, used to determine the ground level exposure rates. The second was the spectral window method, used to determine the man-made radioactivity and the photopeak count rates for specific man-made radionuclides (Maurer 1993). Radionuclides without gamma or strong X-rays, such as transuranics, will not be detected by the aerial survey; however, radiochemical analyses performed during the recent RI of EFPC indicate these radionuclides are not a problem for ingestion pathways. Typical background exposure rates varied from 7 to 11 μR/h (including the estimated cosmic ray contribution of 3.8 μR/h). The results of the aerial and ground-based measurements were found to vary by as much as $\pm$30%.

Terrestrial exposure rates at 1 m above ground level were deduced from aerial measurements, integrated with the corresponding aircraft position coordinates, and compiled to produce a contour map (Fig. 3.58). These contours were superimposed on the high-altitude aerial photographs. The data for BCV are presented in Maurer (1992b). Total terrestrial gamma exposure rates for BCV at 1 m range from <8 to 60 μR/h, with the overwhelming majority of readings being <13 μR/h. One site within BCV was identified with rates between 20 and 60 μR/h. This site corresponds to the Bear Creek Burial Ground, a shallow disposal area for uranium metal tailings. Readings in the vicinity of BCV OU 2 show exposure rates between 8 and 13 μR/h, but these readings are not statistically significant, as exposure rates <10 μR/h above background rates (7 to 11 μR/h within the Oak Ridge area including the cosmic ray contribution of 3.8 μR/h) are considered of no concern, and the correlations between aerial and ground-based measurements vary by as much as $\pm$30%.

The man-made gross count (MMGC) rate for the BCV sites is shown in Maurer (1992b). There is a slightly elevated (1000-3200 counts per second) area in the vicinity of SL-1 and the HCDA. A Region of Interest (ROI 25) was identified at the above mentioned Burial Ground, with MMGC between 1000 and 100,000 counts per second (Fig. 3.59). The gamma spectrum for ROI 25 showed photopeaks for ^{234m}Pa (Fig. 3.60), which indicate the presence of ^{238}U. This is not unexpected due to the nature of the material (uranium tailings) deposited in this area. The SL-1, HCDA, and Burial Ground areas will be investigated further in the RI for BCV OU 1. There is no evidence of radioactivity produced by man-made radionuclides in the BCV OU 2 areas.

3.3 DATA QUALITY REPORT

3.3.1 Purpose

The purpose of this section is to provide an assessment of the QA/QC results from the BCV OU 2 RI to confirm that the data used in this report meet the data objectives established for this investigation. This will be accomplished through an evaluation of the

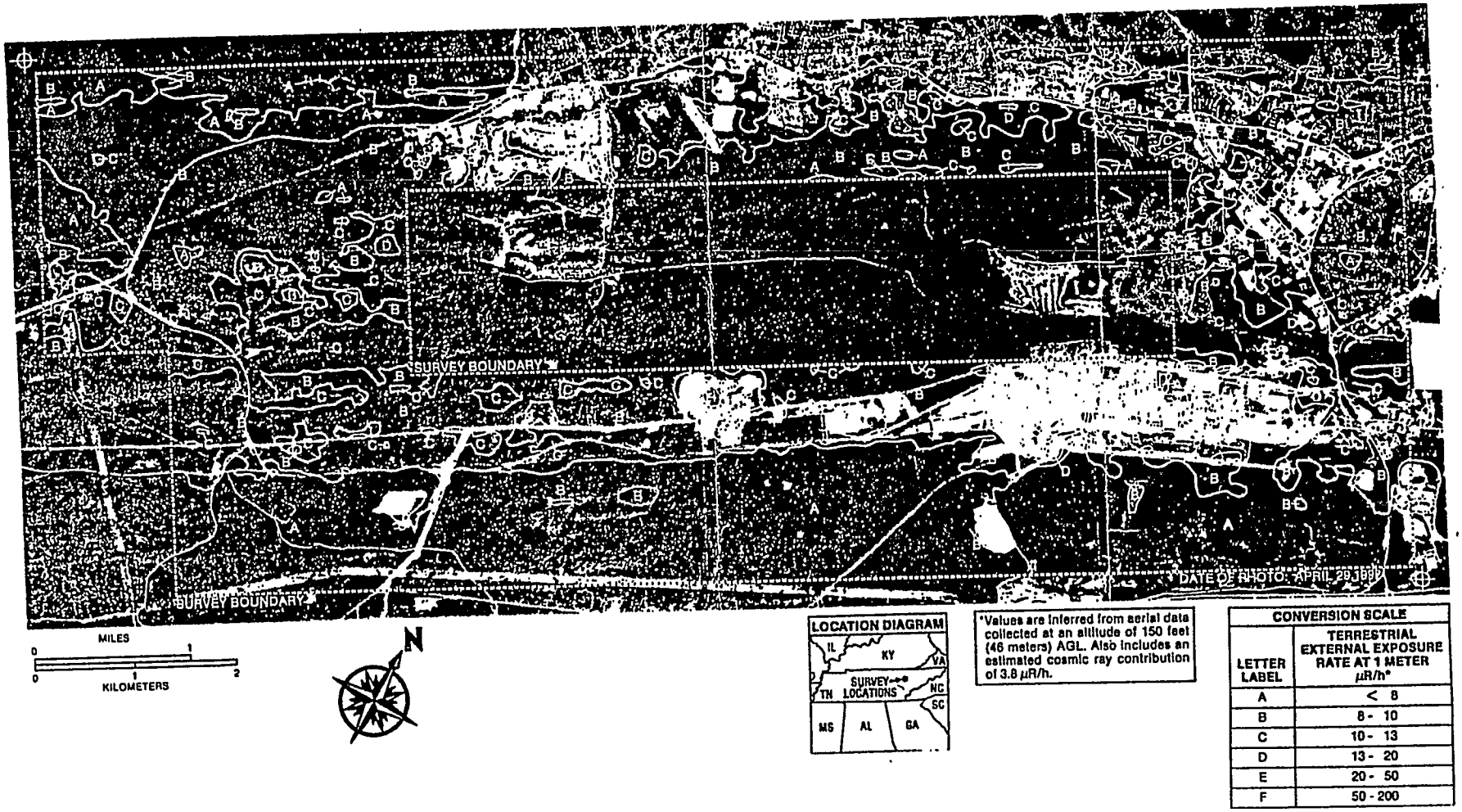


Fig. 3.58. Terrestrial gamma exposure rate contour map for the Y-12 Plant and EFPC sites.

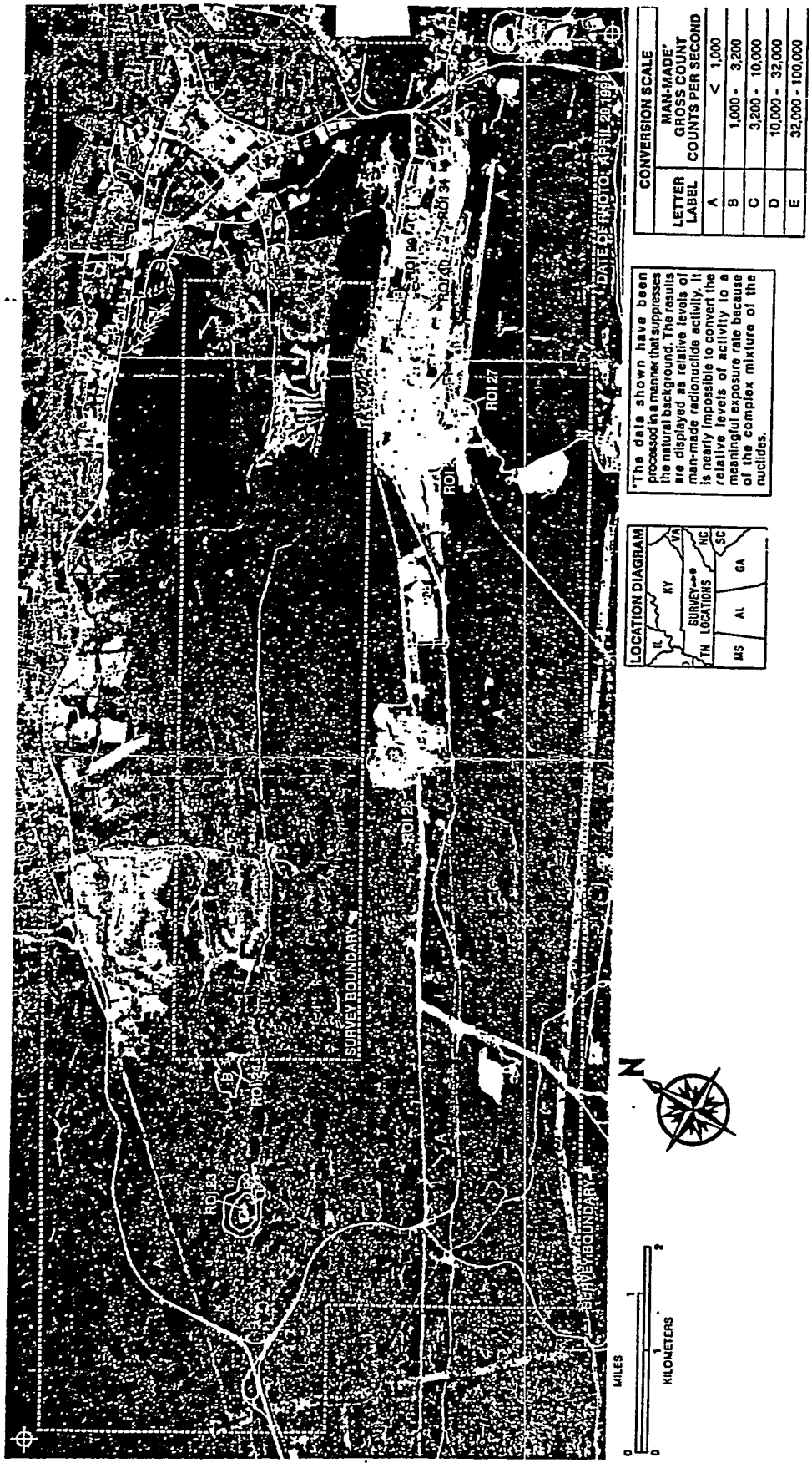


Fig. 3.59. Man-made gross count rate contour map for the Y-12 Plant and EFPC sites.

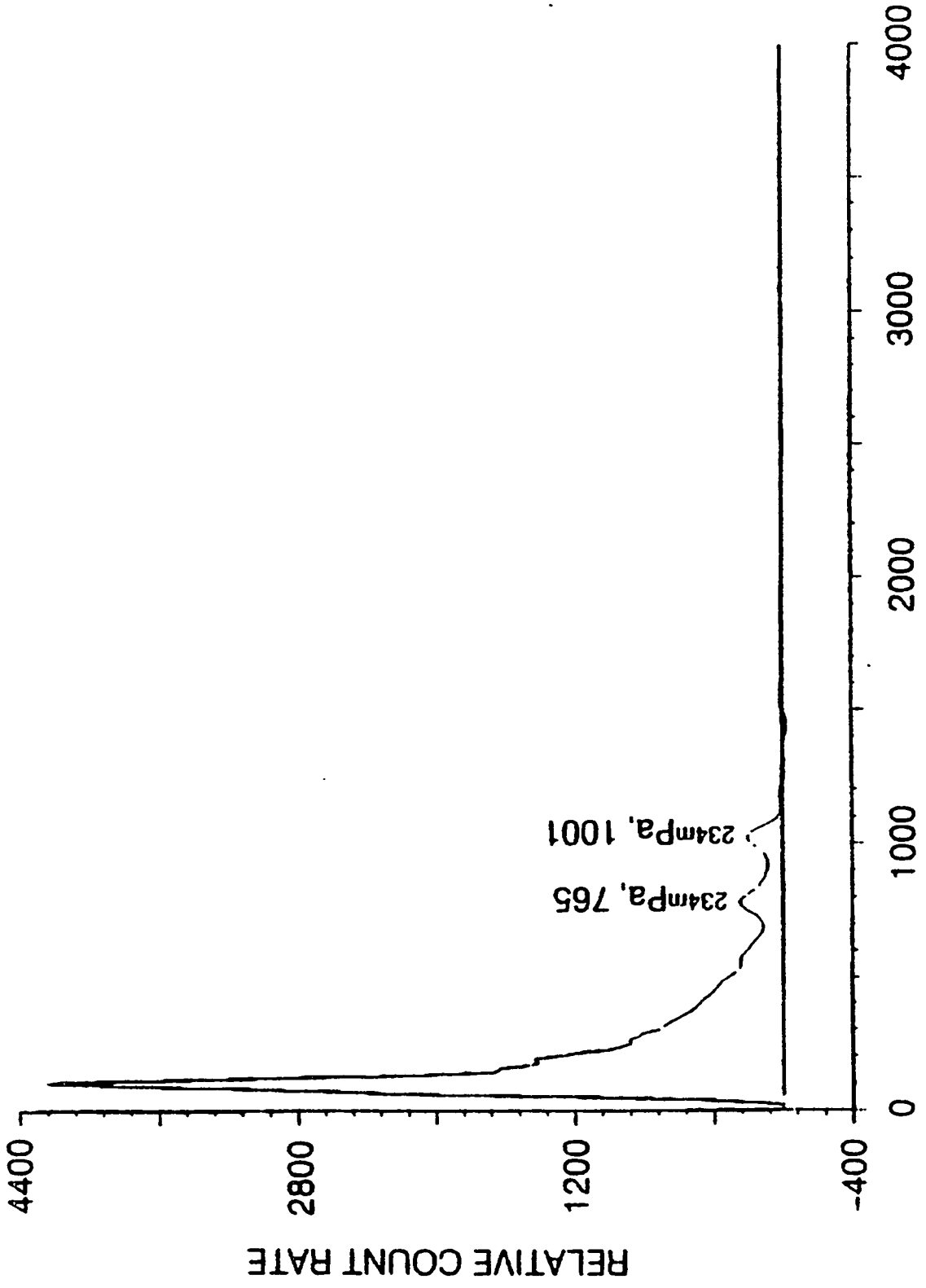


Fig. 3.60. Net gamma spectrum for ROI 25.

performance of field correction activities and laboratory analysis. The effect of field correction activities on analytical data will be assessed by discussing completeness, field QC, and findings of the QA program. The effect of laboratory analysis on analytical data will be addressed by a discussion of QA program findings and a comparison to PARCC parameter goals.

Both quantitative measures and qualitative assessments will be presented to characterize these data as having sufficient quality to satisfy the objectives. The primary intent of this assessment is to illustrate that data originating from the BCV OU 2 RI can withstand scientific scrutiny (for its intended purposes), are technically defensible, and are of a known and acceptable precision and accuracy.

3.3.2 QA Program

A primary goal of the BCV OU 2 QA program is to ensure that the quality of results for analysis of all environmental samples is appropriate for their intended use. To this end, a quality assurance program plan (QAPP), a QAPjP, and field procedures were compiled to guide the investigation (see Sect. 3.2). Audits and surveillances were conducted to determine the adequacy of field and laboratory performance as evaluated against the QA plan and procedures.

The evaluation of field performance was accomplished through the vehicle of audits, surveillances, and SAIC's nonconformance report (NCR) program. Four audits of SAIC field performance were conducted. The chronology of these audits was as follows:

- September 1993, Energy Systems audit of BCV OU 2,
- October 1993, SAIC health and safety audit of BCV OU 2,
- November 1993, Energy Systems industrial hygiene audit of BCV OU 2, and
- December 1993, DOE audit of BCV OU 2.

In general, the auditors were quite complimentary of the BCV OU 2 field effort. The Energy Systems industrial hygiene audit produced no findings but the September Energy Systems audit resulted in one finding. High performance liquid chromatography water was being used in place of ASTM Type II water. A field change order was submitted to correct this deficiency. The December DOE audit revealed three deficiencies:

- Documentation of field checks for sample cooler temperature was not readily traceable to the identification number of the thermometer and the associated calibration data. Logbooks were amended to include a reference to the thermometer number.
- The site-specific health and safety plan was found to be incomplete in addressing site hazards and safety requirements relating to personal protective equipment and was revised.
- Heavy equipment was not being decontaminated before leaving the BCV OU 2 thus providing a potential for the spread of contamination. The project was operating in accordance with the work plan. Since the project was near completion, it was decided that the issue would be addressed as a "lesson learned" for future projects.

SAIC QA conducted seven surveillances of the BCV OU 2 field effort. Of the seven, only one had observations. During this surveillance (conducted 9/16/93), the sampling procedures were surveilled for the first time. The surveillant observed that a 2-in. split spoon produced an inadequate volume of sample and suggested a 3-in. split spoon be used. The surveillant also observed that the table on which samples were collected was cluttered with sampling equipment, compositing equipment, logbooks, and other items. The surveillant suggested a second, clean table be used solely for sample collection activities. A second table was subsequently employed. Lastly, this surveillance noted that the cooler shipping log lacked background readings for radiation screening instruments. This was promptly corrected.

The SAIC NCR program recorded seven NCRs during the field effort. Six of the seven were singly occurring mistakes and were corrected immediately. One NCR noted a failure to properly collect field QC samples. Only 10 out of 12 equipment rinsates and 10 out of 13 pour water field blanks were taken. All other blanks were taken correctly. Although this represents a failure to completely follow procedures, a sufficient number of blanks was taken to assess contamination of samples by field activities. This assessment of possible contamination can be found in the field results portion of this section.

Laboratory performance was evaluated primarily through data validation. Laboratory performance was further evaluated through on-site audits and the SAIC analytical data nonconformance report (ADNCR) program.

Three laboratories were contracted to perform analyses for the BCV OU 2 RI. These laboratories were audited by SAIC in conjunction with the Energy Systems Analytical Project Office prior to sending samples for analysis and were found to be acceptable to perform work for SAIC and Energy Systems. The mixed waste and radiological laboratories were visited at the close of the project by a joint SAIC/Energy Systems auditing team to assess project performance. Both laboratories were found to have performed adequately during the project.

All deficiencies in data received from the laboratories were documented through the ADNCR program. The trending of these ADNCRs reveals no serious deficiencies. In total, 81 ADNCRs were produced. The most frequent findings were of a nature that did not affect data quality. These include inconsistent sample identification, inconsistent dates, etc. Errors were corrected in all cases. One ADNCR noted VOA holding time violations due to "misplacement of samples". This instance involved two field QC samples. Subsequently, two samples were not analyzed for VOAs. Two ADNCRs noted poor pesticide surrogate recovery in the method blank. In one of these, the laboratory control sample (LCS) and most of the samples had acceptable recovery. In the other instance, all samples, the method blank, and the MS sample had poor surrogate recovery. This was attributed to the gel permeation chromatography cleanup process. The laboratory subsequently took measures to improve the gel permeation chromatography performance to prevent recurrence.

3.3.3 Assessment of Laboratory Contribution to Data Quality

3.3.3.1 Data assessment and review process

Analytical data generated under this project have been subjected to a rigorous process of data verification, validation, and review. The following describes this systematic process and the evaluation activities performed. Several criteria have been established against which the data are compared and from which a judgment is rendered regarding the acceptance and

qualification of the data. Because it is beyond the scope of this report to cite those criteria, the reader is directed to the following documents for specific detail:

- Technical Support Contractor QA Technical Procedure (TP-DM-300-7) Data Verification and Validation;
- Region I EPA—Laboratory Data Validation, Functional Guidelines for Evaluating Inorganic Analyses;
- Region I EPA—Laboratory Data Validation, Functional Guidelines for Evaluating Organic Analyses; and
- ES/ER/TM-16 Requirements for Quality Control of Analytical Data for the Environmental Restoration Program, Energy Systems.

Upon receipt of data packages from the analytical laboratory, the data verification staff performed a systematic examination of the reports, following standardized data package checklists to ensure the content, presentation, and administrative validity of the data. Discrepancies identified during this process were recorded and documented utilizing the QA program ADNCR and NCR systems.

In conjunction with the data verification and if standardized laboratory electronic data diskettes were available, the diskette deliverables were subjected to comprehensive review utilizing EPA Contract Compliance Screening (CCS) software. This software performed both a structural and technical assessment of the laboratory-delivered reports. The structural evaluation ensured that all required data had been reported and that they had been reported accurately. This technical evaluation ensured that all contract-specified requirements had been met.

In addition, standardized data diskettes for CLP organic and inorganic analyses were processed by the SAIC-developed software program, Computer Assisted Validation and Evaluation Assessment Tool (CAVEAT). Reports from these software applications were used to support the data validation process by providing data verification and validation summary reports that help direct the data validators to specific problems in the data package.

During the validation phase of the review and evaluation process, data were subjected to a systematic technical review by examining all analytical QC results and laboratory documentation, following the appropriate functional guidelines for laboratory data validation. These EPA data validation guidelines define the technical review criteria, methods for evaluation of the criteria, and actions resulting from the review of these criteria. The primary objective of this phase was to assess and summarize the quality and reliability of the data for the intended use and to document factors that may affect the usability of the data. As stated in the data verification section, both CCS and CAVEAT reports were utilized in the data validation phase to assist in the technical review of data. Technical criteria examined during the data validation phase included but were not limited to the following:

Inorganic	Organic
Data completeness	Data completeness
Holding times	Holding times
Calibration	Calibration

Inorganic	Organic
— Initial	— Initial
— Continuing	— Continuing
Blanks	Blanks
Inductively Coupled Plasma (ICP) interference check sample	Surrogate recovery
Matrix spike (MS) sample analysis	MS sample analysis
Field duplicate sample analysis	MS duplicate analysis
LCS analysis	Internal standards performance
Furnace atomic absorption QC	Gas chromatography (GC)/MS tuning
ICP serial dilution analysis	Target compound list (TCL) compound identification
Detection limits	Compound quantitation and
Sample results verification	reported detection limits
Method of Standard Addition	Tentatively identified compounds (TICs)
	System performance

As an end result of this phase of the review, the data were qualified based on the technical assessment of the evaluation criteria. Qualifiers were applied to each analytical result to indicate the usability of the data for intended purposes.

Procedures for radiological data validation have not been established to the level of inorganic/organic analyses under CLP. The BCV OU 2 RI used a conservative approach to radiological data validation. BCV OU 2 radiochemical analytical data were validated using *Laboratory Data Validation Guidelines for Evaluating Radionuclide Analyses* (SAIC, Rev. 4 1992). This document was developed with the intent to provide data validation guidelines for radioanalytical data equivalent to those provided by EPA under its CLP guidance. This document provides a systematic process for reviewing the data against the defined criteria to provide assurance that the data are adequate for their intended use. The data validation criteria are summarized below:

Holding Times
Calibration
Blanks
Sample-specific Chemical Recovery
LCS
MS Sample
Duplicate Sample
Radionuclide Quantitation
Implied Detection Limits
Chemical Separation Specificity (γ Spec)
Target Radionuclide List Identification (γ Spec)
Systems Performance

The final phase in data assessment and review is the process of data examination in terms of temporal or spatial data comparisons. During this phase, data from similar or related sites

and locations or data collected over time were compared to examine the distribution of data points. Additionally, newly collected sampling data were compared with historical data to determine comparability of data and trends exhibited by different data sets. Extensive use of graphical and spatial mapping data-display tools were also used to allow visual examination of very large data sets. This evaluation is described in Sects. 3.2.1–3.2.4.

3.3.3.2 PARCC Data Assessment

Analytical Completeness. Usable data are defined as those data that passed individual scrutiny of the verification and validation process and have been accepted for unrestricted application to the human health risk assessment or equivalent applications of Level IV data. Certain data may be qualified as estimated; however, these data are acceptable for Level IV use. Other data have been rejected from Level IV use but may be considered for less rigorous applications.

The general completeness objective established for the BCV OU 2 RI has been achieved. The completeness objective was set at 85-90%, (i.e., 85-90% of the samples collected must yield valid analytical results). The BCV OU 2 RI produced valid analytical results in 97.9% of the analyses. The 2.1% data that were rejected were primarily metals and radiological data. See Table E.2 for a breakdown of rejected data.

Selenium and antimony results were rejected in a significant number of soil samples and merit some discussion. Forty-five percent (127/284) of all selenium soil results were rejected. These rejected data points were primarily at the SY-200 Yard and due to matrix interferences. Fifty-two percent (147/284) of all antimony soil results were rejected. These rejected data points were primarily from the SY-200 Yard as well. Poor MS recovery was the cause of the rejections.

Surface water metals data were rejected in a significant number of samples. Beryllium was rejected 40% (4/10) of the time in total surface water data while selenium was rejected 30% (3/10) of the time in total surface waters. The beryllium data were rejected due to negative values in the laboratory blank. This would indicate that the instrument was not accurately detecting low levels of these analytes. Therefore, the "seemingly" nondetected data were rejected. The dissolved data for this analyte had no hits above the quantitation limit goal and were not associated with a negative blank. This would indicate that there probably is not any beryllium in the surface water. Selenium was rejected due to poor MS recovery. This would indicate something present in the samples which "masks" the selenium signal. Apparently some of the matrix interferences were able to be filtered out as the dissolved samples were not rejected.

The shallow groundwater sample data at the SA-1 and the SY-200 Yard areas were determined to be critical to the BCV OU 2 RI. These sampling points yielded valid analytical results 98% of the time. Total arsenic and selenium data were the only data rejected. Total arsenic was rejected in 4 out of 10 samples. Total selenium was rejected in 3 out of 10 samples. These data were rejected due to poor MS recovery. Aluminum was detected at elevated levels in all the arsenic-rejected samples. This was at least one of the likely interferents. Neither the total nor dissolved samples yielded a hit above the quantitation limit goal (for both analytes) of 5 ppb. Thus, arsenic and/or selenium may be present in the shallow groundwater at SA-1 and the SY-200 Yard.

Gross Alpha and Gross Beta Analysis

Gross alpha and gross beta determinations are considered screening methodologies, which provide a general indication of the overall alpha and beta particle emissions without discrimination for specific nuclide identities.

Gross alpha determinations indicated a considerable matrix interference for both the environmental water and environmental solid measurements performed in this investigation. All 10 sediment samples and 52% of the soil sample values were estimated, while 22% of the soil values were rejected. All 10 surface water and six groundwater dissolved gross alpha values were rejected. Rejection of dissolved alpha values was due to low MS recovery determinations, while rejection and estimation of soil and sediment data were due to high MS recoveries. Total surface water and groundwater gross alpha values were acceptable for this investigation. Laboratory control measures and field blank gross alpha determinations were acceptable, leading the investigation to determine the root cause for rejection of data to lie with an undetermined sample matrix interference. None of the sample values exhibited excessive alpha activity and subsequent isotopic uranium, a prime alpha emitter, determinations did not reveal elevated levels. Overall, 77% of the gross alpha data is considered useable for this investigation.

Gross beta measurements did not exhibit the same matrix difficulties as gross alpha. Neither did they encounter any other analytical problems. All of the surface water, groundwater, field blank, and sediment sample gross beta determinations were validated without qualification, with the exception of two total groundwater gross beta measurements being estimated. Only 6% of the soil data was qualified as estimated due to poor duplicate comparison. Thus, 100% of the gross beta information was considered usable for this investigation.

Low chemical recoveries resulted in 9% of the ^{234}U and ^{238}U isotopic results being qualified as usable but estimated for this investigation. Percentages qualified were approximately the same for water and soil/sediment samples. A considerable portion (16%) of the ^{235}U isotopic result was also qualified as usable but estimated due to low LCS analysis. A significant portion (36%) of the ^{235}U results was qualified as unusable (R) because the LCS was outside control criteria. Overall, 88% of the isotopic uranium analysis was considered usable for this investigation.

Project Precision. As a measure of analytical precision, Table E.3 contains the average relative percent difference (RPD) for laboratory duplicate pairs for all inorganic and organic parameters for which both values meet or exceed five times the contract required detections limit for that analyte. As the RPD approaches zero, complete agreement is achieved between the duplicate sample pairs.

Inorganic soils are considered acceptable if the RPD does not exceed 35. This limit was exceeded only in four analytes. Selenium had very high RPD (average 181.467) reflecting the heterogeneity of the soil. Barium, calcium, and nickel also exceeded the limit. This is not unusual for soil samples which are, by nature, very heterogeneous. The RPD values are actually quite good for this medium and reflect great effort on the part of the field team to homogenize the samples prior to aliquotting and sending for analysis. Additionally, all VOA and pesticide/PCB average RPDs were acceptable and all metals and pesticide/PCB average RPDs for water samples were within the acceptable range of 0-20. Two VOAs averaged

slightly elevated RPDs. This represents a small fraction of the total analyses. A measure of the duplicate error ratio for radiological duplicates provides an evaluation for comparison of these two values. Sample homogeneity, analytical method performance, and the quantity of analyte being measured all contribute to this measure of sample analytical precision. Radiochemical analytical precision is also evaluated through review of method-specific LCS information. This measure of precision is independent of sample matrix variabilities.

Evaluation of the duplicate error ratios for BCV OU 2 laboratory analytical duplicates provided acceptable precision information for all matrices and all radiochemical analytes. All ratios were <1.00, which establishes an acceptable comparison level. LCS evaluation provided an acceptable level of precision for all parameters with the exception of the ^{235}U analysis. The available material used by the laboratory for this measure did not contain an adequate quantity of ^{235}U which caused its measurement precision to be poor. Nevertheless, the level of analyte measured in the project samples was near or below the quantitation level, and there was little impact on the viability of the data. Data affected by the poor precision of the LCS were qualified or rejected, when necessary. It is therefore concluded that project precision is acceptable for the BCV OU 2 RI.

Project Accuracy. Accuracy is the closeness of agreement between an observed result and the true value for a sample analysis. Analytical accuracy can be evaluated by measuring the agreement between an analytical result and its known or true value. Accuracy is measured through the use of LCSs and MSs. LCSs measure the accuracy of the methods independent of the sample matrix, while accuracy determined by the sample is a function of both matrix and method. Table E.4 lists the average metals LCS recovery values and Table E.5 lists the average MS recovery values for metals, VOAs, and pesticides/PCBs.

Average LCS percent recovery values for metals analysis of soils ranged from 75.692 for iron to 114.029 for antimony. Limits for soil LCS recovery are analyte-specific and thus will not be discussed herein. LCS recovery did not necessitate qualification of any data. Average LCS percent recovery values for metals analysis of water were all within limits (80-120). Organic LCSs were evaluated only in Level IV packages. No sample data were qualified based on LCS recovery.

MS data demonstrated some soil matrix interferences for antimony, lead, selenium, manganese, and gamma-BHC (Lindane). It was determined that these were matrix-specific and not related to analytical accuracy. MS data also demonstrated some matrix interferences for water media. Arsenic, selenium, aluminum and 4-nitrophenol presented matrix-related analytical problems. Again, it was determined that these were matrix-specific and not related to analytical accuracy. Project radiochemical accuracy goals were 80-120% as expressed in recovery of known analytical spikes into the sample media. Analytical method accuracy is also evaluated through LCS measurements.

Accuracy of radiochemical LCS determinations was found to be within 20% of the expected value. This included the accuracy of the ^{235}U LCS even though its precision was poor. Sample MS data proved satisfactory for all radiochemical parameters with the exception of several gross alpha determinations. In all instances where sample MS information was poor the data were qualified or rejected, when necessary.

Sensitivity (detection limit) can also be related to the radiochemical analytical accuracy. Determination of minimum detectable activities allows the investigation to assess the relative

confidence which can be placed in a value relative to the magnitude or level of analyte concentration observed. The closer to the minimum detectable activity, the less confidence and more variation the measurement will have. Project radiochemical sensitivity goals were expressed as quantitation level goals in the QAPjP. All these levels were achieved through the analytical process, with the exception of some gross alpha soil determination. Data were noted when the original quantitation level was not achieved. The variation observed did not affect the usability of any of the data for the project. It is therefore concluded that project accuracy is acceptable for the BCV OU 2 RI.

Project Representativeness. Representativeness expresses the degree to which the data accurately reflect the analyte or parameter of interest for the environmental site and is the qualitative parameter most concerned with the proper design of the sampling program (EPA 1987a). Factors that affect the representativeness of analytical data include proper preservation, holding times, use of standard analytical methods, and matrix or analyte interferences. No data were rejected based on preservation or holding times. Standard analytical methods were used. However, some matrix interferences caused some data to be rejected (see the analytical completeness portion of this section of the RI report). Overall representativeness therefore is considered to be appropriate for this RI.

Project Comparability. Like representativeness, comparability is a qualitative parameter expressing the confidence with which one data set can be compared to another. The BCV OU 2 RI used narrowly defined sampling methodologies, site surveillances, use of standard sampling devices, training, documentation of sampling, control limits for daily QC checks, appropriate reporting units, and standard analytical methods to ensure comparability.

3.3.4 Assessment of Field Activities Contribution to Data Quality

3.3.4.1 Completeness summary

Completeness is the amount of valid data obtained from the sampling and analysis process. The completeness objective for this project was to obtain valid analytical results for at least 85% of the samples collected during the project. This assumes completeness of sample collection (number planned vs number collected for which valid data can be obtained) to be essentially 100% to allow for some laboratory wastage. See Table E.1 for a comparison of anticipated vs collected samples.

Soil borings were essentially collected at 100%. Borehole depth was estimated to project the numbers of samples. Some boreholes exceeded this estimate while others did not meet it. All boreholes were sampled to refusal (or groundwater).

All planned groundwater samples were collected. Three seep samples were planned for BCV OU 2. Only one of the three actually yielded a seep sample. One of the seven planned surface water samples was not collected due to lack of water. A sediment sample was collected at this location. (Sediment samples were collected at 100%.)

As discussed in Sect. 3.3.3 of this document, and as assumed in the RI work plan, there was some laboratory wastage (97.9% of all analyses yielded valid analytical results). This wastage was not significant compared to the goal of 85%.

3.3.4.2 Field QC results

During all phases of the BCV OU 2 RI sampling program, field QC samples were collected to gauge the impacts from various components of field activities. Approximately 25% (98/385) of the samples taken during the program were QC samples obtained to determine the degree of cross-contamination, ensure successful decontamination, or determine effects of media heterogeneity on results.

Field Duplicates. Field duplicate samples are duplicate samples taken from the same split-spoon sampling device, after homogenizing the samples. Field duplicates are taken to ascertain the contribution of variability (i.e., precision) due to the environmental media. All samples (except VOA aliquots) were homogenized in the field before aliquotting. The BCV OU 2 RI collected field duplicates at a rate of one duplicate per 10 field samples. Table E.6 provides a summary, by medium and by analyte, of the RPD and/or absolute difference for field duplicates. RPD was calculated only when both of the samples were ≥ 5 times the contract required detection limit. If both samples were nondetected for a given analyte, no precision data were produced. Specific control limits for field precision were not established, in part because the natural heterogeneity of the environmental media was much greater than the variability imparted by field activities. As one might expect, soil and sediment heterogeneity imparts a large degree of uncertainty as to what might be considered representative values. Average RPDs in soils range from roughly <1 to 79.34% for CLP metals and 5.18 to 62.06% for CLP organics. Average RPD values for CLP sediment metal analyses are all <25%. This reflects great effort towards sample homogenization in the field. Groundwater metals RPD are all <20%.

Radiochemical field duplicate assessment included the review of data for soil, sediment, surface water, and groundwater. The majority of the analytical values fell within 5 times the project-required quantitation levels, and duplicates were evaluated relative to these levels. Within this range of values, duplicates are considered acceptable when they agree within plus or minus the quantitation level (± 2 times the quantitation level for soil and sediment). When both duplicate values exceeded 5 times the quantitation level, acceptability was determined by $\pm 20\%$ for water and $\pm 35\%$ for soil and sediment.

All gross alpha and gross beta field duplicate comparisons were acceptable based on the above criteria with the exception of the gross alpha groundwater duplicate (B60301 and B60311). This exception does not invalidate any of the analytical information and all data are considered usable based on the field duplicate comparison.

All isotopic uranium field duplicate comparisons were acceptable based on the above criteria with the exception of: ^{234}U soil duplicate, B01003 and B01013; ^{238}U soil duplicate, B01003 and B01013; and ^{234}U sediment duplicate, A10401 and A10412. The differences observed between these field duplicate comparisons do not invalidate any of the analytical information and all data are considered usable based on the field duplicate comparison.

The field duplicate information indicates that the sampling protocol and implementation obtained consistent and reproducible samples for determination of the radiological parameters studied.

Field QC Blanks. Three types of field QC blanks were obtained during sampling activities at BCV OU 2. Contamination detected in these blanks is shown in Table E.7. Three types

of field blanks were collected: (1) a sample of ASTM water was taken from each lot number to assess its impact on the decontamination process, (2) a sample of the decontamination source water was taken every 2 weeks to assess its impact on the decontamination process and (3) a sample of ASTM water was exposed during sampling to assess cross-contamination from improper sampling and handling of the samples. Trip blanks were sent in each cooler containing a VOC sample to determine potential cross-contamination of samples submitted for VOC analysis. Equipment rinsate blanks were sampled in the field after decontamination of sampling/field equipment to ensure that no cross-contamination was occurring due to improper cleaning.

The three types of field blanks will be addressed somewhat separately for the purposes of this report.

The potable source water used for decontamination was sampled six times during the project. The purpose of this sampling is to determine the extent to which this water might contaminate sampling equipment during the cleaning process. No significant contamination was detected in this potable water source. The equipment was rinsed with ASTM water after the potable water rinse. Rinsates were taken to determine the effectiveness of the procedure. Calcium and zinc were detected in all samples at appropriate levels for tap water. Iron was detected in FB00010 at 980 ppb. The rinsate taken that day, however, showed 103 ppb iron (barely above the detection limit 100 ppb). This amount of contamination would not have been transferred to a sample in a detectable amount. Aluminum (2550 ppb) and manganese (75.2 ppb) are detected in FB00025. The rinsate taken after this decontamination process shows no detectable aluminum or manganese. Therefore, this contamination in the potable water source did not affect the samples.

"Pour water" field blanks are samples of ASTM water left open during a sampling event to assess the amount of cross-contamination due to poor sample handling. Ten such blanks were taken during the BCV OU 2 project. Only aluminum was noted at significant levels. This occurred in FB0009 (1020 ppb) and FB00024 (1060 ppb). Both of these blanks are associated with the SY-200 Yard. The two samples associated with these blanks had 7320 to 18,100 ppm aluminum present. Soil samples taken at the SY-200 Yard had consistently high (ppm) levels of aluminum. This indicates that the samples were handled appropriately.

A sample of each lot number of ASTM water was taken to document its lack of contamination. This water was used as the source for the "pour water" field blanks. It was also used as the final rinse in the decontamination procedure. The ASTM water samples showed some acetone and metals (aluminum, iron and manganese). The rinsates taken of the equipment used after decontamination with this water were free of detectable contaminants. Therefore, one can assume no contamination was added to the samples from this water.

Trip blanks were sent in each cooler of VOA samples and analyzed for VOAs to determine the extent to which samples may have been contaminated during shipment. No significant contamination was detected in any trip blank. This indicates that the samples were not contaminated during transport.

Equipment rinsate samples were taken as an indicator of the effectiveness of the decontamination process. Nitrate/nitrite was detected at 7430 ppm in RI00030. This rinsate sample applied to the groundwater and surface water samples. However, no hits in the groundwater or surface water exceeded the water PRG for nitrate/nitrite. Some metals

(manganese, chromium, and iron) contamination was also detected in the rinsate blanks. Manganese was detected at 99.8 ppb, chromium was detected at 50.9 and 103 ppb, and iron was detected at 647 and 839 ppb. These rinsates were associated with the SY-200 Yard area. The soil samples taken at this area had ppm level contamination for these analytes. It is unlikely that cross-contamination would significantly affect data. Finally, heptachlor was detected in one SY-200 Yard rinsate at 0.36 ppb. However, there was no detectable heptachlor in samples from the SY-200 Yard.

Radiological field blank assessment included evaluation of equipment rinsate blank, source water blank, and ASTM water blank data. All values were below the project quantitation goals (gross alpha 10 pCi/L, gross beta 5 pCi/L, and isotopic uranium 1 pCi/L per isotope) with the exception of two samples. Gross beta was determined in field blank FB0018 to be 10.8 pCi/L. Uranium-234 and ^{238}U were determined in rinsate blank RI0009 to be 7.3 pCi/L and 5.9 pCi/L, respectively. These levels of uranium were not seen in any of the other rinsate, field blank, or laboratory blank samples and gross alpha activity was not seen in RI0009. Rinsate RI0009 uranium data are therefore considered invalid and were not used during data interpretation. The FB0018 gross beta level is also inconsistent with the rest of the field blank information and is only two times the quantitation level, therefore, it is not considered a significant factor and need not be used for data interpretation.

The field blank information documents that samples were collected in a clean and effective manner, without external or cross-contamination influences for the radiological parameters studied.

3.3.5 Overall Evaluation of Data Usability

A general evaluation of the data can provide guidance concerning data quality and data limitations to avoid inappropriate use of the data, while not precluding consideration of any data. (Please refer to Sect. 3.3.3.2 for a discussion of data that were rejected based on CLP guidance.)

Data are qualified as usable but estimated when there is an indication that either accuracy or precision is less than is expected. Data are qualified as unusable when significant errors are present. Unusable data may not be expected to be representative of the range of true values but may still be useful in making broad observations and conclusions.

When data are qualified as usable but estimated because data review guidance for precision is not met, the data may be summed or averaged with other data resulting in an improvement in the usability of the estimated data. When data are qualified as estimated because data review guidance for accuracy is not met, summing or averaging the data does not reduce the bias. It is important to distinguish between errors due to a lack of precision and those resulting from a bias.

Inorganic data were qualified with a "U" when a sample value above the instrument detection limit was less than 5 times the concentration of that analyte in a laboratory blank. Organic data having a value less than the action level but greater than the contract required detection limit were qualified "U." The contract required detection limit for that analyte in that sample was then raised to the sample value.

A "U" qualifier indicates the analyte was not detected. However, the analyte could be present at a concentration less than the detection (or quantitation) limit. Therefore, when the detection or quantitation limit exceeds a regulatory limit for that analyte, it is possible that contamination exists. Data should be interpreted accordingly.

3.3.6 Report Summary

Overall quality of the BCV OU 2 RI data exceeds expectations, particularly in the areas of completeness and representativeness. Analytical data should always be interpreted relative to their known analytical problems and their intended use. As should be expected in a project of this magnitude, there are some areas in which the user should use the data with due caution relative to the findings of this quality report.

Analytical difficulties encountered involve matrix interferences primarily at the SY-200 Yard. Many of the data for specific metals, pesticide/PCB analytes, SVOC analytes, VOAs, and radiological parameters have been flagged as estimated or even rejected based on suspected matrix interferences.

4. IDENTIFICATION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

CERCLA was passed by Congress and signed into law on December 11, 1980 (Public Law 96-510). This act was intended to provide for "liability, compensation, cleanup, and emergency response for hazardous substances released into the environment and the cleanup of inactive waste disposal sites." The Superfund Amendments and Reauthorization Act, adopted on October 17, 1986 (Public Law 99-499), did not substantially alter the original structure of CERCLA but provided extensive amendments to it.

In particular, §121 of CERCLA specifies that remedial actions for cleanup of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the hazardous substances or particular circumstances at a site. Inherent in the interpretation of ARARs is the assumption that protection of human health and the environment is ensured.

The purpose of this report is to supply a preliminary list of available federal and state chemical- and location-specific ARARs that might be considered for the cleanup of soils at BCV OU 2. If the RI determines that leachate from contaminated soils is causing contamination in groundwater or surface water at levels that surpass ARARs for the contaminants, remedial alternatives to isolate and control the sources to prevent further contamination of the water will be addressed during the FS. Action-specific ARARs will be identified and analyzed when remedial alternatives are selected during the FS. ARAR identification is an iterative process that continually changes as the RI/FS progresses. Therefore, this list of ARARs represents a compilation of potential ARARs. Subsets of this list will be used or additional ARARs will be added as site-specific contamination at BCV OU 2 is further characterized and remedial alternatives are defined in more detail.

It is understood that DOE will comply with the requirements of NEPA as specified in DOE Order 5440.1E ("National Environmental Policy Act Compliance Program"). DOE Order 5400.4 ("Comprehensive Environmental Response, Compensation, and Liability Act Requirements") called for integration of NEPA and CERCLA requirements for DOE remedial actions at CERCLA sites. This issue was reaffirmed in the FFA, §I(A)(3) and §III(A)(2), and the Secretary of Energy Notice (SEN) of February 5, 1990 (SEN-15-90). DOE's Secretarial Policy Statement on NEPA, however, signed on June 13, 1994, states that, rather than integrating NEPA and CERCLA requirements, DOE will hereafter rely on the CERCLA process for review of actions to be taken under CERCLA and will address and incorporate NEPA values directly into CERCLA documents. To comply with this replacement to incorporate NEPA values into the CERCLA process, Sect. 4.3 discusses the federal and state ARARs protecting environmental resources that may be identified at a site during a sensitive resources assessment.

Title I, §111(c)(6), of CERCLA mandated that the Occupational Safety and Health Administration (OSHA) promulgate standards for regulation of employee health and safety during hazardous waste operations at RCRA or CERCLA sites and during emergency response to hazardous substance releases. The final regulations for "Hazardous Waste Operations and Emergency Response" [29 *CFR* 1910] have appeared in 54 *FR* 9294 (Final Rule, March 6, 1989). These regulations are designed to protect workers involved in cleanup

operations at uncontrolled hazardous waste sites and to provide worker protection during initial site characterization and analysis, monitoring activities, materials handling activities, training, and emergency response. These regulations do not apply to workers who would not be exposed.

Federal construction activities involving potential for toxic substance exposure are covered by the OSHA standards in 29 *CFR* 1926 ("Construction Industry") and 29 *CFR* 1910 ("General Industry"). DOE also addresses occupational safety in the following DOE orders:

- 5480.11 ("Radiation Protection for Occupational Workers"),
- 5480.4 ("Environmental Protection, Safety, and Health Protection Standards"),
- 5483.1A ("Occupational Safety and Health Program for Contractors at Government Owned, Contractor Operated Facilities"),
- 5480.9 ("Construction Safety and Health Program"), and
- 5480.10 ("Contractor Industrial Hygiene Program").

ARARs apply to federal and state regulations designed to protect the environment; they do not usually apply to occupational safety regulations. EPA requires compliance with the OSHA standards in §300.150 of the National Contingency Plan (NCP), not through the ARARs process. Therefore, neither the regulations promulgated by OSHA nor the DOE orders related to occupational safety are addressed as ARARs; these regulations will appear in the site-specific health and safety plan for BCV OU 2.

4.1 DISCUSSION OF TERMS

To aid the reader, this section discusses terms used extensively throughout this report.

Applicable requirements are "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental, state environmental, or facility citing law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site" (40 *CFR* 300.5).

Relevant and appropriate requirements are "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental, state environmental, or facility citing law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site" (40 *CFR* 300.5).

Requirements under federal or state law may be *either* applicable *or* relevant and appropriate to CERCLA cleanup actions, but not both. However, requirements must be *both* relevant *and* appropriate for compliance to be necessary. If a federal and a state ARAR are available, or if two potential ARARs address the same issue, the more stringent regulation must be selected. However, CERCLA §121(d)(4) provides several ARAR waiver options that may be invoked, providing that the basic premise of protection of human health and the environment is not ignored. A waiver is available for state standards that have not been

applied uniformly in similar circumstances across the state. In addition, CERCLA §121(d)(2)(C) forbids state standards that effectively prohibit land disposal of hazardous substances.

CERCLA on-site remedial response actions must only comply with the substantive requirements of a regulation and not the administrative requirements to obtain federal, state, or local permits [CERCLA §121(e) and FFA §XXII]. To ensure that CERCLA response actions proceed as rapidly as possible, EPA has reaffirmed this position in the final NCP (55 *FR* 8756). **Substantive requirements** pertain directly to the actions or conditions at a site; **administrative requirements** facilitate their implementation. EPA recognizes that certain administrative requirements, such as consultation with state agencies and reporting, are accomplished through the state involvement and public participation requirements of the NCP. These administrative requirements should be observed if they are useful in determining cleanup standards at the site (55 *FR* 8757).

In the absence of federal- or state-promulgated regulations, there are many criteria, advisories, guidance values, and proposed standards that are not legally binding but may serve as useful guidance for setting protective cleanup levels. These are not potential ARARs but are **"to-be-considered"** (TBC) guidance.

4.2 SITE BACKGROUND

The RSA is located 0.4 miles west of the Y-12 Plant on Old Bear Creek Road. It served as a solid waste disposal area for nonuranium-contaminated construction debris generated by Rust Engineering, a DOE prime contractor, during various renovation, maintenance, and construction operations from 1975 to 1983. Disposed of material was periodically graded, resulting in topographical changes and in part of the Bear Creek channel being filled.

Although Bear Creek borders the northern edge of the area and the eastern edge is bordered by a spring-fed tributary of Bear Creek known as SS-1, which discharges into Bear Creek, there are no surface waters directly on the Spoil Area. Storm runoff flows directly into Bear Creek or indirectly via the tributary on the eastern border. Direct soil exposure and surface runoff of contaminants is unlikely because disposal operations were discontinued in 1983 and the site was closed in 1984 by capping it with 2 ft of clean soil on which vegetation was grown (Welch 1989a). Small quantities of solvent-contaminated material and material containing asbestos, mercury, and uranium may have been disposed of in this area.

SA-1 is a 5-acre site located west of the Y-12 Plant on Old Bear Creek Road. It began operation in 1980 as a construction waste disposal area. TDEC permitted it in 1985 as a Class IV landfill for solid waste (Registration Number DML-10-103-0012). Wastes deposited at the site include asphalt, masonry and roofing materials, brush, metal, and rock and tile from renovation, maintenance, and construction activities (Welch 1989b). Although plant controls eliminated the disposal of hazardous and radioactive wastes, past plant practices indicate that some of the construction material may have been contaminated with trace amounts of asbestos, mercury, beryllium, thorium, and uranium.

The SY-200 Yard lies in BCV between the RSA and SA-1. The 200- × 300-ft aboveground storage area lies just south of the headwaters of Bear Creek near the base of the northern slope of Chestnut Ridge. Surface runoff from the area drains to the northwest

into Bear Creek, which flows along the northern perimeter of the area. No detailed records are available listing all items that have been stored at the SY-200 Yard, but materials included industrial wastes such as transformers containing PCBs, lead shielding plates, and radioactively contaminated materials. None of the materials at any of the three sites is RCRA-listed or -characteristic waste.

Some site-specific characterization of the nature and extent of groundwater contamination from each of the three sites will be conducted during the RI. If the RI determines that leachate or runoff from the contaminated soils at BCV OU 2 is contaminating groundwater or surface water at levels that surpass ARARs for the contaminants, remedial alternatives to isolate and control the sources to prevent further contamination of groundwater and surface water will be addressed during the FS. If groundwater contamination from BCV OU 2 is confirmed, cleanup of the groundwater will be addressed as part of the BCV OU 4 project, and ARARs will be analyzed. Any contamination of Bear Creek itself will be addressed and remediated under the program for Bear Creek, and ARARs for Bear Creek surface water remediation will be discussed in the appropriate report for that program. This document will address ARARs for soil, the remaining medium of concern at the three sites.

4.3 CHEMICAL-SPECIFIC ARARs

Chemical-specific requirements set health- or risk-based concentration limits or discharge limitations for specific hazardous substances, pollutants, or contaminants in various environmental media (53 *FR* 51437). These requirements generally set protective cleanup levels for the chemicals of concern in the designated media or else indicate a safe level of discharge that may be incorporated when a specific remedial activity is being considered.

4.3.1 Soils

Very little legislation or guidance is available governing cleanup criteria for contaminated soils at CERCLA sites. Since none of the soil and debris at any of these sites is considered RCRA hazardous waste, none of the RCRA regulations, including RCRA Land Disposal Restrictions and the proposed RCRA rule addressing hazardous soils would be an ARAR.

TDEC has issued a final rule, "Inactive Hazardous Substance Site Remedial Action Program" (Rules of the TDEC, Chap. 1200-1-13), effective February 19, 1994, which addresses remediation of CERCLA sites. However, §1200-1-13-.08(3)(a)1.(II) of the rule is reserved for listing soil exemption criteria and preliminary remediation goals, and none has yet been listed in the rule.

The regulations in TSCA contain storage, disposal, and cleanup requirements for materials contaminated with PCBs in concentrations of 50 ppm or greater that have been landfilled after February 17, 1978. No provisions of TSCA may be avoided as a result of any dilution, meaning that spills in soils occurring after the effective date must be treated as having the concentration of the items from which they came, not the actual concentration in the soil. However, EPA has clarified that the TSCA antidilution provisions do not apply to spills found at CERCLA sites; these spills should be evaluated for form and concentration based on the PCBs "as found" at the site (EPA 1990a).

4.3.2 TBC Guidance

EPA has suggested cleanup values for lead in soils based on studies of lead levels in the blood of children. The EPA Office of Solid Waste and Emergency Response Directive 9355.4-02 (September 7, 1989) recommends a cleanup level for soils of 500–1000 ppm lead. The highest concentrations of lead at any of the sites in BCV OU 2 are 389 ppm, indicating a safe level based on this EPA guidance.

Although not an ARAR, EPA has published a TSCA PCB spill cleanup policy (52 *FR* 10688), which recommends cleanup standards for PCBs of 25–50 ppm for sites with restricted access; a 10-ppm cleanup level is recommended for residential and unrestricted access rural areas. In this latter case, a 10-in. cap of clean soil must cover the site. In the EPA guidance report for remedial actions at Superfund sites containing PCBs, preliminary remediation goals are set at 1 ppm for residential land use (a risk of 10^{-5}) and between 10 and 25 ppm for industrial and/or remote areas (a risk of 10^{-4}) (EPA 1990a). Alternatives should reduce concentrations to these levels or limit exposures. These values are considered TBC guidance, not ARARs. Either the 10- or the 1-ppm level would apply, depending on what is determined to be the future land use for these sites.

In the absence of federally or state-promulgated ARARs, or in the case where ARARs are not adequately protective, EPA states a preference for reference doses or reference concentrations for systemic toxicants and carcinogen slope factors for carcinogens (EPA 1988b). These are available through *Integrated Risk Information System* (EPA 1991a) and the EPA *Health Effects Assessment Summary Tables* (EPA 1993b).

4.4 RADIATION PROTECTION STANDARDS

Very few applicable standards are available for the cleanup of radioactively contaminated CERCLA sites. The Atomic Energy Act (AEA) of 1954 and its amendments delegated authority for control of nuclear energy to DOE, the U.S. Nuclear Regulatory Commission (NRC), and EPA. EPA's regulations are derived from several other statutes as well and cover many types of activities and all types of radioactive materials. The NRC licenses the possession and use of various types of radioactive materials at certain types of facilities. Tennessee is an NRC-Agreement state and, as such, has its own authority and licensing regulations. The Tennessee radiation protection standards found at TDEC 1200-2-4 *et seq.* will be addressed during the FS for alternatives that consider transportation of radioactive materials for off-site disposal.

4.4.1 EPA Regulations

Subpart H of 40 *CFR* 61 addresses atmospheric radionuclide emissions from DOE facilities and may apply to airborne emissions during cleanup of BCV OU 2. EPA has issued a final National Emission Standard for Hazardous Air Pollutants rule (54 *FR* 51654, December 15, 1989) that limits emissions of radionuclides to the ambient air from DOE facilities to amounts that would not cause any member of the public to receive an effective dose equivalent of 10 mrem/year (40 *CFR* 61.92).

EPA is developing regulations to establish cleanup levels for sites (including federal facilities) contaminated with radionuclides subject to the AEA and CERCLA (58 *FR* 54474,

October 21, 1993). A Notice of Proposed Rulemaking is due October 1994; when final, this regulation would apply to cleanup of any radioactively contaminated soil at BCV OU 2.

4.4.2 DOE Orders

DOE orders are not promulgated regulations and thus are not considered ARARs by EPA. They are, however, binding between DOE and Energy Systems because of contractual agreements. The radiation exposure limits for the general public defined in DOE Order 5400.5 ("Radiation Protection of the Public and the Environment," February 8, 1990) are an effective dose equivalent of 100 mrem/year from all exposure pathways and all DOE sources of radiation and a dose of <500 mrem/year as a temporary maximum exemption under specially permitted and DOE-approved circumstances. The overriding principle of the order is that all releases of radioactive material shall be "as low as reasonably achievable."

DOE Order 5400.5, Chap. IV, presents guidelines for (1) cleanup of residual radioactive material, (2) management of sites with residual radioactivity above the specified guidelines, and (3) criteria for interim storage and interim and long-term management of properties where residual radioactivity is left in place above the guidelines. Information on the application of the guidelines and requirements presented in the order, including procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits, is contained in *A Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0* (Yu et al. 1993). This manual was issued in September 1993 as a supplement to DOE guidelines for residual radioactive material at Formerly Utilized Sites Remedial Action Program and DOE Surplus Facility Management Program sites. In these situations, administrative controls with an effective life of 25 years are required for interim management. Control and stabilization features for long-term management of areas containing uranium, thorium, and their decay products above the guidelines must be designed to provide, to the extent reasonably achievable, an effective life of 1000 years, with a minimum life of at least 200 years. Administrative and physical controls to limit access to these properties should be effective for at least 200 years.

DOE has proposed these radiation protection standards for the public and the environment for codification at 10 *CFR* 834 (58 *FR* 16268, March 25, 1993). When final, these standards will legally apply to cleanup at DOE sites; a final rule is expected in July 1994.

4.4.3 TBC Guidance

The EPA Office of Radiation Programs has derived slope and unit risk factors for radionuclides of concern at remedial sites for each of three major exposure pathways (inhalation, ingestion, and external exposure to contaminated soil). These are available in the EPA *Health Effects Assessment Summary Tables* (EPA 1993b).

4.5 LOCATION-SPECIFIC ARARs

Location-specific requirements "set restrictions upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations" (53 *FR* 51394). Table 4.1 lists potential location-specific ARARs for BCV OU 2.

4.5.1 Wilderness Areas, Wildlife Refuges, Wildlife Resources, and Scenic Rivers

There are no known designated wilderness areas, wildlife refuges, or scenic rivers at BCV OU 2 or within range of being likely to be affected by remedial action at BCV OU 2. However, if any remedial action is taken that will impact Bear Creek, which borders BCV OU 2 on the north, the Fish and Wildlife Coordination Act and the TDEC Water Quality Control Act and its implementing regulations (Chaps. 1200-4-3, 1200-4-4, and 1200-4-7 of the Rules of the TDEC) may be ARARs (see Table 4.1).

Slightly over 5000 acres of the ORR has been designated as a DOE NERP, which also includes Research Areas located both within and outside of the NERP. A Research Area is designated when a specific area is being used to collect monitoring, baseline, or effect data and therefore requires protection from disturbance. Research Area No. 27, Bear Creek characterization and monitoring, is near BCV OU 2 (Parr and Pounds 1987). Because of the unique purposes and goals in establishing the NERP, the uses and restrictions that apply to these resources should be considered TBC guidance if remedial actions appear likely to affect the designated areas.

4.5.2 Wetlands and Floodplains

The northern portions of the RSA and the SY-200 Yard are within the 100-year flood plain of Bear Creek (Welch 1989b). A recent study by Rosensteel and Trettin (1993) located, identified, and characterized many small wetland areas along Bear Creek Valley. A U.S. Army Corps of Engineers walkover of the site on March 29, 1994, however, identified no wetlands in the areas where BCV OU 2 remedial actions will take place. If any identified wetlands are affected, consideration should be given to Executive Order 11990, 10 *CFR* 1022, and 10 *CFR* 1021. If any remedial actions are chosen that would affect the Bear Creek floodplains, Executive Order 11988, 10 *CFR* 1022, the Clean Water Act § 404, and 40 *CFR* 230 should be considered for applicable requirements (see Table 4.1).

4.5.3 Historic Sites and Archaeological Findings

Numerous studies have indicated the presence of abundant archaeological and historic resources on the reservation (Sanders 1984). These surveys are summarized in Volume 3 of the *Resource Management Plan for the U.S. Department of Energy Oak Ridge Reservation* (Sanders 1984). In addition, DOE is conducting a cultural resources evaluation of the Y-12 site, including BCV OU 2, in conjunction with and for the preparation of the ORR Cultural Resources Management Plan. This study will evaluate the presence of cultural resources (archaeological and historical)at the Y-12 site. If the survey reveals the presence of any potential archaeologic sites within BCV OU 2, or if remedial activities uncover any archaeological artifacts, the provisions of the Archaeological Resources Recovery Act (16 USC 470aa-ll), 43 *CFR* 7, the Archaeological and Historic Preservation Act (16 USC 469a-w) Executive Order 11593, the National Historic Preservation Act, 36 *CFR* 800, and the Native American Graves Protection Act of 1990 may be ARARs. Consultation with the TDEC State Historical Preservation Officer may be required to determine the presence of significant archeological material.

In addition, the specific remedial alternative selected must be reviewed in consultation with DOE, the Tennessee State Historical Preservation Officer, and the Advisory Council on

Table 4.1 Potential location-specific ARARs for BCV OU 2

Location characteristic(s)	Requirement(s)	Operating condition(s)	Citation(s)
Floodplains			
Within "lowland and relatively flat areas adjoining inland and coastal waters and other floodprone areas such as offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year." [Executive Order (EO) 11988 §6(c) and 40 *CFR* 6, Appendix A §4(d)]	Action shall be taken to reduce the risk of flood loss, minimize the impact of floods on human safety, health, and welfare, and restore and preserve the natural and beneficial values of floodplains. The potential effects of actions in floodplains shall be evaluated and consideration of flood hazards and floodplain management ensured. If action is taken in floodplains, alternatives that avoid adverse effects and incompatible development and minimize potential harms shall be considered	Action involving: - acquiring, managing, and disposing of lands and facilities - providing federally undertaken, financed, or assisted construction and improvements - conducting federal activities and programs affecting land use	Executive Order 11988 10 *CFR* 1022
Aquatic resources			
Within area encompassing or affecting waters of the state of Tennessee as defined in TCA[a] 69-3-103(32) and the presence of wildlife or aquatic life	Discharge of "substances" that "will result or will likely result in harm, potential harm or detriment to the health of animals, birds, fish, or aquatic life" is prohibited	Action involving the discharge of any pollutants into the waters of the state [see TCA 69-3-103(18) and (21) for noninclusive list]	Tennessee Water Quality Control Act of 1977 (TCA 69-3-101 *et seq.*) Stream Use Classifications (TDEC[b] Rules, Chap. 1200-4-4)
Within area affecting a stream or river	Must comply with the substantive requirements of the aquatic resource alteration permitting process	Action involving aquatic resource alterations	TDEC Rules, Chap. 1200-4-7

Table 4.1 (continued)

Location characteristic(s)	Requirement(s)	Operating condition(s)	Citation(s)
Within area affecting stream or river *-and-* presence of fish or wildlife resources	The effects of water-related projects on fish and wildlife resources must be considered. Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources. Off-site actions that alter a resource require consultation with the FWS,[c] NMFS,[d] and/or appropriate state agency. Consultation is also strongly recommended for on-site actions	Action resulting in the control or structural modification of a natural stream or body of water	Fish and Wildlife Coordination Act (16 USC 661 *et seq.*)
Location encompassing aquatic ecosystem with dependent fish, wildlife, other aquatic life, or habitat	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges that cause or contribute to significant degradation of the water of such ecosystems are prohibited	Action involving the discharge of dredge or fill material into aquatic ecosystem	Clean Water Act §404 40 *CFR* 230
Archaeologic and Historic Resources			
Presence of archaeological resources on public land	Steps must be taken to protect archaeological resources and sites	Action affecting resources	Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll) 43 *CFR* 7
Presence of archaeologic or historic resources	The Secretary of Interior must be advised of the presence of the data. A survey of affected areas for resources and data must be conducted and steps taken to recover, protect, and preserve data therefrom or request that DOI[e] do so	Action involving dam construction or other alteration of terrain that might cause irreparable loss or destruction of significant scientific, prehistoric, historic, or archaeologic data	Archaeological and Historic Preservation Act (16 USC 469a-c)

Table 4.1 (continued)

Location characteristic(s)	Requirement(s)	Operating condition(s)	Citation(s)
Presence of federally owned, administered, or controlled prehistoric or historic resources *-or-* the likelihood of undiscovered resources	Cultural resources included on or eligible for inclusion on the National Register of Historic Places (36 *CFR* 60) or National Historic Landmark Program (36 *CFR* 65) must be identified. Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered. When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve records and data of the resource. When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed. Consultation is also strongly recommended for on-site actions	Action affecting such resources	National Historic Preservation Act (16 USC 470a-w) Executive Order 11593 36 *CFR* 800

[a]TCA = Tennessee Code Annotated
[b]TDEC = Tennessee Department of Environment and Conservation
[c]FWS = Fish and Wildlife Service
[d]NMFS = National Marine Fisheries Service
[e]DOI = Department of Interior

Historic Preservation to ensure that there will be no adverse impacts to cultural resources. Should adverse impacts be anticipated, the three agencies will negotiate a Memorandum of Agreement before the remediation action proceeds.

4.5.4 Rare, Threatened, or Endangered Species

Although there are a number of state- and federally listed plant species present or potentially present on the ORR, currently there are none present at the BCV OU 2 site that would be impacted by any potential remedial activities.

4.6 ACTION-SPECIFIC ARARs

Performance, design, or other action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous waste (52 *FR* 32496). Selecting a particular remedial action at a site will invoke the appropriate action-specific ARARs that may specify particular performance standards or technologies, as well as specific environmental levels for discharged or residual chemicals. Action-specific ARARs for BCV OU 2 will be developed during selection of remedial alternatives in the FS.

5. BASELINE HUMAN HEALTH RISK ASSESSMENT REPORT

5.1 INTRODUCTION

The overall objective of the Human Health BRA evaluation process is to document potential risks and to provide information necessary for making remediation decisions. The human health risk assessment methodology used in the risk evaluation is based on the *Risk Assessment Guidance for Superfund* (RAGS) (EPA 1989b). A quantitative analysis of the inorganic (metals), organic, and radionuclide analytes found in various media is used to characterize the potential risks to human health associated with exposure to these contaminants. The results of the BRA are used to (1) document and evaluate risks to human health, (2) determine the need for remedial action, (3) determine chemical concentrations protective of current and future human receptors, and (4) help select and compare various remedial alternatives (Energy Systems 1993b).

The regulatory agencies involved in environmental restoration activities on the ORR have partitioned the sites (in this particular case, the Oak Ridge Y-12 Plant Bear Creek Valley) into two categories of OUs, which include source control OUs and integrator OUs. Source OUs are defined as on-site [property owned/managed by DOE Oak Ridge Operations Office (DOE-ORO)] waste areas that are currently releasing or have the potential to release contaminants into the environment. Integrator OUs can receive the contaminants released from source OUs and transport them to an off-site receptor. Because of the complexity of the hydrogeologic regime and because many different sources could contribute to groundwater and surface water contamination, this classification was necessary. As a result, immediate attention can be given to source OUs while continued monitoring, characterization, and investigations of the integrator OU are conducted.

The BRA for exposure to soil/waste associated with BCV OU 2 (i.e., a source OU) is presented in this report; groundwater, surface water, and sediment associated with BCV OU 2 will be evaluated in the Bear Creek Valley integrator OU (i.e., BCV OU 4) risk assessment. For purposes of this source OU BRA, BCV OU 2 is divided into three source areas: (1) RSA, (2) SY-200 Yard (SY-200), and (3) SA-1. This report follows the organization of the standard risk assessment processes described in RAGS (EPA 1989b). First, the data for the soil/waste are evaluated to determine data useability for risk assessment; then contaminants to be considered in the BRA are identified. This process is referred to as the selection of COPCs and, at this point, the representative concentrations for those contaminants included in the risk assessment are determined. Next, an assessment of the exposure potential is performed, and exposure pathways are identified. Subsequently, exposure is estimated quantitatively, and the toxicity of the COPCs is evaluated. The results of the exposure and toxicity assessments are combined and summarized in the risk characterization section (Sect. 5.5).

To comprehensively evaluate the risk to human health from exposure to the soil/waste associated with BCV OU 2 and to provide risk information supportive of the project objectives, both a future hypothetical industrial worker exposure scenario and a future hypothetical reasonable maximum exposure scenario (i.e., residential scenario) will be evaluated; under current land use conditions, there are no completed exposure pathways for BCV OU 2 soils (i.e., these areas are not currently used by workers). BCV OU 2 is located on the ORR, just west of the operational Y-12 Plant facilities. Because the surrounding area

is currently developed, RSA, SY-200, and SA-1 could potentially be used for industrial purposes in the future; therefore, the future industrial worker is a potential receptor of BCV OU 2 soils/wastes. The exposure pathways to be evaluated for the future industrial worker include incidental ingestion of soil, inhalation of dust/particulates and volatile organic compounds (VOCs) in soil, dermal contact with the soil, and external exposure to radionuclides in the soil. This industrial worker evaluation represents the most likely/most reasonable risk estimates that are not likely to overestimate risks at BCV OU 2 under future industrial conditions. Therefore, if risks associated with exposure to COPCs exceed the EPA target level, under this most likely exposure assessment, the COPCs may be considered as high priority for cleanup.

A reasonable maximum exposure estimate of the risk to human receptors will be evaluated using residential parameters. Because BCV OU 2 is on the Y-12 Plant reservation, such a conservative scenario is unlikely. However, the intent of this evaluation is to provide managers with potential risks that are unlikely to underestimate exposure to future receptors of the BCV OU 2 media. The routes/pathways of exposure to be evaluated for the residential exposure scenario include dermal contact with the soil, incidental ingestion of the soil, inhalation of dust/particulates and VOCs in soil, external exposure to radionuclides in the soil, and ingestion of homegrown vegetables and fruit (garden grown in the BCV OU 2 soils). Risks associated with exposure to analytes (i.e., COPCs) below the EPA target level, for this conservative residential evaluation, should require no further action in terms of remediation.

BCV OU 2 is located on the DOE-owned property of the Y-12 Plant just west of the operational Y-12 Plant facilities. This OU is downstream from the S-3 Ponds, which are near the headwaters of Bear Creek, and comprises an equipment storage area (SY-200) and two construction spoil areas (RSA and SA-1).

The RSA is ~5.4 acres and was used (from ~1975 to 1983) for the disposal of spoil materials (solid wastes) generated from renovations, construction, and maintenance activities at the Y-12 Plant. This area was graded periodically (but not necessarily compacted) and is estimated to contain ~100,000 yd^3 of debris. The bulk of the materials disposed of at the RSA include construction debris (i.e., concrete, scrap metal, and masonry) and soils, some of which have been contaminated with traces of mercury and solvents. Significant amounts of chemicals (solvents) and/or other hazardous wastes were prevented from disposal in the RSA via the existing administrative controls. This area currently has a 2-ft soil/clay cover and some vegetative growth, which were implemented in 1984.

The SY-200 was used as an above-ground storage area (from ~1950 to 1986) for mercury flasks, electrical transformers, piping, tanks, and other miscellaneous items. This area was the designated location for the construction of an ESF; however, during excavation for the facility, mercury contamination was detected in soils at the site. Asbestos was also identified in fragments of transit siding found in the soil samples obtained from deeper depths (i.e., greater than 10 ft) at the site. The excavated soils were placed back in the excavated area in 1990 (in the east end of the hole); refer to Sect. 3.1 of this RI for details. Approximately 5 ft of clean borrow material was placed on top of the excavated soils area, and clean borrow was placed in the west end of the hole to deeper depths. Subsequently, the ESF building has been constructed immediately south of SY-200, and part of the SY-200 area is under the parking lot for the ESF building.

The SA-1 was used (from ~1980 to 1989) for the disposal of what was then considered nonhazardous and/or nonradioactive-contaminated construction debris from maintenance activities, construction projects, and renovations at the Y-12 Plant. The debris consisted of items such as concrete, brick, asphalt, brush, metal, rocks, tile, and roofing materials. The site is ~5 acres, and it is estimated that roughly 100,000 yd^3 of noncontaminated debris were disposed of at this site. This site had a TDEC landfill permit, which went into effect in 1985. Currently, SA-1 has 0.5 to 1 ft of clean surface soil and a vegetative cover.

The following sections describe the methodology used in evaluating the BCV OU 2 analytical data, physical characteristics, potential pathways, and receptors to quantify the potential risk to human health from exposure to BCV OU 2 COPCs.

5.2 IDENTIFICATION OF CONTAMINANTS OF POTENTIAL CONCERN

The following sections address data evaluation steps that are necessary to (1) identify a set of chemicals that are likely to be site related and (2) report analyte concentrations that are of acceptable quality for use in a quantitative human health BRA.

5.2.1 General BCV OU 2 Data Collection Considerations

The soil data presented in this BRA are from various sampling time periods (referred to as historical data and current data); both historical and current soils data were reviewed/ evaluated by Energy Systems, Risk Analysis Section (RAS) and are included in this BRA. Historical data include soil samples from RSA, SY-200, and SA-1. Current data include soil samples from SY-200 and RSA. The current data also include surface water, groundwater, and sediment samples for RSA, SY-200, and SA-1; however, with the exception of the groundwater data, which will be used in this BRA as the irrigation source for the homegrown garden, these media (i.e., groundwater, surface water, and sediment) will be evaluated as part of the BCV OU 4 BRA. Refer to Sect. 3.2 for details.

Background levels for analytes detected in the BCV OU 2 soils will be compared with the results from the *Background Soil Characterization Project for the Oak Ridge Reservation* (BSCP) (DOE 1993). Refer to the RI Work Plan (SAIC 1993b) and Sect. 3.2.4 of this RI report for the exact sampling locations, number of samples collected, sampling and analysis guidance used, analysis and analytical techniques used, and the quality assurance/quality control methods used.

5.2.2 General BCV OU 2 Data Evaluation Considerations

BCV OU 2 comprises three distinct areas (i.e., RSA, SY-200, and SA-1), and the data were evaluated separately for these sources. Both historic and current soil data were considered for use in this BRA. The historical data were taken from two sources, Appendix C of the RI Work Plan (SAIC 1993b) and the Analysis Laboratory Information System (AnaLIS). The historical data for the SY-200 area were taken from appendixes of the *Energy Systems RCRA Facility Investigation Plan SY-200 Yard* (Energy Systems 1989). Historical data for the SA-1 area were provided by the Oak Ridge Environmental Information System via electronic files. The historical data for the RSA area were taken from Appendix C or the RI Work Plan (SAIC 1993b). The current data for the SY-200 and RSA areas were taken as part of this RI project.

5.2.3 BCV OU 2 Data Evaluation/Preparation

The soil data were read into a Statistical Analysis System data set and were evaluated in accordance with RAGS (EPA 1989b) for the process of selecting the COPCs to be evaluated quantitatively in this BRA. In the following sections of this BRA, the results (data) from the historical and current sampling events are evaluated and combined into one BCV OU 2 data set (subdivided into the three source areas).

The soil data for BCV OU 2 are summarized and tabulated in Sect. 5.2.3.10. The data included result from the inorganic, organic, and radionuclide analyses of soil samples from various sampling locations within this OU.

5.2.3.1 Data validation considerations

Details of the validation process for the current data can be found in the RI Work Plan (SAIC 1993b). The historical chemical data were validated at various levels. The current data were 100% validated, with the evaluation/validation process including comparison of the samples with associated blanks using two criteria: (1) if the concentration of the analyte in the sample was at least 5 times greater than the maximum concentration detected in the blank, then the analyte concentration was not changed from the reported value and (2) if the concentration of the analyte in the sample was greater than the concentration found in the blank but less than 5 times the concentration in the blank, then the analyte concentration was changed to reflect the concentration reported in the blank, and a nondetect qualifier (U) was also added to the data set for these species. For common laboratory contaminants such as acetone, 2-butanone, methylene chloride, toluene, and phthalate esters, if the concentration of the analyte in the sample was at least 10 times greater than the associated blank maximum concentration detected in the blank, then the analyte concentration was not changed from the reported value [similar to criterion (1) described previously]. The results of a blank/original sample comparison test, described previously, were incorporated into both the historical and current data.

The data were evaluated for this BRA by the methods described in RAGS (EPA 1989b). Data qualifiers were also evaluated where: (1) J were treated as detected analytes and were included in the BRA data set; (2) U were treated as nondetected analytes, and the reported detection limit was used as the concentration value; (3) UJ were treated as data flagged with U; and (4) R were rejected from the BRA data set. When an analyte was not detected (U or UJ) in any of the soil samples, a separate data set (i.e., a nondetected analytes data set) was created; these data are evaluated and discussed in Sect. 5.2.3.14.

5.2.3.2 Original samples compared with duplicate samples

The results of a duplicate/original sample comparison test were incorporated into the historical and current soil data. For original samples with associated duplicates, a comparison of each analyte concentration (original versus duplicate) was performed, and the highest concentration for each analyte was selected for use in this BRA [i.e., the sample concentrations provided were always greater than (or equal to) the duplicate concentrations]. Because this modification to the original data set ensures that the most conservative analyte concentrations are used in the BRA, no further evaluations of duplicate concentrations were considered.

5.2.3.3 Historical data

Historical soils data were available for all three areas (RSA, SY-200, and SA-1). For the RSA area, soil samples were taken to depths of 25 ft; the soil samples considered in this BRA were for depths of 0–10 ft (which included composite samples from 0–5 ft and from 5–10 ft). For the SA-1 area, only historical soil data are available, and depths of 0–12 ft (which included composite samples from 4.5–7.5 ft and from 9–12 ft) were considered in this BRA; depths to ~50 ft were taken for some boreholes.

For the SY-200 Yard, the historical soil data came from two different sampling events (1988 and 1989); in 1988 ~15 samples were collected from four boreholes at various depths. (These samples were taken before excavation activities started for the ESF building.) After the excavation, the bermed material/soil was sampled (in 1989), and 22 composite samples were collected from 11 locations within this 20-ft-high mound of soil. Note: for the SY-200 Yard, mercury concentrations were significantly elevated in the historical soil samples (SAIC 1993b).

5.2.3.4 Current data

Current soil data were collected for the SY-200 Yard and for the RSA areas only. For the RSA area, five locations were sampled; the soil samples collected for depths down to 10 ft (i.e., composites from 0 to 4 ft, 4 to 8 ft, and 8 to 10 ft) were considered in this BRA. For the SY-200 area, a statistical grid was placed over the east and west ends of the area, and a total of 59 boreholes were drilled. Soil samples to depths of 11 ft (i.e., composites from 3 to 7 ft and from 7 to 11 ft) were considered in this BRA; because of the 2-ft clean cover in this area, soil samples were not collected for the 0–3 ft interval). One surface sediment sample was taken within the boundary of the SY-200 area (in a small puddle) and was considered as a soil sample.

5.2.3.5 Further historical data preparation

Radionuclide analyses for the historical soil data were reported as *total* radium activity (pCi/g), *total* thorium (mg/kg), and *total* uranium (mg/kg). For this BRA, the *total* radium concentration (pCi/g) was assigned to the ^{226}Ra isotope. (Toxicity values for ^{226}Ra are the most conservative, that is, give the highest risk, among the radium isotopes.) The reported *total* uranium concentration (mg/kg) was converted to the three most abundant isotopes (^{234}U, ^{235}U, and ^{238}U) in units of activity (pCi/g). The weight percent of ^{235}U was reported as ~0.5%, and the weight percent of ^{238}U was reported as ~99.5% (no weight percent results were reported from the laboratory for the ^{234}U isotope); a natural distribution of the three uranium isotopes was assumed. The *total* thorium concentration (mg/kg) was converted to ^{232}Th, which is the most abundant of the isotopes. Note: no individual radionuclide isotopes were measured or reported in the historical data for BCV OU 2; for the current BCV OU 2 data (for the SY-200 area and the RSA), isotopic uranium activities (i.e., ^{234}U, ^{235}U, and ^{238}U) were measure and reported.

5.2.3.6 Further current data preparation—determination of areal variation in contamination

Numerous soil samples at various locations were taken in the SY-200 area; some samples were taken outside of the boundaries of this area to determine the extent of contamination;

refer to Sect. 3.2.4 for the exact sampling locations and the boundary of this area. The mercury concentrations found in the soil samples (at depths of 3–11 ft) taken outside the boundary of this area were compared with residential ingestion of soil preliminary remediation goals (PRGs) (refer to Sect. 5.2.3.1.4) and were found to be significantly lower than the PRGs. Therefore, only soil samples within the boundary (Sect. 3.2.4) were considered in this BRA.

For the SY-200 area, mercury is the primary COPC. Because of the nature of the excavation activity in this area (refer to Sect. 5.2.1), a statistical test was performed to compare mercury concentrations from the eastern and the western portions of the SY-200 area. Mercury concentrations were determined to be lognormally distributed [using the Shapiro-Wilk statistic (W)] for depths of 3–7 ft and 3–11 ft for both the east and west sections. Upon comparison of the mean mercury concentrations (i.e., the mean of the lognormal distribution), a statistical difference (at the 90% confidence level) was found between the east and west portions of this area at the 3–7 ft depth. At the 3–7-ft depth interval, the mercury concentration was significantly higher for the east end of the SY-200 area. However, the same comparison was performed for the 3–11-ft interval, and no statistical difference (at the 90% confidence level) was found between the east and west portions. This result (i.e., no statistical difference) occurs because the mercury concentrations increase at deeper depths (7–11 ft) in the western portion of this site.

The identification of contaminant "hot spots" in BCV OU 2, in relation to risk to human health, will be addressed in detail in Sect. 5.5.5. All soil data (at depths of 3–11 ft) within the SY-200 area (as defined in Sect. 3.2.4) were considered in this BRA.

5.2.3.7 Historical versus current data comparisons

For the SA-1 area, only historical soil data were available. For the RSA area, for depths of 0–10 ft, statistical comparisons (two sample t-tests) were made between the historical and the current soils data; only 2 of the 23 analytes detected in both data sets were statistically different (at the 90% confidence level), aluminum and cadmium. Because very few differences were found, and to increase the sample size (to better estimate representative analyte concentrations), the historical and current data were combined.

For the SY-200 area, statistical comparisons (two sample t-tests) were made between historical and current soil data (for depths to 11 ft); 11 of the 20 analytes detected in both data sets were statistically different (at the 90% confidence level). Based on best professional judgment, the current data best represents the current conditions at this site because (1) the majority of the analytes showed statistical differences (for the historical versus current data comparison); (2) more than an adequate number of sample results were available for the current data (from 31 to 81 results, depending on the analyte); (3) the location/origin of the historical soil samples is currently unknown (i.e., most of the historical data were taken from the excavation soil mound, which no longer exists; it was placed back into the excavated area supposedly near the east end of the SY-200 Yard); (4) only a limited number of analytes were analyzed for in the historical sampling; and (5) the sampling plan for the current soils data was extensive (it included many sampling locations across the entire boundary of this area to characterize the current conditions of this site).

In addition, mercury (the primary COPC for the SY-200 area) was further statistically evaluated. A comparison was made between the historical and current soils data for mercury;

the 90% confidence intervals around the mean (for the lognormally distributed data) did not overlap. Therefore, there is a statistical difference between these data sets for mercury; for this reason, and for the reasons mentioned in the previous paragraph, only current soils data (3–11 ft) were included in this BRA (for the SY-200 area).

5.2.3.8 Final BCV OU 2 soil data set

Based on the soil data evaluations described at the beginning of Sect. 5.2.3, data availability, and best professional judgment, only historical soils data (4.5–12 ft) were used for the SA-1 area; for the RSA area, both historical and current soils data were used (0–10 ft); and for the SY-200 area, only current soils data were used in this BRA (3-11 ft). Because both the SA-1 and the SY-200 areas have a clean soil cover, data from the shallow surface soil were not collected and, therefore, are not considered in the BRA. To be conservative, in terms of risk to human health, exposure to soils to depths of 12 ft were evaluated in this BRA.

5.2.3.9 Tentatively identified compounds

Tentatively identified compounds (TICs) are analytes not included on the target analyte list (TAL) or on the target compound list (TCL) and for which both the identity and concentration are questionable. A summary of the TIC information was provided to the Energy Systems RAS by SAIC and can be found in Appendix C, Table C.1. According to RAGS (EPA 1989b), when only a few TICs are present, compared to TCL and TAL chemicals, and when historical and/or site-specific information about such analytes are not available, the TICs are generally not included in the risk evaluation. The results illustrated in Table C.1a show that the number of TICs as compared to the number of analytes on the TAL. Tables C.1b–d show the frequency of occurrences for the TICs as well as the concentrations for the RSA, SY-200, and SA-1 area, respectively. No further evaluation of TICs was performed.

5.2.3.10 Summary statistics for BCV OU 2 soil data

Table C.2 lists the summary statistics for the BCV OU 2 soil data set. This table is subdivided into the three areas (RSA, SY-200, and SA-1) and include (1) the analyte type (inorganic, radionuclide, and organic); (2) number of detected concentrations per number of observations (i.e., frequency of detection); (3) distribution type (i.e., normal or lognormal); (4) minimum detected concentration, maximum detected concentration, and mean concentration; (5) upper 95% confidence limit (UCL95) on the mean; (6) the maximum nondetected concentration (for those analytes with all nondetected values); and (7) units of measure. Two distributions were considered for the detected analytes (normal and lognormal), and a UCL95 was calculated according to the appropriate distribution; for lognormal distributions, all calculated values were transformed back into normal space and are reported here (Table C.2). For the analytes with all nondetected values, no test was performed (NT) and, therefore, no UCL95 is reported in this table; the maximum nondetected value is used as the exposure concentration for these analytes. For Note, for ^{235}U and ^{238}U, the weight percent values are reported for the reader's information only.

For the essential nutrients, including calcium, copper, iron, magnesium, phosphorus, potassium, and sodium (Dunne 1990) no adverse effects are expected at the detected levels reported in this study, and these nutrients are not expected to have been deposited in any of

the BCV OU 2 areas. They have been included in the summary statistics for the purpose of reporting all of the available information but are not considered COPCs.

5.2.3.11 Comparison with background soil samples

Many naturally occurring soil constituents also occur as site-related contaminants (i.e., they are detected during the sampling and analyses process along with the site contaminants). Therefore, site-related contaminants must be differentiated from background constituents to ensure that risk management decisions are based on risk posed by contaminants and not risk from background constituents. This aspect of the COPC selection process is carried out by using the results from the *Background Soil Characterization Project for the Oak Ridge Reservation* (DOE 1993). Data collected during the site investigations of the specific waste areas (e.g., areas in BCV OU 2) should be compared to background data to identify COPCs. In most cases, an analyte detected in soil is assumed to be related to site activities and is therefore a COPC; however, if the detected analyte concentration is less than or equal to the background concentration, it should not be considered a COPC.

Analytes detected in the BCV OU 2 soils and reported in the summary statistics (Table C.2) were compared with those analytes found in naturally occurring background soils on the ORR (DOE 1993). (Refer to Table C.3.) The soil/fill material for the three areas in BCV OU 2 is believed to have been taken from Chestnut Ridge, which is in the Copper Ridge Formation (CRG) horizon C. The upper 95% confidence bound (UCB95) on the median BCV OU 2 analyte concentration for each analyte was compared to the UCB95 on the median of the BSCP data (Copper Ridge horizon C). Analytes with a UCB95 concentration less than the UCB95 concentration for background for the CRG formations were not considered to be significantly different from ORR background soils and, therefore, were not considered to be COPCs for this BRA.

5.2.3.12 Toxicity screening of soil data

A concentration-toxicity screen was applied to the BCV OU 2 soil data set (for analytes with at least one detected value) using guidance in RAGS (EPA 1989b). The objective of this screening procedure was to identify those analytes most likely to contribute significantly to the risks and hazard indices [hazard index (HI)] (i.e., those analytes with a negligible contribution to the total adverse health effects posed by site contaminants were identified and were not included on the COPC list). For the ingestion, inhalation, and external exposure toxicity values [i.e., reference doses (RfDs) and slope factors (SFs)], a toxicity score was calculated for each analyte by multiplying the analyte's maximum detected concentration by the toxicity value (i.e., conc. $\times$ SF, and/or conc. $\times$ 1/RfD). Individual analyte toxicity scores were summed to obtain a total chemical score; a ratio of the specific analyte toxicity score to this total chemical score approximates the relative risk [or hazard quotient (HQ)] for each analyte. Analytes with a relative risk or HQ of less than 1% (i.e., less than 1% for all available toxicity scores) were not considered further (as COPCs) in this BRA. The reader should note that this toxicity screen was performed for each area (RSA, SY-200, and SA-1), and radionuclides were evaluated separately from the nonradionuclides (in accordance with EPA guidance, EPA 1989b). The results of the toxicity screening can be found in Table C.4.

Analytes eliminated (via toxicity screening) versus soil preliminary remediation goals. For the analytes eliminated from the soil COPC list based on the toxicity screening (Table C.4), comparisons were made with the appropriate PRGs [i.e., PRGs at a cancer risk level $\geq$

1.0E-06 and/or a noncarcinogenic toxicity level (HQ) $\geq$ 1.0 (refer to Table C.5)]. The maximum detected concentration for these analytes in soils were compared with the residential soil ingestion PRGs. (Radionuclides were compared with ingestion plus external exposure PRGs.) For three analytes in the SY-200 area [benzo(a)anthracene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene], the maximum detected concentration was greater than the corresponding PRG (at a risk level of 1.0E-06); therefore, to be conservative (in terms of potential risk to human health), these three analytes were returned to the soil COPC list for this BRA.

5.2.3.13 Summary of background comparison, toxicity screening, and essential nutrient results

Table C.6 summarizes/lists those detected analytes not included on the COPC list because of (1) a comparison with background soil data (Sect. 5.2.3.11), (2) the toxicity screening assessment results (Sect. 5.2.3.12), or (3) their use as essential nutrients (Dunne 1990) in the human body (Sect. 5.2.3.10).

5.2.3.14 Comparison of nondetected analyte concentrations with soil preliminary remediation goals

Summary statistics for the nondetected BCV OU 2 analytes (i.e., analytes which were not detected in every sample) are included in Table C.2; these nondetected analytes are not believed to be associated with the BCV OU 2 activities. For the nondetected analytes that could be evaluated quantitatively (i.e., those with SFs and/or RfDs available), comparisons were made with PRGs. PRGs are initial guidelines (protective of human health) that are based on readily available information and comply with applicable or relevant and appropriate requirements and are used in the selection of remedial alternatives (EPA 1991a). The maximum reported nondetected concentration for each nondetected BCV OU 2 analyte was compared with the noncarcinogenic (HQ = 1.0) and carcinogenic (risk = 1.0E-04 and risk = 1.0E-06) residential ingestion of soil PRGs; residential PRGs were used to be conservative. Table C.7 shows the BCV OU 2 analytes that had nondetected analyte concentrations above the target PRG concentrations; therefore, the detection limits of the analytical methods used for these analytes were too high (in terms of evaluating risk to human health). The reader should note that analytes that were always nondetected (i.e., frequency of detect was zero) will not be considered further and are not included on the soil COPC list for this BRA.

5.2.4 Summary of Contaminants of Potential Concern for BCV OU 2 Soils

Table 5.1 lists the detected (i.e., at least one detected value) soil COPCs to be evaluated quantitatively in this BRA and their UCL95 concentration; complete summary statistics information can be found in Table C.2. The UCL95 will be used as the exposure concentration (representative concentration) in this BRA. Note: in accordance with RAGS (EPA 1989b), a comparison was made between the UCL95 concentration and the maximum detected concentration; the smaller of these two values is considered the representative concentration and is listed in Table 5.1 (and all subsequent tables) as the UCL95 concentration. The COPCs for the BCV OU 2 soils are specified for the three areas (RSA, SY-200, and SA-1) (Table 5.1); a total of 8 inorganics, 4 radionuclides, and 11 organics are the COPCs associated with the BCV OU 2 soils.

Table 5.1. COPCs for BCV OU 2 soils that will be evaluated quantitatively[a]

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
	RSA		
Inorganics			
Barium	23/23	1.15E+02	mg/kg
Beryllium	23/23	1.05E+00	mg/kg
Cadmium	16/23	4.93E+00	mg/kg
Manganese	23/23	8.99E+02	mg/kg
Mercury	14/23	2.00E+00	mg/kg
Nickel	23/23	4.61E+01	mg/kg
Uranium (soluble salts)	12/12	7.36E+00	mg/kg
Radionuclides			
^{232}Th	2/12	3.09E+00	pCi/g
^{234}U	23/23	2.81E+00	pCi/g
Organics			
1,2,4-Trichlorobenzene	1/11	4.31E+00	mg/kg
1,2-Dichloroethene (total)	4/23	7.22E-02	mg/kg
Aroclor-1254	5/8	9.86E-01	mg/kg
Benzo(a)pyrene	3/11	4.76E-01	mg/kg
Bis(2-ethylhexyl)phthalate	1/11	6.56E+00	mg/kg
Dibenzo(a,h)anthracene	2/11	2.90E-01	mg/kg
Tetrachloroethene	5/23	1.62E-01	mg/kg
	SY-200		
Inorganics			
Cadmium	12/84	3.24E-01	mg/kg
Manganese	75/89	7.32E+02	mg/kg
Mercury	73/89	2.17E+01	mg/kg
Organics			
Aroclor-1254	9/88	3.09E-01	mg/kg
Aroclor-1260	41/88	4.25E-01	mg/kg
Benzo(a)anthracene	7/32	4.97E-01	mg/kg
Benzo(a)pyrene	10/32	4.34E-01	mg/kg
Benzo(b)fluoranthene	9/32	3.23E-01	mg/kg
Dibenzo(a,h)anthracene	4/32	1.20E-01	mg/kg
	SA-1		
Inorganics			
Barium	12/12	2.34E+02	mg/kg
Beryllium	12/12	1.20E+00	mg/kg
Cadmium	12/12	3.31E+00	mg/kg
Chromium VI	12/12	3.59E+01	mg/kg

Table 5.1 (continued)

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
Manganese	12/12	1.20E+03	mg/kg
Mercury	8/12	9.65E-01	mg/kg
Nickel	12/12	3.51E+01	mg/kg
Uranium (soluble salts)	12/12	1.53E+01	mg/kg
Radionuclides			
^{226}Ra	12/12	3.22E+00	pCi/g
^{234}U	12/12	5.15E+00	pCi/g
^{238}U	12/12	5.11E+00	pCi/g
Organics			
Benzo(a)anthracene	5/12	4.16E-01	mg/kg
Benzo(a)pyrene	5/12	3.61E-01	mg/kg
Benzo(b)fluoranthene	4/12	3.76E-01	mg/kg
Indeno(1,2,3-cd)pyrene	3/12	2.60E-01	mg/kg

[a]The analytes to be evaluated quantitatively in this BRA have at least one detected value; these analytes also have EPA-approved SFs and/or RfDs.

[b]The values reported in this column are the exposure concentrations (referred to as UCL95 in all tables in this BRA) used in the risk assessment calculations in this BRA. The concentration listed in this column is actually the smallest of two values: the maximum detected concentration versus the UCL95 on the mean concentration (EPA 1989b).

Identification of the COPCs was based on the methodology from RAGS (EPA 1989b), and the number of COPCs that could be quantitatively evaluated was limited by the availability of chemical-specific EPA-approved toxicity information (i.e., SFs and RfDs) (EPA 1994a).

The analytical laboratory reported detected concentrations for *total* chromium, and although chromium may exist as species of low toxicity, the analytical data cannot substantiate this belief. Therefore, a conservative approach for evaluating human exposure to chromium was taken; chromium was assumed to be in its most toxic form (i.e., chromium VI) for the purposes of this BRA. For the *total* uranium analyte (mg/kg), the toxicity information for uranium (soluble salts) is used.

Table 5.2 lists the soil COPCs (with at least one detected value) for BCV OU 2 that could not be evaluated quantitatively in this BRA (i.e., no current EPA-approved SFs or RfDs exist for these analytes) (EPA 1994a). These analytes (4 inorganics and 11 organics) are only considered qualitatively further in this BRA; refer to Sect. 5.4.6.

The reader should note that the soil COPC lists (Tables 5.1 and 5.2) for human health risk assessment differs from the COPC list reported in Sect. 3.2.4 for various reasons, which include the following: (1) the human health risk assessment in this RI only evaluates soil depths to ~12 ft; (2) when duplicate sample data were available, a comparison was made with

Table 5.2. COPCs for BCV OU 2 soils that will be evaluated qualitatively[a]

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
	RSA		
Inorganics			
Cobalt	23/23	1.69E+01	mg/kg
Thallium	4/11	1.80E-01	mg/kg
Thorium, total	2/12	2.83E+01	mg/kg
Organics			
1,1,1-Trichloroethane	1/23	6.15E-02	mg/kg
2-Methylnaphthalene	1/11	2.70E-01	mg/kg
Acenaphthylene	1/11	5.60E-02	mg/kg
Benzo(g,h,i)perylene	3/11	5.10E-01	mg/kg
Dibenzofuran	1/11	3.80E-02	mg/kg
Endosulfan I	1/7	6.50E-04	mg/kg
Naphthalene	1/11	9.00E-02	mg/kg
Phenanthrene	5/11	5.26E-01	mg/kg
Trichloroethene	3/23	9.70E-02	mg/kg
	SY-200		
Inorganics			
Cobalt	73/89	1.78E+01	mg/kg
Thallium	21/89	2.90E-01	mg/kg
Organics			
4-Chloro-3-methylphenol	1/32	4.50E-02	mg/kg
4-Nitrophenol	1/32	4.60E-02	mg/kg
Benzo(g,h,i)perylene	7/32	4.15E-01	mg/kg
Dibenzofuran	3/32	6.40E-02	mg/kg
Naphthalene	2/32	7.10E-02	mg/kg
Phenanthrene	9/32	3.49E-01	mg/kg
	SA-1		
Inorganics			
Aluminum	11/12	2.62E+04	mg/kg
Cobalt	12/12	1.86E+01	mg/kg
Organics			
Benzo(g,h,i)perylene	3/12	2.80E-01	mg/kg
Dibenzofuran	1/12	1.70E-01	mg/kg
Naphthalene	1/12	1.50E-01	mg/kg
Phenanthrene	5/12	6.29E-01	mg/kg

[a]The analytes to be evaluated qualitatively in this BRA have at least one detected value; however, no EPA-approved SFs or RfDs are currently available.

[b]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b).

the original sample, and for this BRA the maximum of the two concentrations was used in the risk assessment data set; (3) a human health toxicity screening was performed on the data (refer to Sect. 5.2.3.12), and numerous analytes were eliminated from consideration in this BRA; and (4) essential nutrients were not considered in this BRA (refer to Sect. 5.2.3.10).

Table C.8 lists the results of a comparison of the maximum detected concentrations for the BCV OU 2 soil nonradionuclide COPCs vs residential ingestion of soil PRGs; for radionuclide COPCs, the PRG values include residential ingestion of soil and external exposure pathways. This information is provided to the reader (upon request of TDEC) because there can be a substantial differences between the UCL95 analyte concentration (which is used in the BRA calculations) and the maximum detected analyte concentration. EPA guidance (EPA 1989b) recommends using the smaller of two concentrations (i.e., the UCL95 vs the maximum detected value) as the exposure concentration in determining risks to human health; this approach was used in this BRA.

5.2.5 Groundwater Data Evaluation

BCV OU 2 is a source OU and, therefore, soils/wastes only are evaluated in detail in this BRA. Groundwater will be evaluated in terms of risk to human health in the BCV OU 4 (the integrator OU) BRA. Groundwater will only be considered in this BCV OU 2 BRA as the irrigation source for the homegrown garden scenario.

The groundwater data were with background groundwater concentrations from well GW-317 (refer to Sect. 3.2.3 for details of this comparison); the RAS received this data summary subsequent to the background comparison. Note: the summary data set includes only analytes detected (at least once) in the groundwater (i.e., analytes never detected were not included in this data set). For the RSA, the reported *total* uranium concentration (mg/L) was considered in this BRA to be uranium (soluble salts) (mg/L). In addition, the *total* uranium concentration (mg/L) was converted to the three most abundant isotopes (^{234}U, ^{235}U, and ^{238}U) in units of activity (pCi/L); a natural distribution of the three uranium isotopes was assumed. Isotopic data for uranium were provided for the SA-1 and SY-200 areas.

5.2.5.1 Summary statistics for BCV OU 2 groundwater data

Table C.9 lists the summary statistics for the BCV OU 2 groundwater data. This table is subdivided into the three areas (RSA, SY-200, and SA-1) and includes the (1) analyte type (inorganic, radionuclide, and organic); (2) number of detected concentrations per number of observations (i.e., frequency of detection); (3) distribution type (i.e., normal or lognormal); (4) minimum detected concentration, maximum detected concentration, and mean concentration; (5) the UCL95 on the mean; and (6) units of measure.

5.2.5.2 Toxicity screening of groundwater data

A concentration-toxicity screen was applied to the BCV OU 2 groundwater data set using guidance in RAGS (EPA 1989b). The objective of this screening procedure was to identify those analytes most likely to contribute significantly to the risks and HIs. (That is, those analytes with a negligible contribution to the total adverse health effects posed by site contaminants were identified and were not included on the COPC list). For the ingestion toxicity values (i.e., oral RfDs and oral SFs), a toxicity score was calculated for each analyte by multiplying the analyte's maximum detected concentration by the toxicity value (i.e.,

conc. × SF and/or conc. × 1/RfD). Individual analyte toxicity scores were summed to obtain a total chemical score; a ratio of the specific analyte toxicity score to this total chemical score approximates the relative risk (or HQ) for each analyte. Analytes with a relative risk or HQ of less than 1% (i.e., less than 1% for all available toxicity scores) were not considered further (as COPCs) in this BRA. The reader should note that this toxicity screen was performed for each area (RSA, SY-200, and SA-1), and radionuclides were evaluated separate from the nonradionuclides (in accordance with EPA guidance, EPA 1989b). The results of the toxicity screening can be found in Table C.10.

Analytes eliminated (via toxicity screening) versus groundwater PRGs. For the analytes eliminated from the groundwater COPC list based on the toxicity screening (Table C.10), comparisons were made with the appropriate PRGs (i.e., PRGs at a cancer risk level $\geq$ 1.0E-06 and/or a noncarcinogenic toxicity level $\geq$ 1.0). (Refer to Table C.11.) The maximum detected concentration for these analytes in groundwater were compared with the residential groundwater ingestion PRGs. For two analytes in the SA-1 area (bromodichloromethane and methylene chloride), the maximum detected concentration was greater than the corresponding PRG (at a risk level of 1.0E-06); therefore, to be conservative (in terms of risk to human health), these two analytes were returned to the groundwater COPC list for this BRA.

5.2.5.3 Summary of COPCs for BCV OU 2 groundwater

Table 5.3 lists the detected (i.e., at least one detected value) groundwater COPCs to be evaluated quantitatively in this BRA (as the homegrown garden irrigation source) and their UCL95 concentrations; complete summary statistics information can be found in Table C.9. The UCL95 will be used as the exposure concentration (representative concentration) in this BRA. **Note:** in accordance with RAGS (EPA 1989b), a comparison was made between the UCL95 concentration and the maximum detected concentration; the smaller of these two values is considered the representative concentration and is listed in Table 5.3 (and all subsequent tables) as the UCL95 concentration. The COPCs for the BCV OU 2 groundwater are specified for the three areas (RSA, SY-200, and SA-1) (Table 5.3); a total of nine inorganics, six radionuclides, and six organics are the human health COPCs associated with the BCV OU 2 groundwater.

Identification of the COPCs was based on the methodology from RAGS (EPA 1989b), and the number of COPCs that could be quantitatively evaluated was limited by the availability of chemical-specific EPA-approved toxicity information (i.e., SFs and RfDs) (EPA 1994a).

The analytical laboratory reported detected concentrations for *total* chromium, and although chromium may exist as species of low toxicity, the analytical data cannot substantiate this belief. Therefore, a conservative approach for evaluating human exposure was taken; chromium was assumed to be in its most toxic form (i.e., chromium VI) for the purposes of this BRA. For the *total* uranium analyte (mg/L), the toxicity information for uranium (soluble salts) is used.

Table 5.3. COPCs for BCV OU 2 groundwater that will be evaluated quantitatively[a]

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
	RSA		
Inorganics			
Antimony	3/108	2.80E-02	mg/L
Arsenic	8/82	3.05E-02	mg/L
Beryllium	17/108	2.21E-04	mg/L
Cadmium	15/108	2.09E-03	mg/L
Chromium VI	42/108	1.59E-02	mg/L
Manganese	105/108	3.29E+00	mg/L
Nitrate	107/108	4.38E+01	mg/L
Uranium (soluble salts)	70/108	2.06E-03	mg/L
Radionuclides			
^{137}Cs	11/14	4.94E+01	pCi/L
^{90}Sr	5/14	1.03E+02	pCi/L
^{99}Tc	6/11	2.04E+03	pCi/L
^{234}U	70/108	6.95E-01	pCi/L
^{238}U	70/108	6.89E-01	pCi/L
Organics			
1,2-Dichloroethene (total)	52/82	1.93E-02	mg/L
Carbon tetrachloride	35/82	2.73E-03	mg/L
	SY-200		
Inorganics			
Chromium VI	4/4	1.87E-02	mg/L
Manganese	4/4	5.67E+00	mg/L
Radionuclides			
^{234}U	4/4	7.38E+00	pCi/L
^{235}U	4/4	4.29E-01	pCi/L
^{238}U	4/4	8.58E+00	pCi/L
Organics			
Bis(2-ethylhexyl)phthalate	4/4	4.00E-03	mg/L
Chloroform	1/4	1.00E-03	mg/L
	SA-1		
Inorganics			
Beryllium	6/85	2.63E-04	mg/L
Cadmium	9/85	1.98E-03	mg/L
Manganese	70/85	5.88E-02	mg/L
Nitrate	81/83	2.62E+01	mg/L
Vanadium	2/85	3.69E-03	mg/L

Table 5.3 (continued)

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
Radionuclides			
^{234}U	2/2	2.51E+00	pCi/L
^{238}U	2/2	1.70E+00	pCi/L
Organics			
1,2-Dichloroethene (total)	43/67	1.56E-02	mg/L
Bromodichloromethane	7/67	2.58E-03	mg/L
Methylene chloride	9/67	3.18E-03	mg/L

[a]The analytes to be evaluated quantitatively in this BRA have at least one detected value; these analytes also have EPA-approved SFs and/or RfDs.

[b]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b).

Table 5.4 lists the groundwater COPCs (with at least one detected value) for BCV OU 2 that could not be evaluated quantitatively in this BRA (i.e., no current EPA-approved SFs or RfDs exist for these analytes) (EPA 1994a). These analytes (14 inorganics and 2 organics) are only considered qualitatively further in this BRA.

Comparison of UCL95 concentrations for BCV OU 2 groundwater COPCs with PRGs. The reader should note that, as previously stated, the groundwater for this OU will be fully evaluated, in terms of risk to human health, in the BCV OU 4 BRA. The BCV OU 2 groundwater COPCs identified in Table 5.3 will be considered only in terms of ingestion of homegrown vegetables/fruits, which were irrigated with this groundwater. However, to provide a limited but conservative analysis of potential risks to human health from exposure to the groundwater COPCs via groundwater ingestion only, a comparison of the UCL95 concentration with residential ingestion of groundwater PRGs is provided in Table C.12. In summary, for the RSA, antimony, arsenic, beryllium, manganese, ^{137}Cs, ^{90}Sr, ^{99}Tc, and carbon tetrachloride are above residential PRGs (at risk $\geq$ 1.0E-06 and/or HI $\geq$ 1.0). For the SY-200 area, manganese, ^{234}U, and ^{238}U are above PRGs; and for the SA-1 area, beryllium and bromodichloromethane are above PRGs.

5.3 EXPOSURE ASSESSMENT

An exposure assessment combines information about site characteristics and site-related data with the exposure assumptions used by the risk assessor. The objectives of the exposure assessment are to determine or estimate the magnitude, frequency, and duration of potential human exposure to site contaminants by

- characterizing the exposure setting,
- identifying exposure pathways, and
- quantifying exposures.

Table 5.4. COPCs for BCV OU 2 groundwater that will be evaluated qualitatively[a]

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
	RSA		
Inorganics			
Aluminum	101/108	3.99E+00	mg/L
Calcium	108/108	1.73E+02	mg/L
Chloride	107/108	4.48E+01	mg/L
Cobalt	3/108	2.60E-03	mg/L
Iron	105/108	3.87E+00	mg/L
Lithium	9/26	1.63E-02	mg/L
Niobium	6/26	6.34E-03	mg/L
Potassium	108/108	7.82E+00	mg/L
Sodium	108/108	1.43E+01	mg/L
Sulfate	107/108	1.05E+02	mg/L
Zirconium	4/26	4.13E-03	mg/L
Organics			
1,1,1-Trichloroethane	24/82	2.53E-03	mg/L
Trichloroethene	82/82	5.21E-02	mg/L
	SY-200		
Inorganics			
Aluminum	4/4	1.41E+01	mg/L
Calcium	4/4	3.55E+02	mg/L
Chloride	2/4	4.87E+02	mg/L
Cobalt	2/4	6.55E-02	mg/L
Copper	3/4	1.65E-02	mg/L
Iron	4/4	1.51E+01	mg/L
Lead	4/4	2.94E-02	mg/L
Magnesium	4/4	4.39E+01	mg/L
Potassium	4/4	1.29E+01	mg/L
Sodium	4/4	1.40E+02	mg/L
Sulfate	3/4	2.64E+01	mg/L
Organics			
Trichloroethene	1/4	2.00E-03	mg/L
	SA-1		
Inorganics			
Aluminum	66/85	2.07E-01	mg/L
Calcium	85/85	8.88E+01	mg/L
Chloride	84/85	6.36E+00	mg/L
Cobalt	2/85	3.06E-03	mg/L
Lead	2/6	2.40E-01	mg/L

Table 5.4 (continued)

Analyte	Frequency of detection	UCL95 concentration[b]	Units of measure
Niobium	2/18	5.63E-03	mg/L
Potassium	85/85	3.64E+00	mg/L
Sulfate	83/85	1.19E+01	mg/L
Zirconium	1/18	4.70E-03	mg/L
Organics			
Trichloroethene	46/67	6.30E-03	mg/L

[a]The analytes to be evaluated qualitatively in this BRA have at least one detected value; however, no EPA-approved SFs or RfDs are currently available.

[b]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b).

5.3.1 Characterization of Exposure Setting

Characterization of the exposure setting involves identifying the general physical characteristics of the site (e.g., climate, vegetation, soil types) and the characteristics of the populations on or near the site. This characterization ensures that all potential contaminant migration pathways and potential receptors are evaluated in the risk assessment. Details of the physical and environmental characteristics of the Y-12 Plant and the BCV OU 2 site can be found in Chap. 2 and Sect. 3.1 of this RI and in the RI Work Plan (SAIC 1993b).

The Y-12 Plant facility is owned by DOE, consists of ~800 acres, and is located along the northeastern boundary of the ORR, adjacent to the city of Oak Ridge. BCV OU 2 is located in the immediate vicinity of the Y-12 Plant but is just west of the operational Y-12 Plant facility (refer to Chap. 2 of this RI) BCV OU 2 is downstream from the S-3 Ponds, which are near the headwaters of Bear Creek. The construction spoil areas (SA-1 and RSA) are currently inactive and are somewhat vegetated (patchy grassy areas). The ESF building is adjacent to the SY-200 equipment storage area, and the building's parking area/drive partially covers the SY-200 area. BCV OU 2 is in a controlled access area patrolled regularly by security personnel. The individual sites are described in the following paragraphs.

The RSA is ~5.4 acres and was used (from ~1975 to 1983) for the disposal of spoil materials (solid wastes) generated from renovations, construction, and maintenance activities at the Y-12 Plant. This area was graded periodically (but not necessarily compacted) and is estimated to contain ~100,000 yd^3 of debris. The bulk of the materials disposed of at the RSA include construction debris (i.e., concrete, scrap metal, and masonry) and soils, some of which have been contaminated with traces of mercury and solvents. Significant amounts of chemicals (solvents) and/or other hazardous wastes were prevented from disposal in the RSA because of existing administrative controls. This area currently has a 2-ft soil/clay cover and some vegetative growth, which were put in place in 1984.

The SY-200 was used as an above-ground storage area (from ~1950 to 1986) for mercury flasks, electrical transformers, piping, tanks, and other miscellaneous items. This area was intended for use by the ESF. However, during excavation for the facility, mercury contamination was detected in soils at the site. Asbestos was also identified in fragments of

transit siding found in the soil samples obtained from deeper depths (i.e., > 10 ft) at the site. The excavated soils were placed back in the excavated area in 1990 (in the east end of the hole); refer to Sect. 3.1 of this RI for details. Approximately 5 ft of clean borrow material was placed on top of the excavated soils area, and clean borrow was placed in the west end of the hole to deeper depths. Currently, the ESF building has been constructed and is located immediately south of SY-200 area, part of which is under the parking lot for the ESF building.

The SA-1 was used (from ~1980 to 1989) for the disposal of what was then considered nonhazardous and/or nonradioactive contaminated construction debris from maintenance activities, construction projects, and renovations at the Y-12 Plant. The debris consisted of items such as concrete, brick, asphalt, brush, metal, rocks, tile, and roofing materials. The site is ~5 acres, and it is estimated that roughly 100,000 yd^3 of noncontaminated debris was disposed of at this site. This site had a TDEC landfill permit, which was put into effect in 1985. Currently, SA-1 has 0.5 to 1 ft of clean surface soil and a vegetative cover.

The BCV OU 2 areas are currently partially active, and if these sites are considered nonhazardous to human receptors via this BRA and the RI results, these areas may be used for industrial purposes in the future. Therefore, the future industrial worker is the most likely receptor of the BCV OU 2 media. The four primary exposure pathways will be evaluated for the industrial worker and include incidental ingestion of soil, inhalation of dust and VOCs, dermal contact with the soil, and external exposure to radionuclides in the soil. A hypothetical future residential land use will also be evaluated, although such a conservative scenario is unlikely. In addition, children are sensitive subpopulations under the residential scenario.

5.3.2 Identification of Exposure Pathways

Completed and potential exposure pathways are identified by evaluating all exposure pathway components (source, transport medium, exposure point, potential receptors, and routes of exposure) relative to current and future land use. For an exposure pathway to be considered complete, each of these components must be identified and linked to each of the other components. A potential exposure pathway is one that may occur (i.e., may be complete) in the future. Routes of exposure and potential receptors are crucial in identifying the validity of an exposure pathway.

Under the current conditions at BCV OU 2 (i.e., the three areas have clean surface soil, and RSA and SA-1 have some vegetative cover), there are no completed exposure pathways for the deeper contaminated soils under current land-use conditions. The surface soils for these three areas in BCV OU 2 are assumed to be clean because of the soil caps/covers; however, for the purposes of this BRA, a conservative approach was taken with regard to exposure to the deeper contaminated soils. For SA-1 soils, a depth of 12 ft will be used as representative of future "surface soils" for this area. [That is, it is assumed that a future receptor (industrial worker or resident) could be exposed to soils as deep as 12 ft for SA-1; soil depths of 10 ft and 11 ft will be used for RSA and SY-200, respectively.] Either an on-site future industrial worker or a future hypothetical resident could be exposed to these depths of potentially contaminated medium in this BRA.

The source of contamination for BCV OU 2 is the contaminated soils in the SY-200 Yard and contaminated soils/wastes (i.e., soils/spoil materials) in the RSA and the SA-1 area; exposure to the soil medium via the four primary routes of exposure listed previously (and

exposure to a future resident through ingestion of vegetables/fruits grown in the soils) will be evaluated in this BRA. From infiltration, percolation, and runoff, contaminants associated with the soil could be transported to the surface water/sediments and the groundwater. Exposure of a receptor to surface water, sediments, and/or groundwater will be evaluated in association with BCV OU 4.

In this BCV OU 2 BRA, potential health effects from exposure to potentially contaminated soils associated with this OU were considered. To evaluate the risk to human health from exposure to the media associated with the BCV OU 2 comprehensively and to provide risk information in support of the project objectives, both the future most reasonable (and/or most likely) exposure scenario and the future hypothetical reasonable maximum exposure scenario have been evaluated.

Under current land-use conditions, there are no completed exposure pathways for the contaminated soils; the industrial worker represents the future exposure conditions to the BCV OU 2 soils. The exposure pathways that will be evaluated for the industrial worker include (1) incidental ingestion of soils, (2) inhalation of dust and VOCs, (3) dermal contact with the soils, and (4) external exposure to radionuclides in the soils. In the future, an excavation worker could also be exposed to the COPCs in these BCV OU 2 areas; however, the human health risks from exposure of an excavation worker to the soil COPCs would be less than those determined for the future industrial worker. The future industrial worker scenario was chosen as the lower bound on risk to human health for this BRA.

Risks determined for a hypothetical future residential receptor are conservative and unlikely to underestimate exposure to the BCV OU 2 media; these risks provide an upper bound on risk to human health for this BRA. The routes/pathways of exposure that will be evaluated include (1) dermal contact with the soil, (2) incidental ingestion of the soil, (3) inhalation of wind generated soil/dust and inhalation of VOCs, (4) external exposure to radionuclides in the soil, and (5) ingestion of homegrown vegetables and fruit (garden grown in the soils).

The reader should note that a resident or industrial worker would have to dig through the first few feet of clean soil to be exposed to the soils. The conceptual site model for exposure to the BCV OU 2 media for both the future industrial worker and the hypothetical future resident is shown in Fig. 5.1. Also shown in Fig. 5.1 are the media associated with BCV OU 2 that will be evaluated in the integrator OU (i.e., BCV OU 4) BRA.

5.3.3 Quantification of Exposure

Exposure, in the context of risk to human health, is defined as the direct contact of a person with a chemical or physical agent. To quantify exposure, one must determine exposure concentrations and calculate chemical intakes for the various exposure pathways identified for the site. The exposure concentrations and potential exposure pathways for the BCV OU 2 media are considered quantitatively in this section.

Exposure to contaminants can be evaluated quantitatively by developing the chronic daily intake (CDI) of a chemical (also termed "intake" or "dose" for exposure to radionuclides). For this BCV OU 2 BRA, the CDI is the amount of a contaminant that an individual takes

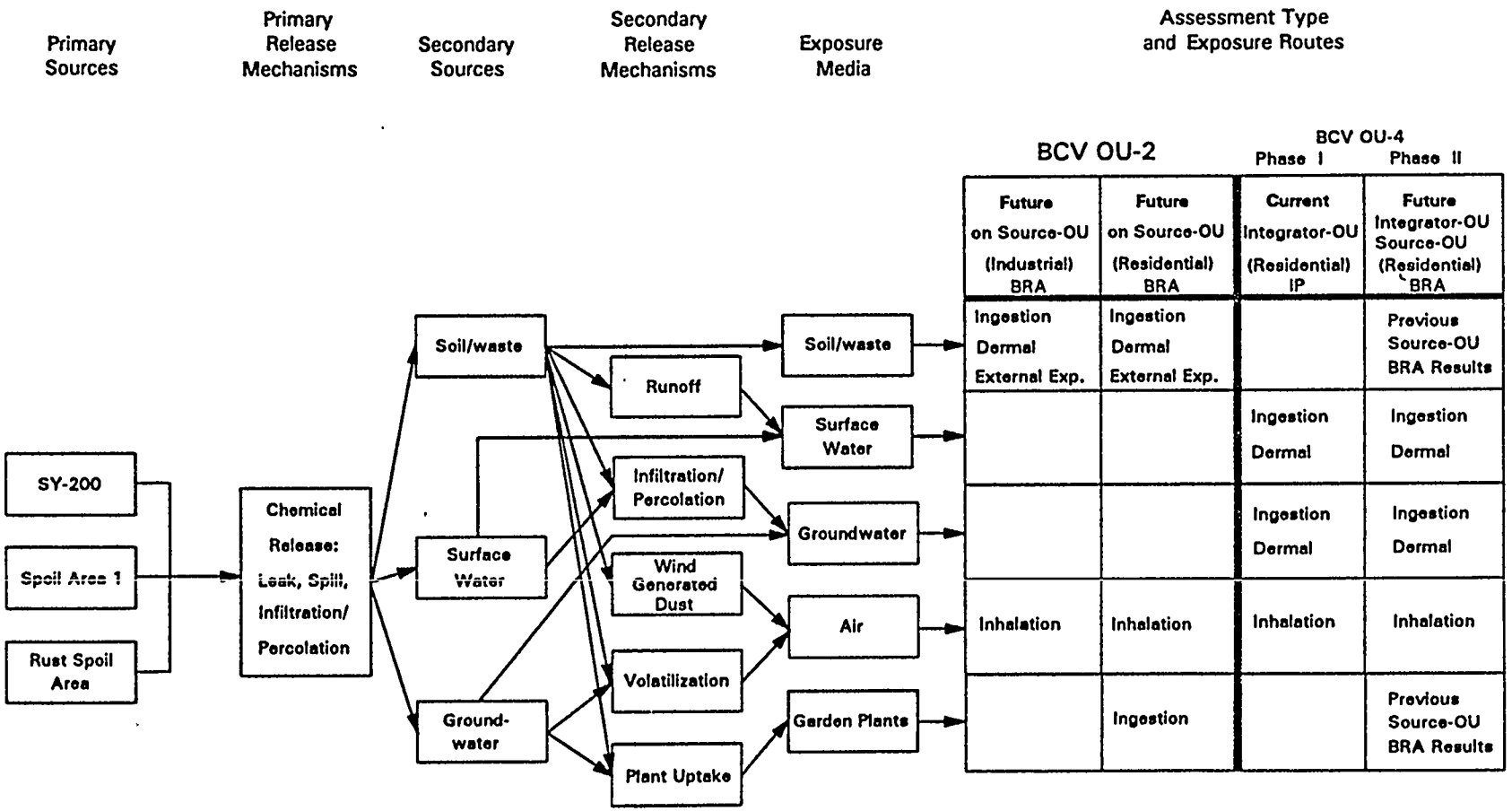


Fig. 5.1. BCV OU 2 conceptual site model for human health risk assessment.

into his/her body per day via ingestion, inhalation, or dermal contact; dose is the total exposure to a radionuclide. The first consideration in deriving the CDI is the methodology employed in the development of an exposure concentration, which is the amount of each chemical in the various media to which receptors are exposed. To calculate the CDI, one evaluates the exposure concentration in the context of the scenario, exposure pathway, and chemical-specific exposure variables, such as duration of exposure and intake rate. Once the CDIs for the various pathways are determined, risk and HQs can be calculated. The quantification of exposure and calculation of the CDI for the hypothetical future resident and the current industrial worker are discussed in Sects. 5.3.3.1 and 5.3.3.2, respectively. In general, the CDI is determined using the following equation:

$$CDI = (CS \times IR \times EF \times ED)/(BW \times AT)$$

where

CDI = chronic daily intake,
CS = contaminant concentration in the soil,
IR = intake rate,
EF = exposure frequency,
ED = exposure duration,
BW = body weight,
AT = averaging time.

The potential direct exposure pathways associated with the hypothetical future on-site residential land use scenario are (1) incidental ingestion of soil, (2) dermal contact with soil, (3) inhalation of soil dust and VOCs, (4) external exposure to the radionuclides in the soil, and (5) ingestion of homegrown vegetables/fruits. The potential exposure pathways for the future industrial worker scenario include 1–4 as listed in this paragraph. The representative concentrations of the COPCs are the concentrations used to quantify exposures via these exposure pathways.

Tables C.13 and C.14 list the exposure variables associated with each exposure route considered for the on-site resident and the on-site industrial worker, respectively; the specific equations used to calculate the CDIs are also given in these tables. The variables used in each exposure equation have been derived from standard intake rates, skin surface areas, and adherence factors (EPA 1989b, EPA 1989a, EPA 1991a, EPA 1991b, EPA 1992a).

5.3.3.1 Derivation of CDIs for the residential scenario

The hypothetical residential exposure scenario considered in this BRA is conservative. As a result of the statistical data evaluation process described in Sect. 5.2, the concentration data set of BCV OU 2 soil COPCs for use in this BRA was compiled (Table 5.1). The UCL95 on the mean concentration (or the maximum detected concentration if it were less than the UCL95) was assumed to be representative of the analyte concentration and, with the exception of the vegetable/fruit ingestion pathway (refer to Sect. 5.3.3.1.1), was used in all calculations of the CDI (as well as dose, risk, and HQ). This upper confidence limit was used to ensure that the exposure concentrations were not underestimated. Refer to Sect. 5.2 for a complete statistical evaluation of the data and the list of COPCs to be evaluated quantitatively in this BRA.

Table C.13 lists the exposure variables associated with each exposure route considered for the on-site residential scenario. For this BRA, CDIs were calculated for an adult person who was exposed for 6 years as a child and for 24 years as an adult (to give a 30-year exposure duration), and the resident was assumed to be exposed to contaminated media for 350 d/year for 30 years. A 6-year exposure duration was evaluated for the "young child" portion of the person's life, which accounts for receptors with high intake rates relative to body weight. A 24-year exposure duration was assumed for the "adult" portion of the person's life. For example, for the soil ingestion pathway, a child ingestion rate (200 mg/day) and body weight (15 kg) was assumed for 6 years, while an adult ingestion rate (100 mg/day) and body weight (70 kg) was assumed for 24 years. The exposure variables associated with each on-site industrial worker exposure route are shown in Table C.14.

Table C.15 lists the CDIs for ingestion, inhalation, and dermal contact with soil COPCs in the BCV OU 2 soils; intakes/doses are listed for external exposure to radionuclides in the soils. The table is divided by area (i.e., RSA, SY-200, and SA-1) and by analyte type (i.e., inorganic, radionuclide, and organic).

Derivation of CDIs for residential ingestion of homegrown vegetables/fruits. To calculate the CDI for ingestion of homegrown fruits and vegetables, estimates of the contaminant concentrations in the vegetables/fruits were determined. For the three areas in BCV OU 2 (i.e., RSA, SY-200, and SA-1), under a residential land-use scenario, it was assumed that a garden containing leafy vegetables, root vegetables, legumes, fruiting vegetables, and fruits would be grown in the soil, with the RSA, SY-200, and SA-1 groundwater as the irrigation sources for the gardens in RSA, SY-200, and SA-1, respectively.

It was assumed that plants could be contaminated by two basic means: (1) root uptake from contaminated soil and (2) contamination from water irrigation. Therefore, the plant concentration C (mg/kg or pCi/kg) is then

$$C = C_r + C_{irr}$$

where C_r is the concentration due to root uptake and C_{irr} is the absorbed concentration due to deposition.

The concentration due to irrigation is calculated assuming that the irrigation process resembles wet deposition (i.e., spray irrigation). Following the methodology used in Remedial Action Priority Systems [i.e., Multimedia Environmental Pollutant Assessment Systems (MEPAS) Application Guidance, Droppo et al. 1989], this concentration is

$$C_{irr} = \frac{(C_w I) \cdot T_f \cdot r}{Y} \frac{1 - e^{-\lambda_e t_e}}{\lambda_e}$$

where

C_w = the concentration in the water used for irrigation (mg/L or pCi/L)
I = the water application rate (L/m^2/day)
T_f = the translocation factor from plant surfaces to edible parts of the plant (dimensionless)
r = the fraction of deposition retained on edible parts of plant (dimensionless)
Y = the plant yield (kg/m^2)
λ_e = the effective weathering and decay constant
t_e = the duration of growing period for crop

Note that the term $C_w I$ is the deposition rate of the contaminant (units of mg/m^2/day or pCi/m^2/day). The specific concentrations, parameters, and constants used in the previous equation can be found in Tables C.16–C.18.

The concentration due to root uptake is estimated by

$$C_r = B_v C_s$$

where B_v is the soil-to-plant transfer coefficient, which is dimensionless (refer to Table C.19), and where C_s is the concentration in the soil in mg/kg or pCi/kg (refer to Table C.16). The concentration in soil is the sum of the most recent measurements available, denoted here by C_{sm}, and an estimate of the soil concentration due to the irrigation process itself, denoted here by C_{si}.

An estimate for C_{si} is now derived. The following assumptions were made: (1) once deposited, the contaminant is uniformly mixed to a fixed depth z (meters) (Table C.17); (2) every year, the concentration due to previous years' irrigation is assumed negligible; and (3) irrigation is assumed to occur for the duration of the growing season. Based on these assumptions, given the concentration at a given time t, the concentration at a later time $t+\Delta t$ is approximated by

$$C_{si}(t+\Delta t) \approx C_{si}(t) + (\textit{conc. due to deposition}) - (\textit{decreased conc. due to decay/degradation})$$

which can be approximated by

$$C_{si}(t+\Delta t) \approx C_{si}(t) + \frac{D}{\rho z}\Delta t - \lambda C(t)\Delta t$$

where D is the deposition rate ($C_w I$) and ρ is the soil density (kg/m^3); refer to Table C.20.

Letting Δt go to zero yields

$$\frac{dC_{si}}{dt} = \frac{D}{\rho z} - \lambda C_{si}(t)$$

Solving this first order differential equation with initial condition $C_{si}(0)=0$ shows that

$$C_{si}(t) = \frac{D}{\rho z}\frac{\left(1-e^{-\lambda_e t}\right)}{\lambda_e}$$

Following Whelan et al. (1987), the concentration at harvest time is used in calculating the concentration in vegetables, in which case

$$C_{si} \equiv C_{si}(t_e) = \frac{D}{\rho z}\frac{(1-e^{-\lambda_e t_e})}{\lambda_e}$$

By definition, the soil-to-plant transfer coefficient (B_v) is the ratio of the concentration of an element in fresh vegetables to that in dry soil (Table C.19). The values for ^{137}Cs, zinc, manganese, and barium are based on experimental results (Ng et al. 1982); in particular, the values used are UCL95s on the mean of values provided in Ng et al. (1982). The values for all other contaminants are from MEPAS, Version 1.0 (Strenge and Peterson 1989).

Table C.20 reports the concentrations of the COPCs in various types of vegetables/fruits as determined using the previous equations. The total concentrations reported in this table are the concentration values (CVs) used in the CDI calculations in Tables C.13e and C.13f. The total CVs found in the vegetables/fruits result from contributions from (1) the unirrigated soil, (2) the irrigated soil, and (3) direct irrigation; also shown in Table C.20 are the relative (percentage) contributions to the total CV from these three contributing sources. The CDIs for the homegrown vegetables/fruits are listed in Table C.21.

5.3.3.2 Derivation of doses for the industrial worker scenario

The most likely future exposure scenario considered in this BRA was the on-site industrial worker who could be exposed to the BCV OU 2 soils via the four primary soil exposure pathways: (1) incidental ingestion of soil, (2) inhalation of dust and VOCs, (3) dermal contact with the soil, and (4) external exposure to radionuclides in the soil. Table C.14 lists the exposure variables associated with these four pathways for the on-site industrial worker scenario.

Table C.22 lists CDIs for the industrial worker from exposure to the BCV OU 2 soils via ingestion, inhalation, and dermal contact; intakes/doses are listed for external exposure to radionuclide COPCs. The tables are divided by area and analyte type; the exposure concentration used in the CDI/dose calculations shown in Table C.14 is the UCL95 (or the maximum detected concentration if it were less than the UCL95).

5.3.4 Identification of Uncertainties

Some uncertainties can be associated with the exposure pathway equations, exposure parameters, land use, and sampling and analysis of the BCV OU 2 media. As discussed previously, two land-use scenarios were chosen to represent potential future risks/HQs to human receptors. For the exposure pathways chosen for analysis in this BRA, numerous exposure parameters (Tables C.13 and C.14) were used in the calculations, which each have some uncertainty (EPA 1989b) associated with them. However, most exposure parameters are conservative; therefore, the error is conservative (i.e., protecting the receptor). Some uncertainties are associated with the inhalation of dust and inhalation of VOCs pathways, although EPA-approved default values were used in the inhalation pathway CDI calculations; modeling results were used in developing these EPA-default parameters (EPA 1989b, 1991a). EPA guidance was followed in this BRA for all types of calculations (EPA 1992b).

5.3.5 Summary of Exposure Assessment

Two land-use scenarios were evaluated for this BRA: (1) a conservative hypothetical residential future land use scenario and (2) a hypothetical future industrial worker scenario. Both land uses were evaluated to comprehensively evaluate the potential risk to human health from exposure to the soils associated with BCV OU 2 and to provide risk information supportive of the project objectives.

For the residential scenario, the pathways of exposure that were evaluated included incidental ingestion of soil, inhalation of soil dust and VOCs, dermal contact with the soil, external exposure to radionuclides in the BCV OU 2 soils, and ingestion of homegrown vegetables/fruits. For the industrial worker scenario, the primary and most direct routes/ pathways of exposure that were evaluated included incidental ingestion of soil, inhalation of soil dust and VOCs, dermal contact with the soil, and external exposure to radionuclides in the BCV OU 2 soils.

5.4 TOXICITY ASSESSMENT

5.4.1 Toxicity Information and EPA Guidance for Noncarcinogens

Noncarcinogenic effects are evaluated by comparing an exposure experienced over a specified time period (e.g., 30 years) with an RfD [or reference concentration (RfC)] derived for a similar exposure period. The RfDs available for the COPCs present in the BCV OU 2 media are given in Table C.23. In this BRA, RfCs were converted to units of mg/kg/day (i.e., RfD units) by using the inhalation rate and body weight of an adult [i.e., RfC $\times$ 20 m^3/d $\times$ (1/70 kg) = RfD) (EPA 1989b)].

To evaluate the noncarcinogenic effects from exposure to COPCs in the BCV OU 2 media, the HQ [the ratio of the exposure dose (i.e., CDI and/or dose from Tables C.15, C.21, and C.22) to the RfD] is calculated for each COPC. This noncarcinogenic HQ assumes that, below a given level of exposure (i.e., the RfD), even sensitive populations are unlikely to experience adverse health effects. A cumulative HI is determined by summing chemical-specific HQs across an exposure pathway. If the exposure level (CDI) exceeds this threshold (i.e., if CDI/RfD exceeds 1.0), there may be concern for potential noncarcinogenic health effects. The level of concern does not necessarily increase linearly as the HQ approaches or exceeds unity; the HQ is not a percentage or probability.

Chronic RfDs are developed for protection from long-term exposure to a chemical (7 years to a lifetime); subchronic RfDs are used to evaluate short-term exposure (2 weeks to 7 years) (EPA 1989b). The reader should note that the numerical values derived for chronic and subchronic RfDs/RfCs are often identical (EPA 1994a). For the purposes of this BRA, chronic RfDs have been used for the assessment of the on-site resident and industrial worker.

5.4.2 Toxicity Information and EPA Guidance for Carcinogens

For carcinogens, risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the carcinogen (i.e., the term "incremental" refers to excess individual lifetime cancer risk). Cancer risk from exposure to contamination is expressed as excess cancer risk—cancer incurred in addition to normally expected rates of cancer development. An excess cancer risk of 1.0E-06 indicates that each person has a one chance in a million of incurring cancer from exposure to this contamination level over a 70-year lifetime. Based on their property of emitting ionizing radiation, all radionuclides are human carcinogens.

To evaluate the carcinogenic risk from exposure to BCV OU 2 COPCs in the various media, the risk is calculated for each COPC [the multiplication of the exposure dose (i.e., CDI and/or dose from Tables C.15, C.21, and C.22) by the SF, which is a chemical-specific value based on carcinogenic dose-response data]. A cumulative risk is determined by summing chemical-specific risks across an exposure pathway. Excess cancer risks falling between 1.0E-06 and 1.0E-04 are considered to be within the EPA range of concern (also referred to as the EPA target risk range); risks within this target risk range are consistent with the cleanup goals of CERCLA, and remedial action is generally not warranted (EPA 1991c). Cancer risks above 1.0E-04 are considered regulatorily unacceptable by the EPA (EPA 1989a); risks that exceed the target risk range indicate that a Feasibility Study is required to determine if remediation is warranted (EPA 1991g). Because the SFs are the UCL95 on the probability of a carcinogenic response, the carcinogenic risk estimate represents an upper confidence bound estimate. Therefore, there is only a small probability that the actual risk will be higher than the estimate presented, and the actual risk may well be less than the estimate. SFs used in the evaluation of risk from exposure to carcinogenic BCV OU 2 COPCs are listed in Tables C.24 and C.25.

5.4.3 Estimation of Toxicity Values for Dermal Exposure

Oral RfDs and SFs are often adjusted for evaluation of the dermal exposure pathway (EPA 1989b); it is conservative, in terms of risk/HQ to human health, to adjust the toxicity values in the manner described in the following discussion. Most RfDs/SFs are expressed as the amount of substance administered per time and body weight; however, dermal exposure to chemicals in soil and water is expressed as absorbed doses.

For the dermal assessments in this BRA, the oral RfD and/or oral SF for each chemical (BCV OU 2 COPCs) was adjusted by the percent gastrointestinal (GI) absorption efficiency (%GI) for that chemical. The %GI are known for only a limited number of chemicals; for those chemicals where a %GI is currently not available in the literature, 100% was assumed. For many chemicals, estimates of %GI were based on qualitative information about the rate and extent of GI absorption; rapid or extensive absorption was assumed to be essentially complete (i.e., %GI = 100%). Wide ranges of %GI values can be found for some chemicals,

and in the absence of chemical-specific absorption data, estimates are often made based on data for related chemical structures. Most organic compounds are readily absorbed (i.e., %GI = 100) from the GI tract, and for this BRA, no adjustments were made to chemicals with %GI $\geq$ 80%.

Minor adjustments to the oral RfDs/SFs (used in the dermal assessments only), which favor conservatism, were made when %GI data were available. The oral RfD was multiplied by the %GI/100, and the SF was divided by the %GI/100 to give the absorbed dose RfD and absorbed dose SF, respectively. These toxicity values (listed in Tables C.23 and C.24) were then used in the evaluation of risk to human health from dermal exposure to the BCV OU 2 soils.

5.4.4 Chemicals Without EPA Toxicity Values

Slope factors and RfDs are not currently available for all detected chemicals in BCV OU 2 because their carcinogenicity and/or noncarcinogenic effects have not yet been determined. These chemicals may contribute to carcinogenic and noncarcinogenic effects from exposure to the BCV OU 2 media, but their effect cannot be quantified at the present time. In addition, for several chemicals, epidemiological studies have indicated that they are not carcinogenic; consequently, these species do not have SFs. A qualitative summary of toxicity information for some COPCs for BCV OU 2 can be found in Sect. 5.4.6.

5.4.5 Methodology and Uncertainties Related to Toxicity Information

The methodology used in developing a noncarcinogenic toxicity value (RfD or RfC) involves identifying a threshold level below which adverse health effects will not occur. The RfD/RfC values are generally based on studies of the most sensitive animal species tested (unless adequate human health data are available) and the most sensitive endpoint measured. There are, of course, uncertainties in the experimental data set for such animal studies. From these studies, the experimental exposure representing the highest dose level tested at which no adverse effects were demonstrated [the no-observed-adverse-effect-level (NOAEL)] was derived; in some cases, only a lowest-observed-adverse-effect-level (LOAEL) is available. The RfD/RfC is derived from the NOAEL (or LOAEL) for the critical toxic effect by dividing the NOAEL (or LOAEL) by uncertainty factors. These factors usually are in multiples of 10, with each factor representing a specific area of uncertainty in the extrapolation of the data. An uncertainty factor of 100 is typically used when extrapolating animal studies to humans; additional uncertainty factors are sometimes necessary when other experimental data limitations are found. Because of the large uncertainties (10–10,000) on some RfD/RfC toxicity values, exact safe levels of exposure for humans are not known.

A two-part evaluation exists for assessing the carcinogenic potential of a chemical: (1) the likelihood that a chemical is a carcinogen (i.e., a weight-of-evidence assessment) and (2) the quantitative dose-response relationship (i.e., potency factor or SF); uncertainties occur with each evaluation. Based on weight-of-evidence studies using human and laboratory animal research, chemicals fall into one of five groups (EPA 1989b, EPA 1994a): (1) Group A, human carcinogen; (2) Group B, probable human carcinogen; (3) Group C, possible human carcinogen; (4) Group D, not classified as to human carcinogenicity; and (5) Group E, evidence of no carcinogenic effects to humans. The SF for a chemical is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime; it is derived by applying a mathematical model to extrapolate from a relatively high

administered dose (to animals) to the lower exposure levels expected for humans. The SF represents the UCL95 on the linear component of the slope of the tumorigenic dose-response curve in the low-dose region. A number of low-dose extrapolation models have been developed, and EPA generally uses the linearized multistage model in the absence of adequate information to support other models.

5.4.6 Summary of Toxicity Information/Profiles for BCV OU 2 COPCs

The purpose of any toxicity assessment is to evaluate the potential for COPCs to cause adverse health effects in exposed individuals. This usually consists of an evaluation of the relationship between the extent of exposure to a particular contaminant and the increased likelihood or severity of adverse health effects as a result of that exposure relative to a baseline. The toxicity assessment generally involves two steps. The first step comprises determining whether exposure to an agent can cause an increase in the incidence of a particular health effect and whether that health effect will occur in humans. The second step involves characterizing the relationship between the received dose of the contaminant and the incidence of adverse health effects in exposed populations.

The chemical-specific information in Sects. 5.4.6.1–5.4.6.3 provides general qualitative information as well as a chemical-specific discussion about health effects related to those COPCs evaluated in this BRA. Carcinogenic and noncarcinogenic health effects are considered. Data used in this section are from human and laboratory animal research and from occupational studies to characterize likely health effects resulting from exposure to the COPCs. Refer to the *Toxicity Profiles* (BEIAS 1993) report for further information regarding specific chemicals. Tables C.23–C.25 summarize the toxicity information for the BCV OU 2 COPCs.

5.4.6.1 Inorganics

Aluminum. Aluminum is found in abundance in the earth but in small amounts in plant and animal tissue. It can be found in tap water because aluminum sulfate is used in the water purification process and not all of the aluminum is filtered out. Aluminum is added to most table salt to prevent caking and is used in certain antacids. Aluminum is also used in foil, deodorants, baking powder, as an emulsifier in some processed cheeses, and as a bleaching agent to whiten flour (Garrison and Somer 1985). In addition, aluminum has been shown to be suitable for food containers since it is practically insoluble and is not harmful to health when dissolved to a slight degree.

Aluminum is a trace mineral in the human body, but it can be dangerous, even fatal, if consumed in excessive amounts. Aluminum has no established function in human nutrition. It weakens the living tissue of the alimentary canal (i.e., the digestive tube from the mouth to the anus). Many of aluminum's harmful effects result from its destruction of vitamins. It binds with many other substances and is never found alone in nature (Dunne 1990).

Aluminum is easily absorbed by the body and is accumulated in the arteries. Highest concentrations are found in the lungs, liver, thyroid, and brain. Usually most of the aluminum taken into the body is ultimately excreted. However, excessive amounts of aluminum can result in symptoms of poisoning including nausea, skin ailments, colic, loss of appetite, excessive perspiration, and loss of energy (Dunne 1990). In addition, aluminum toxicity has

been implicated in brain disorders associated with aging, such as Alzheimer's Disease (Garrison and Somer 1985); however, this theory has not been proven.

Antimony. Antimony is a naturally-occurring metal that is used in various manufacturing processes and exists in valence states of 3 and 5. Metallic antimony and a few trivalent antimony compounds are the most significant regarding exposure potential and toxicity. Antimony is used in metallurgical processes, paints and enamels, various textiles, rubber, and fire retardation (antimony trioxide). Antimony is a common air pollutant; therefore, exposure may occur via inhalation and ingestion of contaminated food. Some antimonials such as potassium antimony tartrate have been used medicinally as parasiticides (BEIAS 1993).

Antimony is sparingly absorbed following inhalation or ingestion. Excretion of antimony is primarily via the urine and feces and is dependent upon valence state. Acute oral exposures of humans or animals to high doses of antimony or antimony-containing compounds may cause GI disorders (vomiting, diarrhea), respiratory difficulties, and death at extremely high doses. Subchronic and chronic oral exposures may effect hematologic parameters. Acute inhalation exposure of humans may cause GI disorders (probably due to ingestion of airborne antimony). Long-term occupation exposure has resulted in electrocardiac disorders, respiratory disorders, and possibly increased mortality. Dermal exposure evidence for humans indicates that eye irritation developed due to exposure to stibine gas and several antimony oxides (BEIAS 1993).

The EPA has not evaluated antimony or antimonials for carcinogenicity, and weight-of-evidence classification is currently unavailable (BEIAS 1993).

Arsenic. Arsenic is a metallic, steel-gray, crystalline, brittle, trivalent and pentavalent, solid, poisonous element. It is commonly used in pesticides. Trivalent compounds are generally more toxic and more likely to have systemic effects than the less soluble compounds, which are more likely to cause chronic pulmonary effects if inhaled.

Water soluble inorganic arsenic compounds are absorbed through the GI tract and lungs. Symptoms of acute inorganic arsenic poisoning in humans are nausea, anorexia, vomiting, epigastric and abdominal pain, and diarrhea. In addition, dermatitis, muscle cramps, cardiac abnormalities, hepatoxicity, bone marrow suppression and hematologic abnormalities, vascular lesions, and peripheral neuropathy have also been reported. Severe exposures can result in acute encephalopathy, congestive heart failure, stupor, convulsions, paralysis, coma, and death. Occupational exposure studies show a clear correlation between exposure to arsenic and lung cancer mortality (BEIAS 1993, ATSDR 1989a).

Barium. Barium is a divalent alkaline-earth metal found only in combination with other elements in nature. The most important of these combinations are the peroxide, chloride, sulfate, carbonate, nitrate, and chlorate. The most likely source of barium in the atmosphere is from industrial emissions. Because of the element's tendency to form salts with limited solubility in soil and water, it is expected to have a residence time of hundreds of years and is not expected to be very mobile. Trace amounts of barium have been found in more than 99% of surface waters and finished drinking water samples (average values of 43 μg/L and 28.6 μg/L, respectively) across the United States (BEIAS 1993).

The soluble salts of barium are toxic to mammalian systems. They are absorbed rapidly from the GI tract and are deposited in the muscles, lungs, and bone. At low doses, barium

acts as a muscle stimulant and at higher doses affects the nervous system, eventually leading to paralysis. Subchronic and chronic oral or inhalation exposure primarily affects the cardiovascular system, resulting in elevated blood pressure. Subchronic and chronic inhalation exposure of human populations to barium-containing dust can result in a benign pneumoconiosis called baritosis, which is a condition often accompanied by an elevated blood pressure but does not usually result in a pulmonary function change. Although the effects of barium on laboratory rats have been documented and include elevated blood pressure, decreased body weight, birth defects, and increased infant mortality, these effects have not been substantiated in humans. In addition, barium has not been evaluated by the EPA for evidence of human carcinogenicity (BEIAS 1993).

Beryllium. Pure beryllium is a hard, grayish metal present in the earth's crust. It can be found in emissions from coal combustion; in surface water and soil; and in house dust, food, drinking water, and cigarette smoke. Industry employs beryllium in several ways, including in brake systems for airplanes, for neutron monochromatization, as window material for x-ray tubes, and in radiation detectors. Additionally, beryllium compounds are used in manufacturing ceramics and refractories, chemical reagents, and gas mantle hardeners. The highest risk for exposure to beryllium occurs among workers employed in beryllium manufacturing, fabricating, or reclaiming industries. However, people who live near these industries and are sensitive to extremely low concentrations of beryllium in the air are also at risk. In addition, smokers inhale unusually high concentrations of beryllium, depending on the source of tobacco.

A limited amount of data indicate that the oral toxicity of beryllium is low; however, the inhaled toxicity of beryllium is well documented. Humans inhaling massive doses of beryllium compounds may develop acute berylliosis. Additionally, beryllium and its compounds are presumed to have cancer-causing potential in the human lung when inhaled. The cancer-causing ability has been investigated in workers exposed to beryllium. The degree of harm depends on the amount and duration of exposure. Short-term exposure to beryllium may cause noncarcinogenic health effects, such as acute pneumonitis berylliosis, while long-term exposure may cause lung cancer (ATSDR 1988a).

Cadmium. Cadmium is a naturally occurring metal used to control mold and diseases that attack home lawns, golf course turfs, and other grasses. It is also used in electroplating processes, rubber tire manufacturing, and plumbing solders. However, less than 0.1% of the annual U.S. consumption of 12 million pounds of cadmium is used in pesticides—most of it is used in industry. An estimated 100,000 workers in the United States are exposed to this metal, which is employed not only in the electroplating and rubber industries but also in the manufacture of nickel-cadmium batteries, brazing-soldering alloys, pigments, and chemicals that act as stabilizers in plastics. Other sources of human exposure are cigarette smoke, air pollution, drinking water, and sludge. Most cadmium gets into sewage treatment plants as part of the discharge from electroplating processes, from disintegration of rubber tires on streets, and from solder in plumbing (Winter 1979).

Cadmium in drinking water has been correlated with cancer of the pharynx, esophagus, intestine, larynx, lung, and bladder. Studies have shown that workers who had labored for at least 2 years in a cadmium smelter had significantly higher death rates from all forms of cancer, especially of the lung and prostate gland. Lung cancer occurred at more than twice the expected rate, and as with many other occupational cancers, the risk of developing the disease increased in relation to the length of elapsed time after initial exposure to the metal.

Cadmium is also believed to cause mutations; this conclusion is based upon finding chromosomal and deoxyribonucleic acid (DNA) damage resulting from the presence of cadmium in the blood of workers and in bacteria. In addition, exposure to home lawn-treatment products containing cadmium may be dangerous to women of child-bearing age (Winter 1979). Cadmium is not excreted from the body and can accumulate over time to toxic levels; symptoms of cadmium toxicity include anemia, muscle wastage, hypertension, and liver and kidney damage (Somer 1992).

Chloride. Chloride is found in abundance in vegetable and animal foods. It is an essential anion that accounts for 0.15% of total body weight. Chloride is obtained from table salt (sodium chloride) or from salt substitutes (such as potassium chloride) (Garrison and Somer 1985). Although chloride is a compound of chlorine, it is not poisonous to the human body (Somer 1992).

Chloride is found primarily in extracellular fluids and is especially abundant in GI secretions and cerebrospinal fluid. Small amounts of chloride are found in bone and connective tissue and lesser amounts in muscle and nerve tissue. Chloride is closely associated with sodium and water in foods, body secretions, fluids, tissues, and excretions. It is important in regulating the body's acid-base balance. Chloride is readily absorbed in the intestines. Intake is usually in excess of sodium, and amounts that are not needed are excreted through the kidneys, primarily as sodium chloride. Some losses occur through sweat and feces (Garrison and Somer 1985).

Chloride deficiency is of concern in the body. Deficiencies can result from diarrhea or vomiting, adrenal insufficiency, and acidosis. A deficiency of chloride in the body results in an acid-base imbalance, called *alkalosis* (Somer 1992). Chloride deficiency in infants can be especially harmful, causing psychomotor defects, memory loss, and growth retardation. These symptoms can be alleviated with administration of chloride (Garrison and Somer 1985). However, deficiencies are uncommon because the element is consumed in salt. No known toxic effects have been recorded for overuse or overingestion of chloride because overabundance of the element is secreted through the kidneys (Somer 1992).

Chromium, chromium III, and chromium VI. Elemental chromium does not occur in nature but is present in ores—primarily chromite. Chromium exhibits several oxidation states, but the most prominent of these are chromium VI and chromium III. Chromium VI in the environment is man-made as a result of industrial emissions; in solution, chromium VI exists as hydrochromate, chromate, and dichromate ionic species and reacts over time to form chromium III. Chromium VI is much more mobile and toxic than chromium III. Chromium is useful in glucose and cholesterol metabolism and therefore is an essential element to humans and animals. Nonoccupational exposure to the metal occurs via the ingestion of chromium-containing food and water, whereas occupational exposure occurs via inhalation. Workers are exposed to chromium during its use in the production of dichromate; the chemical, stainless steel, refractory, and chromium-plating industries; and the production and use of alloys (BEIAS 1993).

Chromium enters the body through the lungs, GI tract, and, to a lesser extent, the skin. Inhalation is the most important route for occupational exposure. Workers exposed to chromium have developed nasal irritation, nasal ulcers, perforation of the nasal septum, hypersensitive reactions, and "chrome holes" of the skin. Among the general population, contact dermatitis has been associated with the use of bleaches and detergents. Inhalation of

chromium compounds has been associated with the development of cancer in workers in the chromate industry. Evidence also suggests an increased risk in developing nasal, pharyngeal, and GI carcinomas. Based on sufficient evidence reporting that humans and animals are at risk of developing cancer, chromium VI has been assigned an EPA weight-of-evidence classification of A, human carcinogen (BEIAS 1993).

Cobalt. Cobalt is a tough, lustrous, silver-white, magnetic, metallic element that is related to and occurs with iron and nickel and is used especially in alloys. Dietary cobalt is found in some foods, such as figs, cabbage, spinach, beet greens, buckwheat, lettuce, and watercress (Garrison and Somer 1985). In addition, organ meats, such as liver and kidneys, oysters, and clams are excellent sources of cobalt, and muscle meats are good dietary sources because these foods supply the mineral as part of vitamin B_{12}. The only known function of cobalt in the human body is as a constituent of vitamin B_{12}. In addition, it is used as an anti-foaming agent in the processing of some beer (Somer 1992).

Cobalt is essential to erythropoiesis (the formation of red blood cells). The average intake of cobalt is 5 to 8 μg/day. No recommended daily allowance of safe and adequate amount has been established for cobalt at this time (Garrison and Somer 1985). The human body does not require or need cobalt alone (Somer 1992).

When fed a pharmacological dose of cobalt, many animals, including humans, develop polycythemia because of increases in the hormone erythropoietin in the blood. Elevated erythrocyte and hemoglobin levels, reticulocytosis, increased red blood cell mass, and normoblastic hyperplasia in the bone marrow have also been reported. Congestive heart failure due to cardiomyopathy has been reported when beer containing 1.2 ppm of cobalt was consumed. Pericardial effusion, thyroid hyperplasia, and neurological disorders have also been noted. Large doses of cobalt may interfere with decarboxylation reactions (by binding to lipoic acid), impair pyruvate and fatty acid metabolism, and enhance iron absorption and globin synthesis (Garrison and Somer 1985).

Lead. Lead is a naturally occurring bluish-gray metal found in small quantities in the earth's crust. Lead and its compounds can be detected in all parts of the environment (e.g., in plants and animals used for human consumption and in air, drinking water, rivers, lakes, oceans, dust, and soil). Lead used by industry comes from mined ores or from recycled scrap metal (ATSDR 1988b).

Lead has a wide range of uses. Its primary use is in the manufacture of storage batteries. Other applications include its use in the production of ammunition; miscellaneous metal products (e.g., sheet lead, solder, and pipes); and various chemicals, including gasoline additives, tetraethyl lead, and tetramethyl lead (ATSDR 1988b).

General population exposure to lead and its compounds results from breathing air, drinking water, and eating many foods that contain lead. Breathing or ingesting dust and soil laden with lead is also a source of exposure. Skin contact with dust and soil containing lead is also expected to occur on a daily basis, but uptake by the skin is not substantial. During the normal use of lead-containing products, little skin contact is expected to take place. Exposure to certain lead compounds that are additives can occur while pumping gasoline containing these additives and possibly during use of some do-it-yourself fuel additives. Children, especially those who are preschool age, are at particular risk to lead exposure since they commonly put their hands, toys, and other items in their mouths. These items frequently come

in contact with lead-containing dust and soil, and as a result, children consume large amounts of lead. In some cases, children may ingest nonfood items such as paint chips and dirt. These items may contain large amounts of lead (ATSDR 1988b).

Little of the lead ingested by adults enters the blood and other parts of the body. However, a much greater proportion of the lead ingested by children enters the blood and other body parts. Exposure of a expectant mother to lead results in the transfer of lead to the fetus and may cause preterm birth, reduced birth weight, and decreased intelligence quotient (IQ) in the infant. Lead exposure may also decrease IQ scores and reduce the growth of young children. At high levels of exposure, lead can severely damage the brain and kidneys in adults and children, cause abortion, and damage the male reproductive system. The effects of lead are the same regardless of whether it enters the body through breathing or ingestion (ATSDR 1988b).

Manganese. Manganese makes up about 0.1% of the earth's crust and is the 12th most abundant element. It can exist in oxidation states from -3 to +7, the most common being +4 in the chemical form of manganese dioxide. The oxides and peroxides are used in industry as oxidizers, and the metal is used for manufacturing metal alloys to increase hardness and corrosion resistance. Manganese is an essential trace element in humans that can elicit a variety of serious toxic responses upon prolonged exposure to elevated concentrations either orally or by inhalation. The central nervous system is the primary target (BEIAS 1993).

Initial symptoms of manganese exposure are insomnia, disorientation, anxiety, lethargy, and memory loss. These symptoms will progress with prolonged exposure and will eventually include motor disturbances, tremors, and walking difficulties similar to Parkinsonism. Effects on reproduction (decreased fertility, impotence) have been observed in humans with inhalation exposure and in animals with oral exposure at the same or similar doses that initiate the central nervous system effects. Data on possible carcinogenesis following injections in mice are inconclusive; however, the EPA weight-of-evidence classification is D, not classifiable as to human carcinogenicity based on no evidence in humans and inconclusive evidence in animals (BEIAS 1993, ATSDR 1990a).

Mercury and mercury salts. Mercury is a naturally occurring element that may exist in elemental, inorganic, or organic forms and in various oxidation states. Mercury is used in a wide variety of products and processes, including pressure sensitive devices (thermometers, barometers), electrical apparatus (wiring, switches, batteries), paints, pharmaceuticals, and in the production of various chemicals. The oxidation state and chemical form of mercury are important in determining its toxicity, with mercurous salts being less toxic than mercuric salts. Organic materials such as methyl mercury are highly toxic. In the environment, mercury may undergo transformations among the various oxidation states and chemical forms. Both environmental and occupational exposure are relevant to mercury and its compounds, although environmental exposure is unimportant for mercury vapor. Mercury intake from occupational exposure is of greater significance than that from environmental exposure to mercury. Environmental exposure to mercury may involve dietary intake (i.e., from fish) and possibly from dental amalgams, the latter being controversial and under dispute (BEIAS 1993).

Ingestion of mercury metal is usually without effect, while ingestion of inorganic salts may cause severe GI irritation, renal failure, and death. Mercury is also known to induce hypersensitive reactions such as contact dermatitis and acrodynia (pink disease). Inhalation

of mercury vapor may cause irritation of the respiratory tract, central nervous system effects characterized by neurobehavioral changes, peripheral nervous system toxicity, renal toxicity, and death. Toxicity resulting from subchronic and chronic exposure to mercury and mercury salts usually involves the kidneys and/or the nervous system. No data are available regarding the carcinogenicity of mercury in humans or animals. The EPA has placed inorganic mercury in weight-of-evidence classification D, not classifiable as to human carcinogenicity (BEIAS 1993).

Nickel and nickel salts. Nickel is a naturally occurring metal existing in various mineral forms. Nickel may be found throughout the environment including rivers, lakes, oceans, soil, air, drinking water, plants, and animals. Soil and sediment are the primary receptacles for nickel, but mobilization may occur depending on physicochemical characteristics of the soil. Nickel is used in a wide variety of metallurgical processes, such as electroplating and alloy production, as well as in nickel-cadmium batteries. Some evidence suggests that nickel may be an essential trace element for mammals. As for most metals, the toxicity of nickel is dependent on the route of exposure and the solubility of the nickel compound (BEIAS 1993).

Pulmonary absorption is the major route of concern for nickel-induced toxicity. Toxic effects of oral exposure to nickel usually involve the kidneys with some evidence from animal studies showing a possible development/reproductive toxicity effect. Inhalation exposure to some nickel compounds will cause toxic effects in the respiratory tract and immune system. Asthmatic conditions have also been documented for inhalation exposure to nickel. In addition, sensitivity reactions to nickel are well documented and usually involve contact dermatitis reactions resulting from contact with items such as cooking utensils, jewelry, coins, etc., containing nickel. Epidemiologic studies have shown that occupational inhalation exposure to nickel dust (primarily nickel subsulfide) at refineries has resulted in increased incidence of pulmonary and nasal cancer (BEIAS 1993).

Niobium. Niobium is a lustrous, platinum-gray, ductile, metallic element that resembles tantalum chemically and is used in alloys. The element was first discovered in a museum and was mistaken for columbium or columbite, which is a compound of chromium. Niobium exists in the earth's crust in proportions of about 20 ppm. It is commercially refined as an alloy with iron and nickel and is used in atomic reactors. When alloyed with tin or aluminum, niobium is known to be superconductive (Heiserman 1992).

Niobium looks much like steel but is soft and ductile. It is a Group VB, vanadium-like element that is commonly mistaken for tantalum because of its similar physical and chemical properties. Little information is available concerning the element's toxic and carcinogenic effects; however, because of its similarity to vanadium, it is believed to exhibit the same effects. These effects include irritation of the respiratory and GI tracts, conjunctivitis, dermatitis, cough, bronchospasm, pulmonary congestion, and bronchitis (Heiserman 1992).

Nitrate/nitrite. Nitrates occur naturally in soil, water, air, and plant material. The levels of nitrates in soil and water can be increased with the use of commercial nitrogenous fertilizers and the subsequent return of waste from grazing animals. Nitrates find their way into crops in amounts based on the genetic character of the species. Spinach, carrots, and beets contain relatively high levels of nitrates. Environmental and land-management practices also play a roll in nitrate uptake. Nitrogen compounds contained in industrial waste can also be converted to nitrates by the nitrogen cycle and contaminate soil and surface water (WHO 1978).

Nitrites are formed by the action of bacteria during the formation of nitrates. Concentrations in plant, soil, and water are usually low. During storage of vegetables at room temperature, bacteria can convert nitrates to nitrites at high levels (3600 mg/kg) (WHO 1978). Nitrite levels in food are allowed to be 0.01%. Nitrates and nitrites are extensively used to prevent growth of toxic-producing bacteria in meat. *Clostridium botulinum* is one of the bacteria of concern because it causes botulism.

The health risk to humans is based on clinical and epidemiological studies. The main toxic effect of nitrate/nitrite exposure is due to ingestion, causing development of methemoglobinemia (irreversible bonding of oxygen to hemoglobin). Health risks are related to high levels in drinking water and food. In healthy adults, the intake of nitrates and nitrites is harmless. Infants are the most vulnerable group. Intestinal bacteria, such as *Bacillus subtilis*, reduce nitrates to nitrites. Intestinally absorbed nitrite reacts with hemoglobin to form methemoglobin, which is converted to oxyhemoglobin by NADH-methemoglobin reductase. However, this enzyme pathway is not developed in infants. Microbes in the infant's intestinal system or food may convert nitrates to nitrites causing methemoglobinemia. The most common way for infants to be exposed to high levels of nitrates is by reconstituting dry milk formula with contaminated water or by feeding infants vegetables stored at room temperature. Nitrate levels of 50 ppm in well water may cause methemoglobin in infants. Nitrates and nitrites in healthy adults are quickly filtered out by the kidneys. Other toxic reactions are vasodilation, loss of blood pressure, cyanosis, vomiting, coma, respiratory failure, or death (Arena 1974).

Sulfate. The sulfate ion, SO_4^{-2}, is one of the major anions occurring in natural waters. The majority of sulfates, with the exception of lead, barium, and strontium sulfates, are soluble in water. Therefore, dissolved sulfate is considered to be a permanent solute of water. Sulfate may be reduced to sulfide, volatilized to the air as H_2S, precipitated as an insoluble salt, or incorporated into living organisms. Sulfates are used for a variety of commercial purposes, including sulfuric acid for the steel and metal industries, as a reagent in manufacturing processes, and as products such as copper sulfate, which is used as a fungicide and algicide (BEIAS 1993).

The major health effect observed with sulfate ingestion is laxative action, and the cation associated with the sulfate appears to have some effect on the salt's potency as a laxative. Sulfate itself slowly penetrates mammalian cellular membranes and is rapidly eliminated through the kidneys. The mechanism by which sulfate ions induce laxative effects is complex and poorly understood. However, retention of excess fluid in the intestinal lumen and increased motor activity in the intestinal tract appear to be involved. It may be the poorly absorbed, soluble ions exert an osmotic pressure that causes retention of fluid in the intestinal lumen, and this increase in bulk indirectly stimulates intestinal transit. In addition to osmotic effects, the sulfate ion may increase the fluid volume of the intestinal tract by decreasing water absorption in the small intestine and by stimulating increases in the secretion of pancreatic, gastric, and intestinal fluids. It is unknown if these effects are caused directly by the ion or by the ion-stimulated release of hormones such as cholecystokinin. In addition, sulfates can contribute to an undesirable taste in water. The Drinking Water Standards of the U.S. Public Health Service recommend that sulfate in water should not exceed 250 mg/L, except when no more suitable supplies are or can be made available (BEIAS 1993). Carcinogenic data are presently unavailable to determine the carcinogenic potential of sulfate.

Thallium. Thallium is a sparsely but widely distributed poisonous metallic element that resembles lead in physical properties and is used chiefly in the form of compounds in photoelectric cells or as a pesticide. It is an elemental metal that occurs naturally in the earth's crust and is released into the environment from industrial sources. Thallium is most commonly found in minerals and as thallium salts. Thallium in the atmosphere can contaminate surface soil; human exposure can occur orally, dermally, or by inhalation. The most common nonoccupational sources of thallium are contaminated food crops and tobacco. Thallium is normally detected in the urine of humans; elevated urinary levels have been correlated with adverse health effects that include neurological and muscular signs and symptoms (BEIAS 1993).

The primary targets of thallium toxicity are the nervous system, the skin, and the reproductive system. In humans, acute doses produce paresthesia, retrobulbar neuritis, ataxia, delirium, tremors, and hallucination, implying central, peripheral, autonomic nervous system involvement. Chronic exposure to humans and animals results in alterations in the brain, spinal cord, and peripheral nerves. In both humans and animals, alopecia (a loss of hair, wool, or feathers; baldness) is the most common indicator of long-term thallium poisoning. An increased incidence of congenital malformations was observed in children whose parents were exposed to thallium through the consumption of home-grown vegetables and fruit, but a causal relationship between these effects and thallium could not be verified. In animal studies, thallium compounds have produced testicular effects in treated males and slight signs of fetotoxicity and significant impairment of learning ability in the offspring of treated animals (BEIAS 1993).

Uranium metal. Natural uranium is a silver-colored metal that is radioactive. Small amounts of uranium are present in rocks, soil, above-ground and underground water, plants, and animals, and it contributes to the weak background radiation from such substances. Natural uranium occurs in three forms (isotopes): ^{234}U, ^{235}U, and ^{238}U. The amount of ^{238}U in natural uranium is more than 99%, but ^{235}U, present at 0.72% in natural uranium, is most radioactive and important for nuclear bombs and nuclear reactors. An industrial process by which the percent of ^{235}U is increased is called enrichment, and the uranium obtained this way is called enriched uranium. It is more radioactive than is natural uranium. Uranium is used mainly in nuclear power plants and nuclear weapons. Small amounts are used in making some ceramics, light bulbs, photographic chemicals, and household products. Some fertilizers and CERCLA hazardous waste sites contain uranium and uranium byproducts (ATSDR 1989c).

The actual effects of natural uranium metal on human health are uncertain. Animals have developed kidney disease when exposed to uranium, but it is uncertain that humans would be affected in the same way. Natural uranium has low levels of radioactivity and has not been known to cause cancer in humans or animals. Nevertheless, it is possible that swallowing or breathing very large amounts of natural uranium may cause cancer. In addition, cancer may not become apparent until many years after exposure to a radioactive material. Small amounts of uranium are always in the human body; these amounts are not known to affect health. Some documented cases, however, reveal that uranium miners have developed lung cancer although it is believed that the cancer is not caused directly by the natural uranium but by the levels of radon gas which is formed when natural uranium decays (ATSDR 1989c).

Animals that have eaten natural uranium or inhaled high levels of uranium have developed kidney damage. This damage is often not permanent, and kidneys often return to

normal once the animal is no longer exposed. However, this evidence has not been confirmed in humans (ATSDR 1989c).

Vanadium. Vanadium is a metallic element that occurs in six oxidation states and numerous inorganic compounds. The element is used primarily as an alloying agent in steels and nonferrous metals such as copper, aluminum, and titanium. Vanadium compounds are also used as catalysts and in chemical, ceramic, or specialty applications. It may also have applications as an intermetallic compound for superconductor applications. Minor uses include applications as color modifiers in mercury-vapor lamps, as driers in paints and varnish, and as corrosion inhibitors in flue-gas scrubbers (BEIAS 1993).

Vanadium compounds are poorly absorbed through the GI system but slightly more readily absorbed through the lungs. Absorbed vanadium is widely distributed in the body, but short-term localization occurs primarily in bone, the kidneys, and the liver. In the body, vanadium can undergo changes in oxidation state and vanadate and can also bind with blood protein (transferrin). The toxicity of vanadium depends on its physicochemical state—particularly on its valence state and solubility. In humans, intestinal cramps and diarrhea may occur following subchronic oral exposures, thereby suggesting that, for subchronic and chronic oral exposures, the primary targets are the digestive system, kidneys, and blood. Inhalation exposures to vanadium and vanadium compounds result primarily in adverse effects to the respiratory system. In studies on workers occupationally exposed to vanadium, the most common reported symptoms were irritation of the respiratory tract, conjunctivitis, dermatitis, cough, bronchospasm, pulmonary congestion, and bronchitis. Little evidence suggests that vanadium or vanadium compounds are carcinogenic; however, few studies have been conducted on the carcinogenicity of vanadium (BEIAS 1993).

5.4.6.2 Radionuclides

Radionuclides are unstable atoms of chemical elements that will emit charged particles to achieve a more stable state. These charged particles are termed "alpha and beta radiation" and "neutral gamma rays." Interaction of these charged particles (and gamma rays) with matter will produce ionization events, or radiation, which may cause living cell tissue damage. Because the deposition of energy by ionizing radiation is a random process, sufficient energy may be deposited (in a critical volume) within a cell and result in cell modification or death (ICRP 1991). In addition, ionizing radiation has sufficient energy that interactions with matter will produce an ejected electron and a positively charged ion (known as free radicals) that are highly reactive and may combine with other elements or compounds within a cell to produce toxins or otherwise disrupt the overall chemical balance of the cell (EPA 1991d). These free radicals can also react with DNA, causing genetic damage, cancer induction, or even cell death.

Radionuclides are characterized by the type and energy level of the radiation emitted. Radiation emissions fall into two major categories: particulate (electrons, alpha particles, beta particles, and protons) or electromagnetic radiation (gamma and x-rays) (ATSDR 1989b). Therefore, all radionuclides are classified by the EPA as Group A carcinogens based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of humans with cancers induced by high doses of radiation. Alpha particles are emitted at a characteristic energy level for differing radionuclides. The alpha particle has a charge of +2 and a comparably large size. Alpha particles have the ability to react (and/or ionize) with other molecules, but they have very little penetrating power and

lack the ability to pass through a piece of paper or human skin. However, alpha-emitting radionuclides are of concern when there is a potential for inhalation or ingestion of the radionuclide. Alpha particles are directly ionizing and deposit their energy in dense concentrations [termed high linear energy transfer (LET)], resulting in short paths of highly localized ionization reactions. The probability of cell damage increases as a result of the increase in ionization events occurring in smaller areas; this may also be the reason for increased cancer incidence caused by inhalation of radon gas. In addition, the cancer incidence in smokers may be directly attributed to the naturally occurring alpha emitter ^{210}Po in common tobacco products (Hammonds 1992).

Beta emissions generally refer to beta negative particle emissions. Radionuclides with an excess of neutrons achieve stability by beta decay. Beta radiation, like alpha radiation, is directly ionizing but, unlike alpha activity, beta particles deposit their energy along a longer track length (low LET), resulting in more space between ionization events (Hammonds 1992). Beta-emitting radionuclides can cause injury to the skin and superficial body tissue but are most destructive when inhaled or ingested. Many beta emitters are similar chemically to naturally occurring essential nutrients and will therefore tend to accumulate in certain specific tissues. For example, ^{90}Sr is chemically similar to calcium and, as a result, accumulates in the bones, where it causes continuous exposure. The health effects of beta particle emissions depend upon the target organ. Those seeking the bones would cause a prolonged exposure to the bone marrow and affect blood cell formation, possibly resulting in leukemia, other blood disorders, or bone cancers. Those seeking the liver would result in liver diseases or cancer, while those seeking the thyroid would cause thyroid and metabolic disorders. In addition, beta radiation may lead to damage of genetic material (DNA), causing hereditary defects.

Gamma emissions are the energy that has been released from transformations of the atomic nucleus. Gamma emitters and x-rays behave similarly but differ in their origin: gamma emissions originate in nuclear transformations, and x-rays result from changes in the orbiting electron structure. Radionuclides that emit gamma radiation can induce internal and external effects. Gamma rays have high penetrating ability in living tissue and are capable of reaching all internal body organs. Without such sufficient shielding as lead, concrete, or steel, gamma radiation can penetrate the body from the outside and does not require ingestion or inhalation to penetrate sensitive organs. Gamma rays are characterized as low-LET radiation, as is beta radiation; however, the behavior of beta radiation differs from that of gamma radiation in that beta particles deposit most of their energy in the medium through which they pass, while gamma rays often escape the medium because of higher energies, thereby creating difficulties in determining actual internal exposure. For this reason, direct whole-body measurements are necessary to detect gamma radiation, while urine/fecal analyses are usually effective in detecting beta radiation (Hammonds 1992).

People receive gamma radiation continuously from naturally occurring radioactive decay processes going on in the earth's surface, from radiation naturally occurring inside their bodies, from the atmosphere as fallout from nuclear testing or explosions, and from space or cosmic sources. Cesium-137 (from nuclear fallout) decays to ^{137}Ba, the highest contributor to fallout-induced gamma radiation (NCRP 1977). Beta radiation from the soil is a less penetrating form of radiation but has many contributing sources. Potassium-40, ^{137}Cs, ^{214}Pb, and ^{214}Bi are among the most common environmental beta emitters. Tritium is also a beta emitter but contributes little to the soil beta radiation because of the low energy of its emission and its low concentration in the atmosphere (NCRP 1977). Alpha radiation is also

emitted by the soil but is not measurable more than a few centimeters from the ground surface. The majority of alpha emissions are attributable to ^{222}Rn and ^{220}Rn and their decay products (NCRP 1977). This contributes to what is called background exposure to radiation (ATSDR 1989b).

The general health effects of radiation can be divided into stochastic (related to dose) and nonstochastic (not related to dose) effects. The risk of developing cancer from exposure to radiation is a stochastic effect. Examples of nonstochastic effects include acute radiation syndrome and cataract formation, which occur only at high levels of exposures (Killough and Eckerman 1983).

Radiation can damage cells in different ways. It can cause damage to DNA within the cell, and the cell either may not be able to recover from this type of damage or may survive but function abnormally. If an abnormally functioning cell divides and reproduces, a tumor or mutation in the tissue may develop. The rapidly dividing cells that line the intestines and stomach and the blood cells in bone marrow are extremely sensitive to this damage. Organ damage results from the damage caused to the individual cells. This type of damage has been reported with doses of 10 to 500 rads (0.1 to 5.0 gray, in SI units). Acute radiation sickness is seen only after doses of >50 rads (0.5 gray) which is a dose rate usually achieved only in a nuclear accident (ATSDR 1989b).

When the radiation-damaged cells are reproductive cells, genetic damage can occur in the offspring of the person exposed. The developing fetus is especially sensitive to radiation. The type of malformation that may occur is related to the stage of fetal development and the cells that are differentiating at the time of exposure. Radiation damage to children exposed in the womb is related to the dose the pregnant mother receives. Mental retardation is a possible effect of fetal radiation exposure (ATSDR 1989b).

The most widely studied population that has had known exposure to radiation is the atomic bomb survivors of Hiroshima and Nagasaki, Japan. Data indicate an increase in the rate of leukemia and cancers in this population. However, the rate at which cancer incidence is significantly affected by low radiation exposures, such as exposure to natural background and industrially contaminated sites, is still undergoing study and is uncertain (Hammonds 1992). In studies conducted to determine the rate of cancer and leukemia increase, as well as genetic defects, several radionuclides must be considered.

Cesium-137. Cesium occurs in nature as ^{133}Cs in the aluminosilicates, pollucite (a hydrated silicate of aluminum and cesium) and lepidolite; in the borate, rhodizite; and in other sources (Budavari et al. 1989, Klassen, Amdur, and Doull 1986). Cesium-137 is one of the artificial isotopes of cesium and one of the principal radionuclides present in reactor effluent under normal operations. Cesium-137 may also be produced in nuclear and thermonuclear explosions, through which it would be a primary contributor to human exposure through fallout radiation, assimilation through the food chain, or beta dose to the skin (Budavari et al. 1989, Klassen, Amdur, and Doull 1986). In addition, ^{137}Cs, along with ^{90}Sr, is one of the most important fission products that was widely distributed in near-surface soils because of historical weapons testing. Measurable concentrations still exist in the soil today, almost exclusively in the upper 15 cm of soil; these concentrations decrease roughly exponentially with depth.

Cesium-137 may also have important roles in medical treatments (a teletherapy source or intercavitary or interstitial radiation source in treatment of malignancies) and as an encapsulated energy source (Budavari et al. 1989, Casarett 1968). Cesium-137 decays to and reaches radioactive equilibrium with its daughter product, ^{137}Ba (Budavari et al. 1989, Casarett 1968). Barium-137m is a very short-lived gamma emitter that can contribute to external gamma exposure (Budavari et al. 1989).

Radium-226. Radium is a naturally occurring radioactive element that exists in several isotopic forms. The radium isotopes are formed from the decay of uranium and thorium. Radium-226 is formed from ^{238}U and ^{234}U, and ^{226}Ra has the longest half-life of the radium isotopes (which also include ^{228}Ra, ^{224}Ra, and ^{223}Ra). In general, the activity concentration of ^{226}Ra measured in most soils and rocks is comparable to those of ^{238}U and ^{234}U, suggesting that radium does not tend to migrate from either of its uranium precursors under stable conditions. Radium-226 is primarily an alpha and gamma emitter (Budavari et al. 1989, Casarett 1968).

Radium has been used as a component of luminous paints for clock and instrument dials. It has also been used in the treatment of cancer, in radiography, and in research. Radium is released into the environment in coal fly ash and in uranium mining and processing wastes. The background level of radium in industrial regions in soil is about 8.1 pCi/g. Clays and soil components generally retard the movement of radium in the environment, but acidic processing wastes can enhance its movement. Radium may bioaccumulate in plants and animals, and exposure through the food chain is possible (Budavari et al. 1989, Casarett 1968).

Many environmental problems can be directly attributed to the decay products or daughters of radium. The primary daughters are isotopes of radon—a colorless, odorless, radioactive gas. Radon gas can infiltrate basements and water systems, resulting in significant exposure via inhalation pathways (Budavari et al. 1989, Casarett 1968).

Strontium-90. Strontium is a soft, silvery metal and is found in the minerals celestite and strontianite. It is malleable and ductile and is an excellent conductor of electricity. Strontium exists as a number of isotopes. One such isotope is ^{90}Sr, which is a dangerous radioisotope found in the fallout of some nuclear explosions.

Radiostrontium is a fallout hazard because, being chemically similar to calcium, it becomes incorporated into bone, where it may damage the bone marrow and induce cancer.

Technetium-99. Technetium-99 is an abundant, man-made radionuclide that is mobile in ecosystems. It is a beta emitter, emitting low-LET ionizing radiation, known to be carcinogenic to humans. As a pure beta emitter, it poses an insignificant external hazard. Assimilation of technetium following ingestion is high (50%), but retention in animal tissues appears low (SAIC 1993b).

The potential health effects associated with exposure to low-level radiation include an increase in the probability of cancer induction and possible genetic effects. The major health concern associated with radiation is cancer induction; the risk of hereditary effects is much lower. Technetium-99 has been classified by the EPA as a Group A (human carcinogen) carcinogen (SAIC 1993b).

Thorium-228, -230, -232, and -234. Thorium is a naturally occurring, radioactive metal. Small amounts of thorium are present in all rocks, soil, above-ground and underground water, plants, and animals. These small amounts of thorium contribute to the weak background radiation for such substances. Soil commonly contains an average of about 6 ppm of soil. Rocks in some underground mines may also contain thorium in a more concentrated form. After these rocks are mined, thorium is usually concentrated and changes into thorium dioxide or other chemical forms. Thorium-bearing rock that has had most of the thorium removed from it is called "depleted" ore or tailings (ATSDR 1990b).

Thorium is a metallic element of the actinide series. It exists in several isotopic forms. The isotope ^{232}Th is a naturally occurring element that is radioactive. It decays through the emission of a series of alpha and beta particles, gamma radiation, and the formation of daughter products, finally yielding the stable isotope of lead, ^{208}Pb. Isotopes ^{234}Th and ^{230}Th are produced during the decay of naturally occurring ^{238}U, the isotope ^{228}Th during the decay of ^{232}Th, and the isotopes ^{231}Th and ^{227}Th during the decay of ^{235}U. Of these naturally produced isotopes of thorium, only ^{232}Th, ^{230}Th, and ^{228}Th have long enough half-lives to be environmentally significant. More than 99.99% of natural thorium is ^{232}Th; the rest is ^{230}Th and ^{228}Th (ATSDR 1990b).

Thorium is used to make ceramics, lantern mantles, and metals used in the aerospace industry and in nuclear reactions. Thorium can also be used as a fuel for generating nuclear energy. More than 30 years ago, thorium oxides were used in hospitals to make certain kinds of diagnostic x-ray photographs (ATSDR 1990b).

Because thorium is found almost everywhere, most people in the United States eat some thorium with their food every day. Normally, little of the thorium in lakes, rivers, and oceans gets into the fish or seafood used commercially. More thorium may be found near uncontrolled hazardous waste sites that contain thorium that might not have been disposed of properly. Consequently, people living near one of these sites may be exposed to slightly more thorium as a result of inhaling windblown dust containing thorium or eating food grown in soil contaminated with thorium. Larger-than-normal amounts of thorium might also enter the environment through accidental releases from thorium processing plants (ATSDR 1990b).

Breathing dust contaminated with thorium is the primary pathway for thorium exposure to the body. A large portion of this dustborne thorium will be eliminated by normal bodily functions (urine/feces); however, a small amount of thorium will be taken up by the blood and subsequently transmitted to the bones. Breathing thorium dust may cause an increased chance of developing lung disease and cancer of the lung or pancreas many years after exposure. Changes in genetic material have also been shown to occur in workers who breathed thorium dust. Liver diseases and effects on the blood have been found in people injected to take special x-rays. Many types of cancer have been shown to occur in these people many years after thorium was injected in their bodies. Since thorium is radioactive and may be stored in bone for a long time, bone cancer is also a potential concern for people exposed to thorium. Animal studies have shown that inhaling thorium may result in lung damage. Other studies in animals suggest drinking massive amounts of thorium can cause death from metal poisoning. The presence of large amounts of thorium in the environment could result in exposure to more hazardous radioactive decay products of thorium, such as radium and thoron, which is an isotope of radon. Thorium is not known to cause birth defects or to affect childbearing abilities (ATSDR 1990b).

Uranium-234, -235, and -238. Naturally occurring uranium is a lustrous, silver-colored, radioactive, malleable, and ductile metal. Uranium is almost exclusively used as a fuel for nuclear energy; however, it can be used in pigments, ceramics, and photographic chemical processes. The three naturally occurring isotopes of uranium are ^{238}U (>99%), ^{235}U (about 0.72%), and ^{234}U (0.06%). The half-lives of ^{234}U, ^{235}U, and ^{238}U are 2.4E+05 years, 7.0E+07 years, and 4.5E+09 years, respectively. The average concentration of uranium in the earth's crust is between 2 and 4 ppm. Some ores contain more concentrated uranium deposits. These deposits are mined, and then the percentage of ^{235}U is increased by an enrichment process. The enriched ^{235}U is more radioactive and of great use as a nuclear reactor fuel or weapon component.

Alpha, beta, and gamma radiation are emitted during the decay of uranium. Loss of alpha particles can give rise to other radioactive elements such as ^{230}Th, ^{226}Ra, ^{222}Rn, and ^{218}Po. Radon is a significant daughter isotope because it is colorless and odorless and, as a gas, can leak into basements or foundations. Significant exposure by inhalation of radon gas can occur unknowingly. Deposition of radon and its daughters onto the lungs exposes them to alpha radiation, increasing the probability of cancer. Radium has been known to produce bone sarcomas in radium dial painters resulting in death. The final decay for ^{238}U and ^{234}U is stable ^{206}Pb, and the final decay for ^{235}U is stable ^{207}Pb (ATSDR 1989c).

Uranium may be released into the air by natural processes such as volcanic eruption or resuspension of soil. The combustion of fossil fuels is a potential contamination route. Coal and shale oils have varying levels of uranium depending on ore location. Subsequent burning can concentrate the levels of uranium. Groundwater and surface water releases of uranium are primarily caused by the disposal of uranium mining waste, disposal of nuclear reactor waste, and reactor emissions. Soil naturally contains uranium, but levels may be concentrated by the addition of mining waste and nuclear facility waste. Carrots, potatoes, and other root vegetables contain higher levels of uranium than leafy vegetables. Higher levels of uranium have also been found in cattle that graze near nuclear facilities (ATSDR 1989c).

Concentrated uranium is a highly toxic element both chemically and radiologically. Kidney damage is the primary toxic effect of uranium. Chemical exposure to uranium may cause dermatitis, weight loss, acute necrotic arterial lesions, and possibly liver damage (Sanders 1986). Spontaneous ignition of finely divided uranium at room temperature is a dangerous physical property. Radiological effects are more prominent if uranium is inhaled and subsequently absorbed in the blood stream. Radioactivity in natural uranium is quite low and exists in food, water, and even in human bones. However, exposure to enriched uranium may cause damage to somatic cells resulting in tumors or cause damage to reproductive cells, affecting the next generation. Higher incidence of lung cancer have been observed in uranium mine workers. Exposure to radionuclides with greater specific-activity and shorter half-life increases the risk for developing cancer (ATSDR 1989c).

5.4.6.3 Organics

***Bis*(2-ethylhexyl)phthalate.** *Bis*(2-ethylhexyl)phthalate is a colorless, oily liquid that is extensively used as a plasticizer in a wide variety of industrial, domestic, and medical products. It is primarily used in the plastics industry as a plasticizer with such varied applications as wire insulation, food packaging, and biomedical applications such as tubing and blood containers. Other uses include vacuum pump oil and as a dielectric fluid in capacitors. In addition, it is an environmental contaminant and has been detected in groundwater, surface water, drinking

water, air, soil, plants, fish, and animals. It is rapidly absorbed from the GI tract primarily as *mono*(2-ethylhexyl)phthalate (BEIAS 1993).

Animal studies have indicated that primary organs are the liver and kidneys; however, higher doses are reported to result in testicular effects and decreased hemoglobin and packed cell volume. The primary intracellular effects of *bis*(2-ethylhexyl)phthalate in the liver and kidneys are an increase in the smooth endoplasmic reticulum and a proliferation in the number and size of peroxisomes. An epidemiological study reported no toxic effects from occupational exposure to air concentrations of *bis*(2-ethylhexyl)phthalate up to 0.16 mg/m^3. Other studies on occupational exposures to mixtures of phthalate esters containing *bis*(2-ethylhexyl)phthalate have reported polyneuritis and sensory-motor polyneuropathy with decreased thrombocytes, leukocytes, and hemoglobin in some exposed workers. Based on EPA guidelines, *bis*(2-ethylhexyl)phthalate was assigned to weight-of-evidence Group B2, probable human carcinogen, on the basis of an increased incidence of liver tumors in rats and mice (BEIAS 1993).

Bromodichloromethane. Bromodichloromethane is one of several trihalomethanes (including chloroform, bromoform, and dibromochloromethane) that are formed from the interaction of chlorine with organic materials found in water. Little data are available concerning the exposure effects of bromodichloromethane in humans; however, studies conducted on rats show liver and kidney effects, such as degeneration of the liver and necrosis of the kidney.

EPA has determined bromodichloromethane to have a weight-of-classification of B2 (probable human carcinogen) based on inadequate human data and sufficient evidence of carcinogenicity in two animal species (mice and rats) as shown by increased incidence of kidney tumors and tumors of the large intestine in male and female rats, kidney tumors in male mice, and liver tumors in female mice (EPA 1994a).

Carbon tetrachloride. Carbon tetrachloride is a clear, oily liquid at room temperature with an aromatic sweet odor. It is heavier than water and is volatile with a vapor pressure of 90 mm Hg at 20°C and a boiling point of 76.5°C. Carbon tetrachloride is not flammable and, until the 1960s, was used in fire extinguishers. Other uses, which have been discontinued, include a solvent for cleaning and household products, as a fumigant for insects, and as an oral treatment for certain parasitic infections. Industrial uses include the production of chlorofluorocarbons used in refrigeration and as a degreasing solvent (BEIAS 1993).

Subchronic and chronic exposure to doses as low as 10 ppm can result in liver and kidney damage. Lung damage has also been reported in animals and humans but is not route specific and is believed to be secondary to kidney damage. Prolonged exposure has been observed to cause visual effects in both humans and animals. Increased hepatic enzyme activities indicative of liver damage have also been observed (BEIAS 1993).

Although data for the carcinogenicity of carbon tetrachloride in humans are inconclusive, there is ample evidence in animals that the chemical can cause liver cancer. Hepatocellular carcinomas have been induced in hamsters, rats, and mice after oral carbon tetrachloride treatment for 16 to 76 weeks. Liver tumors have also been demonstrated in rats following inhalation exposure, but the doses were not quantitatively established. The EPA weight-of-evidence classification for both oral and inhalation exposure is B2, probable human carcinogen, based on adequate animal evidence (BEIAS 1993).

Chloroform. Chloroform is a colorless, volatile liquid that is widely used as a general solvent and as an intermediate in the production of refrigerants, plastics, and pharmaceuticals. In the past, chloroform has been used extensively as a surgical anesthetic, but this use was discontinued because exposure to narcotic concentrations resulted in adverse side effects. The Food and Drug Administration has banned the use of chloroform as an ingredient in human drug and cosmetic products as of July 1976. Chloroform is the principal trihalomethane generated as by-products during the chlorination process. The primary sources of chloroform in the environment are chlorinated drinking water and wastewater, pulp and paper mills, and chemical and pharmaceutical manufacturing plants (BEIAS 1993).

Chloroform is rapidly absorbed from the lungs and the GI tract and to some extent through the skin. Target organs for chloroform toxicity are the liver, kidneys, and central nervous system. Liver effects (hepatomegaly, fatty liver, and hepatitis) were observed in individuals occupationally exposed to chloroform. Chloroform is a central nervous system depressant, inducing narcosis and anesthesia at high concentrations. Lower concentrations may cause irritability, lassitude, depression, GI symptoms, and frequent and burning urination (BEIAS 1993).

Epidemiological studies indicate a possible relationship between exposure to chloroform present in chlorinated drinking water and cancer of the bladder, large intestine, and rectum. Chloroform is one of several contaminants present in drinking water, but it has not been identified as the sole or primary cause of the excess cancer rate. Based on EPA guidelines, chloroform was assigned to weight-of-evidence Group B2, probable human carcinogen, on the basis of an increased incidence of several tumor types in rats and in three strains of mice (BEIAS 1993).

1,2-Dichloroethene. No data are currently available for 1,2-dichloroethene. The EPA has determined 1,2-dichloroethene as classification D, not classifiable as to human carcinogenicity, based on no data in humans or animals and generally nonpositive results in mutagenicity assays (EPA 1994a).

Methylene chloride. Methylene chloride, also known as dichloromethane, is a colorless liquid that has a mild sweet odor, evaporates easily, and does not burn easily. It is widely used as an industrial solvent and as a paint stripper. It can be found in certain aerosol and pesticide products and is used in manufacturing photographic film. The chemical may be found in some spray paints, automotive cleaners, and other household products. Methylene chloride does not appear to occur naturally in the environment. It is made from methane gas or wood alcohol. Most of the methylene chloride released to the environment results from its use as an end product by various industries and the use of aerosol products and paint removers in the home (ATSDR 1993c).

Since methylene chloride evaporates into air rapidly, exposure by breathing is the most likely source of exposure at hazardous waste sites, in the home, and in the workplace. Inhalation exposure in small amounts may cause impaired hearing and vision; inhalation in large amounts may affect reflexes and coordination. In addition, long-term inhalation exposure may cause dizziness, nausea, tingling and numbness in the fingers and toes, and drunkenness. Very high doses can lead to unconsciousness and death. Breathing methylene chloride also causes changes in the liver and kidney in animals, but these symptoms have not been observed in humans. In humans, direct skin contact with methylene chloride causes intense burning and mild redness of the skin (ATSDR 1993c).

Methylene chloride has not been shown to cause cancer in humans exposed to vapors in the workplace. However, breathing high concentrations of methylene chloride for long periods did increase the incidence of cancer in mice. Therefore, the EPA has determined that methylene chloride is a probable human carcinogen (ATSDR 1993c).

Tetrachloroethene. Tetrachloroethene is a synthetic chemical that is widely used for dry cleaning fabrics and for metal-degreasing operations. It is also used as a starting material (building block) for making other chemicals and is used in some consumer products. Tetrachloroethene, also known as perchloroethene, PCE, perclene, perchlor, and tetrachloroethylene, is a nonflammable liquid at room temperature that evaporates easily into the air producing a sweet, sharp odor (ATSDR 1993b).

Tetrachloroethene has been used as a general anesthetic agent. Therefore, when concentrations in air are high—particularly in closed, poorly ventilated areas—single exposures to tetrachloroethene can cause dizziness, headache, sleepiness, confusion, nausea, difficulty in speaking and walking, and possibly unconsciousness and death. Skin irritation may result from repeated or extended contact with the chemical. Animal studies, conducted with amounts of tetrachloroethene much higher than those that most people are exposed to, show that it can cause liver and kidney damage and liver and kidney cancers. However, it has not been shown to cause cancers in humans, but the Department of Health and Human Services has determined that tetrachloroethene may reasonably be anticipated to be a carcinogen (ATSDR 1993b).

1,2,4-Trichlorobenzene. Little data are available for 1,2,4-trichlorobenzene (TCB); however, in studies conducted on rats, adrenal glands have the highest concentration of TCB immediately following a single oral dose. Later during the first week following dosing, only abdominal fat, the kidneys, and the liver showed higher concentrations than the adrenal gland. The EPA has determined this adrenal gland effect as one of significance. It should be noted however that this adrenal gland effect has not been proven in humans.

No carcinogenic data for TCB are available for humans, and carcinogenic data for animals are inadequate (EPA 1994a).

Polycyclic aromatic hydrocarbons. Polycyclic aromatic hydrocarbons (PAHs), which include BCV OU 2 COPCs phenanthrene and 2-methylnaphthalene, share a remarkable stability and, because of this stability, they have been found to be quite useful in industry (in solvents, lubricants, dyes, etc). Combustion produces a wide variety of aromatic compounds. Ideally, when hydrocarbon (fossil) fuels are burned, carbon dioxide and water are the resulting combustion products. However, complete combustion is rare; therefore, combustion results in the production of soot and smoke. Soot and smoke contain a number of PAHs, some of which are highly toxic and most of which are toxic in large enough doses. Soot from the exhaust of diesel engines contains small PAHs such as benzene, naphthalene, and phenanthrene and larger PAHs such as coronene and ovalene. Soot is believed to be an aggregate of large molecules that have many benzene rings, PAHs included (Aihara 1992).

The degree of carcinogenicity in humans exposed to PAHs directly corresponds to the size of the PAH molecule. Data prove that many PAHs are carcinogenic, as in the case of benzo(a)pyrene, which is a component in coal tar, soot, and tobacco. The oral SFs for PAHs are derived by multiplying the benzo(a)pyrene SF by the chemical-specific toxicity equivalency factor (EPA 1993a). Researchers have proven the damage cigarette smoking can cause to the

lungs over prolonged periods, and tumors have been discovered in occupational workers such as those who fuel coal-fired furnaces and chimney sweeps (Aihara 1992). However, the acute chronic and subchronic effects of PAHs on humans is not well documented, and complete data are unavailable. One reason for the lack of valuable information regarding the toxic effects of PAHs is the difficulty in determining the source of such illnesses as lung cancer, liver cancer, skin cancer, and various other ailments. Studies of aromatic compounds show that they also exist naturally in space; carbonaceous chondrite meteorites, for example, are known to contain many kinds of aromatic compounds (Aihara 1992). Therefore, the source of such ailments as lung or liver cancer is difficult to determine because researchers are unsure how large an amount of exposure to aromatics an average person will acquire in a lifetime. However, general ailments such as headaches, dizziness, nausea, and malaise have been attributed to automobile exhaust inhalation (Aihara 1992).

PCBs (Aroclor-1254 and Aroclor-1260). PCBs are a group of man-made chemicals that contain 209 individual compounds (known as congeners); they are either oily liquids or solids and are colorless to light yellow, without any known smell or taste. Seven types of PCB mixtures include 35% of all the different PCBs commercially produced and 98% of PCBs sold in the United States since 1970. Some commercial PCB mixtures are known in the United States by their industrial trade name, Aroclor (i.e., Aroclor-1254, Aroclor-1260). The name Aroclor-1254 signifies that the molecule contains 12 carbon atoms (the first two digits) and ~54% chlorine by weight (the second two digits). PCBs do not burn easily and are a good insulating material; therefore, they have been used widely as coolants and lubricants in transformers, capacitors, and other electrical equipment. However, in 1977, manufacture of PCBs stopped in the United States because evidence showed that PCBs tend to build up in the environment and cause harmful effects (ATSDR 1993a).

In the past, PCBs entered the environment through their manufacture and use. Today, they can enter the environment from poorly maintained hazardous waste sites; illegal or improper dumping of PCB wastes; leaks or releases from electrical transformers containing PCBs; and disposal of PCB-containing consumer products into municipal landfills rather than into landfills designed for hazardous waste. PCBs can exist in air as both solid and liquid aerosols and as vapor that eventually returns to the land and water by settling or washout by snow or rainwater. Even extremely small amounts of PCBs can remain in water for several years, and they will bind strongly with soil and remain bonded for several years (ATSDR 1993a).

PCBs can be ingested or inhaled and can cause skin and nose irritations. Although several health effects as a result of exposure to PCBs have been seen in rats (i.e., liver damage and sometimes death after ingesting large amounts of PCBs for a short period and liver, stomach, and thyroid gland injuries; anemia; acne; and damaged reproduction organs after ingesting smaller amounts of PCBs but for a longer period), little conclusive evidence concerning the effects of PCBs on humans is available. In addition, rats that ate certain PCB mixtures throughout their lives developed liver cancers; however, it is not known if the same effects would occur in people. Aroclors do not have individual SFs; the oral SF for PCBs is used. After inhalation exposure, workers have exhibited respiratory tract and eye irritation, coughs, and tightness of the chest, as well as GI symptoms (anorexia, weight loss, nausea, vomiting, and abdominal pain); none of these symptoms were reported in a great quantity, and therefore results are inconclusive (ATSDR 1993a).

Studies of PCB-exposed workers provide inconclusive evidence for exposure-related cancer; however, an excess risk of cancer of the liver, biliary tract, and gall bladder has been reported in workers in two capacitor plants where PCB mixtures are commonly used. The International Agency for Research on Cancer has determined that PCBs are *probably* carcinogenic to humans, and the EPA has determined that PCBs are probable human carcinogens (ATSDR 1993a).

5.5 RISK CHARACTERIZATION

The purpose of the risk characterization is to integrate and summarize the information presented in the exposure and toxicity assessments; it is the final step in the human health risk assessment process. Potential carcinogenic effects are characterized by estimating the probability that an individual will develop cancer over a lifetime from projected intakes (and exposure) and chemical-specific dose-response data (i.e., SFs). Potential noncarcinogenic effects are characterized by comparing projected intakes of contaminants to toxicity values (i.e., RfDs). The numerical risk/HQ estimates that are presented in this section must be interpreted in the context of the uncertainties and assumptions associated with the risk assessment process and with the data upon which the risk estimates are based (refer to Sects. 5.2, 5.3.4, 5.4.5, and 5.5.5). COCs are identified as analytes that provide a human exposure risk >1.0 E-6 and/or HQ>1.0.

5.5.1 General Considerations for Evaluating Risks to Human Health

The inorganic analytes listed in the COPC tables (Tables 5.1 and 5.3) include chromium VI, nickel, and mercury. The analytical laboratory reported detected concentrations for *total* chromium, *total* mercury, and *total* nickel found. Because the concentrations were reported in this form (i.e., no distinction between valences and speciation), it was necessary to assess all types of these analytes, which included the most toxic forms of the metals (for example, chromium VI, nickel salts, and mercury salts).

For the dermal contact pathways, nickel salts and mercury salts were used in the calculations of HQ, because the %GI absorption values were available for these salts and were not available for the metals. (This is the most conservative approach in terms of evaluating risks to human receptors.) For all other pathways, metallic nickel and metallic mercury were evaluated. The concentrations of the nickel salts and mercury salts (used in the dermal calculations) were assumed to be the same as those for metallic nickel and metallic mercury, respectively.

Radionuclide analyses for the historical soil data were reported as *total* radium activity (pCi/g), *total* thorium (mg/kg), and *total* uranium (mg/kg). For this BRA, the *total* radium concentration (pCi/g) was assigned to the ^{226}Ra isotope. (Toxicity values for ^{226}Ra are the most conservative, that is, give the largest risk, among the radium isotopes.) The reported *total* uranium concentration (mg/kg) was converted to the three most abundant isotopes (^{234}U, ^{235}U, and ^{238}U) in units of activity (pCi/g). The *total* thorium concentration (mg/kg) was converted to ^{232}Th, which is the most abundant of the isotopes.

5.5.1.1 Methodology for evaluating carcinogens and noncarcinogens

Risks and HQs, for carcinogens and noncarcinogens, respectively, are calculated for the BCV OU 2 COPCs. These risks and HQs are based upon EPA-approved or -suggested SFs and RfDs. The SF is based upon an estimate of the incremental lifetime cancer risk, which equates to incidence per unit of exposure, and the RfD is a level of exposure (threshold) below which no noncarcinogenic adverse health effects are expected to occur.

Carcinogenic risk is calculated by multiplying the EPA-approved SFs for inorganics, organics, and radionuclides by an estimate of the actual exposure to these contaminants (i.e., CDI and/or dose) via external exposure, ingestion, inhalation, or dermal contact. These risk estimates indicate the potential for an individual developing *excess* cancer over a lifetime (EPA 1989b), above the normal (unavoidable) cancer rate in a population.

The HQ estimate for noncarcinogens is calculated by determining the ratio of the CDI for ingestion, inhalation, and dermal contact of a contaminant to the contaminant-specific RfD. This HQ assumes that below a given level of exposure (i.e., the RfD) even subpopulations are unlikely to experience adverse health effects.

To estimate the potential carcinogenic risk and noncarcinogenic hazards to human health from all contaminants in a particular pathway, a cumulative risk (Total Pathway Risk) and/or a cumulative HI (Total Pathway HI) is determined for exposure to all contaminants in a given exposure pathway (EPA 1989b). In addition, an overall cumulative risk or HI can be determined by summing the risks or HQs from all analytes across all of the pathways; summations are conducted separately for carcinogens and noncarcinogens.

5.5.1.2 EPA guidance for carcinogens and noncarcinogens

The constituents detected in the BCV OU 2 media were evaluated within the context of EPA-approved guidelines (EPA 1989b) in which there are three regions for carcinogenic risk [risk $<$ 1.0E-06, no concern; risk between 1.0E-06 and 1.0E-04, range of concern (or target risk range); and risk $\geq$ 1.0E-04, regulatorily unacceptable] and two regions in terms of noncarcinogenic toxicity (HI $<$ 1.0, no concern, and HI $\geq$ 1.0, concern).

In relationship to the regulatory decisions to be made, if the BRA (and comparisons of exposure concentrations to other chemical-specific criteria/standards) indicates there are no unacceptable risks to human health or the environment, a Feasibility Study and remedial action are generally not warranted (EPA 1991c). When the BRA indicates that risks to a hypothetical resident (or a reasonable maximum exposure scenario) are regulatorily unacceptable (i.e., risk $\geq$ 1.0E-04), action (i.e., an FS and remedial action) is generally warranted, and risk management decisions are made. EPA considers risks between 1.0E-06 and 1.0E-04 in the target risk range, and an FS is generally performed to determine if remedial action would both reduce risk and be cost effective (EPA 1991c).

5.5.2 Current land use conditions—industrial worker scenario

5.5.2.1 Carcinogenic risk characterization for the BCV OU 2 COPCs —industrial worker

The industrial worker land-use scenario was evaluated for the three areas in BCV OU 2 (RSA, SY-200, and SA-1). The carcinogenic risks to an industrial worker were determined for exposure to the soils via (1) incidental ingestion of soil, (2) inhalation of dust and VOCs, (3) dermal contact with the soil, and (4) external exposure to radionuclides in the soil.

The inhalation (dust, VOCs) pathway could only be evaluated (risk/HQ) for those COPCs with an inhalation SF or RfD. (Refer to Tables C.23–C.25.) The inhalation exposure pathway was evaluated for both inhalation of soil particulates (dust) and for inhalation of VOCs in soil. The ingestion and dermal contact pathways (for soil) were evaluated for all COPCs when possible (i.e., when oral SFs or RfDs were available; refer to Tables C.23–C.25). The external exposure to radionuclides in the soil pathway was evaluated for all radionuclide COPCs.

Table 5.5 lists the risk estimates for the exposure of an industrial worker to the BCV OU 2 carcinogenic COPCs in the soil via the four primary exposure pathways listed earlier. The risks from exposure to individual analytes are $\leq$ 1.3E-06 for all three areas (RSA, SY-200, and SA-1), with the exception of risks from exposure to ^{226}Ra in SA-1. The cumulative pathway risks for the RSA and SY-200 areas (i.e., the sum of the risks from all analytes across all exposure pathways) are 5.6E-06 and 2.9E-06, respectively. The cumulative pathway risk for the SA-1 area is 4.8E-04; ^{226}Ra is driving this risk via exposure by the inhalation and external exposure pathways.

The COCs that are the main contributors (i.e., that have individual risks $\geq$ 1.0E-06) to the total cumulative risks are beryllium and Aroclor-1254 (for RSA) and beryllium and ^{226}Ra (for SA-1). No analytes have individual risks $\geq$ 1.0E-06 for the SY-200 area.

5.5.2.2 Noncarcinogenic HQ characterization for the BCV OU 2 COPCs —industrial worker

Table 5.6 lists the HQ estimates for the exposure of an industrial worker to the BCV OU 2 noncarcinogenic COPCs in soil via the four primary exposure pathways listed earlier. The HQs from exposure to individual analytes are all less than 1.0 for all three areas (RSA, SY-200, and SA-1). In addition, the cumulative pathway HIs (i.e., the sum of the HQs from all analytes across all pathways) are also less than 1.0. Therefore, no noncarcinogenic COCs are identified for the industrial worker exposure scenario.

5.5.3 Future Land Use Conditions–Residential Scenario

For the residential land use conditions, the four primary exposure pathways (listed in Sect. 5.5.2.1) and the ingestion of homegrown vegetables/fruits pathway (mentioned previously in Sects. 5.1 and 5.3.3.1.1) were evaluated in terms of carcinogenic risk and noncarcinogenic toxicity to human health. The risk/HQ table format illustrates these exposure pathways for the various COPCs associated with each area (RSA, SY-200, and SA-1).

Table 5.5. Carcinogenic risks for BCV OU 2 soil COPCs—industrial scenario

Analyte	UCL95[a] (mg/kg; pCi/g)	Ingestion risk	Dermal risk	Inhalation risk	External exposure risk	Total risk[b]
			RSA			
Inorganics						
Barium	1.15E+02					
Beryllium	1.05E+00	7.9E-07	1.0E-06	1.3E-10		1.8E-06
Cadmium	4.93E+00			4.5E-10		4.5E-10
Manganese	8.99E+02					
Mercury	2.00E+00					
Nickel	4.61E+01					
Uranium (soluble salts)	7.36E+00					
Radionuclides						
^{232}Th	3.09E+00	1.2E-08		2.3E-09	3.7E-10	1.4E-08
^{234}U	2.81E+00	1.4E-08		2.0E-09	3.8E-10	1.6E-08
Organics						
1,2,4-Trichlorobenzene	4.31E+00					
1,2-Dichloroethene (total)	7.22E-02					
Aroclor-1254	9.86E-01	1.3E-06	8.4E-07			2.2E-06
Benzo(a)pyrene	4.76E-01	6.1E-07	3.8E-07			9.9E-07
Bis(2-ethylhexyl)phthalate	6.56E+00	1.6E-08	1.0E-08			2.6E-08
Dibenzo(a,h)anthracene	2.90E-01	3.7E-07	2.3E-07			6.0E-07
Tetrachloroethene	1.62E-01					
Total pathway risk[c]		3.1E-06	2.5E-06	4.9E-09	7.5E-10	5.6E-06[d]
			SY-200			
Inorganics						
Cadmium	3.24E-01			3.0E-11		3.0E-11
Manganese	7.32E+02					
Mercury	2.17E+01					
Organics						
Aroclor-1254	3.09E-01	4.2E-07	2.6E-07			6.8E-07
Aroclor-1260	4.25E-01	5.7E-07	3.6E-07			9.3E-07
Benzo(a)anthracene	4.97E-01	6.3E-08	4.0E-08			1.0E-07

Table 5.5 (continued)

Analyte	UCL95[a] (mg/kg; pCi/g)	Ingestion risk	Dermal risk	Inhalation risk	External exposure risk	Total risk[b]
Benzo(a)pyrene	4.34E-01	5.5E-07	3.5E-07			9.0E-07
Benzo(b)fluoranthene	3.23E-01	4.1E-08	2.6E-08			6.7E-08
Dibenzo(a,h)anthracene	1.20E-01	1.5E-07	9.7E-08			2.5E-07
Total pathway risk[c]		1.8E-06	1.1E-06	3.0E-11		2.9E-06[d]
			SA-1			
Inorganics						
Barium	2.34E+02					
Beryllium	1.20E+00	9.0E-07	1.1E-06	1.5E-10		2.0E-06
Cadmium	3.31E+00			3.1E-10		3.1E-10
Chromium VI	3.59E+01			2.2E-08		2.2E-08
Manganese	1.20E+03					
Mercury	9.65E-01					
Nickel	3.51E+01					
Uranium (soluble salts)	1.53E+01					
Radionuclides						
^{226}Ra	3.22E+00	1.2E-07		3.9E-04	8.8E-05	4.8E-04
^{234}U	5.15E+00	2.6E-08		3.6E-09	7.1E-10	3.0E-08
^{238}U	5.11E+00	4.5E-08		7.2E-09	8.4E-07	8.9E-07
Organics						
Benzo(a)anthracene	4.16E-01	5.3E-08	3.4E-08			8.7E-08
Benzo(a)pyrene	3.61E-01	4.6E-07	2.9E-07			7.5E-07
Benzo(b)fluoranthene	3.76E-01	4.8E-08	3.0E-08			7.8E-08
Indeno(1,2,3-cd)pyrene	2.60E-01	3.3E-08	2.1E-08			5.4E-08
Total pathway risk[c]		1.7E-06	1.5E-06	3.9E-04	8.9E-05	4.8E-04[d]

[a]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 limit on the mean concentration (EPA 1989b); units of measure are mg/kg for inorganics and organics, and pCi/g for radionuclides.

[b]The sum of the ingestion risk, dermal risk, inhalation risk, and external exposure to radionuclides risk for each analyte.

[c]The sum of the risks from all analytes for each pathway.

[d]The sum of the risks from all analytes across all pathways.

Table 5.6. Hazard quotients for noncarcinogenic BCV OU 2 soil COPCs—industrial scenario

Analyte	UCL95[a] (mg/kg)	Ingestion HQ	Dermal HQ	Inhalation HQ	Total HI[b]
		RSA			
Inorganics					
Barium	1.15E+02	8.1E-04	5.1E-04	3.4E-05	1.4E-03
Beryllium	1.05E+00	1.0E-04	1.3E-04		2.3E-04
Cadmium	4.93E+00	2.4E-03	2.5E-03		5.0E-03
Manganese	8.99E+02	3.1E-03	4.0E-03	2.7E-03	9.8E-03
Mercury	2.00E+00	3.3E-03	1.4E-03	9.9E-07	4.6E-03
Nickel	4.61E+01	1.1E-03	1.4E-03		2.6E-03
Uranium (soluble salts)	7.36E+00	1.2E-03	1.5E-03		2.7E-03
Organics					
1,2,4-Trichlorobenzene	4.31E+00	2.1E-04	3.2E-04	2.2E-04	7.5E-04
1,2-Dichloroethene (total)	7.22E-02	3.9E-06	2.5E-06		6.4E-06
Aroclor-1254	9.86E-01				
Benzo(a)pyrene	4.76E-01				
Bis(2-ethylhexyl)phthalate	6.56E+00	1.6E-04	1.0E-04		2.6E-04
Dibenzo(a,h)anthracene	2.90E-01				
Tetrachloroethene	1.62E-01	7.9E-06	5.0E-06		1.3E-05
Total pathway HI[c]		1.2E-02	1.2E-02	2.9E-03	2.7E-02[d]
		SY-200			
Inorganics					
Cadmium	3.24E-01	1.6E-04	1.7E-04		3.3E-04
Manganese	7.32E+02	2.6E-03	3.2E-03	2.2E-03	8.0E-03
Mercury	2.17E+01	3.5E-02	1.5E-02	1.1E-05	5.0E-02
Organics					
Aroclor-1254	3.09E-01				
Aroclor-1260	4.25E-01				
Benzo(a)anthracene	4.97E-01				
Benzo(a)pyrene	4.34E-01				
Benzo(b)fluoranthene	3.23E-01				
Dibenzo(a,h)anthracene	1.20E-01				

Table 5.6 (continued)

Analyte	UCL95[a] (mg/kg)	Ingestion HQ	Dermal HQ	Inhalation HQ	Total HI[b]
Total pathway HI[c]		3.8E-02	1.8E-02	2.2E-03	5.9E-02[d]
		SA-1			
Inorganics					
Barium	2.34E+02	1.6E-03	1.0E-03	6.9E-05	2.7E-03
Beryllium	1.20E+00	1.2E-04	1.5E-04		2.6E-04
Cadmium	3.31E+00	1.6E-03	1.7E-03		3.3E-03
Chromium VI	3.59E+01	3.5E-03	2.1E-03		5.6E-03
Manganese	1.20E+03	4.2E-03	5.3E-03	3.5E-03	1.3E-02
Mercury	9.65E-01	1.6E-03	6.6E-04	4.8E-07	2.2E-03
Nickel	3.51E+01	8.6E-04	1.1E-03		1.9E-03
Uranium (soluble salts)	1.53E+01	2.5E-03	3.2E-03		5.7E-03
Organics					
Benzo(a)anthracene	4.16E-01				
Benzo(a)pyrene	3.61E-01				
Benzo(b)fluoranthene	3.76E-01				
Indeno(1,2,3-cd)pyrene	2.60E-01				
Total pathway HI[c]		1.6E-02	1.5E-02	3.6E-03	3.5E-02[d]

[a]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b).
[b]The sum of the ingestion HQ, dermal HQ, and inhalation HQ for each analyte; the HI is the sum of individual HQs.
[c]The sum of the HQs from all analytes for each pathway.
[d]The sum of the HQs from all analytes across all pathways.

The inhalation (dust, VOCs) pathway could only be evaluated (risk/HQ) for those COPCs with an inhalation SF or RfD. (Refer to Tables C.23–C.25.) The inhalation exposure pathway was evaluated for both inhalation of soil particulates (dust) and for inhalation of VOCs in soil. The ingestion pathway (for soil and vegetables/fruits) was evaluated for all COPCs when possible (i.e., when oral SFs or RfDs were available; refer to Tables C.23–C.25). The external exposure to radionuclides in the soil pathway was evaluated for all radionuclide COPCs.

5.5.3.1 Carcinogenic risk characterization for the BCV OU 2 COPCs —residential

Table 5.7 lists the risk estimates for the exposure of a resident to the carcinogenic BCV OU 2 soil COPCs via the four primary exposure pathways listed earlier; the carcinogenic risks from exposure to COPCs via ingestion of homegrown vegetables/fruits pathway are presented in Table 5.8. The results shown in Table 5.7 are for the ingestion, dermal contact, inhalation, and external exposure pathways for the BCV OU 2 soils.

The risks from exposure to individual analytes (refer to Table 5.7) are $\leq$ 8.0E-06 for all three areas (i.e., RSA, SY-200, and SA-1), with the exception of risks from exposure to ^{226}Ra in SA-1 and risks from exposure to Aroclor-1254 in the RSA. The cumulative pathway risks for the RSA and SY-200 (i.e., the sum of the risks from all analytes across all exposure pathways) are 3.6E-05 and 2.0E-05, respectively. The cumulative pathway risk for SA-1 is 1.1E-03; the ^{226}Ra COC is driving this risk via exposure by the inhalation and external exposure pathways.

The COCs that are the main contributors (i.e., that have individual risks $\geq$ 1.0E-06) to the total cumulative risks are beryllium, Aroclor-1254, benzo(a)pyrene, and dibenzo(a,h)anthracene for the RSA; Aroclor-1254, Aroclor-1260, benzo(a)pyrene, and dibenzo(a,h)anthracene for the SY-200 area; and beryllium, benzo(a)pyrene, ^{238}U, and ^{226}Ra for SA-1.

Table 5.8 shows the risks due to ingestion of various types of homegrown vegetables/ fruits. The gardens are planted in the soil (depths of 0–12 ft) in the three areas (i.e., RSA, SY-200, and SA-1) of BCV OU 2 and are irrigated with the groundwater associated with each area (refer to Table 5.3 in Sect. 5.2.5.3). For the RSA area, the pathway risks from ingestion of the various homegrown produce are between 4.1E-02 and 3.7E-04; for the SY-200 area, the pathway risks are between 2.2E-05 and 2.0E-03, and risks between 1.2E-05 and 4.8E-04 are seen in the SA-1 area. The main contributors to these pathway risks are beryllium, ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{234}U, ^{235}U, ^{238}U, Aroclor-1254, Aroclor-1260, benzo(a)anthracene, benzo(a)pyrene, carbon tetrachloride, and dibenzo(a,h)anthracene. Refer to Table C.20 and Sect. 5.5.4 for quantitative information concerning the relative contributions of these vegetable COCs from groundwater versus soil contamination.

5.5.3.2 Noncarcinogenic HQ characterization for the BCV OU 2 COPCs —residential

Table 5.9 lists the HQ estimates for the exposure of a resident to the BCV OU 2 soil noncarcinogenic COPCs via the incidental ingestion, dermal contact, and inhalation pathways. The HQs from exposure to individual analytes are all less than 1.0 for all three areas (i.e.,

Table 5.7. Carcinogenic risks for BCV OU 2 soil COPCs—residential scenario

Analyte	UCL95[a] (mg/kg; pCi/g)	Ingestion risk	Dermal risk	Inhalation risk	External exposure risk	Total risk[b]
		RSA				
Inorganics						
Barium	1.15E+02					
Beryllium	1.05E+00	7.1E-06	3.2E-06	3.9E-10		1.0E-05
Cadmium	4.93E+00			1.3E-09		1.3E-09
Manganese	8.99E+02					
Mercury	2.00E+00					
Nickel	4.61E+01					
Uranium (soluble salts)	7.36E+00					
Radionuclides						
^{232}Th	3.09E+00	4.7E-08		3.9E-09	1.8E-09	5.3E-08
^{234}U	2.81E+00	5.7E-08		3.3E-09	1.9E-09	6.2E-08
Organics						
1,2,4-Trichlorobenzene	4.31E+00					
1,2-Dichloroethene (total)	7.22E-02					
Aroclor-1254	9.86E-01	1.2E-05	2.6E-06			1.5E-05
Benzo(a)pyrene	4.76E-01	5.4E-06	1.2E-06			6.6E-06
Bis(2-ethylhexyl)phthalate	6.56E+00	1.4E-07	3.2E-08			1.8E-07
Dibenzo(a,h)anthracene	2.90E-01	3.3E-06	7.4E-07			4.1E-06
Tetrachloroethene	1.62E-01					
Total pathway risk[c]		2.8E-05	7.8E-06	9.0E-09	3.8E-09	3.6E-05[d]
		SY-200				
Inorganics						
Cadmium	3.24E-01			8.7E-11		8.7E-11
Manganese	7.32E+02					
Mercury	2.17E+01					

Table 5.7 (continued)

Analyte	UCL95[a] (mg/kg; pCi/g)	Ingestion risk	Dermal risk	Inhalation risk	External exposure risk	Total risk[b]
Organics						
Aroclor-1254	3.09E-01	3.7E-06	8.3E-07			4.6E-06
Aroclor-1260	4.25E-01	5.1E-06	1.1E-06			6.3E-06
Benzo(a)anthracene	4.97E-01	5.7E-07	1.3E-07			6.9E-07
Benzo(a)pyrene	4.34E-01	5.0E-06	1.1E-06			6.1E-06
Benzo(b)fluoranthene	3.23E-01	3.7E-07	8.2E-08			4.5E-07
Dibenzo(a,h)anthracene	1.20E-01	1.4E-06	3.1E-07			1.7E-06
Total pathway risk[c]		1.6E-05	3.6E-06	8.7E-11		2.0E-05[d]
		SA-1				
Inorganics						
Barium	2.34E+02					
Beryllium	1.20E+00	8.0E-06	3.6E-06	4.4E-10		1.2E-05
Cadmium	3.31E+00			8.9E-10		8.9E-10
Chromium VI	3.59E+01			6.5E-08		6.5E-08
Manganese	1.20E+03					
Mercury	9.65E-01					
Nickel	3.51E+01					
Uranium (soluble salts)	1.53E+01					
Radionuclides						
^{226}Ra	3.22E+00	4.9E-07		6.5E-04	4.4E-04	1.1E-03
^{234}U	5.15E+00	1.0E-07		6.1E-09	3.6E-09	1.1E-07
^{238}U	5.11E+00	1.8E-07		1.2E-08	4.2E-06	4.4E-06
Organics						
Benzo(a)anthracene	4.16E-01	4.8E-07	1.1E-07			5.8E-07

Table 5.7 (continued)

Analyte	UCL95[a] (mg/kg; pCi/g)	Ingestion risk	Dermal risk	Inhalation risk	External exposure risk	Total risk[b]
Benzo(a)pyrene	3.61E-01	4.1E-06	9.2E-07			5.0E-06
Benzo(b)fluoranthene	3.76E-01	4.3E-07	9.6E-08			5.3E-07
Indeno(1,2,3-cd)pyrene	2.60E-01	3.0E-07	6.6E-08			3.6E-07
Total pathway risk[c]		1.4E-05	4.8E-06	6.5E-04	4.5E-04	1.1E-03[d]

[a]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b); units of measure are mg/kg for inorganics and organics, and pCi/g for radionuclides.

[b]The sum of the ingestion risk, dermal risk, inhalation risk, and external exposure to radionuclides risk for each analyte.

[c]The sum of the risks from all analytes for each pathway.

[d]The sum of the risks from all analytes across all pathways.

Table 5.8. Carcinogenic risk for BCV OU 2 COPCs—residential homegrown garden scenario

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Fruit conc. (mg/kg; pCi/g)[a]	Ingestion risk
				RSA						
Inorganics										
Antimony	1.76E-01		8.61E-05		5.88E-02		5.88E-02		5.88E-02	
Arsenic	1.92E-01		8.53E-05		6.41E-02		6.41E-02		6.41E-02	
Barium	5.75E-01		5.75E-01		5.75E-01		5.75E-01		5.75E-01	
Beryllium	1.89E-03	6.6E-06	4.94E-04	1.7E-06	9.57E-04	3.4E-06	9.57E-04	3.4E-06	9.57E-04	1.8E-06
Cadmium	1.49E+00		1.48E+00		1.48E+00		1.48E+00		1.48E+00	
Chromium VI	1.00E-01		1.11E-06		3.34E-02		3.34E-02		3.34E-02	
Manganese	4.77E+01		2.70E+01		3.39E+01		3.39E+01		3.39E+01	
Mercury	7.60E-01		7.60E-01		7.60E-01		7.60E-01		7.60E-01	
Nickel	8.76E-01		8.76E-01		8.76E-01		8.76E-01		8.76E-01	
Nitrate	2.76E+02		0.00E+00		9.19E+01		9.19E+01		9.19E+01	
Uranium (soluble salts)	3.14E-02		1.84E-02		2.27E-02		2.27E-02		2.27E-02	
Radionuclides										
^{137}Cs	3.11E+02	7.3E-03	2.76E-02	6.5E-07	1.04E+02	2.4E-03	1.04E+02	2.4E-03	1.04E+02	1.3E-03
^{90}Sr	6.54E+02	2.0E-02	5.76E+00	1.7E-04	2.22E+02	6.7E-03	2.22E+02	6.7E-03	2.22E+02	3.5E-03
^{99}Tc	1.30E+04	1.4E-02	1.43E+02	1.6E-04	4.42E+03	4.8E-03	4.42E+03	4.8E-03	4.42E+03	2.5E-03
^{232}Th	1.30E-02	1.3E-07	1.30E-02	1.3E-07	1.30E-02	1.3E-07	1.30E-02	1.3E-07	1.30E-02	6.9E-08
^{234}U	4.38E+00	5.9E-05	7.51E-03	1.0E-07	1.47E+00	2.0E-05	1.47E+00	2.0E-05	1.47E+00	1.0E-05
^{238}U	4.34E+00	1.0E-04	4.82E-04	1.1E-08	1.45E+00	3.4E-05	1.45E+00	3.4E-05	1.45E+00	1.8E-05
Organics										
1,2,4-Trichlorobenzene	1.38E-01		1.38E-01		1.38E-01		1.38E-01		1.38E-01	
1,2-Dichloroethene (total)	2.30E-01		1.09E-01		1.49E-01		1.49E-01		1.49E-01	
Aroclor-1254	3.06E-03	1.9E-05	3.06E-03	1.9E-05	3.06E-03	1.9E-05	3.06E-03	1.9E-05	3.06E-03	1.0E-05
Benzo(a)pyrene	1.43E-03	8.5E-06	1.43E-03	8.5E-06	1.43E-03	8.5E-06	1.43E-03	8.5E-06	1.43E-03	4.5E-06
Bis(2-ethylhexyl)phthalate	1.77E-04	2.0E-09	1.77E-04	2.0E-09	1.77E-04	2.0E-09	1.77E-04	2.0E-09	1.77E-04	1.1E-09
Carbon tetrachloride	1.74E-02	1.8E-06	2.22E-04	2.3E-08	5.95E-03	6.3E-07	5.95E-03	6.3E-07	5.95E-03	3.3E-07

Table 5.8 (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Fruit conc. (mg/kg; pCi/g)[a]	Ingestion risk
Dibenzo(a,h)anthracene	1.60E-03	9.5E-06	1.60E-03	9.5E-06	1.60E-03	9.5E-06	1.60E-03	9.5E-06	1.60E-03	5.0E-06
Tetrachloroethene	4.86E-02		4.86E-02		4.86E-02		4.86E-02		4.86E-02	
Total pathway risk[b]		4.1E-02		3.7E-04		1.4E-02		1.4E-02		7.4E-03
				SY-200						
Inorganics										
Cadmium	9.72E-02		9.72E-02		9.72E-02		9.72E-02		9.72E-02	
Chromium VI	1.18E-01		1.31E-06		3.92E-02		3.92E-02		3.92E-02	
Manganese	5.77E+01		2.20E+01		3.39E+01		3.39E+01		3.39E+01	
Mercury	7.52E+00		7.52E+00		7.52E+00		7.52E+00		7.52E+00	
Radionuclides										
^{234}U	4.65E+01	6.2E-04	5.16E-03	6.9E-08	1.55E+01	2.1E-04	1.55E+01	2.1E-04	1.55E+01	1.1E-04
^{235}U	2.70E+00	3.6E-05	3.00E-04	4.0E-09	9.01E-01	1.2E-05	9.01E-01	1.2E-05	9.01E-01	6.4E-06
^{238}U	5.40E+01	1.3E-03	6.00E-03	1.4E-07	1.80E+01	4.2E-04	1.80E+01	4.2E-04	1.80E+01	2.2E-04
Organics										
Aroclor-1254	9.58E-04	6.0E-06	9.58E-04	6.0E-06	9.58E-04	6.0E-06	9.58E-04	6.0E-06	9.58E-04	3.2E-06
Aroclor-1260	3.02E-04	1.9E-06	3.02E-04	1.9E-06	3.02E-04	1.9E-06	3.02E-04	1.9E-06	3.02E-04	9.9E-07
Benzo(a)anthracene	2.78E-03	1.7E-06	2.78E-03	1.7E-06	2.78E-03	1.7E-06	2.78E-03	1.7E-06	2.78E-03	8.7E-07
Benzo(a)pyrene	1.30E-03	7.7E-06	1.30E-03	7.7E-06	1.30E-03	7.7E-06	1.30E-03	7.7E-06	1.30E-03	4.1E-06
Benzo(b)fluoranthene	9.69E-04	5.8E-07	9.69E-04	5.8E-07	9.69E-04	5.8E-07	9.69E-04	5.8E-07	9.69E-04	3.0E-07
Bis(2-ethylhexyl)phthalate	2.52E-02	2.9E-07	3.02E-08	3.4E-13	8.40E-03	9.6E-08	8.40E-03	9.6E-08	8.40E-03	5.0E-08
Chloroform	6.49E-03	3.2E-08	1.96E-04	9.7E-10	2.29E-03	1.1E-08	2.29E-03	1.1E-08	2.29E-03	6.0E-09
Dibenzo(a,h)anthracene	6.60E-04	3.9E-06	6.60E-04	3.9E-06	6.60E-04	3.9E-06	6.60E-04	3.9E-06	6.60E-04	2.1E-06
Total pathway risk[b]		2.0E-03		2.2E-05		6.7E-04		6.7E-04		3.5E-04
				SA-1						

Table 5.8 (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Vegetable conc. (mg/kg; pCi/g)[a]	Ingestion risk	Fruit conc. (mg/kg; pCi/g)[a]	Ingestion risk
Inorganics										
Barium	1.17E+00		1.17E+00		1.17E+00		1.17E+00		1.17E+00	
Beryllium	2.22E-03	7.8E-06	5.64E-04	2.0E-06	1.12E-03	3.9E-06	1.12E-03	3.9E-06	1.12E-03	2.1E-06
Cadmium	1.01E+00		9.93E-01		9.97E-01		9.97E-01		9.97E-01	
Chromium VI	8.98E-03		8.98E-03		8.98E-03		8.98E-03		8.98E-03	
Manganese	3.64E+01		3.60E+01		3.61E+01		3.61E+01		3.61E+01	
Mercury	3.67E-01		3.67E-01		3.67E-01		3.67E-01		3.67E-01	
Nickel	6.67E-01		6.67E-01		6.67E-01		6.67E-01		6.67E-01	
Nitrate	1.65E+02		0.00E+00		5.50E+01		5.50E+01		5.50E+01	
Uranium (soluble salts)	3.83E-02		3.83E-02		3.83E-02		3.83E-02		3.83E-02	
Vanadium	2.32E-02		1.34E-06		7.75E-03		7.75E-03		7.75E-03	
Radionuclides										
^{226}Ra	4.51E-03	4.5E-07	4.51E-03	4.5E-07	4.51E-03	4.5E-07	4.51E-03	4.5E-07	4.51E-03	2.4E-07
^{234}U	1.58E+01	2.1E-04	1.46E-02	2.0E-07	5.28E+00	7.1E-05	5.28E+00	7.1E-05	5.28E+00	3.7E-05
^{238}U	1.07E+01	2.5E-04	1.40E-02	3.3E-07	3.58E+00	8.4E-05	3.58E+00	8.4E-05	3.58E+00	4.4E-05
1,2-Dichloroethene (total)	1.04E-01		6.11E-03		3.89E-02		3.89E-02		3.89E-02	
Benzo(a)anthracene	2.33E-03	1.4E-06	2.33E-03	1.4E-06	2.33E-03	1.4E-06	2.33E-03	1.4E-06	2.33E-03	7.3E-07
Benzo(a)pyrene	1.08E-03	6.4E-06	1.08E-03	6.4E-06	1.08E-03	6.4E-06	1.08E-03	6.4E-06	1.08E-03	3.4E-06
Benzo(b)fluoranthene	1.13E-03	6.7E-07	1.13E-03	6.7E-07	1.13E-03	6.7E-07	1.13E-03	6.7E-07	1.13E-03	3.5E-07
Bromodichloromethane	1.66E-02	8.4E-07	3.54E-04	1.8E-08	5.77E-03	2.9E-07	5.77E-03	2.9E-07	5.77E-03	1.5E-07
Indeno(1,2,3-cd)pyrene	4.42E-04	2.6E-07	4.42E-04	2.6E-07	4.42E-04	2.6E-07	4.42E-04	2.6E-07	4.42E-04	1.4E-07
Methylene chloride	2.15E-02	1.3E-07	1.51E-03	9.2E-09	8.19E-03	5.0E-08	8.19E-03	5.0E-08	8.19E-03	2.6E-08
Total pathway risk		4.8E-04		1.2E-05		1.7E-04		1.7E-04		8.9E-05

[a]The vegetable/fruit concentrations are in pCi/g for radionuclides, and in mg/kg for inorganic and organic analytes.
[b]The sum of the risks from all analytes for ingestion of each vegetable/fruit-type.

Table 5.9. Hazard quotients for noncarcinogenic BCV OU 2 soil COPCs—residential scenario

Analyte	UCL95[a] (mg/kg)	Ingestion HQ	Dermal HQ	Inhalation HQ	Total HI[b]
		RSA			
Inorganics					
Barium	1.15E+02	6.0E-03	1.3E-03	8.3E-05	7.4E-03
Beryllium	1.05E+00	7.7E-04	3.4E-04		1.1E-03
Cadmium	4.93E+00	1.8E-02	6.7E-03		2.5E-02
Manganese	8.99E+02	2.3E-02	1.0E-02	6.5E-03	4.0E-02
Mercury	2.00E+00	2.4E-02	3.6E-03	2.4E-06	2.8E-02
Nickel	4.61E+01	8.4E-03	3.8E-03		1.2E-02
Uranium (soluble salts)	7.36E+00	9.0E-03	4.0E-03		1.3E-02
Organics					
1,2,4-Trichlorobenzene	4.31E+00	1.6E-03	8.4E-04	5.4E-04	2.9E-03
1,2-Dichloroethene (total)	7.22E-02	2.9E-05	6.5E-06		3.6E-05
Aroclor-1254	9.86E-01				
Benzo(a)pyrene	4.76E-01				
Bis(2-ethylhexyl)phthalate	6.56E+00	1.2E-03	2.7E-04		1.5E-03
Dibenzo(a,h)anthracene	2.90E-01				
Tetrachloroethene	1.62E-01	5.9E-05	1.3E-05		7.2E-05
Total pathway HI[c]		9.3E-02	3.1E-02	7.1E-03	1.3E-01[d]
		SY-200			
Inorganics					
Cadmium	3.24E-01	1.2E-03	4.4E-04		1.6E-03
Manganese	7.32E+02	1.9E-02	8.5E-03	5.3E-03	3.3E-02
Mercury	2.17E+01	2.6E-01	3.9E-02	2.6E-05	3.0E-01
Organics					
Aroclor-1254	3.09E-01				
Aroclor-1260	4.25E-01				
Benzo(a)anthracene	4.97E-01				
Benzo(a)pyrene	4.34E-01				

Table 5.9 (continued)

Analyte	UCL95[a] (mg/kg)	Ingestion HQ	Dermal HQ	Inhalation HQ	Total HI[b]
Benzo(b)fluoranthene	3.23E-01				
Dibenzo(a,h)anthracene	1.20E-01				
Total pathway HI[c]		2.8E-01	4.8E-02	5.3E-03	3.4E-01[d]
		SA-1			
Inorganics					
Barium	2.34E+02	1.2E-02	2.7E-03	1.7E-04	1.5E-02
Beryllium	1.20E+00	8.7E-04	3.9E-04		1.3E-03
Cadmium	3.31E+00	1.2E-02	4.5E-03		1.7E-02
Chromium VI	3.59E+01	2.6E-02	5.5E-03		3.2E-02
Manganese	1.20E+03	3.1E-02	1.4E-02	8.6E-03	5.4E-02
Mercury	9.65E-01	1.2E-02	1.7E-03	1.2E-06	1.4E-02
Nickel	3.51E+01	6.4E-03	2.9E-03		9.3E-03
Uranium (soluble salts)	1.53E+01	1.9E-02	8.3E-03		2.7E-02
Organics					
Benzo(a)anthracene	4.16E-01				
Benzo(a)pyrene	3.61E-01				
Benzo(b)fluoranthene	3.76E-01				
Indeno(1,2,3-cd)pyrene	2.60E-01				
Total pathway HI[c]		1.2E-01	4.0E-02	8.8E-03	1.7E-01[d]

[a]The concentration listed in this column is actually the smallest of two values: the maximum detected concentration vs the UCL95 on the mean concentration (EPA 1989b).
[b]The sum of the ingestion HQ, dermal HQ, and inhalation HQ for each analyte; the HI is the sum of individual HQs.
[c]The sum of the HQs from all analytes for each pathway.
[d]The sum of the HQs from all analytes across all pathways.

RSA, SY-200, and SA-1). In addition, the cumulative pathway HIs (i.e., the sum of the HQs from all analytes across all pathways) are also less than 1.0. Therefore, no noncarcinogenic COCs are identified for the residential exposure scenario via the four primary exposure pathways listed earlier.

Table 5.10 shows the HQs due to ingestion of various types of homegrown vegetables/fruits. The gardens are planted in the soil (depths of 0–12 ft) in the three areas (i.e., RSA, SY-200, and SA-1) of BCV OU 2 and are irrigated with the groundwater associated with each area (refer to Table 5.3 in Sect. 5.2.5.3). For the RSA, the pathway HIs from ingestion of the various homegrown produce are between 13 and 31; for the SY-200 area, the pathway HIs are between 32 and 70, and pathway HIs between 11 and 20 are seen in SA-1. The main contributors to these pathway HIs are arsenic, cadmium, manganese, and mercury.

5.5.4 Risk Characterization Summary

The results of the carcinogenic risk (Tables 5.5, 5.7, and 5.8) and noncarcinogenic HI (e.g., systemic toxicity) (Tables 5.6, 5.9, and 5.10) assessments for the BCV OU 2 COPCs are summarized in Tables 5.11–5.14. Tables 5.11 and 5.12 contain the BCV OU 2 contaminants of concern (COCs) that have a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0 for the industrial worker and residential land uses, respectively. The results summarized in Tables 5.13 and 5.14 are the cumulative risks and HIs for the industrial worker and residential scenarios, respectively.

Industrial Worker—Individual Analyte Risks/HQs. For the industrial worker land use scenario (Table 5.11), two carcinogenic COCs are identified for the RSA (Aroclor-1254 and beryllium); no carcinogenic COCs are identified for the SY-200 area; and two carcinogenic COCs are identified for SA-1 (beryllium and ^{226}Ra). Radium-226 (SA-1) is the only COC identified with an individual risk greater than 1.0E-04 under the industrial worker scenario. No noncarcinogenic COCs are identified for any of the three areas under this industrial land use scenario (i.e., no HQs greater than 1.0 were found for the COPCs; refer to Table 5.11).

Resident—Individual Analyte Risks/HQs. For the residential land use scenario (Table 5.12a) and for the four primary exposure pathways, four carcinogenic COCs are identified for the RSA area (beryllium, Aroclor-1254, benzo(a)pyrene, and dibenzo(a,h)anthracene); four carcinogenic COCs are identified for the SY-200 area (Aroclor-1254, Aroclor-1260, benzo(a)pyrene, and, dibenzo(a,h)anthracene); and four carcinogenic COCs are identified for the SA-1 area (beryllium, ^{226}Ra, ^{238}U, and benzo(a)pyrene). Radium-226 is the only COC identified with an individual risk greater than 1.0E-04 under the residential scenario (SA-1). No noncarcinogenic COCs are identified for any of the three areas under this residential land use scenario (i.e., no HQs greater than 1.0 were found for the COPCs; refer to Table 5.12a).

Resident/Garden—Individual Analyte Risks/HQs. For the residential land use scenario (Table 5.12b) and for the ingestion of homegrown fruits/vegetables pathway, many COCs were identified as having risks greater than 1.0E-06 and/or HQs greater than 1.0. (Refer to Table 5.12b.) In general, the leafy vegetables show the highest risks and HQs when compared to the other vegetable/fruit types; therefore, this vegetable type will be discussed further

Table 5.10. Hazard quotients for noncarcinogenic BCV OU 2 COPCs—residential homegrown garden scenario

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ
				RSA						
Inorganics										
Antimony	1.76E-01	8.4E-01	8.61E-05	4.1E-04	5.88E-02	2.8E-01	5.88E-02	2.8E-01	5.88E-02	1.5E-01
Arsenic	1.92E-01	1.2E+00	8.53E-05	5.4E-04	6.41E-02	4.1E-01	6.41E-02	4.1E-01	6.41E-02	2.1E-01
Barium	5.75E-01	1.6E-02	5.75E-01	1.6E-02	5.75E-01	1.6E-02	5.75E-01	1.6E-02	5.75E-01	8.2E-03
Beryllium	1.89E-03	7.2E-04	4.94E-04	1.9E-04	9.57E-04	3.6E-04	9.57E-04	3.6E-04	9.57E-04	1.9E-04
Cadmium	1.49E+00	5.7E+00	1.48E+00	5.6E+00	1.48E+00	5.6E+00	1.48E+00	5.6E+00	1.48E+00	3.0E+00
Chromium VI	1.00E-01	3.8E-02	1.11E-06	4.2E-07	3.34E-02	1.3E-02	3.34E-02	1.3E-02	3.34E-02	6.7E-03
Manganese	4.77E+01	1.8E+01	2.70E+01	1.0E+01	3.39E+01	1.3E+01	3.39E+01	1.3E+01	3.39E+01	6.8E+00
Mercury	7.60E-01	4.8E+00	7.60E-01	4.8E+00	7.60E-01	4.8E+00	7.60E-01	4.8E+00	7.60E-01	2.5E+00
Nickel	8.76E-01	8.3E-02	8.76E-01	8.3E-02	8.76E-01	8.3E-02	8.76E-01	8.3E-02	8.76E-01	4.4E-02
Nitrate	2.76E+02	3.3E-01	0.00E+00	0.0E+00	9.19E+01	1.1E-01	9.19E+01	1.1E-01	9.19E+01	5.7E-02
Uranium (soluble salts)	3.14E-02	2.0E-02	1.84E-02	1.2E-02	2.27E-02	1.4E-02	2.27E-02	1.4E-02	2.27E-02	7.5E-03
Organics										
1,2,4-Trichlorobenzene	1.38E-01	2.6E-02	1.38E-01	2.6E-02	1.38E-01	2.6E-02	1.38E-01	2.6E-02	1.38E-01	1.4E-02
1,2-Dichloroethene (total)	2.30E-01	4.9E-02	1.09E-01	2.3E-02	1.49E-01	3.1E-02	1.49E-01	3.1E-02	1.49E-01	1.7E-02
Aroclor-1254	3.06E-03		3.06E-03		3.06E-03		3.06E-03		3.06E-03	
Benzo(a)pyrene	1.43E-03		1.43E-03		1.43E-03		1.43E-03		1.43E-03	
Bis(2-ethylhexyl)phthalate	1.77E-04	1.7E-05	1.77E-04	1.7E-05	1.77E-04	1.7E-05	1.77E-04	1.7E-05	1.77E-04	8.8E-06
Carbon tetrachloride	1.74E-02	4.7E-02	2.22E-04	6.0E-04	5.95E-03	1.6E-02	5.95E-03	1.6E-02	5.95E-03	8.5E-03

Table 5.10 (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ
Dibenzo(a,h)anthracene	1.60E-03		1.60E-03		1.60E-03		1.60E-03		1.60E-03	
Tetrachloroethene	4.86E-02	9.2E-03	4.86E-02	9.2E-03	4.86E-02	9.2E-03	4.86E-02	9.2E-03	4.86E-02	4.8E-03
Total pathway HI[a]		3.1E+01		2.1E+01		2.4E+01		2.4E+01		1.3E+01
				SY-200						
Inorganics										
Cadmium	9.72E-02	1.8E-01	9.72E-02	1.8E-01	9.72E-02	1.8E-01	9.72E-02	1.8E-01	9.72E-02	9.7E-02
Chromium VI	1.18E-01	4.5E-02	1.31E-06	5.0E-07	3.92E-02	1.5E-02	3.92E-02	1.5E-02	3.92E-02	7.8E-03
Manganese	5.77E+01	2.2E+01	2.20E+01	8.4E+00	3.39E+01	1.3E+01	3.39E+01	1.3E+01	3.39E+01	6.8E+00
Mercury	7.52E+00	4.8E+01	7.52E+00	4.8E+01	7.52E+00	4.8E+01	7.52E+00	4.8E+01	7.52E+00	2.5E+01
Organics										
Aroclor-1254	9.58E-04		9.58E-04		9.58E-04		9.58E-04		9.58E-04	
Aroclor-1260	3.02E-04		3.02E-04		3.02E-04		3.02E-04		3.02E-04	
Benzo(a)anthracene	2.78E-03		2.78E-03		2.78E-03		2.78E-03		2.78E-03	
Benzo(a)pyrene	1.30E-03		1.30E-03		1.30E-03		1.30E-03		1.30E-03	
Benzo(b)fluoranthene	9.69E-04		9.69E-04		9.69E-04		9.69E-04		9.69E-04	
Bis(2-ethylhexyl)phthalate	2.52E-02	2.4E-03	3.02E-08	2.9E-09	8.40E-03	8.0E-04	8.40E-03	8.0E-04	8.40E-03	4.2E-04
Chloroform	6.49E-03	1.2E-03	1.96E-04	3.7E-05	2.29E-03	4.3E-04	2.29E-03	4.3E-04	2.29E-03	2.3E-04
Dibenzo(a,h)anthracene	6.60E-04		6.60E-04		6.60E-04		6.60E-04		6.60E-04	
Total pathway HI[a]		7.0E+01		5.6E+01		6.1E+01		6.1E+01		3.2E+01

Table 5.10 (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ
				SA-1						
Inorganics										
Barium	1.17E+00	3.2E-02	1.17E+00	3.2E-02	1.17E+00	3.2E-02	1.17E+00	3.2E-02	1.17E+00	1.7E-02
Beryllium	2.22E-03	8.4E-04	5.64E-04	2.1E-04	1.12E-03	4.3E-04	1.12E-03	4.3E-04	1.12E-03	2.2E-04
Cadmium	1.01E+00	3.8E+00	9.93E-01	3.8E+00	9.97E-01	3.8E+00	9.97E-01	3.8E+00	9.97E-01	2.0E+00
Chromium VI	8.98E-03	3.4E-03	8.98E-03	3.4E-03	8.98E-03	3.4E-03	8.98E-03	3.4E-03	8.98E-03	1.8E-03
Manganese	3.64E+01	1.4E+01	3.60E+01	1.4E+01	3.61E+01	1.4E+01	3.61E+01	1.4E+01	3.61E+01	7.2E+00
Mercury	3.67E-01	2.3E+00	3.67E-01	2.3E+00	3.67E-01	2.3E+00	3.67E-01	2.3E+00	3.67E-01	1.2E+00
Nickel	6.67E-01	6.3E-02	6.67E-01	6.3E-02	6.67E-01	6.3E-02	6.67E-01	6.3E-02	6.67E-01	3.3E-02
Nitrate	1.65E+02	2.0E-01	0.00E+00	0.0E+00	5.50E+01	6.5E-02	5.50E+01	6.5E-02	5.50E+01	3.4E-02
Uranium (soluble salts)	3.83E-02	2.4E-02	3.83E-02	2.4E-02	3.83E-02	2.4E-02	3.83E-02	2.4E-02	3.83E-02	1.3E-02
Vanadium	2.32E-02	6.3E-03	1.34E-06	3.6E-07	7.75E-03	2.1E-03	7.75E-03	2.1E-03	7.75E-03	1.1E-03
Organics										
1,2-Dichloroethene (total)	1.04E-01	2.2E-02	6.11E-03	1.3E-03	3.89E-02	8.2E-03	3.89E-02	8.2E-03	3.89E-02	4.3E-03
Benzo(a)anthracene	2.33E-03		2.33E-03		2.33E-03		2.33E-03		2.33E-03	
Benzo(a)pyrene	1.08E-03		1.08E-03		1.08E-03		1.08E-03		1.08E-03	
Benzo(b)fluoranthene	1.13E-03		1.13E-03		1.13E-03		1.13E-03		1.13E-03	
Bromodichloromethane	1.66E-02	1.6E-03	3.54E-04	3.4E-05	5.77E-03	5.5E-04	5.77E-03	5.5E-04	5.77E-03	2.9E-04
Indeno(1,2,3-cd)pyrene	4.42E-04		4.42E-04		4.42E-04		4.42E-04		4.42E-04	

Table 5.10 (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ	Vegetable conc. (mg/kg)	Ingestion HQ
Methylene chloride	2.15E-02	6.8E-04	1.51E-03	4.8E-05	8.19E-03	2.6E-04	8.19E-03	2.6E-04	8.19E-03	1.4E-04
Total pathway HI[a]		2.0E+01		2.0E+01		2.0E+01		2.0E+01		1.1E+01

[a]The sum of the HQs from all analytes for ingestion of each vegetable/fruit type; the HI is the sum of the HQs.

Table 5.11. Summary of significant risks and hazard quotients from BCV OU 2 COCs—industrial worker scenario[a]

Analyte	Risk	HQ	Pathway[b]
	RSA		
Aroclor-1254	1.3E-06		Ingestion
Beryllium	1.0E-06		Dermal
	SA-1		
Beryllium	1.1E-06		Dermal
^{226}Ra[c]	8.8E-05		External exposure
	3.9E-04[d]		Inhalation[d]

[a]COCs reported have a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0, under the industrial worker land use scenario.
[b]This is the pathway for which the reported COC has a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0.
[c]This analyte has a risk $\geq$ 1.0E-04 under the industrial worker land use scenario.
[d]The inhalation pathway for ^{226}Ra includes contributions from inhalation of ^{222}Rn.

Table 5.12a. Summary of significant risks and hazard quotients from BCV OU 2 COCs—residential scenario[a]

Analyte	Risk	HQ	Pathway[b]
	RSA		
Beryllium	7.1E-06		Ingestion
	3.2E-06		Dermal
Aroclor-1254	1.2E-05		Ingestion
	2.6E-06		Dermal
Benzo(a)pyrene	5.4E-06		Ingestion
	1.2E-06		Dermal
Dibenzo(a,h)anthracene	3.3E-06		Ingestion
	SY-200		
Aroclor-1254	3.7E-06		Ingestion
Aroclor-1260	5.1E-06		Ingestion
	1.1E-06		Dermal
Benzo(a)pyrene	5.0E-06		Ingestion
	1.1E-06		Dermal
Dibenzo(a,h)anthracene	1.4E-06		Ingestion
	SA-1		
Beryllium	8.0E-06		Ingestion
	3.6E-06		Dermal
^{226}Ra[c]	4.4E-04		External exposure
	6.5E-04[d]		Inhalation[d]
^{238}U	4.2E-06		External Exposure
Benzo(a)pyrene	4.1E-06		Ingestion

[a]The COCs reported in this table have a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0, under the residential land use scenario; this table does not include risks/HQs from residential ingestion of homegrown vegetables/fruits.
[b]This is the pathway for which the reported COC has a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0.
[c]Those analytes marked with an asterisk (*) have a risk $\geq$ 1.0E-04, under the residential land use scenario.
[d]The inhalation pathway for radium-226 includes contributions from inhalation of radon-222.

Table 5.12b. Summary of significant risks and hazard quotients from BCV OU 2 COCs—residential ingestion of homegrown vegetables/fruits scenario[a]

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ
				RSA						
Inorganics										
Arsenic		1.2E+00								
Beryllium	6.6E-06		1.7E-06		3.4E-06		3.4E-06		1.8E-06	
Cadmium		5.7E+00		5.6E+00		5.6E+00		5.6E+00		3.0E+00
Manganese		1.8E+01		1.0E+01		1.3E+01		1.3E+01		6.8E+00
Mercury		4.8E+00		4.8E+00		4.8E+00		4.8E+00		2.5E+00
Radionuclides										
^{137}Cs	7.3E-03				2.4E-03		2.4E-03		1.3E-03	
^{90}Sr	2.0E-02		1.7E-04		6.7E-03		6.7E-03		3.5E-03	
^{99}Tc	1.4E-02		1.6E-04		4.8E-03		4.8E-03		2.5E-03	
^{234}U	5.9E-05				2.0E-05		2.0E-05		1.0E-05	
^{238}U	1.0E-04				3.4E-05		3.4E-05		1.8E-05	
Organics										
Aroclor-1254	1.9E-05		1.9E-05		1.9E-05		1.9E-05		1.0E-05	
Benzo(a)pyrene	8.5E-06		8.5E-06		8.5E-06		8.5E-06		4.5E-06	
Carbon tetrachloride	1.8E-06									
Dibenzo(a,h)anthracene	9.5E-06		9.5E-06		9.5E-06		9.5E-06		5.0E-06	
Inorganics										
Manganese		2.2E+01		8.4E+00		1.3E+01		1.3E+01		6.8E+00
Mercury		4.8E+01		4.8E+01		4.8E+01		4.8E+01		2.5E+01
Radionuclides										
^{234}U	6.2E-04				2.1E-04		2.1E-04		1.1E-04	
^{235}U	3.6E-05				1.2E-05		1.2E-05		6.4E-06	
^{238}U	1.3E-03				4.2E-04		4.2E-04		2.2E-04	

Table 5.12b (continued)

Analyte	Leafy vegetables		Root vegetables		Legume vegetables		Fruiting vegetables		Fruits	
	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ
Organics										
Aroclor-1254	6.0E-06		6.0E-06		6.0E-06		6.0E-06		3.2E-06	
Aroclor-1260	1.9E-06		1.9E-06		1.9E-06		1.9E-06			
Benzo(a)anthracene	1.7E-06		1.7E-06		1.7E-06		1.7E-06			
Benzo(a)pyrene	7.7E-06		7.7E-06		7.7E-06		7.7E-06		4.1E-06	
Dibenzo(a,h)anthracene	3.9E-06		3.9E-06		3.9E-06		3.9E-06		2.1E-06	
				SA-1						
Inorganics										
Beryllium	7.8E-06		2.0E-06		3.9E-06		3.9E-06		2.1E-06	
Cadmium		3.8E+00		3.8E+00		3.8E+00		3.8E+00		2.0E+00
Manganese		1.4E+01		1.4E+01		1.4E+01		1.4E+01		7.2E+00
Mercury		2.3E+00		2.3E+00		2.3E+00		2.3E+00		1.2E+00
Radionuclides										
^{234}U	2.1E-04				7.1E-05		7.1E-05		3.7E-05	
^{238}U	2.5E-04				8.4E-05		8.4E-05		4.4E-05	
Organics										
Benzo(a)anthracene	1.4E-06		1.4E-06		1.4E-06		1.4E-06			
Benzo(a)pyrene	6.4E-06		6.4E-06		6.4E-06		6.4E-06		3.4E-06	

[a]The COCs reported in this table have a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0, under the residential ingestion of homegrown vegetables/fruits scenario.

Table 5.13. Cumulative risk and HI summary for BCV OU 2 soil COPCs—industrial worker scenario

	Ingestion	Dermal	Inhalation	External exposure	Cumulative risk or HI
			RSA		
Pathway risk	3.1E-06	2.5E-06	4.9E-09	7.5E-10	5.6E-06
Pathway HI	1.2E-02	1.2E-02	2.9E-03		2.7E-02
			SY-200		
Pathway risk	1.8E-06	1.1E-06	3.0E-11		2.9E-06
Pathway HI	3.8E-02	1.8E-02	2.2E-03		5.9E-02
			SA-1		
Pathway risk	1.7E-06	1.5E-06	3.9E-04	8.9E-05	4.8E-04
Pathway HI	1.6E-02	1.5E-02	3.6E-03		3.5E-02

Table 5.14. Cumulative risk and HI summary for BCV OU 2 COPCs—residential scenario

	Ingestion	Dermal	Inhalation	External exposure	Cumulative risk or HI[a]	Ingestion of leafy vegetables[b]
			RSA			
Pathway risk	2.8E-05	7.8E-06	9.0E-09	3.8E-09	3.6E-05	4.1E-02
Pathway HI	9.3E-02	3.1E-02	7.1E-03		1.3E-01	3.1E+01
			SY-200			
Pathway risk	1.6E-05	3.6E-06	8.7E-11		2.0E-05	2.0E-03
Pathway HI	2.8E-01	4.8E-02	5.3E-03		3.4E-01	7.0E+01
			SA-1			
Pathway risk	1.4E-05	4.8E-06	6.5E-04	4.5E-04	1.1E-03	4.8E-04
Pathway HI	1.2E-01	4.0E-02	8.8E-03		1.7E-01	2.0E+01

[a]The cumulative risks/HIs reported in this column do not include contributions from residential ingestion of homegrown vegetables/fruits.

[b]Cumulative risks/HIs from residential ingestion of homegrown vegetables/fruits are the largest for leafy vegetables; the pathway risks/HIs for the other vegetable/fruit-types can be found in Tables 5.8 and 5.10.

herein. **Note:** the concentrations of COPCs in vegetables (i.e., CV) were calculated from exposure (i.e., uptake) of various vegetable/fruit types to the contaminated soil and groundwater associated with each area/site. (Refer to Table C.20 and Sect. 5.3.3.1.1.) Table C.20 lists the relative contributions (in percent) to the CV from soil and from groundwater. For the RSA, arsenic is a COC in leafy vegetables (Table 5.12b), but 99.96% (refer to Table C.20) of the CV due to arsenic is from direct irrigation with the RSA groundwater, not from exposure of the leafy vegetables to the contaminated soil. The same observation [i.e., that the COPC in the CV results from exposure of the leafy vegetables to the contaminated groundwater, not the soil (at $\geq$ 95%)] also holds true for the ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{234}U, ^{238}U, and carbon tetrachloride COCs listed in Table 5.12b for the RSA; similar observations can be made for SY-200 and SA-1. (refer to Tables 5.12b and C.20.) Therefore, for the RSA, for the ingestion of leafy vegetables exposure pathway, risks and/or HQs from beryllium, cadmium, manganese, mercury, Aroclor-1254, benzo(a)pyrene, and dibenzo(a,h)anthracene can be attributed to contaminated RSA soils (although these COCs in the CVs are not necessarily 100% from soil; refer to Table C.20).

The cumulative risk and cumulative HI results are summarized in Tables 5.13 and 5.14 for the industrial worker and residential land uses, respectively. The cumulative risk/HI values reported in Tables 5.13 and 5.14 do not include contributions from ingestion of fruits and vegetables. The reader should note that leafy vegetable ingestion is reported separately in Table 5.14; the risks and HQs for ingestion of this vegetable/fruit type were greater than the risks/HQs determined for ingestion of the other vegetable/fruit types (i.e., root vegetables, legumes, fruiting vegetables, and fruits).

Industrial Worker—Pathway Risks/HIs. The pathway risks/HIs (i.e., the sum of the risks/HQs from each analyte in that pathway) and the cumulative risks/HIs (i.e., the sum of the risks/HQs from all analytes across all pathways) for the industrial worker scenario are reported in Table 5.13. The exposure pathways include incidental ingestion of soil, dermal contact with the soil, inhalation of dust and VOCs in soil, and external exposure to radionuclides in the soil. The pathway risks are less than 3.1E-06 for all three areas (RSA, SY-200, and SA-1) for all pathways, with the exception of the inhalation and external exposure pathways for the SA-1 area. The cumulative risks are less than 5.6E-06 for the RSA and SY-200; the cumulative risk is greater than 1.0E-04 for SA-1. Both the pathway HIs and the cumulative HIs are all much less than 1.0 for the three areas under the industrial worker exposure scenario.

Resident/Resident Garden—Pathway Risks/HIs. The pathway risks/HIs and the cumulative risks/HIs for the residential scenario are reported in Table 5.14; the cumulative risks/HIs reported in this table do not include contributions from the vegetable/fruit ingestion pathway. The exposure pathways include incidental ingestion of soil, dermal contact with the soil, inhalation of dust and VOCs in soil, and external exposure to radionuclides in the soil; ingestion of leafy vegetables is shown separately. The pathway risks are less than 2.8E-05 for all three areas (RSA, SY-200, and SA-1) for all pathways, with the exception of the inhalation and external exposure pathways for SA-1 (and the leafy vegetable ingestion pathway for all three areas). The cumulative risks are less than 3.6E-05 for the RSA and SY-200; the cumulative risk is 1.1E-03 for SA-1. The cumulative risk estimates for each area, for the carcinogenic BCV OU 2 soil COPCs, under the residential land use scenario *and not including contributions from the vegetable/fruit ingestion pathway*, are 3.6E-05, 2.0E-05, and 1.1E-03 for the RSA, SY-200, and SA-1, respectively. (Refer to Table 5.14.) The pathway HIs and the cumulative HIs are all less than 1.0 for the three areas, under the residential exposure

scenario *and not including contributions from the vegetable/fruit ingestion pathway.* When the ingestion of homegrown vegetables/fruits pathway is considered (for leafy vegetables), cumulative risks between 4.8E-04 and 4.1E-02 and cumulative HIs between 20 and 70 are seen (refer to Table 5.14).

5.5.5 Uncertainties and Assumptions in the Baseline Risk Assessment

Risk assessment as a scientific activity is subject to uncertainty (Table C.26), although the methodology used in this BRA follows EPA guidelines. The risk evaluation in this report is subject to uncertainty pertaining to sampling and analysis, exposure assessment estimations, and availability of toxicological data.

The major assumptions used in risk assessment are (1) that contaminant concentrations detected and reported by the analytical laboratory are representative of true analyte concentrations in soils (i.e., the analyte concentration remains constant over the sampled area and the sampling and analysis time period), (2) that the intake rates and exposure parameters are representative of actual potentially exposed populations, and (3) that all contaminant exposures and intake are from the site-related exposure media (i.e., no other sources contribute to the receptor's health risk).

Even if these assumptions are true, other areas of uncertainty may apply. The toxicological data (SFs and RfDs) are frequently updated and revised, which can lead to overestimation or underestimation of risks. These values are often extrapolations from animals to humans, which also induces uncertainties in toxicity values; differences may exist in chemical absorption, metabolism, excretion, and toxic response between animals and humans. EPA takes into account differences in body weight, surface area, and pharmacokinetic relationships between animals and humans to minimize these uncertainties. Other uncertainties associated with toxicological and exposure assessments are discussed in Sects. 5.3.4 and 5.4.5.

For each exposure pathway, assumptions were made about the parameters (e.g., exposure frequency and duration), the routes of exposure, the amount of the contaminated media an individual could be exposed to, and intake rates for different routes of exposure. In the absence of site-specific data, the assumptions used in this BRA are consistent with EPA guidance (EPA 1989b, EPA 1989a, EPA 1991a, EPA 1991b, EPA 1992a). However, the residential scenario was a conservative exposure estimate with EPA-approved parameters (and default values) that may substantially overestimate the risks. Many exposure variables/ parameters recommended by EPA for the residential scenario represent 90th and 95th percentile values. When several of these upper-bound values are combined in estimating exposure for any one pathway, the resulting risks can be in excess of the 99th percentile exposure and therefore outside the range that may be reasonably expected.

The risk of increased cancer incidence from exposure to low-level radiation is estimated by application of a risk factor to either the radiation dose or the radionuclide intake. Regardless of the type of risk factor used, the same basic uncertainties remain. These uncertainties are related to the model used for determining the health effects of radiation exposure. The model most frequently used for determining risk of radiation exposure is the linear nonthreshold model which assumes there is some increased risk for any increment of radiation exposure with no threshold below which effects are not seen. This is the most conservative model for evaluating radiation risk; it uses data from high-dose radiation

exposures (such as from the survivors of the atomic bomb) and extrapolates risk from these high exposures to the low-level environment or occupational dose range. The current EPA-recommended radiation risk factors are based on the 1980 National Academy of Sciences Biological Effects of Ionizing Radiation Committee (BEIR III 1980) report. The BEIR III recommendations were increased slightly by EPA to reflect recent information on the health effects of exposure to ionizing radiation. In early 1990, the National Academy of Sciences published the results of the most recent studies of the health effects of ionizing radiation, the BEIR V report, which increases the estimates of cancer risk by a factor of 3 to 5 over the BEIR III report. These increases are based primarily on a re-evaluation of the doses received by the atomic bomb victims.

The quality of the analytical data used in risk assessment depends on the adequacy of the set of procedures that specify how samples were selected and handled (SAIC 1993b). Uncertainties associated with the data can include sampling errors, laboratory analysis errors, and data analysis errors. The quality assurance/quality control procedures (Kimbrough, Long, and McMahon 1990) are used to minimize these uncertainties which are expected to have a low effect on either overestimating or underestimating the risks.

In addition, some current analytical methods are limited in their ability to achieve detection limits appropriate for use in risk assessment. Therefore, risks may be overestimated as a result of analyte concentrations being reported at the method detection limit, which may be greater than the concentration at which adverse health effects would occur.

The more extensive the data base, the more certain are the results of the assessment. The number of samples collected (for the various media) to represent the BCV OU 2 contamination were relatively small, and it is unknown how representative the samples are of the OU. According to EPA guidance (EPA 1992d), a minimum of 20 samples are required to provide consistent estimates of the mean. In calculating the representative concentrations for each BCV OU 2 COPC, the UCL95 (or the maximum concentration if it were less than the UCL95) was used as a conservative estimate of the concentration to minimize the likelihood that exposures would be underestimated; this assumption may moderately overestimate the risks.

As mentioned previously, in the analytical analyses for metals (total metals only), risks may be overestimated because the metals that are present are conservatively assumed to be in their most toxic forms. Furthermore, not all of the BCV OU 2 COPCs (Tables 5.2 and 5.4) currently have toxicity values; this can lead to an underestimation of total risk because quantitative analysis of such chemicals is currently not possible.

In the absence of information on the toxicity of specific chemical mixtures, additive (cumulative) risks and HIs are assumed (EPA 1989b). Limitations of this approach for noncarcinogens (HI) include the following: (1) the effects of a mixture of chemicals are generally unknown; it is possible that the interactions could be *synergistic or antagonistic*; (2) the RfD/RfCs have different accuracy and precision and are not based on the same severity or effect; and (3) HI adaptivity (or CDI adaptivity) is most properly applied to compounds that induce the same effects by the same mechanism. Therefore, the potential for occurrence of noncarcinogenic effects can be overestimated for chemicals that act by different mechanisms and on different target organs.

Limitations of this additive risk approach for multiple carcinogens include (1) the SFs represent the upper 95th percentile estimate of potency; therefore, summing individual risks can result in an excessively conservative estimate of total lifetime cancer risk, and (2) the target organs of multiple carcinogens may be different, so the risks would not be additive. In the absence of data, adaptivity for risks and HIs was assumed for this BRA. However, because total risks and HIs are usually driven by a few specific chemicals, segregation of risks and HIs by target organ would not have resulted in significantly different outcomes.

5.5.5.1 RSA

Specific uncertainties and additional information associated with the risk assessment for the RSA are discussed in the following paragraphs. High concentration zones (i.e., "hot spots"), in terms of risk to human health, were evaluated for this area (0–10 ft for RSA soils). Detected and nondetected concentrations for COPCs were compared to residential ingestion of soil PRGs (at an HQ = 1.0 and/or a risk = 1.0E-06) to identify high concentration zones. Upon examination of the Aroclor-1254 (to represent PCBs) soil concentrations vs sampling locations and sampling depth intervals, no high concentration zones could be identified for this area in BCV OU 2. For Aroclor-1254, only eight data points were available; four of the eight data points had concentrations above the residential ingestion of soil PRGs, and these four concentrations were located at three different depths in three different boreholes.

Trichloroethene (TCE) is a COPC in the BCV OU 2 soils (refer to Table 5.2) and in the groundwater associated with the RSA (refer to Table 5.4). Both an oral and an inhalation SF are available for this COPC (BEIAS 1993); however, these values are not EPA-approved (i.e., EPA-accepted SFs for TCE are not listed in IRIS; EPA 1994a) and, therefore, TCE was not evaluated quantitatively in this BRA. If the currently available SFs (BEIAS 1993) were used to evaluate the risk to human health from exposure to TCE in the RSA soils, the total cumulative risk (under the residential scenario, ingestion plus inhalation plus dermal exposure to soils) from exposure to TCE (at the maximum detected soil concentration of 1.0E+02 mg/kg; refer to Table C.2) is 3.7E-05.

The PRG for TCE in groundwater is 7.7E-01 mg/L (for residential groundwater ingestion risk = 1.0E-04); TCE was detected in 82 out of 82 groundwater samples associated with the RSA (Tables C.9 and 5.4). The mean, maximum, and UCL95 concentrations for TCE in groundwater (Table C.9) are 4.4E-02 mg/L, 1.2E-01 mg/L, and 5.2E-02 mg/L, respectively. Therefore, the mean and the UCL95 concentrations of TCE in groundwater are below the PRG for risk = 1.0E-04 (i.e., 7.7E-01 mg/L).

5.5.5.2 SY-200 area

Specific uncertainties and additional information associated with the risk assessment for the SY-200 area are discussed below. High concentration zones (i.e., "hot spots"), in terms of risk to human health, were evaluated for this area (3–11 ft for SY-200 soils). Detected and nondetected concentrations for COPCs were compared to residential ingestion of soil PRGs (at an HQ = 1.0 and/or a risk = 1.0E-06) to identify high concentration zones.

Upon examination of the mercury soil concentrations versus sampling locations and sampling depth intervals, a high concentration zone for mercury could be identified on the east end of the SY-200 area; refer to Fig. 5.2. Quantitative information (for mercury) for the individual sampling depths, location (borehole), identification, and the detected or

nondetected concentrations can be found in Table C.27a. The results reported in Table C.27b show the mercury summary statistics for the soil samples within this high concentration zone area (refer to Fig. 5.2); the summary statistics include a UCL95 concentration for soil samples at three depth intervals (3–7 ft, 7–11 ft, and 3–11 ft).

Mercury was not identified as a COC in soil (Tables 5.11–5.14) for the SY-200 boundary, as defined in Sects. 3.2.4 and 5.2. When the HI for mercury was determined for this high concentration zone area in SY-200 (Fig. 5.2), under the residential exposure to soils scenario, total cumulative mercury HIs between 1.3 and 2.1 were determined (depending on sampling depth) (refer to Table C.27c). The total cumulative mercury HI under the industrial scenario did not show values greater than 1.0; pathways included in the total cumulative mercury HI are ingestion, inhalation, and dermal contact. Therefore, for the mercury "hot spot" located on the east end of the SY-200 area, at soil depths of 3–7 ft, 7–11 ft, and 3–11 ft, mercury is a COC under residential land use conditions (refer to Table C.27c).

Aroclor-1254 soil concentrations were also evaluated to identify high concentration zones in the SY-200 area. Aroclor-1254 was not identified as a COC in soil (Tables 5.11–5.14) for the SY-200 boundary, as defined in Sects. 3.2.4 and 5.2, under the industrial scenario, but was identified as a COC under the residential scenario. Upon examination of the Aroclor-1254 soil concentrations, sampling locations, and sampling depth intervals, a high concentration zone for Aroclor-1254 could be identified on the west end of the SY-200 area. (Refer to Fig. 5.3.) Quantitative information (for Aroclor-1254) for the individual sampling depths, location (borehole), sample identification, and the detected or nondetected concentrations can be found in Table C.28a. The results reported in Table C.28b show the Aroclor-1254 summary statistics for the samples within this high concentration zone area (refer to Fig. 5.3); the summary statistics include a UCL95 concentration for soil samples at three depth intervals (3–7 ft, 7–11 ft, and 3–11 ft).

When the risk for Aroclor-1254 was determined for this high concentration zone area in the SY-200 area (Fig. 5.3), under the residential exposure to soils scenario, total cumulative risks between 6.3E-07 and 2.0E-05 were determined (depending on sampling depth); refer to Table C.28c. The total cumulative risk under the industrial scenario did not show values greater than 3.0E-06; pathways included in the total cumulative risk are ingestion, inhalation, and dermal contact. Therefore, for the Aroclor-1254 "hot spot" located on the west end of the SY-200 area, at depths of 7–11 ft, Aroclor-1254 is a COC under residential and industrial land use conditions. (Refer to Table C.28c.)

Aroclor-1260 (a PCB) and benzo(a)pyrene (to represent PAHs) soil concentrations were also evaluated to identify high concentration zones in the SY-200 area. No "hot spots" could be identified; Aroclor-1260 and benzo(a)pyrene concentrations above the residential ingestion PRG of risk = 1.0E-06 were found at numerous sampling locations and sampling depths across the entire SY-200 boundary, as defined in Sects. 3.2.4 and 5.2. Beryllium soil concentrations were also evaluated to identify high concentration zones in the SY-200 area. Beryllium concentrations above the residential ingestion of soil PRG (risk = 1.0E-06) were found for all sampling locations and all depths (3–11 ft); therefore, no high concentration zones could be identified.

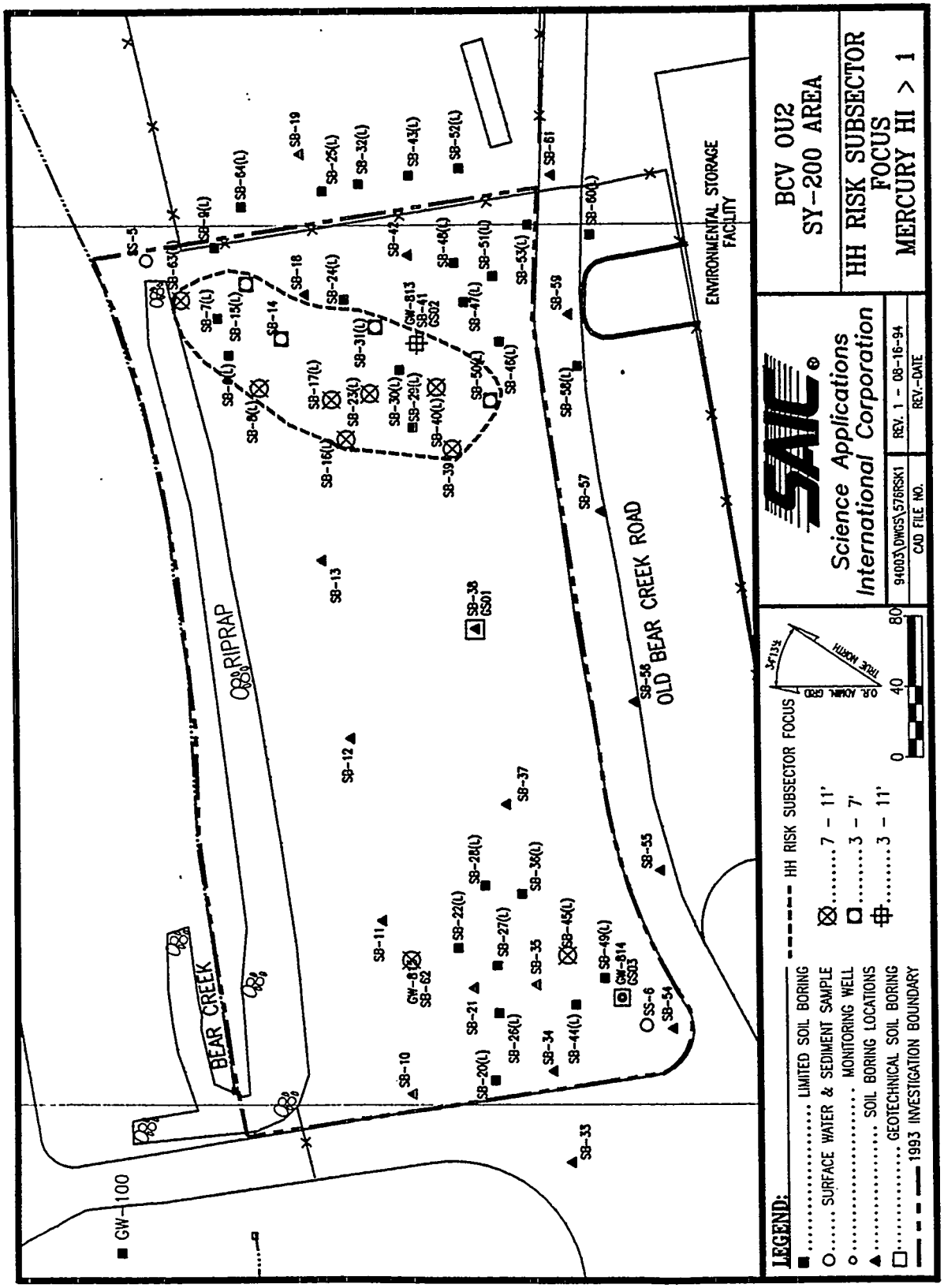


Fig. 5.2. High concentration zone for mercury in the SY-200 Yard: human health risk/HQ evaluation.

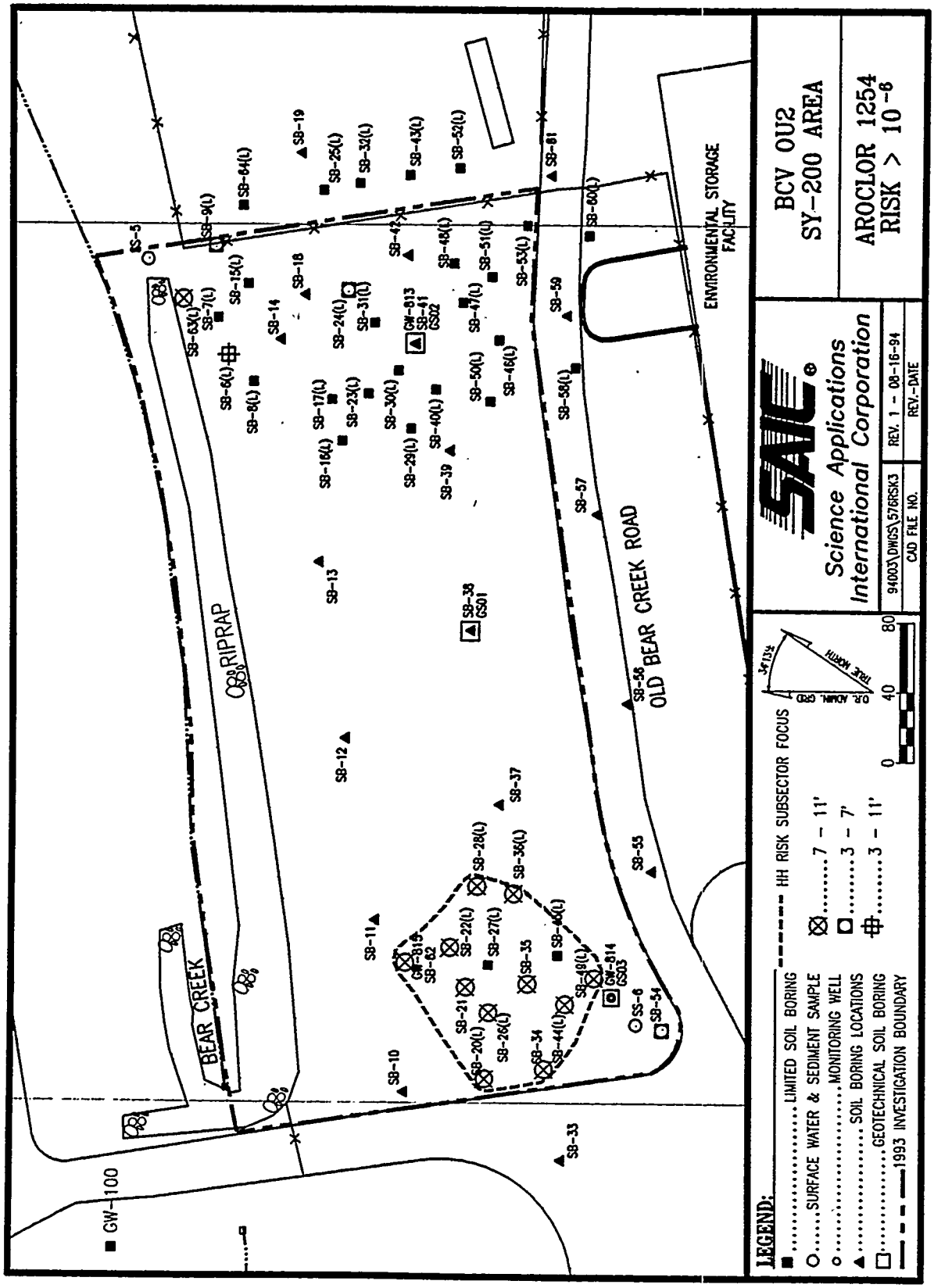


Fig. 5.3. High concentration zone for Arocior-1254 in the SY-200 Yard: human health risk/HQ evaluation.

The reader should note that the groundwater data associated with this SY-200 area were limited to four samples (refer to Sect. 3.2.3); the uncertainty associated with having few data points is in estimating a representative exposure concentration.

5.5.5.3 SA-1

Specific uncertainties and additional information associated with the risk assessment for the SA-1 area are discussed in the following paragraphs. High concentration zones (i.e., "hot spots"), in terms of risk to human health, were evaluated for this area (4.5–12 ft for SA-1 soils). Detected and nondetected concentrations for COPCs were compared to residential ingestion of soil PRGs (at a HQ = 1.0 and/or a risk = 1.0E-06) to identify high concentration zones. Upon examination of the COPC soil concentrations versus sampling locations and sampling depth intervals, no high concentration zones could be identified for this area in BCV OU 2.

Radium-226 was identified as a COC (Tables 5.11–5.14) under both the industrial and the residential land use scenarios for SA-1 (inhalation and external exposure pathways). Note: only historical soils data were available for this area, and radionuclide analyses for the historical soil data were reported as *total* radium activity (pCi/g). For this BRA, the *total* radium concentration was assigned to the ^{226}Ra isotope. (Toxicity values for ^{226}Ra are the most conservative, i.e., give the largest risk, among the radium isotopes). Radium-226 is formed from the decay of ^{234}U and ^{238}U. In general, the activity concentration of ^{226}Ra in most soils is comparable to those of ^{234}U and ^{238}U (Budavari et al. 1989, Casarett 1968); for SA-1 (refer to Table C.2) the mean concentrations for these three isotopes are similar.

A "hot spot" for ^{226}Ra could not be identified; ^{226}Ra concentrations above PRGs were seen across SA-1. In addition, for the inhalation pathway, toxicity information for ^{222}Rn was used [in accordance with EPA guidance (EPA 1991a)], because ^{222}Rn is a major daughter product of ^{226}Ra. Many conservative assumptions were made for the radium data used in the SA-1 area to evaluate human health risk; therefore, overestimation of the actual risk may occur.

Furthermore, the background level (DOE 1993) for ^{226}Ra (Copper Ridge horizon C; refer to Table C.3) is 2.11 pCi/g, and this background concentration is above both the residential and industrial PRGs (6.9E-01 pCi/g and 8.3E-01 pCi/g, respectively) for a risk of 1.0E-04; therefore, cleanup to background levels of ^{226}Ra would still leave a regulatorily unacceptable risk of greater than 1.0E-04. The UCL95 concentration used to evaluate risk from exposure to ^{226}Ra in SA-1 in this BRA was 3.22 pCi/g. (Refer to Table 5.1.) In addition (refer to Sect. 5.4.6.2.2), radium can be released into the environment in coal fly ash, and the background level of radium in industrial regions in soil is ~8.1 pCi/g (Budavari et al. 1989, Casarett 1968).

5.6 SUMMARY AND CONCLUSIONS

5.6.1 Contaminants of Potential Concern

Table 5.1 lists the BCV OU 2 soil COPCs evaluated quantitatively in this BRA. Regulatorily unacceptable carcinogenic risks (i.e., risks $\geq$ 1.0E-04) and/or noncarcinogenic

HQs (i.e., HQs $\geq$ 1.0) were found for a few of these analytes. (Refer to Tables 5.11 and 5.12.)

The soil COPC lists (Tables 5.1 and 5.2) for human health risk assessment differ from the COPCs list reported in Sect. 3.2.4 for various reasons, which include: (1) the human health risk assessment in this RI only evaluates soil depths to ~12 ft; (2) when duplicate sample data were available, a comparison was made with the original sample, and for this BRA the maximum of the two concentrations was used in the risk assessment data set; (3) a human health toxicity screening was performed on the data (refer to Sect. 5.2.3.12) and numerous analytes were eliminated from consideration in this BRA; and (4) essential nutrients were not considered in this BRA. (Refer to Sect. 5.2.3.10.)

The analytes listed in Table 5.2 are soil COPCs (with at least one detected value) for BCV OU 2 that could not be evaluated quantitatively in this BRA [i.e., no current EPA-approved SFs or RfDs exist for these analytes (EPA 1994a)]. Therefore, because these analytes could not be evaluated in terms of potential risk to human health, they are still considered COPCs for BCV OU 2.

In SA-1 (inhalation and/or external exposure pathways), ^{226}Ra was identified as showing the highest carcinogenic risk (i.e., individual risks $\geq$ 1.0E-04 for both industrial and residential land uses) and is, therefore, a COC in SA-1.

Mercury (in the high concentration zone of the SY-200 area; refer to Sect. 5.5.5.2) was identified as having an HQ slightly greater than 1.0 for the incidental ingestion of soil pathway (under residential conditions only) and is, therefore, a COC in the east end of the SY-200 area.

Arsenic, cadmium, manganese, and mercury (ingestion of homegrown vegetables/fruits) show the highest HQs (i.e., individual HIs $\geq$ 1.0) and are, therefore, COCs for BCV OU 2. Cesium-137, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of homegrown vegetables/fruits in the RSA), and ^{234}U and ^{238}U (ingestion of homegrown vegetables/fruits in SY-200 and SA-1) were identified as showing the highest carcinogenic risks (i.e., individual risks $\geq$ 1.0E-04) and are, therefore, COCs in these areas.

5.6.2 Exposure Assessment

Two exposure scenarios—a future industrial worker scenario and a future residential scenario—were evaluated in this BRA; under current land-use conditions, there are no completed exposure pathways for BCV OU 2 soils. Because of the location and current land use of BCV OU 2, an industrial worker was evaluated as the most reasonable and most likely receptor of the BCV OU 2 media in the future. This future industrial worker evaluation represents a risk estimate that is not likely to overestimate risks at BCV OU 2 under future industrial land-use conditions. A reasonable maximum exposure estimate of the risk to human receptors was evaluated using residential parameters to provide managers with potential risks that are conservative and unlikely to underestimate exposure to future receptors of the BCV OU 2 media.

The exposure routes that were evaluated for each BCV OU 2 medium (i.e., evaluated in terms of CDI, risk, and HQ for both the residential and industrial worker land uses) included incidental ingestion of soil, inhalation of dust and VOCs, dermal contact with soil,

and external exposure to radionuclides in the soil; in addition, ingestion of homegrown vegetables/fruits was evaluated for the residential scenario.

For the BCV OU 2 COC that was identified as showing the highest carcinogenic risk (i.e., ^{226}Ra, risk $\geq$ 1.0E-04; refer to Sect. 5.6.1), risks from the external exposure pathway (for ^{226}Ra) and the inhalation pathway (for ^{226}Ra/^{222}Rn) contributed the most to the total cumulative carcinogenic risk for SA-1. Cesium-137, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of homegrown vegetables/fruits in the RSA), and ^{234}U and ^{238}U (ingestion of homegrown vegetables/fruits in SY-200 and SA-1) were identified as showing the highest carcinogenic risks (i.e., risks $\geq$ 1.0E-04) and contributed the most to the total cumulative carcinogenic risk for these areas.

For the BCV OU 2, COCs that were identified as having the highest noncarcinogenic/ toxic effects, arsenic, cadmium, manganese, and mercury (ingestion of homegrown vegetables/fruits) contributed the most to the total cumulative HIs.

5.6.3 Toxicity Assessment

A few BCV OU 2 COPCs were identified as having regulatorily unacceptable carcinogenic and/or noncarcinogenic effects to human health [i.e., these COCs have a risk $\geq$ 1.0E-04 and/or HI $\geq$ 1.0 (EPA 1989b); refer to Sect. 5.6.1]. Both qualitative and quantitative toxicity information for each COPC (Tables C.23–C.25) can be found in Sect. 5.4 of this BRA.

5.6.4 Risk Characterization

The results of the carcinogenic risk (Tables 5.5, 5.7, and 5.8) and noncarcinogenic HI (e.g., systemic toxicity) (Tables 5.6, 5.9, and 5.10) assessments for the BCV OU 2 COPCs are summarized in Tables 5.11–5.14. Tables 5.11 and 5.12 contain the BCV OU 2 COCs that have a risk $\geq$ 1.0E-06 and/or an HQ $\geq$ 1.0 for the industrial worker and residential land uses, respectively. The results summarized in Tables 5.13 and 5.14 are the cumulative risks and HIs for the industrial worker and residential scenarios, respectively. The reader should note that EPA guidelines (EPA 1989b) for contaminated sites consider three regions of carcinogenic risk [risk < 1.0E-06, no concern; risk between 1.0E-06 and 1.0E-04, range of concern (or target risk range); and risk $\geq$ 1.0E-04, regulatorily unacceptable] and two areas of concern in terms of noncarcinogenic effects (HI < 1.0, no concern, and HI $\geq$ 1.0, concern).

To reiterate a previous discussion in this report, ^{226}Ra (residential and industrial inhalation and/or external exposure pathways in SA-1); ^{137}Cs, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of homegrown vegetables/fruits in the RSA); and ^{234}U and ^{238}U (ingestion of homegrown vegetables/fruits in SY-200 and SA-1) were identified as showing the highest carcinogenic risks (i.e., the individual risks from these COCs were $\geq$ 1.0E-04 for exposure to these media in these areas).

Mercury (in the high concentration zone of the SY-200 area; refer to Sect. 5.5.5.2) was identified as having a HQ slightly greater than 1.0 for the ingestion pathway, under residential land-use conditions only. Arsenic, cadmium, manganese, and mercury (ingestion of homegrown vegetables/fruits pathway) show the highest HQs (i.e., the individual HQs from these COCs were $\geq$ 1.0 for exposure to these media in the three areas).

A cumulative risk $\geq$ 1.0E-04 was found for SA-1 (the four primary pathways were included in this total), and cumulative risks between 1.0E-05 and 1.0E-04 were found for the RSA and SY-200. When the vegetable/fruit ingestion pathway is considered, cumulative risks greater than 1.0E-04 were found for all three areas.

Cumulative HIs $\geq$ 1.0 were *not* found for the three areas (with the exception of the mercury high concentration zone in the SY-200 area; refer to Sect. 5.5.5.2). However, when the vegetable/fruit ingestion pathway is considered, cumulative HIs greater than 1.0 were found for all three areas. Refer to Sect. 5.5.3.

Remedial Goal Options for the COCs identified in this BRA are listed in Table 7.1 of Chap. 7 of this RI report. As noted in Table 7.1, the background concentrations (DOE 1993) for beryllium, ^{226}Ra, and ^{238}U (three COCs identified in this BRA based on a risk greater than 1.0E-06; refer to Tables 5.11-5.12) are above residential soil ingestion and/or external exposure PRGs.

When only the four primary soil exposure pathways (i.e., ingestion, inhalation, dermal, and external exposure to radionuclides) are considered, *no* carcinogenic risks (neither individual nor cumulative) greater than 1.0E-04 are found for exposure to RSA or SY-200 soils (under both the residential and industrial scenarios). For SA-1, exposure to ^{226}Ra in the soils via inhalation (of ^{222}Rn) and external exposure (to ^{226}Ra) gives a carcinogenic risk greater than 1.0E-04 under the residential scenario, and exposure to ^{226}Ra in the soils via inhalation (of ^{222}Rn) under the industrial scenario gives a carcinogenic risk greater than 1.0E-04.

The uncertainties associated with the ^{226}Ra risk estimates are discussed in detail in Sect. 5.5.5.3 and are summarized here. Only historical soils data were available for SA-1, and radionuclide analyses for the historical soil data were reported as *total* radium activity (pCi/g). For this BRA, this *total* radium concentration was assigned to the ^{226}Ra isotope (toxicity values for ^{226}Ra are the most conservative, i.e., give the largest risk, among the radium isotopes). For the inhalation pathway, toxicity information for ^{222}Rn was used [in accordance with EPA guidance (EPA 1991a)], because ^{222}Rn is a major daughter product of ^{226}Ra. Many conservative assumptions were made for the radium data used in the SA-1 area to evaluate human health risk and overestimation of the actual risk may occur. Therefore, the risk numbers reported in this BRA, although above the upper risk limit (i.e., risk $\geq$ 1.0E-04), should not be used solely to make the final decision for the SA-1.

Note: the background level (DOE 1993) for ^{226}Ra (Copper Ridge horizon C; refer to Table C.3) is 2.11 pCi/g, and this background concentration is above both the residential and industrial PRGs (6.9E-01 pCi/g and 8.3E-01 pCi/g, respectively) for a risk of 1.0E-04; therefore, cleanup to background levels of ^{226}Ra would still leave a regulatorily unacceptable risk of greater than 1.0E-04. The UCL95 concentration used to evaluate risk from exposure to ^{226}Ra in the SA-1 area in this BRA was 3.22 pCi/g (refer to Table 5.1). In addition (refer to Sect. 5.4.6.2.2), radium can be released into the environment in coal fly ash, and the background level of radium in industrial regions in soil is ~8.1 pCi/g (Budavari et al. 1989, Casarett 1968).

6. ASSESSMENT OF BASELINE ECOLOGICAL RISK

The RI includes a BERA. The BERA evaluates the baseline risk to ecological resources and also determines if and where there is imminent and substantial danger to the animal and plant populations and their habitats. Thus, the BERA represents the risk characterization for current and future conditions of the "no action" alternative, as required by CERCLA. Under CERCLA the "no action alternative" equates with doing nothing further at the site. This implies that the site would be left available for completely unrestricted use. The CERCLA interpretation differs from the NEPA definition of "no action." Under NEPA, the "no action alternative" involves doing nothing beyond the pre-existing conditions at the site, which could include continued implementation of institutional actions or any other pre-existing safeguards that are already a part of the status quo. The BERA also provides the basis for coordinating with DOE and meeting the requirements of DOE as a Natural Resource Trustee, as well as those of cooperating trustees as specified under 43 *CFR* 11, Natural Resource Damage Assessments (NRDAs). This coordination is essential to the development of assessment and measurement endpoints and to the ultimate selection of remediation alternatives in the FS/EIS.

An environmental evaluation process for hazardous waste sites is outlined in the *Risk Assessment Guidance for Superfund, Vol. II, Environmental Evaluation Manual, Interim Final* (EPA 1989c) and further developed in subsequent documents (EPA 1989d, 1991e, 1992c). "Ecological risk assessment" ("ERA") has become common usage and will be used throughout this chapter in place of "environmental evaluation." The *Environmental Evaluation Manual* does not provide a step-by-step approach to ecological risk assessment, as does the *Human Health Evaluation Manual* (EPA 1989b) for human health risk assessment. Instead, it discusses an overall framework for considering environmental effects and identifies sources of pertinent information. A discussion of the scientific basis for assessing ecological effects is found in *Ecological Assessments of Hazardous Waste Sites: A Field and Laboratory Reference Document* (EPA 1989d).

The BERA for BCV OU 2 is structured according to a proposed general framework for ERAs (EPA 1991e, 1992c). This framework comprises four interrelated activities: hazard identification or problem formulation (including Sect. 6.1), exposure characterization (Sect. 6.2), effects assessment (Sect. 6.3), and risk characterization (Sect. 6.4). These activities are defined here.

Problem formulation establishes the goals, breadth, and focus of the assessment and provides a preliminary characterization of chemical and physical stressors present in the ecosystem, the components and especially the indicator organisms of the ecosystem likely to be at risk, and the potential ecological effects, along with a selection of assessment and measurement endpoints as a basis for a conceptual model of stressors, components, and effects (Sect. 6.1).

Exposure characterization evaluates the interactions of the stressors with the ecosystem attributes and describes the biotic and abiotic ecosystem attributes, along with the route, magnitude, frequency, duration, trend, and spatial pattern of exposure of each indicator population or habitat component in relation to a chemical or physical stressor (Sect. 6.2).

Effects assessment evaluates the ecological response to chemical and physical stressors in terms of the selected assessment and measurement endpoints and, depending on the parameters of exposure, results in a profile of response to stressors at concentrations or doses or other units of stress to which populations and habitats are exposed. Data from both field observations and controlled laboratory studies are used to evaluate ecological effects (Sect. 6.3).

Risk characterization integrates the effects of exposure and stressor response on indicator populations or habitat components using risk quotients (a ratio of exposure value to effect value) and interprets and summarizes the ecological significance, including the potential for ecosystem recovery (Sect. 6.4).

Because of the semiquantitative nature of the characterization of biota and habitats at risk, the assessment of potential impacts to wildlife and vegetation from exposure to contaminants must be based largely on toxicological effects reported in the literature for many of the COPCs and expected mechanisms of transport, biological uptake, and accumulation. Where toxicity data were available, a semiquantitative characterization of the risk to BCV OU 2 biotic communities from exposure to the COPCs was based on the ratio of measured concentrations of COPCs in environmental media to toxicity threshold concentrations (Barnthouse et al. 1986).

A qualitative habitat characterization identifies organisms and habitats potentially exposed to contaminants. Field measurements of contaminant concentrations and published toxicity data for terrestrial organisms allow for identifying which COPCs are of concern to those organisms and a quantitative estimate of risk using the ratio or quotient method. This information is used in the RI to characterize the magnitudes of baseline risks to ecological resources from contaminated media in the BCV OU 2 source units—SA-1, the SY-200 Yard, and RSA—under current conditions, and it is used in the FS to assess the residual risks in the future following various remedial alternatives.

The scope of this BERA includes terrestrial organisms that may be directly exposed to COPCs associated with BCV OU 2 source units. Soils outside the source units delineated in Fig. 3.1 and not included in OU 1 are assumed to be free of contamination and are not evaluated for ecological risks. Transport of contaminants from the source units to Bear Creek is evaluated in Sect. 3.2.5. Exposures that occur outside the source units and exposures to receptors that range beyond the source units are not considered here but will be addressed in the RI for BCV OU 4. The approved work plan did not call for ecological surveys or analyses of biota for contaminant body burdens. Therefore, the BERA will not be based on direct measures of ecological exposure. Identifying and assessing the risks to local biota and habitats from exposure to site COPCs is feasible, even though environmental and toxicological data are limited. Concentration data exist for COPCs in environmental media at BCV OU 2, but no quantitative site-specific biological studies have been conducted there. A field reconnaissance forms the basis of the habitat overview (Sect. 6.1.2.1). Site contaminants that qualify as COPCs for quantitative risk assessment (Sect. 6.1.3.3) are screened further for assessment as ecological COPCs (Sect. 6.1.3.5) using published screening benchmarks (e.g., Suter, Will, and Evans 1993; Opresko, Sample, and Suter 1993) or published toxicity data. Because aquatic exposures in the source units are very limited, emphasis is given to terrestrial organisms at all three BCV OU 2 source units. Terrestrial plants may be exposed to contaminants in soil directly through root uptake and small mammals through ingestion of soil. Although contaminants in surface and subsurface soil and in groundwater at BCV OU 2

can be released via surface water runoff to Bear Creek, thereby exposing aquatic communities to COPCs in water and sediment, the risk to aquatic communities is outside the scope of the BERA for BCV OU 2. The risks to organisms exposed to COPCs at the BCV OU 2 source units were estimated using ratios of the measured environmental concentrations of contaminants to toxicity threshold concentrations obtained from published toxicology data. In the screen for soil ingestion, exposures were also adjusted to reflect ingestion rates calculated from published data.

Several assumptions were made in preparing the BCV OU 2 BERA: the BERA assumes that the basic approach to ERAs described in EPA guidance (EPA 1989c; EPA 1989d) is acceptable. Site visits and historical descriptions are assumed to be sufficient to identify potentially exposed habitats and species known or likely to occur in those habitats (EPA 1991e). This BERA assumes that a separate screening of contaminants to identify COPCs based on ecological criteria is necessary because not all contaminants that pose a risk to human health are ecologically important and vice versa (EPA 1991e). Further, separate exposure, effects, and risk assessments are required (EPA 1991e).

Identifying ecological COPCs and characterizing risks requires toxicity thresholds based on chronic exposure. Published chronic toxicity data are assumed to be applicable and are assumed to be protective to most organisms most of the time. When chronic data are not available, chronic thresholds are derived from data for exposures to acutely toxic concentrations. Thresholds derived from published acute toxicity data are assumed to have more uncertainty than those derived from exposure to chronic toxic concentrations. Site contaminants qualifying as ecological COPCs based on screening-level toxicity benchmarks are assumed to be sufficiently persistent to warrant an assessment of risk to ecological resources at the sites.

The extent of migration of the COPCs from source units is evaluated in Sect. 3.2.5. Risks to aquatic communities in Bear Creek will be determined in the BCV OU 4 RI. Assumptions about primary exposure pathways and differences in exposure to various classes of ecological receptors are based on professional judgment. In general, it is assumed that the ecological COPC screening process is conservative and the probability of underestimating the risk to ecological receptors is small.

6.1 IDENTIFICATION OF ECOLOGICAL HAZARD SOURCES

This section presents the assessment endpoints, identifies the ecological hazard sources (ecological COPCs in exposure media), and describes the environmental setting at the BCV OU 2 source units. The conceptual model of BCV OU 2, which identifies the potential contaminants and their sources at the three source units, is presented in Chap. 3. According to this model, fill containing predominantly industrial spoil, and at SA-1 and the SY-200 Yard lying beneath a layer of clean soil, is infiltrated by subsurface water in the stormflow zone. As described in Sect. 6.1.2.3, ecological exposures are predominantly to plants and small mammals through surface soils. At SA-1, there is a small outcrop of subsurface water at an intermittent seep. However, this seep is too small to provide significant ecological exposures. It is described in more detail in Sect. 6.1.2.1, but is not evaluated for risks.

6.1.1 Ecological Assessment Endpoints

The protection of ecological resources is mandated by a variety of legislation and government agency policies. Statements of key aspects of ecological protection are presented in this section as goals to be attained by the RI and any subsequent cleanup. To evaluate the attainment of those goals, assessment endpoints are used to define the specific ecological values by which baseline ecological risks will be evaluated. These are also values to be protected as a result of the remediation process. Where assessment endpoints are not directly measurable, one or more measurement endpoints were chosen to determine, either qualitatively or quantitatively, site-specific impacts on the assessment endpoints. Assessment goals and measurement endpoints described in this section were developed within the context of guidance in EPA (1992c) and Suter (1993).

The following ecological goals are relevant to the RI of BCV OU 2. Measurement endpoints are indicated as are any legislation, executive orders, regulations, or guidelines that were directly relevant to the endpoint. Some goals and assessment endpoints have less exact legislative authority and are technical interpretations of the broad requirement to protect and restore the environment associated with CERCLA and NEPA. Assessment and measurement endpoints are provided within the context of the ecological goals.

Goal 1: The conservation of threatened, endangered, and rare species and their critical habitats.

Assessment Endpoint 1: No harm to any state- or federal-designated threatened or endangered species and their critical habitats in BCV OU 2.

Measurement Endpoint 1: Evaluation of the presence or absence of species and their habitats in BCV OU 2.

Legislation: The Endangered Species Act of 1973, the Tennessee Non-Game and Endangered or Threatened Wildlife Species Conservation Act of 1974, and the Tennessee Rare Plant Protection and Conservation Act are relevant. Also, CERCLA and NEPA provide authority and a process to protect these ecological resources.

Goal 2: No adverse effects from contaminants in soils to ecological populations within BCV OU 2.

Assessment Endpoint 2: No adverse effects to vegetation.

Measurement Endpoint 2a: No visible evidence of phytotoxicity.

Measurement Endpoint 2b: Surface soil concentrations less than published phytotoxicity data for plants (grasses, forbs, and trees) representative of those known to occur on the ORR.

Assessment Endpoint 3: No more than 20% reduction of populations of small mammals residing and ingesting soil and vegetation at the site.

Measurement Endpoint 3a: Surface and subsurface soil concentrations less than published chronic toxicity levels for estimated intakes by small mammals.

Measurement Endpoint 3b: Surface and subsurface soil concentrations less than those causing biouptake by plants greater than dietary benchmarks for herbivorous mammals.

Legislation: Relevant authorities are CERCLA and NEPA for protection of the environment.

Assessment Endpoint 4: No more than 20% reduction in populations of biota exposed to sediments derived exclusively from BCV OU 2.

Measurement Endpoint 4: Sediment concentrations less than published toxicity values for sediment biota.

Legislation: Relevant authorities are CERCLA and NEPA for protection of the environment.

COCs for these endpoints were selected from the list of COPCs by an iterative screening process. This process is summarized in Table 6.1 and described in detail in the sections indicated.

Table 6.1. Evaluation of COPCs for ecological risk assessment

Endpoint	Procedure	Section
COPCs	Compare site UCB to background UCB. Evaluate frequency of occurrence	6.1.3.3
Ecological COPCs	Compare site UCL to ecological screening benchmarks	6.1.3.5
Ecological quotients (EQs)	Compare site UCL to ecological toxicity values.	6.4.1.1
Exposure quotients (XQs)	Adjust exposure, compare adjusted site UCL exposure to ecological toxicity values	6.4.1.2
Ecological COCs	Evaluate EQs and XQs for current and future exposures	6.4.1.1 6.4.1.2 6.4.2

6.1.2 Environmental Description

This subsection describes the ecological setting of each source unit in BCV OU 2, including habitats (Sect. 6.1.2.1), consideration of threatened and endangered species (Sect. 6.1.2.2), the exposure environment (Sect. 6.1.2.3), and the ecological succession expected to occur at BCV OU 2 (Sect. 6.1.2.4).

6.1.2.1 Overview of habitats

A discussion of the ecological resources of BCV is presented in Sect. 2.7. The following provides site-specific information for each area within BCV OU 2, along with some details from a site visit conducted in February 1994.

SA-1. Closure of the SA-1 disposal area created a 1.9-ha (4.72-acre) area of a maintained grass (fescue) habitat. About 15% of this area is covered by a graveled parking lot and a circular access road (Fig. 6.1). This disposal area sits as a raised bench on the north side of a ridge, with a gently eastward sloping surface and a steeply sloping side on the north. Patches of moss among the grass indicate areas of somewhat acidic soil conditions of the surface soil, even though limestone gravel is found mixed with the soil. A hardwood forest exists along the ridgeline above the grass habitat of the landfill and outside the boundaries of the OU. A row of planted pines borders the grass area along the edge of the woodland. The edge between these two habitats, along with the relatively low level of human activity in the immediate area, provides an area attractive to many wildlife species. A number of deer tracks and other signs (fox scat) of wildlife use of this area were observed during the site visit. Breeding songbirds that prefer edge habitat, such as indigo buntings (*Passerina cyanea*), and birds that prefer open grassy areas for feeding, such as American robins (*Turdus migratorius*), would be expected to be common in this area. Groundhogs (*Marmota monax*) could be expected to move onto the grass habitat. Groundhog burrows can create problems in closed landfills and are usually discouraged by preventive measures, although no preventive measures have been taken at SA-1. Populations of soil invertebrates are expected to be reasonably high in this area, depending upon the type of soil used for final cover and the degree to which this layer of soil was compacted. A small seep exists at the base of the slope along the northern perimeter of the disposal area, probably as an outcrop of water from the stormflow zone (Sect. 2.5.1.1). While this provides a potential source of surface water to wildlife, its size [<1 m^2 (11 ft^2), with only a similarly sized area for pooling immediately beside the roadway] and its intermittent nature probably prevent it from being a significant source of water for wildlife usage. It could potentially support populations of microcrustaceans and insects.

SY-200 Yard. This 1.1-ha (2.84-acre) area supports very little vegetation, recently having been cleared and graded for use as a building site. The building plans for this site were abandoned, and a major portion of the site has been filled to an elevation of about 3 m (10 ft) above Bear Creek. A narrow band ($\sim$15 m or 50 ft) of mostly herbaceous vegetation covers the area between the riprap and the channel of Bear Creek (Fig. 6.2). This area slopes at $\sim$40% down to Bear Creek. The band of vegetation, covering about 10% of the total area, includes scattered trees [e.g., American sycamore (*Platinus occidentalis*) and alder (*Alnus* spp.)]. Much of the band of vegetation appears to have been disturbed during site preparation. Little use of this site by wildlife would be expected because of its lack of habitat and its proximity to human activity. However, animal tracks were found along the cleared area near the vegetated band. Frost heaving made the tracks difficult to read, but the tracks were considered most likely to have been those of a fox [gray (*Urocyon cinereoargenteus*) or red (*Vulpes vulpes*)]. Wildlife using the band of vegetation along the creek would be expected to be predominantly songbirds, such as the Carolina wren (*Thryothorus ludovicianus*), and small mammals, such as the white-footed mouse (*Peromyscus leucopus*). Bear Creek and the associated narrow band of riparian habitat provide a more or less continuous corridor that is probably used as a travel lane by such wildlife species as

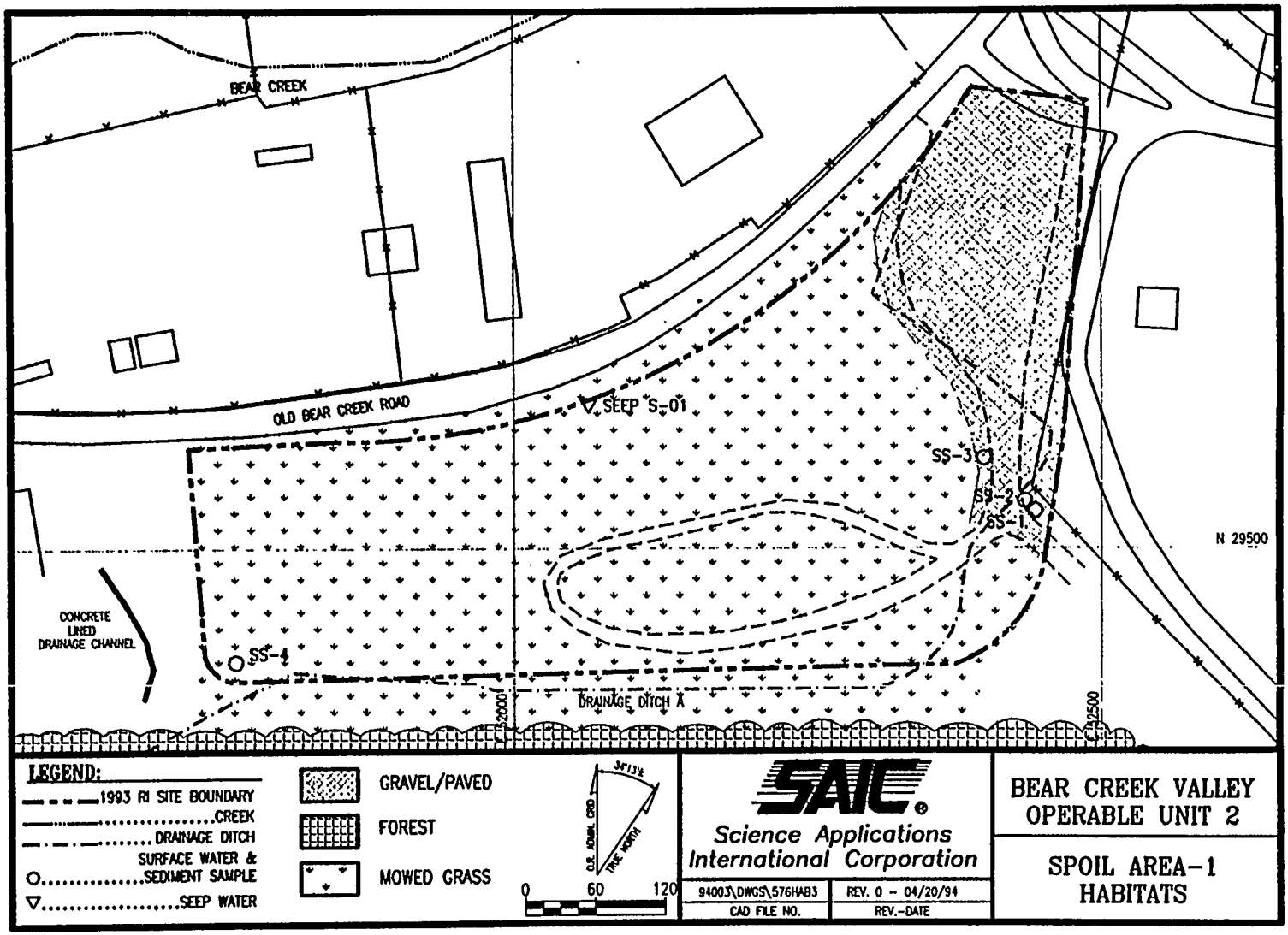


Fig. 6.1. SA-1 habitats.

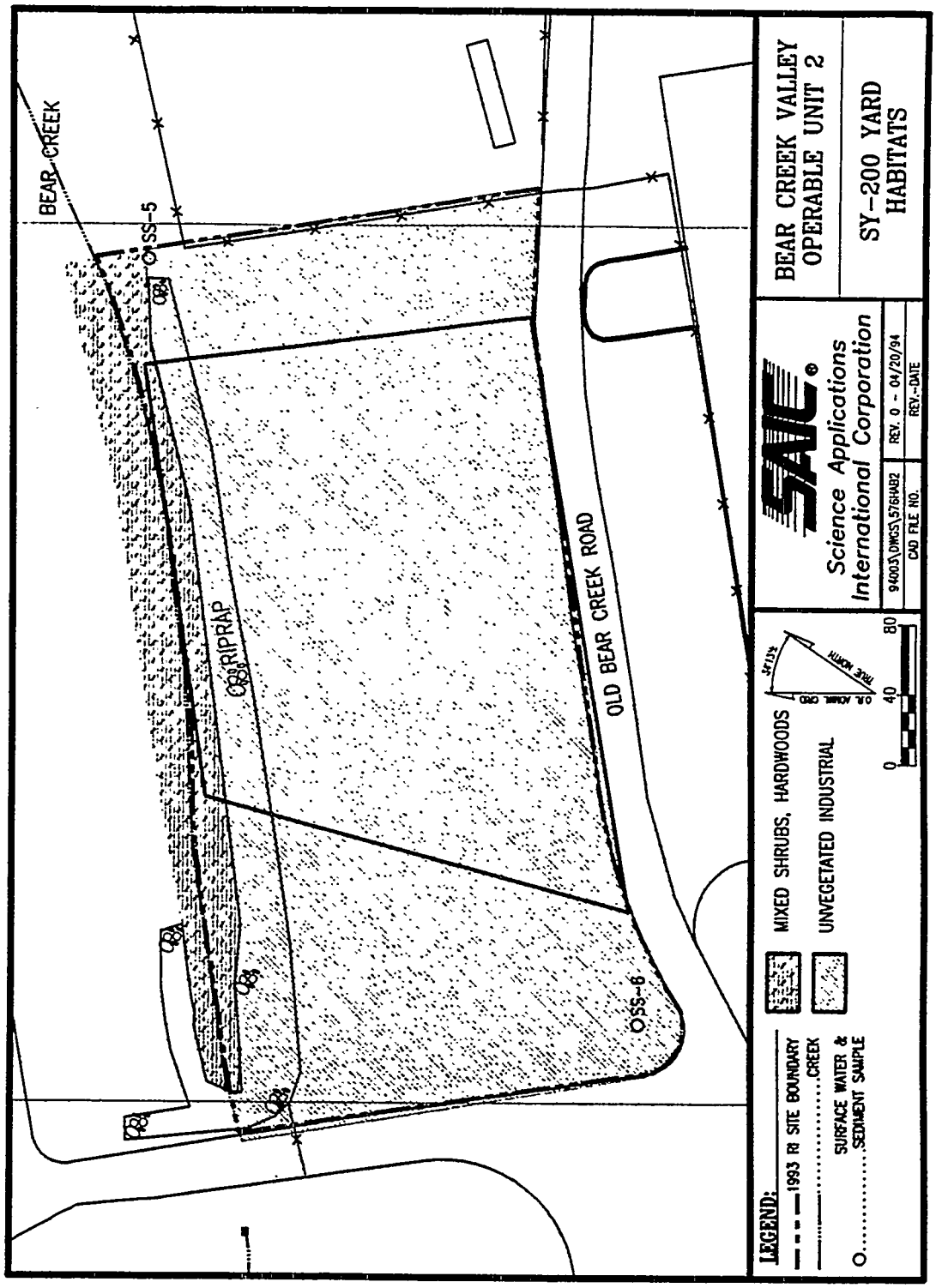


Fig. 6.2. SY-200 Yard habitats.

foxes, muskrats, opossums, and raccoons. Very low populations of soil invertebrates (e.g., earthworms) would be expected in most of the SY-200 Yard because of the recent compaction and disturbance of the soil profile.

RSA. The RSA is a 2.9-ha (7.21-acre) open-storage area surrounded by an 8-ft-high chain link fence on three sides (Fig. 6.3). It is predominantly a large gravel pad overgrown with grass and interspersed with small areas of grass and/or herbaceous old-field species typical of those found on abandoned pastures or fields. The area is bordered on the east by a small tributary to Bear Creek, which flows parallel to the site just beyond the site boundary to the north. The banks of the tributary are forested. Typical trees are oaks (*Quercus* spp.), American sycamore, and persimmon (*Diospyros virginiana*), which range in size from seedlings to mature trees. The spoil area slopes down to Bear Creek's floodplain. This slope supports mostly old field species [such as grasses, goldenrod (*Solidago* spp.), and blackberries (*Rubus* spp.)] with some scattered saplings. The Bear Creek floodplain supports a bottomland hardwood forest that is bordered on the north by a maintained powerline right-of-way that parallels the creek. The linear configuration makes the floodplain forest/powerline right-of-way a likely travel corridor for large wildlife species such as deer, as well as providing excellent habitat for many other species. The proximity of this wildlife corridor to the spoil area makes occasional-to-frequent visits to the RSA by wildlife likely. Deer, rabbit, and fox signs (fecal pellets and scat) were seen during the site visit. A dead opossum (*Didelphis virginiana*) found within the graveled area of the RSA during the site visit exhibited no observable wounds or signs indicative of poisoning. The ~1 ha (2.5 acres) of old field habitat on the sloping portion of this site offers suitable habitat for several wildlife species, such as the eastern cottontail rabbit (*Sylvilagus* spp.) and the field sparrow (*Spizella pusilla*). Wildlife use of the graveled portion of this site is probably limited, although ground-nesting birds such as killdeer (*Charadrius vociferus*) and nighthawks (*Chordeiles* spp.) are likely to nest here. The pallets and stored items may provide structural habitat for reptiles, such as lizards and snakes. Populations of soil invertebrates are expected to be very low in the graveled portion of this area, while the old field and forested portions likely support normal numbers expected for the type of vegetative cover.

6.1.2.2 Threatened or endangered species

Site-wide overviews on the occurrence of threatened and endangered plant and animal species on the ORR have been compiled in the past (Cunningham, Pounds, and Oberholster 1993; Parr 1984; and Kroodsma 1987). Additional site-specific as well as species-specific surveys have been conducted for numerous proposed actions on the reservation (e.g., SAIC 1994). The information within these reports details the occurrence of threatened and endangered species on the ORR, while expert opinions are provided as to the potential for occurrence of these same species at given locations on the ORR or for the occurrence of other listed species. Based on these references, it is considered highly unlikely that an endangered or threatened plant or animal species would be adversely impacted at any BCV OU 2 site.

The probability of the occurrence of a threatened or endangered plant species on either the SA-1 or the SY-200 Yard is considered to be extremely low because of the disturbances to these sites and the continued maintenance of the vegetation on SA-1. The probability of a listed plant species occurring on the RSA is very low, although there exists the slight possibility that some listed plant species could occur in the adjacent floodplain of Bear Creek.

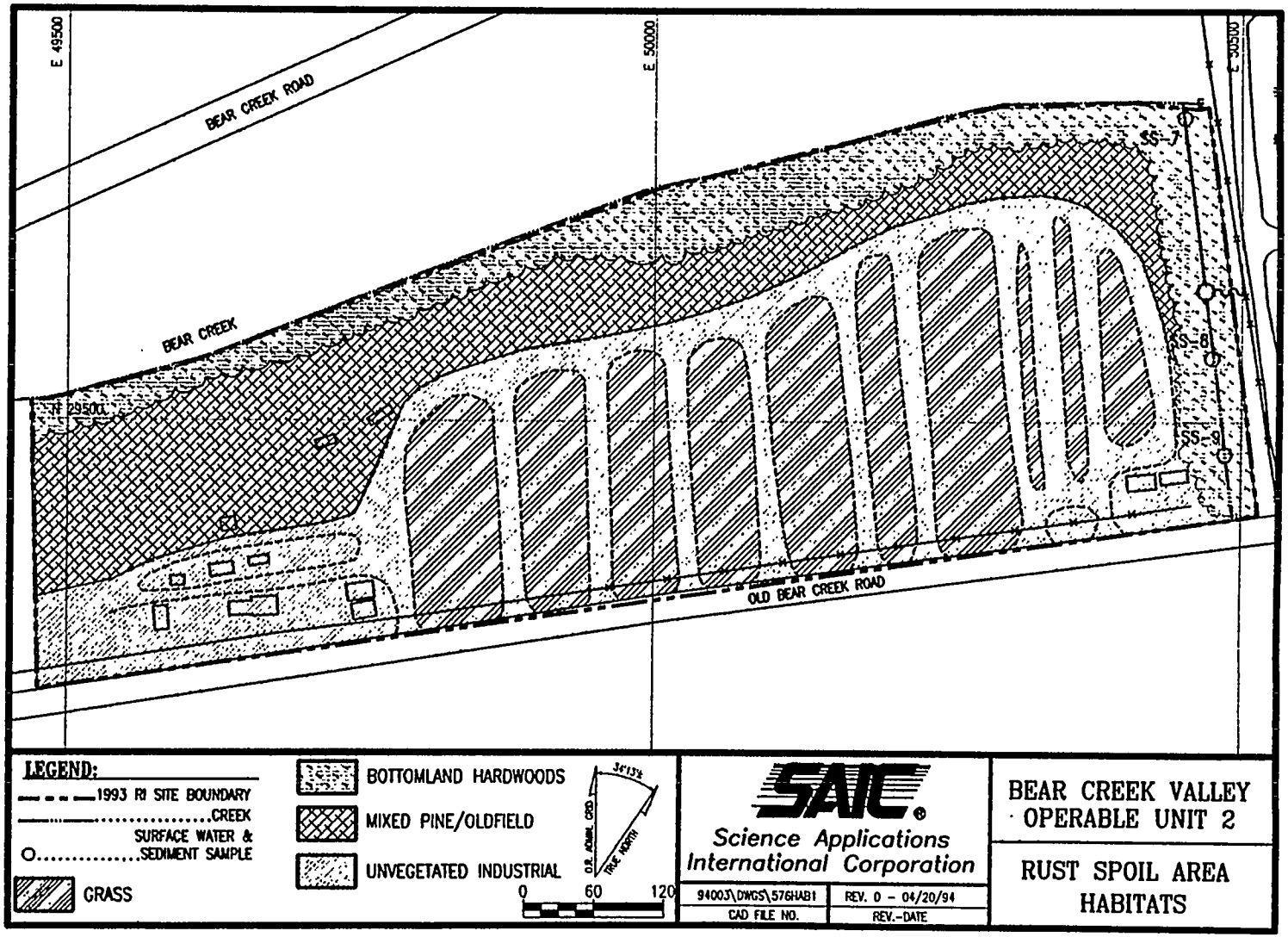


Fig. 6.3. RSA habitats.

No significant habitat values are offered to threatened or endangered species by any of these sites except as part of an overall mosaic of habitats. Even then, the landscape offered by the immediate area containing all three sites would be considered limited for most threatened and endangered species. A very low probability exists that some listed species could use the habitats available at SA-1 or RSA for resting, feeding, or watering.

6.1.2.3 Exposure environment, media, and species

The SY-200 Yard is a denuded and graded lot surrounded on three sides by open industrial areas and, on the fourth side, by a vegetated bank dropping down to Bear Creek. This sloping side of the landfill represents the primary exposure environment for ecological receptors at the SY-200 Yard, primarily from vegetation growing on and animals burrowing into contaminated soils. Because the surface soil at the SY-200 Yard is not contaminated, airborne dust is not an exposure pathway. Erosion from the site is modeled in Sect. 3.2.5, and risks to off-site receptors will be addressed in the BCV OU 4 ERA.

SA-1 is a grass-covered, terraced hillside bordered at the top by a forest. There is a small seep at the base of SA-1 alongside a road. The primary exposure environment at SA-1 is the grassed soil surface and the underlying soil. The RSA is a grass- and gravel-covered storage yard surrounded by secondary successional forests and bounded on two sides by the wooded floodplain of Bear Creek and a drainage ditch confluent with Bear Creek. The primary exposure environment for the RSA is the vegetated surface and sloping bank soils.

Current exposures are assumed in this BERA to be limited to the vegetation types currently found on the source units, to small mammals whose range would be expected to be restricted to the source units, and to aquatic receptors exposed to sediments that may have been derived from RSA soils. Because the contaminated portions of the source units are now covered with grass or no vegetation, the endpoint for current exposure of vegetation is phytotoxicity to grasses. Future exposures of vegetation were evaluated assuming a succession from grasses through forbs to a mature forest (see Sect. 6.1.2.4). Therefore, the endpoints for future ecological risks to vegetation include phytotoxicity to grasses, forbs, and trees of species that occur on the ORR.

Sediment in the perennial stream bordering RSA is considered in this BERA. However, the other sediment samples were taken from drainage areas that are wet only during and immediately after rains. The latter areas do not represent likely habitats for aquatic biota because of their transient nature, so the sediments were not evaluated for risk to aquatic receptors. Surface water at RSA is derived predominantly from a spring whose source is predominantly outside the OU. Therefore, ecological risks from exposure to this surface water will be included in the BERA for BCV OU 4. Because there is sufficient evidence that sediment concentrations are likely to change, without remediation, future risks from sediment exposure are assumed to be identical to current risks.

6.1.2.4 Ecological succession

Construction of the spoil areas at BCV OU 2 has resulted in destruction of natural habitats. Recovery from these physical disturbances takes place primarily through the process of ecological succession. Ecological succession is the orderly and, therefore, often predictable process of community change resulting from the modification of the physical environment by the resident organisms, and culminating in the establishment of a regenerative ecosystem

(Odum 1971). The general pattern of ecological succession in BCV OU 2, which comprises mainly upland areas outside the zone of frequently recurring floods, would be one of transition from grassland to shrubs, followed by colonization by pine and eventual replacement of these by various shade-tolerant hardwood species. If current land management practices and activities are discontinued, the human-maintained BCV OU 2 communities (e.g., the grass cover at SA-1) would move toward the more forested climax state. Ecological succession in the more heavily disturbed areas at the SY-200 Yard and RSA would also undergo shifts in dominance toward a climax state, but this would occur over a longer period of time (~200 years).

Changes in resident animal populations at the BCV OU 2 source units are expected as a result of changes in vegetation. Revegetation of the sites with wild plant species (both native and alien species) from surrounding areas will proceed at different rates due to differences in the degree of physical disturbance to the soils and the distance from vegetated habitats acting as seed sources. Unless disturbed soil conditions or phytotoxicity of soil COCs alter the possible species composition of plant communities at the BCV OU 2 source units, these sites are expected to eventually return to a relatively natural state capable of supporting animal communities typical of similar habitats in the area. The climax state for BCV OU 2 is assumed to be a mixed hardwood forest that would develop through old fields and developing forest. Therefore, the phytotoxicity endpoints comprise toxicity to grasses, forbs, and trees.

Soil conditions at these sites are not expected to be sufficiently disturbed to preclude colonization of the sites by typical plant communities. The possibility of permanent alteration of plant community structure from phytotoxicity of soil COCs is considered in the effects assessment and risk characterization.

6.1.3 Sources of Contamination

This subsection provides a brief overview of the types and sources of historical contamination (Sect. 6.1.3.1). Following this, the nature of the source data for this BERA is provided (Sect. 6.1.3.2). Sources of background data and the nature of the data are presented next (Sect. 6.1.3.3). Section 6.1.3.4 concludes with a brief mention of routes of exposure. COCs are discussed in Sect. 6.1.3.5.

6.1.3.1 Historical source information

Historical information on past uses, operations, and releases at the BCV OU 2 source units is presented in Sects. 3.1.2–3.1.4. Historical data do not exist for sediment in the one perennial stream in BCV OU 2, which is located at RSA. Historical data for soil are discussed in Sect. 3.2.4. Historical data are useful to show the existence of soil contamination at the SY-200 Yard, but because the soils have been redistributed since the historical samples were taken, those data do not provide useful information on the location of soil contaminants. Therefore, they were not used in the BERA.

Only historical data exist for soil at SA-1 (Sect. 3.2.4). Historical data for soil at depths of 0 to 3 m (0 to 10 ft) at SA-1 were aggregated and used in the RI as the source data for this unit; these data are discussed below. Historical data for soil at depths of 0 to 3 m (0 to

10 ft) at RSA were combined with newly acquired data for the same soil depths and used in the BERA. Historical data for groundwater at BCV OU 2 (Sect. 3.2.3) are not used in this BERA.

6.1.3.2 RI source data

The source data for the BCV OU 2 RI are summarized in Sect. 3.2. RI source data used in the BERA include data for sediments at RSA and for soils at all three source units at BCV OU 2. Soil data were aggregated to include surface samples along with subsurface samples to 3 m (10 ft) to represent potential current and future exposures at SA-1, the SY-200 Yard, and RSA. Data used for the BERA include analyses of inorganics, VOCs and SVOCs, pesticides/PCBs, and radionuclides. Discussions of the quality of the RI source data are found in Sect. 3.2.4.

6.1.3.3 Background

Background data for the BCV OU 2 BERA exist for soil only. The soil background data come from the Copper Ridge formation, Horizon C, as reported in *Final Report on the Background Soil Characterization Project at the Oak Ridge Reservation, Oak Ridge, Tennessee* (DOE 1993). These data are described in Sect. 3.2.4. Because soil data were aggregated over only the top 3 m (10 ft) for the BERA, those data are compared here to background concentrations. As in Sect. 3.2.4, the UCBs of the site soil concentrations were compared to the UCBs of the background soil concentrations. Table 6.2 shows that 20 of 26 inorganic analytes exceeded background concentrations at a BCV OU 2 site and were retained as preliminary ecological COPCs. All organic analytes were retained because there are no background data for organics. There are no background data for sediments at BCV OU 2.

6.1.3.4 Exposure routes

The primary exposure routes for biota at all three sites are in direct contact with and ingestion of contaminated soil and ingestion of contaminated vegetation. The two assessment endpoints involve vegetation and small mammals. Plants are exposed to contaminants via direct contact of roots with contaminated soil and soil-pore water. Small mammals are exposed to soil, contaminants through ingestion, both incidental and intentional, and through ingestion of plants that have taken up contaminants from soil. Exposure of wide-ranging predators by ingestion of contaminated biota at the BCV OU 2 source units will be evaluated in the site-wide risk assessment for BCV (OU 4).

6.1.3.5 Screening of contaminants

Ecological COPCs are substances detected at BCV OU 2 source units that have the potential to pose a hazard to the assessment-endpoint receptors: plants and small mammals. According to EPA (1989b), factors determining whether a contaminant should qualify as an ecological COPC include environmental concentration, frequency of occurrence, background levels, bioavailability, physical and chemical properties (e.g., solubility), potential for bioaccumulation, toxicity, and effects. COPCs at the BCV OU 2 source units were first identified from a comparison of site and background concentrations, the frequency of occurrence, and sample quantification limits (see Sect. 6.1.3.3).

Table 6.2. Screening of soil COPCs against background concentrations

Compound name	Background maximum or UCL (mg/kg)	SA-1 historic	SA-1 greater than background?	SY-200 Yard 0–10 ft (mg/kg)	SY-200 Yard greater than background?	RSA 0–10 ft (mg/kg)	RSA greater than background?
Aluminum	23,400	29,313	Y	17,202	N	19,704	N
Antimony			N	0.46	Y	0.36	Y
Arsenic	655	14.8	N	40.74	N	11.0	N
Barium	14.2	385	Y	87.63	Y	115.4	Y
Beryllium	0.96	1.29	Y	0.96	N	1.15	Y
Cadmium		3.6	Y	0.12	Y	5.7	Y
Calcium	219	57,800	Y	15,907	Y	153,941	Y
Chromium (IV)	35.7	35.7	N	27	N	37.23	Y
Cobalt	4.2	20	Y	19.8	Y	16.17	Y
Copper	35.9	28.2	N	35.3	N	57.60	Y
Cyanide			N		N	2.65	Y
Iron	53,900	33.766	N	30,954	N	31,664	N
Lead	39.2	110	Y	58.8	Y	43.65	Y
Magnesium	722	20,500	Y	3217	Y	11,894	Y
Manganese	106	2030	Y	729	Y	953	Y
Mercury	0.3	2.6	Y	69.8	Y	4.28	Y
Nickel	21.3	51	Y	27.1	Y	47.3	Y
Niobium			N		N	0.87	N
Phosphorus		447	Y		N		N
Potassium	1040	4753	Y	1498	Y	2209	Y
Selenium	1.3		N	1.33	Y	0.72	N
Silver			N	1.51	Y	1.10	Y
Sodium	380	180.3	N	42.9	N	134.5	N
Thallium			N	0.3	Y	0.15	Y
Thorum						25.6	Y
Vanadium	101	51.2	N	61.7	N	44.2	N
Zinc	6.9	78.1	Y	115.26	Y	129.5	Y

At the screening level, these contaminants were assumed to be sufficiently soluble to be bioavailable; contaminants listed as above background in Table 6.2 were screened further as ecological COPCs solely on the basis of their toxicity. The physical and chemical characteristics of COPCs determining their mobility, persistence, and potential for bioaccumulation were considered in the risk characterization. If no COPCs in a given medium at a source unit qualified as ecological COPCs, then effects and risks to assessment endpoints for exposures to that medium at that site were not assessed further.

Toxicological screening benchmarks for ecological COPCs were chosen using available published data; no toxicity testing was performed for the BCV OU 2 BERA. Screening benchmarks were considered for each COPC in each environmental medium and corresponding to the primary modes of exposure to COPCs: soil (root uptake by plants, ingestion of soil or biota for terrestrial animals); and sediment (direct contact by aquatic biota). Screening benchmarks for phytotoxicity are those presented in Suter, Will, and Evans (1993). Sediment screening benchmarks are "effects range-low" values (Long and Morgan 1990). Screening benchmarks for soil at BCV OU 2 were compiled from published summaries (Suter, Will, and Evans 1993) and electronic data bases containing toxicity data [e.g., (EPA 1992c), HSDB (NLM 1992), RTECS (NIOSH 1992)].

Published toxicity data for soil were used in the following order of preference:

- government standard,
- published toxicity benchmarks,
- upper-bound concentrations showing no effect,
- chronic toxicity concentrations, and
- acute toxicity concentrations.

There are no national soil standards equivalent to ambient water quality criteria for surface water. For this BERA, chronic phytotoxicity benchmarks (Suter, Will, and Evans 1993) and soil screening benchmarks for wildlife (Opresko, Sample, and Suter 1993) were used for those COPCs for which they were available. Chronic or long-term toxicity is defined to be that occurring during exposures longer than 96 h. In all cases, the appropriateness of study methods, chemical species, and test organisms relative to BCV OU 2 was considered. Screening benchmarks for the COPCs at BCV OU 2 source units, along with summary data on other toxicity screens, are given in Tables D.1 through D.3.

Toxicity studies may report concentrations that produce no observable effect or no observable adverse effect. The highest concentration showing no effect in a given study is termed the no observed adverse effect level (NOAEL). The lowest published NOAELs were the preferred choice for oral toxicity thresholds for organisms ingesting soil. Because different species may have different responses to toxicants, NOAELs may vary. Choosing the lowest reported NOEALs ensures a conservative screen.

When NOAELs were unavailable, oral toxicity screening thresholds were based on the lowest published toxicity concentrations available across all appropriate species. Chronic oral LD_{50}s, in most cases reported as the amount of toxicant in the diet per kilogram of body weight that causes 50% mortality, or similar measures of toxicity were used to set threshold concentrations for contaminants in soil.

Screening Rules. To select ecological COPCs, the mean concentrations of COPCs were compared to benchmark values to screen out contaminants that did not need further consideration. The COPCs for BCV OU 2 were screened according to the following rules:

1. If the 95% UCL mean environmental concentration at the site does not exceed the toxicity screening–benchmark concentration, then consideration of other special qualities of the COPC (e.g., the contaminant concentration exceeds an ARAR) is required for the contaminant to qualify as an ecological COPC.
2. In cases in which a toxicity screening–benchmark concentration could not be established, the contaminant is defined as an ecological COPC.

Rule 1 reflects the fact that toxicity is the primary consideration. Because deposition of potentially contaminated materials at the source units had ceased several years before contaminant concentrations were measured, it is reasonable to assume that most COPCs at BCV OU 2 source units are persistent. Rule 2 ensures that potentially dangerous contaminants are not excluded as ecological COPCs strictly for lack of toxicity data. This is a conservative assumption. For example, there are no oral toxicity data for cyanide and thallium or phytotoxicity data for most organics; therefore, they qualify as ecological COPCs.

Screening of Ecological COPCs. The soil COPCs (Table 6.2) were screened against benchmarks for phytotoxicity and soil ingestion. The results are shown in Appendix D, Tables D.1–D.3. Using the screening rules listed above, 21 of the 23 inorganics identified as preliminary COPCs qualify as ecological COPCs in at least one environmental medium in BCV OU 2 because they exceed screening levels (Table 6.3). For example, aluminum qualifies as an ecological COPC in SA-1 soils because its UCL concentration (29,800 mg/kg) exceeds the phytotoxicity screening benchmark (10 mg/kg). An additional 80 organic analytes (see Tables 3.22, 3.24, and 3.25) were retained as ecological COPCs because there were no screening values for them.

Sediments from RSA (samples SS-7 and SS-8) were screened against National Oceanic and Atmospheric Administration biological effects levels (Long and Morgan 1990), and against soil background concentrations. The initial screening values were those designated Low Effects Range (ER-L). Table 6.4 lists the maximum concentrations of all analytes detected in sediments SS-7 and SS-8. The maximum concentration of each contaminant detected in the two sediment samples was compared to its ER-L. Of 29 analytes detected, 12 had ER-Ls. The maximum concentrations of 19 analytes exceeded soil UCBs. Of these, 6 were below ER-L values and 10 had no biological effects levels (Table 6.4). Therefore, 13 sediment analytes—barium, calcium, cobalt, lead, magnesium, manganese, nickel, thallium, zinc, 3 isotopes of uranium, and tetrachloroethene—were retained as ecological COPCs for sediment.

Following the screening, qualifying ecological COPCs were considered further to evaluate whether other considerations would cause a COPC to be rejected as an ecological COPC. Aluminum was rejected as an ecological COPC. Despite the presence of aluminum at all BCV OU 2 sites at concentrations in excess of phytotoxicity screening benchmark values, aluminum is not considered further as an ecological COPC for two reasons. First, the UCL concentrations of aluminum at the SY-200 Yard exceed background only slightly and did not exceed background at RSA, whereas natural soils may contain aluminum levels more than eight times the ORR background level (Bohn, McNeal, and O'Conner 1985). Second,

Table 6.3. Inorganic ecological COPCs in soils for BCV OU 2[a]

Inorganic analyte	Ecological COPC?
Aluminum	Y
Antimony	Y
Barium	Y
Beryllium	N
Cadmium	Y
Calcium	Y
Chromium	Y
Cobalt	N
Copper	Y
Cyanide	Y
Lead	Y
Magnesium	Y
Manganese	Y
Mercury	Y
Nickel	Y
Niobium	Y
Phosphorus	Y
Potassium	Y
Selenium	Y
Silver	Y
Thallium	Y
Thorium	Y
Zinc	Y

[a]Ecological COPCs are those COPCs that failed either the phytotoxicity screen, the soil toxicity screen, or the sediment toxicity screen. All organic COPCs except toluene are retained as ecological COPCs.

Table 6.4. Screening of analytes detected in RSA sediments[a]

Analyte	Background reference[b] (mg/kg)	Screening level (mg/kg)	Maximum concentration (mg/kg)	Above background ?	Above screening level?
Aluminum	23,400		17,900	N	
Antimony	<0.4	25	0.34	?	N
Arsenic	655	33	50.3	N	
Barium	14.2		47.9	Y	—
Beryllium	0.96		0.93	N	
Cadmium	<0.24	5	3.5	Y	N
Calcium	219		87,100	Y	—
Chromium	35.7	80	23.9	N	N
Cobalt	3.68		20.6	Y	—
Copper	35.9	70	40.4	Y	N
Iron	53,900		32,500	N	
Lead	39.2	35	84.3	Y	Y
Magnesium	722		1350	Y	—
Manganese	106		865	Y	—
Mercury	0.3	0.15	0.29	N	
Nickel	21.3	30	31	Y	Y
Potassium	1040		829	N	
Selenium	1.3		0.7	N	
Silver	<1.2	1.0	0.63	?	N
Sodium	380		116	N	
Thallium	<0.48		0.33	?	—
Vanadium	101		75	N	
Zinc	6.9	120	195	Y	Y
^{234}U	1.15		3.86	Y	—
^{235}U	0.35		0.397	Y	—
^{238}U	2.7		3.95	Y	—
Tetrachloroethene			7	—	—
Fluoranthene		4000[c]	49	Y	N
Aroclor-1260		50	41	Y	N

[a]Data were not used if the sample point was only intermittently under water. Therefore, only sites SS-7 and SS-8 were used for this analysis. The maximum value of these samples is reported and compared to the UCL for ORR Copper Ridge soil, Horizon C, and to the smaller of published ER-L or apparent effects threshold (AET) values (Long and Morgan 1990).

[b]Smaller of background UCB or maximum.

[c]ER-L value for total PAHs.

experimental conditions in phytotoxicity tests on aluminum are not representative of soil conditions at BCV OU 2. The phytotoxicity screening level is intended to represent added soluble aluminum salts, whereas the majority of aluminum in BCV OU 2 soils is a component of the clay minerals prevalent at the site. As a result, while published toxicity thresholds may be accurate for aluminum dissolved in soil-pore water, measured concentrations of aluminum in natural clay soil, such as that found at BCV OU 2, grossly overestimate the concentration of aluminum available for root uptake by plants.

Calcium, magnesium, sodium, and potassium were also rejected as ecological COPCs. These analytes are considered essential nutrients. Elevated calcium and magnesium levels are characteristic of limestone gravel (Bohn, McNeal, and O'Conner 1985), which was observed in the fill areas (Sect. 3.2.4). Sodium is not considered further as an ecological COPC because sodium concentrations did not exceed background at the SY-200 Yard and RSA and exceeded background at SA-1 by only ~20%. Furthermore, the high concentrations of calcium counteract toxicity of sodium to vegetation (Follet, Murphy, and Donahue 1981). Potassium exceeded background by as much as about fivefold at SA-1, but soil chemistry texts (Bohn, McNeal, and O'Conner 1985; Follet, Murphy, and Donahue 1981) did not reveal any adverse effects to plants of elevated potassium. The resulting ecological COPCs and the BCV OU 2 source units with which they are associated are listed in Table 6.5. These ecological COPCs are examined further in the exposure characterization (Sect. 6.2), ecological effects assessment (Sect. 6.3), and ecological risk characterization (Sect. 6.4).

6.2 EXPOSURE CHARACTERIZATION

Exposure characterization should include quantification of release, migration, and fate of contaminants; characterization of receptors; and quantification of concentrations at the point where organisms are actually exposed (EPA 1991e). This exposure characterization evaluates the exposure environment, exposure routes (expected pathways and modes of exposure) and magnitude of exposure of assessment endpoints to ecological COPCs at BCV OU 2 source units. Ecological receptors are identified in Sect. 6.1.1.

This BERA takes two approaches to quantifying exposure. The first is to assume that all plants are exposed to the UCL of the measured environmental concentrations in the appropriate media. The second approach is to modify the exposure concentration for small mammals to correct for specific rates of incidental ingestion of soil. These approaches are described in Sect. 6.2.3.

6.2.1 Characterization of the Exposure Environment

Contaminant sources evaluated for the BERA at BCV OU 2 include surface and subsurface soil [0 to 3 m (0 to 10 ft)] and sediment as defined in Sect. 6.1.2.3. Leaching of surface or subsurface contaminants may affect groundwater, but the risks from exposure to groundwater are outside the scope of the BERA for BCV OU 2. Contaminated soil from the

BCV OU 2 source units can be transported by erosion and runoff to Bear Creek, but the risks from exposure to surface water and sediments in Bear Creek are outside the scope of the BERA for BCV OU 2.

Table 6.5. Inorganic ecological COPCs by site at BCV OU 2[a]

Inorganic analyte	SA-1[b]	SY-200 Yard[b]	RSA[b]
Antimony		M	
Barium	M	M	M
Cadmium	P		
Copper			P, M
Cyanide			P
Lead	P, M	P, M	
Manganese	P, M	P, M	P, M
Mercury	P, M	P, M	P, M
Nickel	P, M	P, M	P, M
Selenium		P, M	
Silver		P	P
Thallium		M	M
Vanadium	P, M		
Zinc	P, M	P, M	P, M

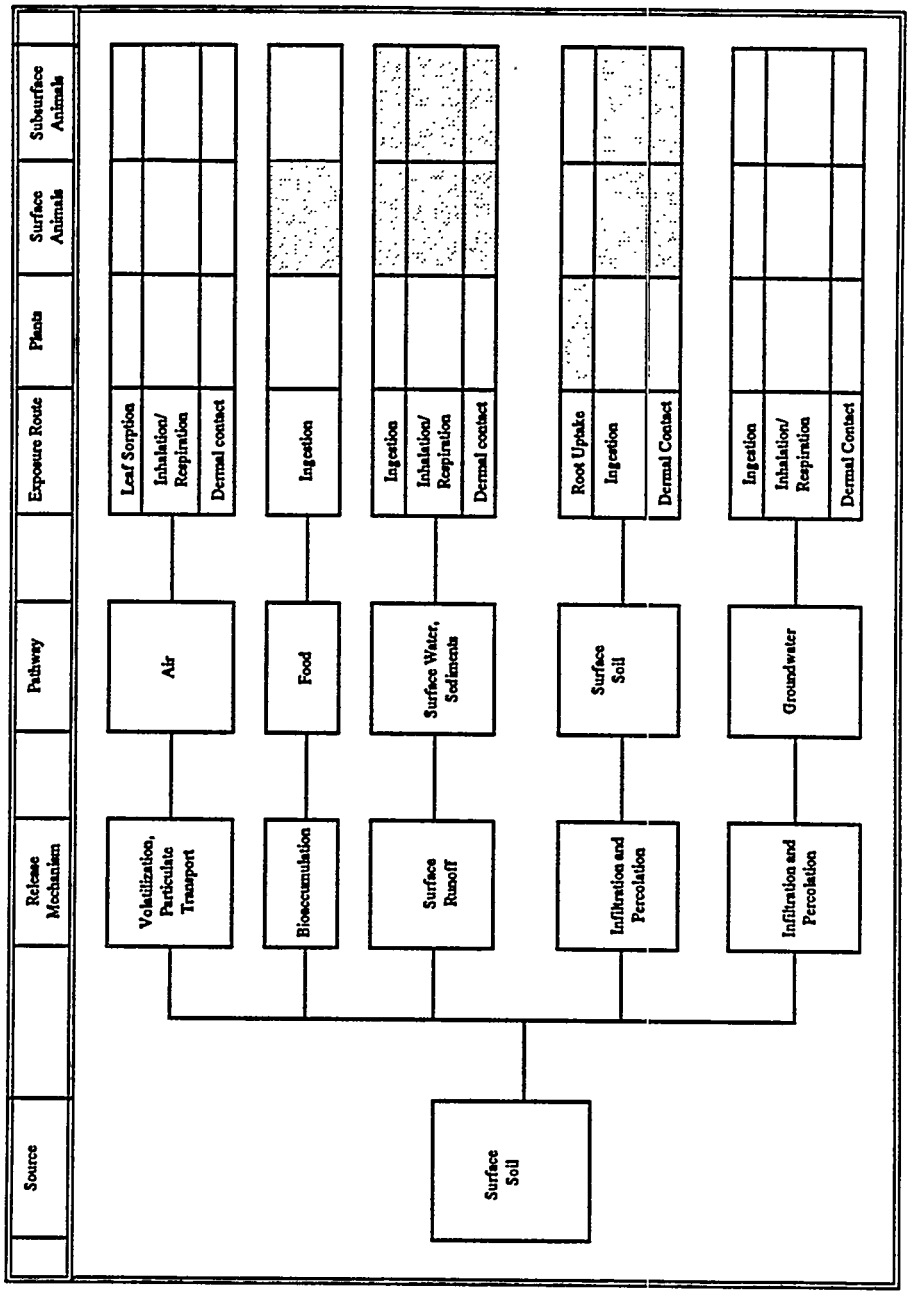
[a]*Ecological COPCs are those COPCs that failed either the phytotoxicity screen, the soil toxicity screen, or the sediment toxicity screen. All organic COPCs except toluene are retained as ecological COPCs.*

[b]*P = phytotoxicity COPC; M = mammal COPC.*

When the exposure of plants and small mammals to ecological COPCs from BCV OU 2 source units is evaluated, soil is considered the primary environmental exposure medium. Current exposures at SA-1 and the SY-200 Yard were not evaluated because it is assumed that those areas are covered with clean soil. For future exposures, it is assumed that penetration of the soil by roots exposes vegetation, especially trees, to contaminants in subsurface soil. The depths of most of the roots of vegetation likely to occur on the ORR do not penetrate below about 3 m (10 ft) (Suter, Will, and Evans 1993). It is also assumed that over a long period of time, the activities of burrowing animals will result in mixing of the soil in the top 3 m (10 ft). Therefore, data for the uppermost 3 m (10 ft) were aggregated for future exposures. These data were also used to estimate current risks at RSA. It is assumed that in the absence of clean fill at SA-1 and the SY-200 Yard, current risks are the same as the estimated future risks.

6.2.2 Description of Exposure Routes

Organisms at BCV OU 2 source units are potentially exposed to contaminants by one or more pathways (Fig. 6.4). Pathway analysis links contamination in the biota to contaminant



[a] Shaded cells indicate complete exposure pathways.

Fig. 6.4. Conceptual site model of exposures from BCV OU 2 surface soils.[a]

sources (e.g., soil, sediment, surface water) via mechanisms of release to the environment and the movement of contaminants through the ecosystem. Exposures occur via direct and indirect pathways from contaminant sources to ecological receptors. For this BERA, external exposure by means of direct contact with contaminants is assumed to be unavoidable when an organism lives in a contaminated medium (e.g., vegetation in soil). Internal exposures, which are potentially avoidable, can result from direct ingestion of contaminated food and abiotic material (e.g., soil) during feeding and grooming/preening. Internal exposure via ingestion of contaminated soil is considered here to be the primary mode of exposure to chemical contaminants for small mammals residing entirely within BCV OU 2 source unit boundaries, such as mice. These will have additional but secondary exposures from direct contact with contaminated soil, inhalation of fumes or dust and, where applicable, direct radiation by radionuclides. Subterranean organisms (e.g., earthworms) will receive primary exposure by ingestion of contaminated matter (soil, plant material) and secondary exposure from direct contact with contaminated soil and inhalation of soil vapor and particles. Few vertebrate organisms of a limited number of types are expected to reside currently within contaminated soil at the BCV OU 2 source units, but the number and diversity of burrowing organisms would be expected to increase in the future when these areas become more vegetated.

To estimate the relative risk to classes of ecological receptors potentially exposed by different modes and pathways, the environmental concentrations of contaminants must be adjusted according to how the pathways and modes modify the exposure to contaminants (e.g., dilution, biomagnification). The resulting exposure concentrations are used to characterize the risk to the nonhuman populations (Sect. 6.4). This approach to exposure assessment recognizes the possibility that the endpoint organisms for BCV OU 2 are exposed to environmental concentrations less than that measured in media. Bioaccumulation and biomagnification of COPCs are possible also. However, the BCV OU 2 assessment endpoints organisms (plants and small mammals) are unlikely to be exposed to contaminant concentrations elevated by biological processes.

6.2.3 Quantification of Exposure

The concentration of a contaminant to which ecological receptors are potentially exposed (i.e., exposure concentration), as opposed to that measured (i.e., environmental concentration), depends on the pathway and mode of exposure. Organisms exposed externally to contaminated media by direct contact are exposed to the full environmental concentration for the time they reside in the media. The exposure concentration for organisms that ingest contaminated media must be corrected for the fraction of their diet that is contaminated. Organisms living in contaminated media are exposed both internally and by external contact with contaminated media.

Environmental concentrations of the COPCs at the BCV OU 2 source units are given in Tables D.1 through D.3 (see also Sect. 3.2). UCLs of the measured concentrations are presented. The measured concentrations are taken as the exposure concentrations for vegetation in direct contact with soil. The exposures to small mammals by way of ingestion of contaminated soil are calculated from measured UCL soil concentrations of ecological COPCs and an estimate of the endpoints' specific rate of incidental soil ingestion. For the exposure estimate, it was assumed that daily soil ingestion occurs at 0.3% of the body weight. This is a conservative approach to screening ecological COPCs because most small mammals [e.g., rats and mice (Harkness and Wagner 1989; Opresko, Sample, and Suter 1993)] do not

consume >15% of body weight daily as food, and soil ingestion by mice has been estimated as <2% of the diet (EPA 1994b) of the dietary intake.

Exposure by ingestion of contaminated plants is estimated by calculating the concentration of contaminants transported from soil into plants and the amount of plant material consumed daily by the indicator animal. Soil-to-plant uptake factors have been determined or assumed for most inorganics by Baes et al. (1984) and NCRP (1989). The former authors used literature values to compare plant tissue concentrations to soil concentrations of contaminants whenever they were available; otherwise, values of B_v were derived from the general chemical properties of the analytes and solubility and transport properties of similar chemicals. The authors presented a single uptake factor for all vegetative tissue, even though contaminants are likely to be transported less to fruits and seeds than to leaves and stems. The biological availability of ions in soils varies with soil structure and composition. However, detailed information on the effects of soil composition and structure on plant uptake of inorganics is not available. The uptake of organic chemicals by plants is inversely related to the octanol-water partitioning coefficient of the chemicals (Travis and Arms 1988).It was assumed that the indicator animal is a small herbivore that ingests 15% of its body weight daily (Harkness and Wagner 1989; Opresko, Sample, and Suter 1993). Mean contaminant concentrations were used to calculate dietary exposure via plants since animals forage throughout their feeding range and would be exposed to a wide range of contaminant concentrations rather than at a limited area that would be characterized by the UCL concentration. The resulting exposure factors are discussed in more detail in Section 6.4.1.2.

No investigations into chronic effects on local biota as a result of exposure to wastes have been conducted at BCV OU 2, nor have analyses been performed to determine the radionuclide or chemical contaminant concentrations in the tissues of the biota because of the industrial character and relatively small geographic size of these areas. The UCL radionuclide concentrations observed at BCV OU 2 were 1.8 pCi/g ^{234}U, 0.1 pCi/g ^{235}U, 1.7 pCi/g ^{238}U, and 4.03 pCi/g ^{226}Ra. Risks from radiation exposures are evaluated in Sect. 6.4.

6.3 EFFECTS ASSESSMENT

An effects assessment quantitatively links concentrations of contaminants to adverse effects in receptors (EPA 1991e). Because no site-specific and few laboratory toxicological studies using species common to BCV OU 2 have been conducted, this effects assessment uses data that were obtained from compiled databases [e.g., HSDB (NLM 1992); IRIS (EPA 1992e); RTECS (NIOSH 1992); Long and Morgan (1990); Opresko, Sample, and Suter (1993); and Suter, Will, and Evans (1993)]. Summaries of data from the electronic databases are presented in Table D.4. Information on test concentrations, modes of exposure, and effects on similar species in toxicity studies was used to establish toxicity-threshold concentrations (Table D.4). Here we review chemical toxicity, media toxicity, and biological survey data on the effects of exposure of endpoint organisms to ecological COPCs.

Available data document some of the possible acute or chronic toxic effects on the nonhuman biotic receptors in the BCV OU 2 environment. Only terrestrial biotic receptors are considered (e.g., plants and small animals). Information describing chemical uptake or accumulation of radionuclides by plants and animals is limited and often based on short-term,

high-exposure laboratory experiments. Those studies may not be applicable to the long-term, low-level exposures presented at BCV OU 2.

Chronic toxicity of persistent contaminants is the primary concern for ecological risk at BCV OU 2. Unless VOCs are at very high volume or are being released continually at a site, they are unlikely to remain at high concentrations for very long because they will diffuse or be transported off site. The likelihood of exposures of surface-dwelling biota to acutely toxic concentrations of contaminants will be low. Although metals and SVOCs can occur in high concentrations in soil, small mammals do not ingest large amounts of soil and, thus, are unlikely to be exposed to concentrations above acute toxicity thresholds. Plants may accumulate contaminants from soil, providing a chronic exposure rate to herbivores. Plants can be adversely affected by soil contaminants in numerous ways including seed production, seed germination, growth rate, and accumulation of plant mass.

Methods to establish chronic toxicity levels for humans include application of uncertainty factors, typically of 30- to 1000-fold, to ensure that sensitive humans are protected even though the data used to derive the levels may come from studies of laboratory animals. Large uncertainty factors are not typically applied in the derivation of toxicity benchmarks for biota (Opresko, Sample, and Suter 1993). Instead, toxicity data are extrapolated to a level that is expected to protect particular species from the contaminant (Opresko, Sample, and Suter 1993). Screening thresholds derived from toxicity data for this BERA were set below published values to compensate for the uncertainty introduced by using laboratory toxicity data for organisms other than those found at BCV OU 2. The values were also chosen for computational convenience. For example, the single datum found for the chronic oral toxicity of selenium was a threshold dose (TDLo) for laboratory mice. Accordingly, the toxicity threshold was set at 100 mg/kg, below the published TDLo of 134 mg/kg. For arsenic, the chronic threshold value for mouse (250 mg/kg) was based on a published value of 280 mg/kg. This approach to using chronic toxicity values is conservative but reasonable, because there is often uncertainty about where the threshold lies in relation to the NOAEL and lowest observed adverse effects level for the organisms actually found at BCV OU 2.

6.3.1 Conventional Toxicity Data

This subsection describes toxic effects of radiation and chemicals on plants and small mammals.

6.3.1.1 Chemical toxicity

Chemicals in the ecosystem may be directly toxic to biota or they may decrease a population's ability to survive and reproduce by decreasing reproductive rates, reducing the viability of offspring, causing alterations in behavior patterns, or increasing susceptibility to disease or predators. These disparate endpoints are characterized by different dose responses and may result from different exposure pathways.

Toxicity of soil contaminants varies depending on the receptor species and on the attending physical and chemical factors such as pH, the presence of complexing agents, or other chemicals at the site. Because the ratio of plant uptake to substrate concentrations of metals is not linear, it is difficult to determine the soil concentrations of metals that are toxic to plants. Suter, Will, and Evans (1993) catalogue published data on effects of different contaminants on different species of plants grown under various conditions. Plants grown in

soil containing metals can accumulate higher-than-background levels of some metals. Bioaccumulation is generally most significant in the roots of plants; however, several metals can be translocated to aboveground parts of the plants. Some metals (e.g., mercury) accumulate in animal tissues and can have subtle deleterious effects over long exposure times. Many organic contaminants (e.g., PCBs and pesticides) are extremely lipophilic and can biomagnify in organisms.

Descriptions of the toxicities of ecological COPCs are found in Appendix D. Toxicity profiles are presented there, followed by summary data on toxic levels and solubility/mobility parameters (Table D.4).

6.3.1.2 Radiation toxicity

Most of the biological effects from radiation, such as chromosomal aberrations and organ failure, are similar among different species of biota (NCRP 1990). However, most plants and cold-blooded animals are more resistant to radiotoxicity effects than warm-blooded species, including humans. The National Council on Radiation Protection (NCRP) conducted a review of available information on the effects of ionizing radiation on aquatic biota (NCRP 1990) and concluded that no deleterious effects could be detected for radiation dose rates below 1 rad/d. No similar review of effects on terrestrial biota is available. Fertility and fecundity of organisms and embryonic development are the most sensitive radiation response endpoints for most biota, with somatic effects and mortality occurring only at much higher dose levels.

Plants interact with radionuclides by foliar absorption of radionuclides deposited on leaf and stem surfaces or by uptake through plant roots. Information describing uptake and accumulation of radionuclides by plants is based mostly on short-term, relatively high-exposure laboratory experiments (Knight 1983) that may not be applicable to long-term, low-level exposure conditions, such as those at BCV OU 2. While an herb, *Tradescantia*, exposed to 6 mR/d experienced an increased mutation rate (Mericle and Mericle 1965), the lowest levels of long-term ionizing radiation at which nongenetic effects on higher plants were observed was ~2 rad/d (Woodwell 1962).

Uptake of radionuclides by plants could lead to subsequent animal exposure via ingestion of contaminated vegetation. Because there is little vegetation at BCV OU 2, it is more likely that animals are exposed to radiological contaminants in soil rather than through ingestion of plants.

As of 1982, there was no substantiated evidence that chronic exposures to dose rates below 1 rad/d causes observable effects on populations of warm-blooded animals (Whicker and Schultz 1982). Sacher and Staffeldt (1973) studied the effects of gamma radiation at dose rates ranging from 12 to 125 R/d on the life spans of 13 species of rodents in the laboratory; they reported that some species were highly resistant to chronic irradiation (the ground squirrel, *Tamias striatus*), others were relatively resistant (mice, *Mus musculus*, and rats, *Rattus* spp.), and several were extremely radiosensitive (hystricomorphs such as *Chinchilla laniger*, *Cavia porcellus*).

Studies of mammals living in areas of naturally high radiation levels did not demonstrate negative effects. Gruneberg (1964) studied black rats, *Rattus rattus*, in an area of India with external dose rates of 0.004 R/d, ~7.5 times greater than control areas, due to the presence of monazite sands containing thorium phosphate. Measurements of the skeletons and teeth

showed no significant differences between experimental and control rat populations. The degree of sex gland damage observed in tundra voles (*Microtus oeconomus*) from an area with radiation levels two orders of magnitude higher than surrounding areas due to the presence of uranium was directly related to incorporated radionuclides and the total radiation dose (Verkhovshaya, Maslov, and Maslova 1965). Aliyev, Korzhuev, and Kashkin (1972), Aliyev and Kashkin (1973), and Aliyev and Korzhuev (1973) found deviations in morphology of the red blood cells and blood plasma characteristics in these animals, but there was no indication that there were any ecological effects from total doses of 0.1 to 0.2 R/d.

The effects of ionizing radiation on populations, communities, and ecosystems can be traced back to effects on organisms, tissues, cells, and, ultimately, to molecular and genetic changes. At the molecular level, high doses of ionizing radiation produce chemical toxins, such as free radicals and hydrogen peroxide which can cause cell malfunction or death, and DNA strand breaks that can have genetic and somatic effects (Whicker and Schultz 1982). Low dose effects on organisms include mitotic delay, shortened life span, premature aging, and cancer, with the probability of occurrence of these effects generally increasing with the dose. Reproduction appears to be the most susceptible process in terrestrial animal populations (Whicker and Schultz 1982).

At low radiation doses, populations may not be affected by increased mortality or reduced fecundity of exposed individuals because healthy organisms may compensate by producing more young than they otherwise would as a result of increased resources. This compensatory mechanism is more likely to be realized in species with shorter life spans and greater fecundity. At intermediate doses, mortality and reduced natality may begin to affect populations, the community, and the ecosystem. At the community and ecosystem levels, radiation has indirect effects through the interaction of populations, such as competition and predation, and the possible disruption of ecosystem functions through species extinctions.

6.3.2 Media Toxicity Data

In accordance with the approved RI work plan (SAIC 1993a), toxicity tests were not conducted for exposure media at the BCV OU 2 source units.

6.3.3 Biological Survey Data

In accordance with the approved RI work plan (SAIC 1993a), quantitative biological surveys of the BCV OU 2 source units were not conducted. There are no abundance and distribution data to assess the effects of ecological COPCs on assessment endpoints at the BCV OU 2 source units.

6.4 RISK CHARACTERIZATION

Risk characterization compares exposures to effects (EPA 1991e). An evaluation of the risk to endpoints of the ecological COPCs at BCV OU 2 forms the basis of this risk characterization (EPA 1992c). The use of quotient methods for calculating the risks to ecological receptors is supported by available guidance (EPA 1989c). Here, EQs compare the measured environmental concentration of a contaminant to its toxicity threshold concentration. XQs compare the estimated exposure concentrations to toxicity threshold concentrations. Exposure concentrations are derived from measured mean environmental

concentrations by multiplying by an exposure factor (EF), which incorporates likely modifications of the measured environmental concentration, for example, specific rates of ingestion of contaminated media for small mammals exposed to ecological COPCs in soil. Assuming that toxicity threshold and exposure concentrations are accurate, a quotient greater than or equal to unity indicates that there is the potential for adverse ecological effects, and the more the ratio exceeds unity the greater the risk of potential effects. At all sites, EQs for vegetation (grasses) estimate the current risk of adverse effects; future risks to vegetation (forbs, trees) are estimated by the EQs for trees, which are more sensitive to soil contaminants than forbs (Suter, Will, and Evans 1993). XQs for small mammals estimate both the current and future risk of adverse effects.

Calculating EQs and XQs requires a toxicity threshold for each contaminant for the appropriate mode of exposure. Sediment thresholds are based on AETs (Long and Morgan 1990), and soil thresholds are based on oral toxicity screening thresholds (Table 6.6). The toxicity thresholds used in Sect. 6.1.5 to screen contaminants as ecological COPCs in soil and sediments at the BCV OU 2 source units (Table 6.6) are used to calculate risk quotients in those cases where more appropriate toxicity data are not available.

A phytotoxicity value was not available for beryllium. However, beryllium concentrations in natural soils range up to 10 mg/kg without toxicity (Bohn, McNeal, and O'Conner 1985), above the maximum concentrations observed at the SY-200 Yard and RSA (1.8 and 1.1 mg/kg, respectively) and slightly below the maximum of 11 mg/kg observed at SA-1. Therefore, beryllium was not evaluated further as a phytotoxic COPC.

A preliminary evaluation of risks from radionuclides showed that potential exposures were far below 1 rad/d. For example, exposure by inhalation of ^{238}U occurs at a rate of 0.12 mrem/pCi (HEW 1970). Burrowing animals cannot be expected to inhale >1 g of soil daily. At the maximum observed concentration of 13.3 pCi/g, the exposure would be <1.6 mrem/d (approximately equal to 0.002 R/d). Exposure by ingestion and direct radiation pathways is similar or lower. Therefore, isotopes of uranium, thorium, and radium were not evaluated further as ecological COPCs.

6.4.1 Risk Integration for Current Conditions

Assessment endpoint 2a (Sect. 6.1.1) is an absence of visible phytotoxicity. A current evaluation of that endpoint was made during a site visit on April 20, 1994. At that time an abundant growth of grass was noted on both SA-1 and RSA. At the latter site, grass was growing through graveled areas as well as on cleared parts of the site. There was no grossly visible evidence of phytotoxicity to the trees and shrubs in the area between Bear Creek and the spoil areas. At the SY-200 Yard there was no gross evidence of phytotoxicity at the borders of the disturbed area. There was no vegetation on the disturbed portion of the site. Because that area was covered with clean soil, it is unlikely that phytotoxicity rather than recent disturbances of the soil caused the lack of vegetation; phytotoxicity testing would have to be done to determine directly whether the soil is toxic to vegetation. Risk to ecological receptors under current conditions is further characterized by calculating EQs for vegetation (grasses), which is exposed continuously to soil contaminants, and XQs for small mammals, whose exposures are modified by soil ingestion rates, at the BCV OU 2 sites.

Table 6.6. Toxicity values in calculation of EQs

Chemical	Environmental receptor				
	Grass (mg/kg)	Forbs (mg/kg)	Trees (mg/kg)	Mammal (mg/kg)	Sediment (mg/kg)
		Inorganics			
Aluminum	12.0	12.0	200.0	1000	
Antimony					25.0
Barium				1.31	
Chromium	7.4	6.8		6.17	80.0
Copper	60.0	200.0		3.6	70.0
Iron				800	
Lead	450.0	250.0	100.0	2.01	35.0
Manganese				2.07	
Mercury	5.0			0.016	0.15
Nickel	180.0	100.0	50.0	62.1	30.0
Sodium					
Thallium					
Zinc	1000.0	300.0		24.9	120.0
		Organics			
Acenaphthene				175	0.007
Aroclor-1254			40.0	0.17	0.40
Aroclor-1260			40.0	0.17	0.40
Benzene				6.4	
Benzo(a)anthracene				180	1.60
Benzo(a)pyrene				0.011	2.50
Bis(2-ethylhexyl)phthalate				1.61	
Dibenzo(a-h)anthracene				200	0.260
Di-n-butyl phthalate			200.0	48.4	
1-2-Dichlorobenzene				14.4	
1-2-Dichloropropane				50	
Fluoranthene				125	3.60
Fluorene				125	0.640
Phenanthrene				10	1.38
Phenol				60	
Pyrene				75	2.20

6.4.1.1 Ecological quotients

EQs are calculated to characterize the risk under current conditions to grasses and the risks under future conditions to grasses, forbs, and trees, in terrestrial habitats currently found at the BCV OU 2 sites. Table 6.7 lists the EQs for the BCV OU 2 ecological COPCs in the various source media for these endpoint receptors. EQs were calculated for UCL ecological COPC concentrations of analytes listed in Table 6.5 by dividing the concentration by the toxicity-threshold values. When calculated as the ratio of the UCL to the toxicity threshold concentration, EQs represent a high-end estimate of the risk to populations. This assumes that the environmental concentration of the ecological COPC is not increased by physical or biological processes in the transport and exposure pathways. Because grasses are exposed by direct contact with soil, that is a reasonable assumption.

For many ecological COPCs, an EQ could not be calculated because insufficient data were available to establish a toxicity threshold. These ecological COPCs are carried through the risk characterization as ecological COPCs of uncertain risk to ecological receptors. The majority of these ecological COPCs are organic compounds.

The highest EQs at the BCV OU 2 sites were calculated for the exposure of grasses to mercury and copper. At SA-1 and RSA, no EQs were above 1. The EQ for mercury was 14.0 at the SY-200 Yard.

6.4.1.2 Exposure quotients

To characterize the risk to small mammals, XQs were calculated for each ecological COPC at each of the BCV OU 2 source units, as presented in Table 6.5. UCL environmental COPC concentrations at BCV OU 2 (Table 6.7) were multiplied by an EF (i.e., a specific rate of ingestion) to calculate an exposure concentration at each site. Exposure concentrations are divided by toxicity threshold concentrations to give XQs.

The EF for the small mammal endpoint exposed to ecological COPCs in soil at BCV OU 2 is a specific rate of ingestion. Based on published values for laboratory mice (Harkness and Wagner 1989) and white-footed mice (Opresko, Sample, and Suter 1993; EPA 1994b), a value of 0.003 mg soil per kilogram of body weight per day (0.3% of body weight per day) was chosen as a conservative specific rate of incidental soil ingestion for small mammals at BCV OU 2.

The highest XQ for current exposures of small mammals to soil ecological COPCs at SA-1 was ~3 for manganese. The manganese XQ was also slightly >1 at the SY-200 Yard and RSA. There were no EQs or XQs >1 for organics for which toxicity benchmark values were available. However, the high maximum concentrations of tetrachloroethylene, 1,2,4-trichlorobenzene, trichlorotrifluoroethane, and trichloroethylene (Table D-3) may indicate a potential for toxicity at some locations at RSA.

Exposure factors for ingestion of contaminated plants were calculated from soil-to-plant uptake factors reported by NCRP (1989) or by Baes et al. (1984) where values were not available in NCRP; those values were multiplied by 0.25 to adjust them from a dry weight

Table 6.7. Site-based EQs for COPCs in soils (0 to 10 ft) at BCV OU 2[a] (current exposure)

Compound name	SA-1			SY-200 Yard			RSA		
	UCL Conc. (mg/kg)	Grass EQ	Small mammal XQ	UCL conc. (mg/kg)	Grass EQ	Small mammal XQ	UCL conc. (mg/kg)	Grass EQ	Small mammal XQ
				Inorganics					
Antimony				0.46		0.00			
Barium				87.63		0.20	115.4		0.26
Cadmium	1.31		0.88				5.7	NC	
Chromium	3.6	NC					37.2	5.0	0.02
Copper							57.6	0.96	0.17
Cyanide							2.65	NC	
Lead	110	0.24	0.33	58.8	0.13	0.18	43.65		0.13
Manganese	2030	NC	2.94	729	NC	1.06	708	NC	1.38
Mercury	2.6	0.52	0.01	69.8	13.96	0.21	1.43	0.29	0.01
Nickel	51	0.28	0.01	27.1	0.15	0.00	33.3	0.19	0.01
Selenium				1.33	0.13	0.06			
Silver							1.1	NC	
Thorium							25.6	NC	NC
Vanadium	51.2	NC	0.02						
Zinc	78.1	0.08	0.02	115.26	0.12	0.03	129.5	0.13	0.04
				Organics					
Arcolor-1254							8.9	0.16	
Aroclor-1260				0.423		0.01			
Benzo(a)pyrene	0.22	NC	0.06	0.264	NC	0.07	0.361	NC	0.10

[a]Blank cells represent chemicals that do not pass screening and are not COPCs in that medium.
[b]NC = EQ not calculated because toxicity value was not available.

to a wet weight basis before being used for this analysis. For organics, B_v was calculated by the empirically derived (Travis and Arms 1988) equation:

$$\log B_v = 1.588 - 0.578 \log K_{ow}$$

where K_{ow} is the octanol-water partition coefficient. Values for K_{ow} were taken from the U.S. EPA RREL Treatability Database (Risk Reduction Engineering Laboratory, Cincinnati, OH) and the Soil and Transport and Fate Database Version 2.0 (Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, Ada, OK). It was assumed that the indicator animal ingests 15% of its body weight daily as vegetative plant tissue (Harkness and Wagner 1989; Opresko, Sample, and Suter 1993). Mean contaminant concentrations were used to calculate dietary exposures via plants. The resulting equation for dietary exposure concentration was:

$$DXQ = SC*B_v*0.25*DI / CD$$

where

DXQ = dietary exposure quotient
SC = mean contaminant concentration in soil
B_v = soil-to-plant uptake factor for vegetative tissue
0.25 = factor to convert B_v from dry-weight to wet-weight basis
DI = daily dietary intake (0.15 kg/kg body weight), and
CD = comparison dose for daily contaminant ingestion (mg/kg body weight).

Values for DXQ for ecological COPCs at each site are presented in Table 6.8.

Dietary exposure quotients >1 were observed at all three sites for manganese and at the SY-200 Yard and RSA for mercury. This indicates a slight potential for exposure to those contaminants by ingestion of vegetation. At the SY-200 Yard, a DXQ of 13 was observed for mercury, indicating a potential for toxicity to herbivores by ingestion of vegetation at that site. Published values of B_v were available for only a few organic analytes; for those analytes, values of DXQ were below 1 at all sites, indicating little potential for exposure to those contaminants by ingestion of vegetation.

6.4.1.3 Evaluation of sediment toxicity

Eight inorganic analytes, three radionuclides, and one organic analyte were retained in the initial screen of sediment analytes (Table 6.4). Additional sediment toxicity data were not available for calcium, cobalt, and magnesium. The maximum barium concentration was less than the state of Wisconsin SQC (Hull and Suter 1992). Lead and zinc levels were below the National Oceanic and Atmospheric Administration apparent effects threshold levels (Long and Morgan 1990). Nickel was barely above the effects range-low and was below the effects range-median (Long and Morgan 1991). The maximum manganese concentration was below the guideline of 1200 mg/kg quoted by Hull and Suter (1992) but above the EPA Region V "Polluted" sediment classification. As previously stated, calcium and radionuclides were not evaluated further.

The screening results indicate that there is a potential for toxicity of cobalt, magnesium, and tetrachloroethylene in RSA sediments to sediment-dwelling biota. The degree of risk cannot be evaluated without further toxicity data.

Table 6.8. Dietary exposure quotients for herbivores

Analyte	B_v[a]	Benchmark[b]	Mean conc. (mg/kg)			DXQ[c]		
			SA-1	SY-200	RSA	SA-1	SY-200	RSA
Acenaphthene	2.1×10^{-1}	175	—	0.207	0.184	—	9.3×10^{-6}	8.3×10^{-6}
Acetone	53.3	26	0.025	0.076	0.492	1.9×10^{-3}	5.8×10^{-3}	3.8×10^{-3}
Anthracene	1.0×10^{-1}	1000	—	—	0.176	—	—	6.8×10^{-7}
Antimony	2.0×10^{-1}	0.35	—	0.4	0.2	—	8.1×10^{-3}	4.4×10^{-3}
Aroclor 1254	1.7×10^{-2}	0.17	—	0.046	0.452	—	1.7×10^{-4}	1.7×10^{-3}
Aroclor 1260	1.1×10^{-2}	0.17	—	0.212	—	—	5.3×10^{-4}	—
Barium[d]	1.0×10^{-2}	1.31	247	64.6	98.7	7.1×10^{-3}	1.8×10^{-2}	2.8×10^{-2}
Benzene	2.3	6.4	—	—	0.02	—	—	2.7×10^{-4}
Benzo[a]anthracene	2.2×10^{-2}	180	0.247	—	0.189	1.1×10^{-6}	—	8.7×10^{-7}
Benzo[a]pyrene	5.6×10^{-2}	0.011	0.23	0.212	0.235	4.4×10^{-2}	4.0×10^{-2}	4.5×10^{-2}
Beryllium	1.0×10^{-2}	1.39	1	0.9	0.9	2.7×10^{-4}	2.4×10^{-4}	2.5×10^{-4}
Bis-2-ethylhexyl phthalate	3.3×10^{-2}	15	—	0.201	0.879	—	1.7×10^{-5}	7.4×10^{-5}
Bromodichloromethane	3.2	15	—	—	0.02	—	—	1.6×10^{-5}
2-Butanone	26.3	3.3	—	—	0.05	—	—	1.5×10^{-2}
Cadmium	5.5×10^{-1}	20	2.7	0.1	4.3	2.7×10^{-3}	1.0×10^{-4}	4.4×10^{-3}
Carbon tetrachloride	1.0	0.183	—	—	0.02	—	—	4.2×10^{-3}
Chloroform	1.2	23	—	—	0.024	—	—	4.8×10^{-3}
Chromium	7.5×10^{-3}	6.17	30.3	26.5	31.1	1.4×10^{-3}	1.2×10^{-3}	1.4×10^{-3}
Chrysene	7.0×10^{-4}	450	0.28	0.231	0.207	1.6×10^{-8}	1.4×10^{-8}	1.2×10^{-8}
Cobalt[d]	3.0×10^{-2}	60	16.3	16.1	13.0	3.1×10^{-4}	3.0×10^{-4}	2.4×10^{-4}

Table 6.8 (contined)

Analyte	B_v[a]	Benchmark[b]	Mean conc. (mg/kg)			DXQ[c]		
			SA-1	SY-200	RSA	SA-1	SY-200	RSA
Copper	4.0×10^{-1}	3.6	21.9	31.8	40.3	9.1×10^{-2}	1.3×10^{-1}	1.7×10^{-1}
Cyanide	—	27.8	—	—	1.2	NC	NC	NC
Dibenzo[a,h]anthracene	1.4×10^{-2}	200	—	—	0.211	—	—	5.4×10^{-7}
Dibromochloromethane	2.4	60	—	—	0.02	—	—	3.0×10^{-5}
Di-n-butyl phthalate	3.8×10^{-2}	48.4	—	—	0.484	—	—	1.4×10^{-5}
1,2-Dichlorobenzene	4.3×10^{-1}	14.4	—	—	0.2	—	—	2.2×10^{-4}
1,2-Dichloroethane	1.0×10^{-1}	1.9	—	—	0.02	—	—	4.1×10^{-5}
1,1-Dichloroethylene	2.3	2.31	—	—	0.023	—	—	8.5×10^{-4}
1,2-Dichloroethylene	38.7	100.3	—	—	1.637	—	—	2.4×10^{-2}
1,2-Dichloropropane	1.9	50	—	—	0.02	—	—	2.8×10^{-5}
2,4-Dimethylphenol	1.5	750	—	—	0.201	—	—	1.6×10^{-5}
Fluoranthene	3.2×10^{-2}	125	0.379	0.216	0.261	3.7×10^{-6}	2.1×10^{-6}	2.5×10^{-6}
Fluorene	1.5×10^{-1}	125	—	—	0.184	—	—	8.2×10^{-6}
Lead[d]	1.0×10^{-2}	2.01	38.1	49.9	36.5	1.0×10^{-3}	9.3×10^{-3}	6.8×10^{-3}
Manganese[d]	4.0×10^{-1}	2.07	1136.5	588	689	8.2	4.3	5.0
Mercury[d]	3.0×10^{-1}	0.016	1.0	19.1	1.9	7.3×10^{-1}	13.0	1.3
Methylene chloride	7.3	15.04	0.0033	0.023	0.152	6.0×10^{-5}	4.2×10^{-4}	2.8×10^{-3}
2-Methylnaphthalene	2.3×10^{-1}	1630	—	—	0.195	—	—	1.0×10^{-6}
4-Methyl-2-pentanone	12.0	12.9	—	0.0135	0.044	—	4.7×10^{-4}	1.5×10^{-3}
Napthalene	4.4×10^{-1}	400	—	—	0.179	—	—	7.3×10^{-6}

Table 6.8 (contined)

Analyte	B_v[a]	Benchmark[b]	Mean conc. (mg/kg)			DXQ[c]		
			SA-1	SY-200	RSA	SA-1	SY-200	RSA
Nickel[d]	5.0×10^{-2}	62.1	29.5	24.0	32.8	8.9×10^{-4}	7.2×10^{-4}	9.9×10^{-4}
Niobium	2.0×10^{-2}	—	—	—	0.8	NC	NC	NC
Phenathrene	1.0×10^{-1}	10	0.275	0.239	0.293	1.1×10^{-4}	9.2×10^{-5}	1.1×10^{-4}
Phenol	5.5	60	—	—	0.311	—	—	1.1×10^{-3}
Pyrene	4.2×10^{-2}	75	0.352	0.225	0.296	7.4×10^{-6}	4.7×10^{-6}	6.2×10^{-6}
Selenium	2.5×10^{-2}	0.065	—	0.8	0.5	—	1.1×10^{-2}	7.2×10^{-3}
Silver[d]	2.0×10^{-1}	50	—	1.2	0.8	—	9.8×10^{-4}	1.3×10^{-4}
1,1,2,2-Tetrachloroethane	4.3×10^{-1}	10	—	—	0.02	—	—	3.2×10^{-5}
Thallium	4.0×10^{-3}	—	—	0.3	0.14	NC	NC	NC
Thorium	8.5×10^{-4}	—	—	—	24.4	NC	NC	NC
Toluene	1.1	57.3	—	—	0.03	—	—	2.1×10^{-5}
1,1,1-Trichloroethane	1.4	90	—	—	0.027	—	—	1.6×10^{-5}
Trichloroethylene	2.2	193	—	—	0.178	—	—	7.5×10^{-5}
Vinyl chloride	17.4	0.33	—	—	0.034	—	—	6.7×10^{-2}
Xylenes	6.8×10^{-1}	1286	—	—	0.034	—	—	6.7×10^{-7}
Zinc[d]	4.0×10^{-1}	10	65.3	101.5	101.3	9.8×10^{-2}	1.5×10^{-1}	1.5×10^{-1}

[a]Soil-to-plant uptake factor (dry-weight basis).
[b]Contaminant exposure (mg/kg/body weight/day).
[c]Dietary exposure quotient.
[d]B_v value from NCRP (1989).
NC = not calculated because uptake or benchmark values were not available.

6.4.2 Risk Integration for Future Conditions

The risks to the biota at BCV OU 2 can be considered long-term risks. Toxicity threshold concentrations were based on chronic or subacute exposures. Based on their physical and chemical properties (e.g., half-lives, K_{oc}, and water solubilities), the ecological COPCs at the site can be expected to continue to persist for an extended period of time. To characterize the risk to vegetation under future conditions, EQs were calculated for each ecological COPC at each of the BCV OU 2 using toxicity thresholds for forbs and trees that currently are not found at these sites but that would be expected as a result of natural ecological succession. Mean environmental concentrations at BCV OU 2 were divided by toxicity threshold concentrations for forb and tree species to give separate EQs for forbs and trees (Table 6.9).

EQs for exposure of vegetation (forbs and trees) to ecological COPCs under future conditions could be calculated for only a few COPCs at the BCV OU 2 sites. EQs could be calculated for only two ecological COPCs for forbs (lead and zinc) and one ecological COPC for trees (lead). Lead and zinc did not have EQs >1 for forbs. EQs for lead and nickel at SA-1 were only slightly greater than 1 for trees. An EQ for forbs exposed to mercury at the SY-200 Yard could not be calculated, but it is possible that forbs and trees are more sensitive to mercury than grasses.

As described in Sect. 3.2.4, mercury is not uniformly distributed at the SY-200 Yard. Instead, there are areas of elevated concentration that contribute more to toxicity than other areas. These areas are delineated in Fig. 3.42. Those figures show that the majority of samples with mercury concentrations above the benchmark of 5 mg/kg were located at the east side of the SY-200 Yard fill area. It is likely that toxicity to plants would be limited to those portions of the SY-200 Yard.

In summary, ecological COPCs did not have EQs (for plants) significantly >1 at any BCV OU 2 site, except for mercury at the SY-200 Yard. XQs (for small mammals) >1 and elevated contaminant concentrations in sediment indicate that ecological receptors are at some degree of risk (P >0) at the BCV OU 2 sites. Risk quotients >10 would indicate that these ecological COPCs are very likely to be a source of adverse effects if the site is not remediated. The highest XQs were for manganese at all three sites and none but manganese is greater than 1. However, EQs and XQs for numerous organic compounds could not be calculated because of insufficient toxicity data. Where toxicity thresholds could be established for organic ecological COPCs, those thresholds seldom exceeded mean environmental concentrations. Most organic ecological COPCs with toxicity thresholds did not pose a risk to ecological receptors.

6.4.3 Uncertainties

Uncertainties in each of the four interrelated activities of the ERA process are addressed in the following discussion. Generally, there is uncertainty about whether characterizing the risk to organisms underestimates or overestimates the risk to populations at BCV OU 2 and the ecosystems that comprise them. The issue remains unresolved, so at present, there is no alternative to organismal-based ERA using conservative estimates of toxicity and exposure.

Table 6.9. Site-based EQs for COPCs in soils (0 to 10 ft) at BCV OU 2[a] (future exposure)

Compound name	SA-1			SY-200 Yard			RSA		
	UCL conc. (mg/kg)	Forb EQ	Tree EQ	UCL conc. (mg/kg)	Forb EQ	Tree EQ	UCL conc. (mg/kg)	Forb EQ	Tree EQ
Inorganics									
Copper							51.6	0.29	NC[b]
Lead	110	0.44	1.10	58.8	0.24	0.59			
Nickel	51	0.51	1.02	27.1	0.27	0.54	47.3	0.47	0.95
Selenium				1.33	0.05	NC			
Zinc	78.1	0.26	NC	115.26	0.38	NC	129.5	0.43	NC

[a]Blank cells represent chemicals that do not pass screening and are not COPCs in that medium.
[b]NC = EQ not calculated because toxicity value was not available.

6.4.3.1 Uncertainties in ecological hazard identification

The structure of the biotic communities (i.e., the distribution and abundance of organisms) at BCV OU 2 source units was not quantified for the BERA. The lack of quantitative data introduces uncertainties concerning whether, and to what extent, the risk characterization based on assessment endpoints underestimates or overestimates the risk to the remainder of the ecological communities. On-site reconnaissance establishes the nature and quality of habitat and confirms the presence of vegetation types and of active, visible animal species. These observations justify assumptions about the presence of unobserved organisms that are essential to normal ecosystem functioning, such as soil dwelling worms and arthropods, or herbivorous insects. It is possible that one (or more) unobserved species of organism at BCV OU 2 is more sensitive than assessment endpoints or those species for which toxicity data were available for use in setting toxicity thresholds. It does not necessarily follow that these organisms are at significantly greater risk of adverse ecological effects than that estimated in this BERA, because exposure concentrations could be overestimated.

Environmental concentrations of contaminants at BCV OU 2, which are used to calculate EQs and XQs and which are, thus, critical to the characterization of ecological risk, are based on a limited number of nonrandomly located samples (Sect. 3.2.4). Given that assumptions on the distribution of the data are correct, there is a quantifiable degree of uncertainty about the actual spatial distribution of contaminants, that is, whether a site chosen at random would have a contaminant concentration above or below a given value. For example, the concentration in 19 of every 20 samples will, on average, not be >95th percentile (UCL) concentration. UCL contaminant concentrations were calculated assuming either normal or lognormal distribution of sampling results. If the data do not fit well the assumed distribution, the number of ecological COPCs and their exposure concentrations could be overestimated or underestimated depending on how the actual data distribution differs from the assumed data distribution.

Soil samples were taken only from areas identified as likely to be contaminated, that is, areas where fill had been deposited. There are additional areas in BCV OU 2 (the vegetated banks sloping to Bear Creek at both the SY-200 Yard and RSA) that were not sampled and are assumed not to be contaminated. The contribution of these areas to exposures in BCV OU 2 is not known, but if the soils and plants are not contaminated, they could reduce the overall contamination of biota that spend time in the uncontaminated parts of the OU.

The ecological COPC screening process likely overestimated the number of organic substances that pose potential risks to ecological resources at BCV OU 2.

6.4.3.2 Uncertainties in ecological exposure assessment

Rigorous tracing of the movement of contaminants from BCV OU 2 source media to ecological endpoints, including quantification of a site-specific food web, was not performed for this BERA. This introduces uncertainties about the actual modes and pathways of exposure for the endpoints and the actual exposure concentrations of contaminants. Exposures to biota using the sites are also made uncertain by restricting the evaluation to biota that do not receive exposures outside BCV OU 2. Exposure concentrations can differ from measured environmental concentrations as a result of physical and chemical processes during transport from source to receptor and as a result of biomagnification through the food web. These processes could not be evaluated explicitly and quantitatively in this BERA. It is

reasonable to assume that exposure to some organisms would be underestimated due to neglect of biomagnification of contaminant concentrations in their prey. The exposure experienced by others would be overestimated by neglecting processes that dilute contaminants or otherwise make them unavailable to organisms, especially those organisms exposed by direct contact or inhalation and ingestion of contaminated media.

There is little uncertainty that the modes and pathways used to characterize the exposure to ecological endpoints at BCV OU 2 are most important for the large, active organisms in terrestrial habitats. Soil-dwelling terrestrial animals may be exposed to contaminants in soil primarily by way of inhalation following volatilization, but gaseous concentrations in soil interstices, cavities, and burrows were not available. Therefore, the exposure to burrowing organisms at BCV OU 2 source units from direct contact with and ingestion of contaminated soil and soil interstitial water may be underestimated if gas concentrations are larger than soil concentrations, which is unlikely. The risk will also be underestimated if toxicity thresholds are lower for inhalation than they are for ingestion. Overestimating exposure by using conservative exposure concentrations and toxicity thresholds balances the underestimating of exposure due to neglecting exposure modes and pathways of lesser importance.

Some soil contaminants might be present in forms that are not biologically available or not readily measured. For example, elemental mercury was reported in some samples from the SY-200 Yard. Mercury concentrations were not as high in those samples as in some in which no elemental mercury was observed. Elemental mercury can be oxidized to a more soluble ionic state by microbial processes in soil. Ionic mercury would be more likely than metallic mercury to be mobilized by groundwater and transported to other locations. Therefore, there is uncertainty about the relation between currently measured mercury concentrations and future concentrations of biologically available mercury. This is particularly important for uptake of metals by plants, which varies according to soil structure and composition. Finally, some contaminants in soils may be toxic to BCV OU 2 organisms at concentrations below analytical detection limits, and, thus, the exposure to biota may be underestimated.

6.4.3.3 Uncertainties in ecological effects assessment

There is little doubt that, for most BCV OU 2 organisms, the identified ecological COPCs have deleterious effects at concentrations above the threshold concentrations used to screen contaminants as ecological COPCs and to characterize the risks at BCV OU 2. Toxicity thresholds were either based on concentrations reported not to have an effect on the study organism or were estimated conservatively. These thresholds would underestimate the risks only to organisms at BCV OU 2 that are considerably more sensitive than the study organisms, and overestimate the risk to organisms equally or less sensitive than the study organisms. There remains the possibility that some thresholds were set at levels at or above which some harm would occur to the study organism or to similar organisms at BCV OU 2.

Additional uncertainty exists as to the pertinence of laboratory toxicity data for characterizing the risk to populations and ecosystems in nature. It is possible that populations may compensate for the loss of large numbers of juveniles or adults with increased survival or fecundity, and ecosystems may possess functionally redundant species that are less sensitive to contaminants. The great uncertainty as to whether ecosystems at BCV OU 2 (e.g., the SY-200 Yard) possess these buffering mechanisms justifies a conservative approach to risk assessment based on laboratory toxicity data.

6.4.3.4 Uncertainties in ecological risk characterization

In addition to the uncertainties described above, which ultimately produce the uncertainty in the assessment of current risks for BCV OU 2, there are two additional areas of uncertainty in the risk characterization: cumulative risks and future risks.

The BERA estimates the risk to ecological receptors from individual contaminants. Generally, the methods used were sufficiently conservative that individual risks are overestimated. Nevertheless, synergistic effects are possible when toxicants interact in biological systems. Deleterious effects in ecosystems (including effects on individual organisms) may cascade throughout the system and have indirect effects on the ability of a population to persist in the area even though the population is not directly sensitive to the given contaminants. Therefore, the ecological risk characterization for BCV OU 2 may underestimate actual risks to biotic receptors from chemical mixtures.

A second area of uncertainty in the ecological risk characterization is the future risk to the environment from contamination at BCV OU 2. The BERA characterizes the current risk based on chronic exposure to measured concentrations of toxicants with the potential to persist in the environment for extended periods of time. Nevertheless, possible mechanisms exist that could significantly increase (e.g., erosion, leaching to surface or groundwater) or decrease (e.g., enhanced microbial degradation) the risk to future nonhuman inhabitants of BCV OU 2. Mechanisms that would increase the concentration of ecological COPCs in soil are unlikely to exist at BCV OU 2; risks to off-site receptors exposed to contaminants potentially concentrated by physical processes will be considered in the BCV OU 4 RI. Microbial processes influencing soil contaminants are inevitable, but there is no established basis for concluding that contaminants would decrease in concentration or be made less toxic in the future.

6.4.3.5 Summary

The major uncertainties in this BERA center around the estimates of the contaminant concentrations to which ecological receptors at BCV OU 2 are actually exposed (exposure concentrations) and the concentrations that present an acceptable level of risk of adverse effects to the BCV OU 2 populations and the ecosystems that comprise them (toxicity thresholds). These uncertainties arise from many sources, especially the lack of site-specific data on contaminant transport and transformation processes, organismal toxicity, animal behavior and diet, population parameters, interspecific interactions, and how BCV OU 2 ecosystems respond to environmental perturbations.

The calculated risks to the ecological receptors at BCV OU 2 are the risks of individual contaminants. The risks from exposure to multiple contaminants depend on contaminant interactions; effects could be additive, synergistic, or antagonistic. This BERA provides a foundation for an extended characterization of the risks from exposure to multiple contaminants by providing ecological COPC-specific risk estimates, but such an extended effort cannot be conducted without additional data and evaluation of alternative models of contaminant interaction.

6.4.4 Comparison to Human Health Risks

The evaluations of both human health and ecological risks assumed that soil pathways provide the primary exposures at BCV OU 2. At all three source units, human health hazard indexes (HIs) were >1, whereas EQs and XQs were >1 for manganese and mercury (Sects. 6.4.1 and 6.4.2). Risk estimations imply that there are human cancer risks above 1×10^{-6} at all three source units. Because limits for cancer risks to wildlife have not been established, those risks were not established. Radiation risks to humans at SA-1 were estimated at above 4×10^{-4}, whereas radiation levels to biota appeared to be below deleterious levels.

6.4.5 Summary of Ecological Risk Characterization

In summary, ecological COPCs with EQs (for plants) and XQs (for small mammals) >1 and elevated concentrations of cobalt and magnesium in RSA sediments indicate that ecological receptors are at some degree of risk (P >0) at the BCV OU 2 sites. Risk quotients >10 would indicate that these ecological COPCs are very likely to be a source of adverse effects if the site is not remediated. EQs and XQs were above 10 only for mercury at the SY-200 Yard, XQs or DXQs were >1 but <10 for mercury at two sites and manganese at all three sites. No other XQs at BCV OU 2 sites were significantly greater than 1, the highest being that for small mammals exposed to barium in soil at SA-1 (DXQ = 1.1), followed by those for grasses and forbs exposed to lead and nickel at SA-1 and mercury and copper in soil at the SY-200 Yard. Most EQs and XQs for current and future exposure of vegetation and small mammals to soil ecological COPCs are less than 5. However, EQs and XQs for numerous organic compounds could not be calculated because of insufficient toxicity data. Where toxicity thresholds could be established for organic ecological COPCs, those thresholds seldom exceeded mean environmental concentrations. Organic ecological COPCs with toxicity thresholds did not pose a risk to ecological receptors.

6.5 SUMMARY AND CONCLUSIONS

Ecological risks at BCV OU 2 were evaluated in accordance with EPA's *Framework for Ecological Risk Assessment* (EPA 1992c). This framework comprises four interrelated activities: hazard identification or problem formulation, exposure assessment, effects assessment, and risk characterization. Problem formulation (Sect. 6.1) included a description of the components and especially the indicator organisms of the ecosystem likely to be at risk, and the potential ecological effects, along with a selection of assessment and measurement endpoints as a basis for a conceptual model of stressors, components, and effects. A model was developed that included soils and sediments as the exposure media of concern. This section also included a preliminary screen for ecological COPCs that was based on a comparison of site contaminant concentrations and frequency of occurrence with soil background data. Exposure assessment (Sect. 6.2) described ecological stressors at BCV OU 2, especially locations of areas disturbed by waste disposal and the nature and extent of exposure to ecologically significant contaminants. Effects characterization (Sect. 6.3) provided summaries of toxicological data relevant to indicator biota and contaminants at the site. This information was integrated to perform the risk characterization (Sect. 6.4). Because the approved work plan had not called for ecological sampling, there were no data on biota body burdens or media toxicity. As a result, the BERA was done by screening data on physical media against benchmark values for toxicity.

6.5.1 Habitats and Wildlife

Habitats at BCV OU 2 include an unvegetated industrial site at the SY-200 Yard, grass-covered and graveled areas at SA-1 and RSA, and some old field and early successional forest bordering the fill areas at the SY-200 Yard and RSA. These habitats do not provide significant habitat values to threatened or endangered species separate from the surrounding habitats on the ORR. No evidence was found for the presence of threatened or endangered species in BCV OU 2. Therefore, Assessment Endpoint 1, no harm to any state- or federal-designated threatened or endangered species and their critical habitats in BCV OU 2, appears to be met at BCV OU 2.

Evidence of use of BCV OU 2 areas by wildlife was observed during site surveillances. In a surveillance in mid-April 1994, there was an abundant growth of grass on both SA-1 and RSA fill areas, and there was no visible evidence of phytotoxicity in the peripheral areas at the SY-200 Yard and RSA. Therefore, Measurement Endpoint 2a, no visible evidence of phytotoxicity, appears to be met at BCV OU 2.

6.5.2 Chemicals of Ecological Concern

Chemicals of ecological concern were selected by a series of screens in which contaminant concentrations were compared to various benchmark values. An initial screen against soil background reduced the number of inorganic COPCs; background data were not available for inorganics. The remaining preliminary COPCs for soil were screened against a set of screening benchmarks for grasses and small mammals to yield a list of ecological COPCs. This list included inorganics (antimony, barium, cyanide, lead, magnesium, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc), organics (again few screening data were available), and radionuclides (radium and isotopes of uranium).

6.5.3 Risk Characterization

Risk characterization was performed by calculating EQs, which reflect direct exposure of plants to soil contaminants, XQs, which reflect soil ingestion rates for small mammals, and DXQs, which reflect ingestion of plants contaminated by uptake from soil. EQs were calculated as the ratios of soil contaminant concentrations to a benchmark value for toxicity, whereas XQs and DXQs were calculated as the ratio of soil contaminant concentration times an exposure factor for soil or plant ingestion to the toxicity benchmark. Current risks from soil were calculated for grasses and small mammals, which were assumed to be exposed to the 95% UCL concentrations of soil contaminants. Future risks were assumed to be the same for grasses and small mammals, but because ecological succession should result in the appearance of grasses and forbs, XQs for forbs and trees were calculated for future risks. Potential risks for sediment were evaluated by comparing sediment concentrations with benchmarks such as NOAA biological effects levels (Long and Morgan 1990).

Contaminants with EQs or XQs >1 were retained as ecological COCs. Soil COCs were mercury for plants at the SY-200 Yard, chromium for plants at RSA, and mercury and manganese for small mammals at all three sites. However, only mercury at SY-200 had a DXQ or EQ >10. Potential sediment COCs (for which toxicity data were not available) were cobalt, magnesium, and tetrachloroethylene at RSA.

6.5.4 Conclusions

There was no evidence for harm to threatened or endangered species at BCV OU 2 (Assessment Endpoint 1). Similarly, there was no visible evidence of phytotoxicity in BCV OU 2 soils (Measurement Endpoint 2a), but soil mercury concentrations in the rooting zone (upper 3 m) exceeded published toxicity endpoints (Measurement Endpoint 2b) for grasses (and possibly forbs and trees) at the SY-200 Yard. Therefore, Assessment Endpoint 2, no adverse effects on vegetation, appears to be met at SA-1 and RSA but may not be met at the SY-200 Yard. Soil manganese concentrations were in excess of published chronic toxicity levels for estimated intakes by small mammals (Measurement Endpoint 3a) at SA-1. Therefore, Assessment Endpoint 3, no more than 20% reduction of populations of small mammals residing and ingesting soil at the site, appears to be met at the SY-200 Yard and RSA but may not be met at SA-1. Soil concentrations of manganese at all three sites and mercury at two sites exceed levels that might cause toxicity to herbivores ingesting plants at the site. Therefore, Assessment Endpoint 3, no more than 20% reduction of populations of small mammals residing and ingesting vegetation at the site, may not be met. However, further refinement of soil-to-plant uptake values would be required to determine that remediation was required to meet this endpoint. Sediment biota may be exposed to toxic levels of cobalt, magnesium, and tetrachloroethylene at RSA. Therefore, Assessment Endpoint 4, no more than 20% reduction in populations of biota exposed to sediments derived exclusively from BCV OU 2, appears to be met at SA-1 and the SY-200 Yard but may not be met at RSA.

7. REMEDIATION GOAL OPTIONS

This section presents remediation goal options (RGOs) for contaminants in environmental media of Bear Creek Valley (BCV) Operable Unit (OU) 2. These RGOs are based on an evaluation of risks to human health and ecological receptors. An overview of the regulatory use remediation goals and methods for deriving these numbers are provided in this section. In addition, an inclusive listing of RGOs for chemicals and radionuclides found in BCV OU 2 is provided.

7.1 INTRODUCTION

Remedial action objectives (RAOs) for waste site remediation are overall cleanup objectives established on the basis of the nature and extent of contamination, the resources that are currently or potentially threatened, and the potential for human and environmental exposure. Examples of response objectives include protection of human health and environmental receptors, protection of the groundwater resource, and restoration of contaminated surface soil for current and future use. RGOs, a subset of RAOs, are site-specific, chemical-specific concentrations that define the extent of cleanup required to achieve the RAO.

The Environmental Protection Agency (EPA) has specified the following two "threshold criteria" as the basis for deriving target cleanup levels for contaminated environmental media at waste sites (EPA 1988c, EPA 1989b):

- concentrations of chemicals in the environment must comply with federal and state applicable or relevant and appropriate requirements (ARARs) and
- the remediation objectives must afford overall protection of human health and the environment.

EPA has stated that these "threshold criteria" must be satisfied before a remedial alternative is eligible for selection (53 *FR* 51394, 55 *FR* 8666). As a result, RGOs are based on both ARARs and risk assessment considerations.

ARARs are not a uniformly derived set of similar standards and do not incorporate consideration of the effects of combined exposure to mixtures of chemicals. As such, ARARs cannot be categorically adopted as target cleanup levels. In addition, not all ARARs have been promulgated using the same risk goals as adopted by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program. Thus, although alternatives for site remediation must comply with ARARs, they must also address risk-based action levels.

For carcinogenic effects, these health advisory or risk-based levels are to be selected such that the total (excess) risk of all contaminants falls within the acceptable range of 10^{-4} to 10^{-6} (55 *FR* 8666). The 10^{-6} risk level is specified by EPA as a point of departure for determining remediation goals when ARARs are not available or are not sufficiently protective. For noncarcinogenic effects, cleanup levels should be based on acceptable levels of exposure as determined by the EPA reference doses (RfDs), taking into account the effects of other contaminants at the site.

As noted above, the requirement that a remedial alternative meet chemical-specific ARARs does not ensure that the proposed alternative is protective and thereby potentially acceptable. This can be determined only by (1) evaluating the combined carcinogenic risk associated with the ARAR limits for all chemicals at a given site (assuming additivity of effect in the absence of data on synergism or antagonism), (2) establishing that ARARs do not exceed EPA RfDs for noncarcinogenic effects, and are sufficiently protective when multiple chemicals are present,; (3) determining whether environmental effects (in addition to human health considerations) are adequately addressed by the ARARs, and (4) evaluating whether the ARARs adequately cover all significant pathways of human exposure identified in the Baseline Risk Assessment (BRA).

The establishment of target cleanup levels typically begins during project scoping or concurrent with preliminary Remedial Investigation (RI) activities. Because these preliminary remediation goals (PRGs) are established before completion of the BRA, they are initially equated with ARARs or other readily available environmental or health-based limits. As the RI and Feasibility Study (FS) progress, the results of risk assessment modify the PRGs. These new targets are called RGOs. The RGOs are risk-based concentrations in environmental media that have been derived (back calculated) based upon site-specific exposure assumptions. These RGOs may be further modified based on regulatory comments on the RI and FS.

Ultimately, final remediation levels are derived which ensure that remedial alternatives comply with ARARs *and* are protective of human health and the environment. The final remediation levels are chosen for the contaminants of concern (COCs) and are included in the Proposed Plan and the Record of Decision.

Based on the available EPA guidance, an outline may be developed of the general approach to derivation of RGOs for the protection of human health as follows:

- assemble a listing of all available ARARs;
- identify a target risk level for carcinogens or a target hazard index for noncarcinogens;
- identify subject COCs;
- identify potential exposure pathways and receptors at risk; and
- develop exposure scenarios and characterize environmental concentrations/activities at the points of exposure using available monitoring data and/or the results of environmental fate modeling.

These steps have been used in developing remediation goals for contaminated environmental media in BCV OU 2. Note that ARARs and risk-based numbers are treated equally at this point.

The exposure pathways that form the basis for risk characterization in the BRA should be used in deriving the risk-based RGOs. The point to keep in mind is that chemical-specific remediation levels for contaminants must afford overall protection to human health and the environment. Overall protection as defined by EPA (and noted previously) should take into consideration combined exposure across all chemicals and pathways of concern for receptor groups at primary risk of exposure.

7.2 DERIVATION OF RGOs

EPA guidance for deriving PRGs is presented in *Risk Assessment Guidance for Superfund* (RAGS) Vol. 1, Part B (EPA 1991c). PRGs are initial remediation goals derived based upon default exposure assumptions. These goals are developed early in the site evaluation process based upon readily available information. RGOs are subsequently developed during the RI BRA based upon site-specific exposure assumptions. Final remediation levels are developed as part of the FS process. Figure 7.1 shows the process for moving toward final remediation levels in CERCLA.

The process of deriving an RGO consists of establishing an acceptable target risk value for exposure to a contaminant and back-calculating the corresponding concentration in the environmental medium under evaluation. As discussed in RAGS (EPA 1991c), the 10^{-6} risk level is specified as the point of departure for determining remediation goals for carcinogens, and noncancer risk is expressed in terms of the hazard quotient (HQ) > 1 for individual chemicals or hazard index (HI), which is equal to the sum of the HQ values, also > 1 for combined exposure across chemicals.

To determine risk, the chronic daily intake (CDI) for each contaminant of potential concern is first calculated by evaluating the exposure concentration in the context of the scenario, exposure pathway, and chemical-specific exposure variables such as duration of exposure and intake rate. Table C.13 lists the exposure variables associated with each exposure route considered for the on-site residential scenario, and Table C.14 lists the exposure variables associated with each on-site industrial worker exposure route. For residential RGOs, it was assumed that a receptor could be exposed for 30 years, with the receptor spending 6 years as a child and the remaining 24 years as an adult. (see Sect. 5.3.3.) Once the parameters for the various pathways are determined, risk-based RGOs can be calculated using available toxicity information [i.e., RfD (see Table C.23) and slope factor (see Tables C.24 and C.25), as discussed in Sect. 5.4.].

Table 7.1 lists the RGOs for each of the three sites for both an on-site industrial scenario (includes cumulative contribution from soil ingestion, inhalation, and dermal contact pathways for nonradionuclides and soil ingestion, inhalation, and external exposure for radiological chemicals) and the residential scenario (includes cumulative contribution from soil ingestion, inhalation, and dermal contact for nonradionuclides and soil ingestion, inhalation, and external exposure for radiologic chemicals). RGOs for the residential scenario do not include the contribution from home-grown fruits and vegetables.

Several points are important in understanding and interpreting the draft RGOs derived for BCV OU 2:

- RGOs are derived on a chemical-by-chemical basis and do not reflect combined exposure across contaminants.
- RGOs for a single chemical do not reflect combined exposure across all environmental media in which the contaminant has been found. RGOs were derived only for the soil medium; groundwater, surface water, and sediments will be evaluated during the BCV OU 4 RI. RGOs for a given chemical are based on all the exposure pathways of potential concern for that contaminant and are derived for combined exposure across

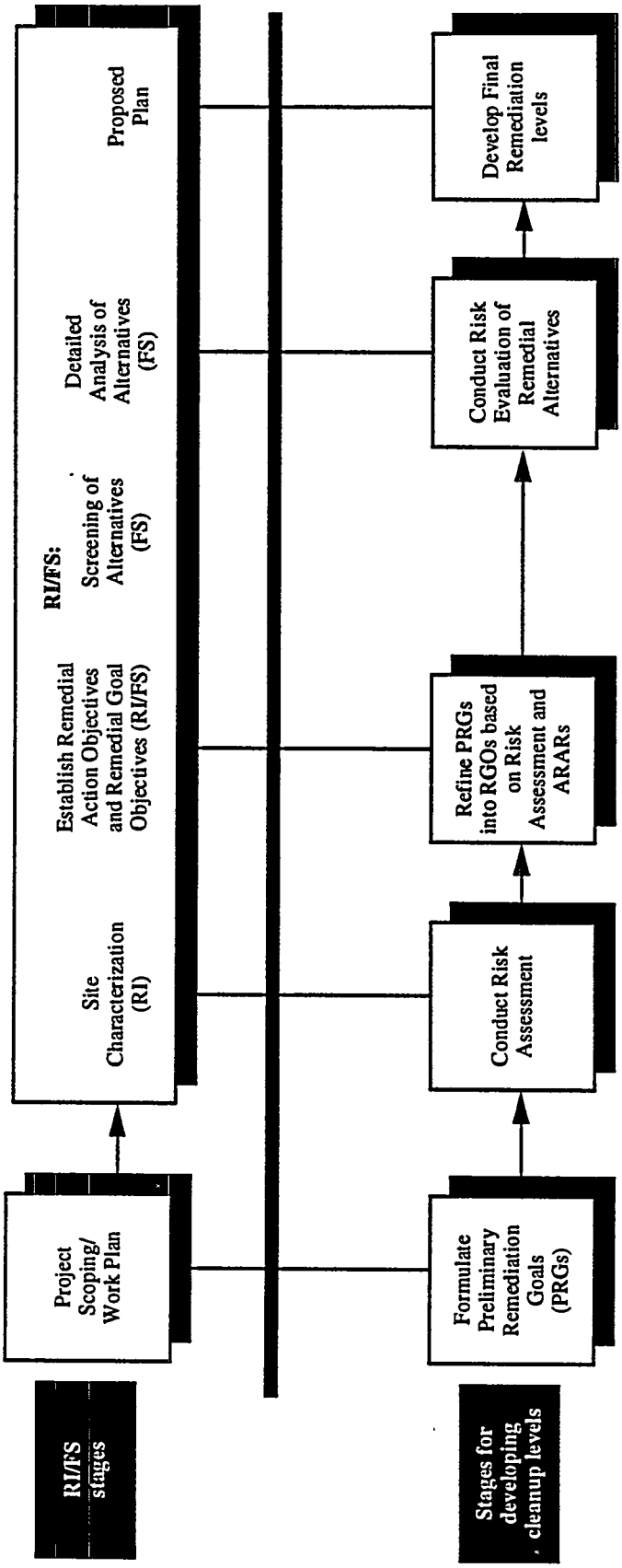


Fig. 7.1. CERCLA process for developing final remediation levels.

Table 7.1. Residential and industrial RGOs for BCV OU 2 soil COCs (based on human health risk assessment)[a]

Contaminant of concern	Concentration detected at site (UCL95[d])	Risk-based RGOs[b,c]				ARAR-based RGOs
		Residential land use[b,c]		Industrial land use[b,c]		
		Carcinogenic	Noncarcinogenic	Carcinogenic	Noncarcinogenic	
			RSA			
Inorganic (mg/kg)						
Beryllium[e]	1.05E+00[e]	1.0E-01	NA	5.9E-01	NA	
Organic (mg/kg)						
Aroclor-1254	9.86E-01	6.8E-02		4.6E-01		1.0E-01
Benzo(a)pyrene	4.76E-01	7.2E-02		NA		
Dibenzo(a,h)anthracene	2.90E-01	7.2E-02		NA		
			SY-200 Yard			
Inorganic (mg/kg)[f]						
Mercury[f]	9.41E+01[g]		7.2E+01		NA	
Organic (mg/kg)						
Aroclor-1254	3.09E-01	6.8E-02		NA		1.0E-01
Aroclor-1260	4.25E-01	6.8E-02		NA		1.0E-01
Benzo(a)pyrene	4.34E-01	7.2E-02		NA		
Dibenzo(a,h)anthracene	1.20E-01	7.2E-02		NA		
			SA-1			
Inorganic (mg/kg)						
Beryllium[e]	1.20E+00[e]	1.0E-01	NA	5.9E-01	NA	

Table 7.1 (continued)

Contaminant of concern	Concentration detected at site (UCL95[d])	Risk-based RGOs[b,c]				
		Residential land use[b,c]		Industrial land use[b,c]		
		Carcinogenic	Noncarcinogenic	Carcinogenic	Noncarcinogenic	ARAR-based RGOs
Radionuclides (pCi/g)						
^{226}Ra[h]	3.22E+00[h]	2.9E-03		6.8E-03		5
^{238}U[i]	5.11E+00[i]	1.2E+00		NA		
Organic (mg/kg)						
Benzo(a)pyrene	3.61E-01	7.2E-02		NA		

[a]RGOs are shown for a target risk of 1.0E-06 and for a target HI of 1.0.

[b]RGOs presented in this table include contributions from the incidental ingestion of soil, dermal contact with soil, and inhalation of soil/dust (and VOCs in soil) pathways for nonradionuclide soil COCs; RGOs include contributions from the incidental ingestion of soil, inhalation of soil/dust (and VOCs in soil), and external exposure to radionuclides in soil pathways for radionuclide soil COCs. Specific equations used to calculate these RGOs (and the risks/HQs in the human health BRA) are discussed in Sect. 5.3 and shown in Tables C.13 and C.14.

[c]When toxicity information (i.e., RfDs and/or slope factors) was available but the calculated risk was <1.0E-06 and/or the HI was <1.0, "not applicable" (NA) is reported in the table; when toxicity information was not available, risk/HQ to human health could not be determined quantitatively, and no value is reported in the table.

[d]The upper 95% confidence limit (UCL95) is the exposure concentration used in the human health BRA (refer to Sect. 5.2; Table 5.1).

[e]The background concentration (DOE 1993) for beryllium (Copper Ridge Horizon C; refer to Table C.3) is 9.6E-01 mg/kg (i.e., the background concentration for beryllium is above both the residential and industrial RGOs).

[f]Mercury is not a COC for the SY-200 Yard area when the entire boundary is evaluated; however, when only the *high concentration area* is considered (refer to Sect. 5.5.5.1 and Fig. 5.2), mercury is a COC under residential exposure conditions.

[g]The UCL95 concentration for mercury reported in this table is for the *high concentration area* within the SY-200 Yard area (refer to Table C.25 and Fig. 5.2 in Sect. 5.5.5.1); this UCL95 is for the depth of 3 to 11 ft (The UCL95 at 3 to 7 ft is 97.6 mg/kg, and the UCL95 at 7 to 11 ft is 148 mg/kg).

[h]The background concentration (DOE 1993) for ^{226}Ra (Copper Ridge Horizon C; refer to Table C.3) is 2.11 pCi/g (i.e., the background concentration for ^{226}Ra is far above both the residential and industrial RGOs).

[i]The background concentration (DOE 1993) for ^{238}U (Copper Ridge Horizon C; refer to Table C.3) is 2.52 pCi/g (i.e., the background concentration for ^{238}U is above the residential RGO).

pathways such as soil ingestion, inhalation, and dermal contact which are likely to occur simultaneously.

- Multiple RGOs may be developed for each single contaminant identified. These different RGOs reflect target goals for sets of relevant exposure pathways. In the current evaluation of BCV OU 2, two RGOs have been developed for each COC: one for the residential scenario and one for the individual worker scenario using the combined exposure pathways of soil ingestion, inhalation, and dermal contact (nonradiological) and soil ingestion, inhalation, and external exposure (radiological chemicals).
- The equations presented by EPA in RAGS Vol. 1, Part B, (EPA 1991c) are recommended for use in calculating risk-based PRGs at the scoping stages of the RI/FS. EPA indicates that these equations are based on standard default assumptions that may not reflect site-specific conditions. EPA specifies that when risk-based goals are to be calculated based upon site-specific conditions, the risk assessor should modify the full equations and/or develop additional ones. RGOs have been derived in this manner. In the evaluation of BCV OU 2, the exposure equations were designed to reflect site-specific considerations and to be consistent with the assumptions adopted in the BRA.

To summarize, RGOs have been developed for COCs in soil. No RGOs have been developed for the groundwater, surface water, or sediment pathways; these pathways will be evaluated during the integrator OU (BCV OU 4) RI. For each chemical, two RGOs have been derived which include all exposure pathways noted above. Table 7.1 presents the results of preliminary calculations.

7.3 DERIVATION OF ECOLOGICALLY BASED REMEDIATION GOAL OPTIONS

7.3.1 Introduction

Ecologically based RGOs are chosen to protect the environment from contaminants in the physical media. Because the assessment endpoints of the Baseline Ecological Risk Assessment (BERA) are based on ARARs and risk to ecological receptors, reducing contaminant levels to RGOs should meet all assessment endpoints.

Chemical-specific ARARs (Sect. 4.1) have been established to define the maximum allowable levels of contamination of physical media that are consistent with the protection of animal and plant populations and maintenance of the ecosystem. ARARs may apply to air, surface water, groundwater, sediment, or soil. For BCV OU 2, air and groundwater were not considered significant exposure media for ecological receptors, and surface water risks from site contaminants will be considered in the RI of BCV OU 4. There did not appear to be unacceptable risks to ecological receptors from exposure to sediment contaminants for which toxicity data were available; soil is discussed below.

The RGOs presented here are based on physical media sampling and published information about the toxicity of COCs. As is the case with RGOs for human health, the ecological RGOs are based on single chemicals and do not yet take into consideration combined exposure and potential antagonistic or synergistic effects among contaminants.

Potential ecological exposure routes for contaminants in BCV OU 2 are shown schematically in Fig. 6.4. This figure shows that some transport pathways and some exposure routes are more important than others in ecological exposure to contaminants. Exposures through contaminated physical media may be reduced by cleaning up the media; RGOs that will ensure that residual contaminant levels will be protective of ecological resources are to be established. In this BERA it is assumed that soil is the predominant route of exposure.

EPA has provided guidance for calculating RGOs for human health by a variety of exposure pathways (EPA 1991f), but analogous guidance for nonhuman biota is not available. In addition, a quantitative linkage between toxicity of contaminants to a small mammal and their concentrations in the soil near where the animal was trapped has yet to be established. Also, data on exposure rates and toxicity for terrestrial animals are limited. Therefore, there are several limitations associated with the derivation of ecological RGOs.

Evaluation of ecological risks resulting from the nature and extent of contamination (Sect. 6.4) showed that mercury and manganese are significant potential toxicants to ecological receptors at BCV OU 2. RGOs for mercury and manganese, the two chemicals judged to be the most important contributors to ecological risk, are evaluated in the following subsections.

7.3.2 Sediment

In-stream sediments provide a habitat essential to some biota, so they may be an important source of ecological exposure to contaminants released from soils. Benthic infaunal invertebrates live within the sediment layer and are exposed by dermal absorption and ingestion. Sediment may also provide the means for exposure at other levels of the aquatic food chain. However, there is little perennially submerged sediment in BCV OU 2, and exposures are therefore limited. Advisory action levels for sediment concentrations have been proposed by the National Oceanic and Atmospheric Administration (NOAA). These values are not ARARs, but are to-be-considered guidance intended to identify sediments for which further study may be necessary. Contaminant levels in sediments at BCV OU 2 sample sites did not exceed the lower of the NOAA AET or median effects range (ER-M) benchmarks, so RGOs for sediment are not needed.

7.3.3 Soil

Terrestrial plants and animals may accumulate contaminants from soils exceeding guidelines for protection from toxicity (Sect. 6.3.1). Soil is a potential source of exposure root uptake by direct ingestion. These pathways ARE discussed in the following subsections. In the absence of specific toxicological data for the biota present at BCV OU 2, the screening benchmarks presented in Sect. 6.1.3.5 were used as comparison doses in the calculation of RGOs.

7.3.3.1 Root uptake

The characterization of current and future risks to plants (Sects. 6.4.1 and 6.4.2) showed that the upper confidence limit concentration of mercury exceeds potentially toxic levels by as much as a factor of 14 at the SY-200 Yard. In the absence of further evidence of toxicity, RGOs of 5 mg of Hg/kg would appear to be protective of plants. Alternatively, site-specific

phytotoxicity testing of these soils would provide a better estimate of safe levels of mercury and chromium at BCV OU 2.

7.3.3.2 Ingestion

RGOs for exposure by ingestion of soil are calculated by modifying the standard formulae for calculating the HQ (EPA 1989a):

$$EQ = \frac{(C_{soil} \times 10^{-3}\ \text{kg/g} \times SI \times FI \times ABS)}{(CD \times BW \times 10^{-3}\ \text{kg/g})}$$

and

$$C_{soil} = \frac{(EQ \times CD \times BW \times 10^{-3})}{(SI \times 10^{-3} \times FI \times ABS)},$$

where

EQ = Ecological quotient = 1,
C_{soil} = Contaminant concentration in soil (mg contaminant/kg soil),
CD = Comparison dose (mg contaminant/kg body weight/day),
BW = Body weight (25 g),
SI = Soil intake (0.003 × BW),
FI = Fraction of soil from contaminated area (1.0),
ABS = Fraction of ingested dose absorbed (1.0).

Justification and comments on variables:

EQ: The target *EQ* is always 1. Assuming other parameters are known reliably, a higher value would not be protective and lower values would be overly protective.

CD: The comparison dose is the toxicological benchmark to which the organism is to be protected. It should preferably be a lowest-observed-adverse-effect level, a no-observed-adverse-effect level, or similar measure of effect. For manganese, a value of 2.07 was used (Opresko, Sample, and Suter 1993).

BW: Body weights of small mammalian species vary. Variability in body weight is likely to be compensated by a similar variability in soil ingestion.

SI: Incidental ingestion of soil by small mammals is likely to be variable, depending on feeding habits. For example, birds may ingest soil intentionally for grit to help grind their food, and small mammals may ingest soil while grooming. For this calculation, 0.3% of body weight is used as the value of *SI* (Sect. 6.2.3).

FI: It is assumed here that the home range of the subject animal is restricted to the contaminated area of BCV OU 2 (*FI* = 1). That assumption is probably reasonable for some small mammals such as mice living on BCV OU 2.

ABS: The absorption factor may depend on both the contaminant and the medium in which the contaminant is contained. Typically, the absorption factor of organic chemicals is assumed to be 1, whereas it is usually lower for inorganic chemicals. If the medium used to determine the comparison dose was the same as the exposure medium, no correction for absorption should be made. Toxicological studies of inorganic chemicals may be based on absorption of 20% or less of the administered dose (EPA 1989a). However, for calculating RGOs, a conservative value of $ABS = 1$ is used. RGOs for ingestion of soil by small mammals are shown in Table 7.2.

Table 7.2. Soil RGO values for protection of the environment (mg/kg)

Contaminant of concern	Plant uptake	Small mammal soil ingestion
Mercury	5.0	—
Manganese	—	690

7.4 COMPARISON OF RGOs FOR HUMAN HEALTH AND ECOLOGICAL PROTECTION

In this section, the RGOs for human health and ecological protection are compared. RGOs are discussed by medium, and final values are compared.

7.4.1 Introduction

RGOs for human health and ecological protection are based on different exposure pathways, exposure concentrations, and receptor populations. As a result, RGOs are likely to be different for each environmental medium considered. The following subsections compare the RGOs for COCs evaluated for both human health (Sect. 7.2) and ecological risk (Sect. 7.3) in BCV OU 2 media. The comparisons are summarized in Table 7.3.

7.4.2 Air

Air was not considered a significant exposure medium for either humans or ecological receptors. Therefore, remedial goals for air were not proposed for either human health or environmental protection.

7.4.3 Surface Water

Surface water is not a significant exposure pathway for humans in BCV OU 2. Aquatic biota are exposed to contaminants coming exclusively from the source units at a single seep, but they are exposed ephemerally, and the area of the seep is very small (Sect. 6.1.2.1). Surface water was not considered an exposure medium for humans. Therefore, no RGO for surface water was proposed.

Table 7.3. Comparison of RGO values for protection of human health and the environment

Contaminant of concern	Soil (mg/kg)		
	Plant uptake	Small mammal soil ingestion	Human ingestion[a]
Beryllium	—	—	0.1
Mercury	5.0	0.3	72
Manganese	—	690	—
Benzo(a)pyrene	—	—	72
Dibenzo(a,h)anthracene	—	—	72
Aroclor-1254	—	—	68
Aroclor-1260	—	—	68
^{226}Ra	—	—	2.9×10^{-3}
^{238}U	—	—	1.2

[a]Soil ingestion in the residential scenario.

7.4.4 Groundwater

Groundwater is not an important current source of risk to biota, so remediation is not required to protect the environment. RGOs were not derived for protection of human health.

7.4.5 Sediment

Because sediment exposure to contaminants for which toxicity data were available was determined not to cause unacceptable risks to humans or the environment, RGOs were not calculated.

7.4.6 Soil

A comparison of RGOs for soil is given in Table 7.2. Incidental ingestion of soil provides risks to both humans and ecological receptors at BCV OU 2. Exposure of plants to soil contaminants is continuous, and ingestion of soil by small mammals living on the source units is assumed to involve a larger fraction of body weight than for humans. Therefore, ecologically based soil RGOs for inorganics are lower than the corresponding RGOs for soil ingestion by humans. In contrast, RGOs to protect humans from carcinogens are much lower than the animal-toxicity–based RGOs for the same compounds. Soil RGOs for humans, small mammals, and plants are compared graphically in Fig. 7.2.

To protect all potential receptors, the lowest of the RGOs for each analyte should be chosen. The only analyte with an RGO for both human health and the environment in SY-200 Yard soils was mercury. The phytotoxicity level was based on studies in which mercury salts were added to the test soils. The toxicity of mercury species might be different in weathered soils. Therefore, cleanup levels required to protect plants should be established by conducting phytotoxicity tests on SY-200 Yard soil.

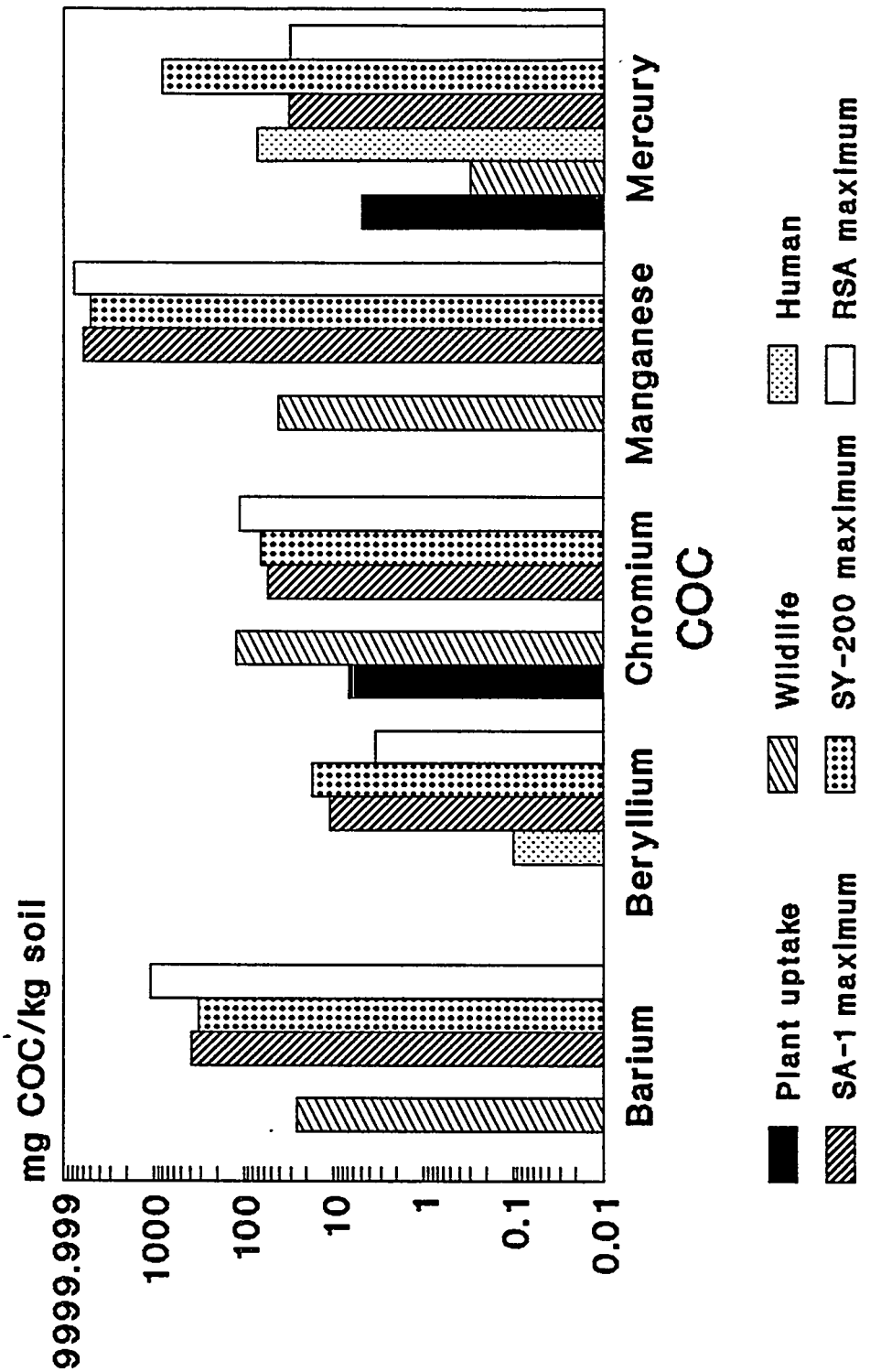


Fig. 7.2. Comparison of soil RGOs and maximum concentrations for metals at BCV OU 2.

7.5 SUMMARY AND CONCLUSIONS

Several points are important in understanding and interpreting the draft RGOs derived for BCV OU 2:

- RGOs in general are derived on a chemical-by-chemical basis and do not reflect combined exposure *across contaminants.*
- RGOs for a single chemical do not reflect combined exposure *across all environmental media* in which the contaminant has been found. RGOs for a given chemical are based on a subset of all of the exposure pathways of potential concern for that contaminant.
- Because the derivation of RGOs does not reflect combined exposure across chemicals and all exposure pathways of potential concern, RGOs cannot categorically be adopted as final remediation goals.
- Multiple RGOs may be developed for each single contaminant identified. These different RGOs reflect target goals for sets of relevant exposure pathways. In the current evaluation of BCV OU 2, for each COC an RGO has been derived for: soil ingestion and dermal contact using commercial assumptions, ingestion of soil using residential assumptions, ingestion of soil by small mammals, and direct uptake of contaminants from soil by plants. Mercury was the only analyte for which more than one RGO was derived; the RGO for plants was much less than the RGO for humans. The final choice of cleanup goals for mercury will be made in the FS/Environmental Impact Statement (EIS).
- The equations presented in RAGS (EPA 1991c) are recommended for use in calculating risk-based RGOs at the scoping stage of the RI/FS. EPA indicates that these equations are based on standard default assumptions that may not reflect site-specific conditions. EPA specifies that when risk-based RGOs are to be based on site-specific conditions, the risk assessor should modify the full equations and/or develop additional ones. In the evaluation of BCV OU 2, the exposure equations were designed to reflect site-specific considerations and to be consistent with the assumptions adopted in the BRA.
- The reasonable maximum exposure assumptions adopted in the baseline human health risk assessment of BCV OU 2 have been used in the derivation of draft RGOs. To derive conservative estimates, most likely exposure assumptions have not been used.

It is important to recognize that the numbers provided in this section are preliminary goals and do not in any way constitute final remediation goals. Risk assessment is a dynamic, iterative process, and the exposure assumptions and risk assessment methods will undergo refinement during the FS/EIS process and following review by the regulatory agencies.

8. CONCLUSIONS

8.1 CURRENT CONDITIONS (NATURE AND EXTENT OF CONTAMINATION)

The BCV OU 2 investigation began originally under RCRA. RCRA Facility Investigation work plans prepared in mid-1989 indicated the presence of COPCs at the three sites, including arsenic, beryllium, barium, chromium, lead, mercury, fluoranthene, phenanthrene, pyrene, radium, and uranium at SA-1; barium, chromium, lead, mercury, PCBs, and uranium at the SY-200 Yard; and arsenic, beryllium, lead, mercury, selenium, thorium, uranium, and tetrachloroethene at RSA. CERCLA became the driving regulator when the ORR was placed on NPL in December 1989. RCRA and NEPA are integrated into the RI/FS process, which requires an RI to be conducted along with BRA and BERA.

The RI field activities were conducted from September 1993 to December 1993. The field activities included collection of subsurface soil samples from 5 borings at RSA and 59 borings at the SY-200 Yard; collection of 3 geotechnical subsurface soil samples from the SY-200 Yard; installation and sampling of 3 unconsolidated (shallow) groundwater monitoring wells at the SY-200 Yard and 2 at SA-1; collection of surface water samples from 3 locations at SA-1, 2 locations at the SY-200 Yard, and 3 at RSA; collection of sediment samples from 4 locations at SA-1, 2 locations at the SY-200 Yard, and 3 locations at RSA; and collection of 1 seep sample from SA-1 (Sect. 3.2).

The analytes selected for each medium were chosen based on historical data results and the data objectives that were identified using the site conceptual model.

After the data were collected and analyzed, the results were evaluated for each medium by comparing the data to several different criteria (Sect. 3.2). A comprehensive list of COPCs from historical and current data was developed for each medium (soil, sediment, and groundwater) for each site by comparing the upper 95% confidence limit of the background median to the upper confidence limit of the site median. The list of COPCs for each medium (Sect. 3.2) was provided to the BRA and BERA (soil and groundwater) teams as the initial basis for the risk assessments presented in Chaps. 5 and 6. Data for surface water were compared to Safe Drinking Water Act MCLs and groundwater PRGs to determine a list of COPCs for surface water. Surface water and the majority of the sediment data were not evaluated in the risk assessments for the BCV OU 2 RI, as surface water, groundwater, and sediments will be included in the ongoing valley-wide integrator media RI. To provide a more focused discussion of the data in Chap. 3, the COPCs were further refined by comparison to known benchmark values such as MCLs and soil and groundwater PRGs.

RSA was evaluated by using data collected during the RI field activities and from previous investigations. The SY-200 Yard was evaluated using only the RI-derived data, and SA-1 was evaluated using both RI-derived and historical data (soil and groundwater only).

8.1.1 Soils

- The analytical soil data evaluation identified 57 soil COPCs at SA-1, 65 COPCs at the SY-200 Yard, and 88 soil COPCs at RSA.

- Only 15 analytes at SA-1, 7 at the SY-200 Yard, and 25 at RSA warranted further discussion in the nature and extent section based on benchmark comparisons.
- The focused list included metals, VOCs, SVOCs, PCBs, and radionuclides.
- Evaluation of the soil COPC list indicates that beryllium, total radium, combined Aroclor-1254 and -1260, benzo(a)pyrene (PAH representative), and mercury were the only analytes above PRGs.
- Although beryllium is above the PRG of 0.15 ppm at all three sites, the higher concentrations were associated with the native soil encountered at the bottom of the boreholes. This suggests that the values detected should be considered background and not contamination.
- Total radium was only detected above the PRG at SA-1. However, the highest value was only slightly over background concentrations and should be considered background level.
- The combined PCB concentrations of Aroclor-1254 and -1260 were above the PRG of 0.083 ppm in the SY-200 Yard and RSA only in isolated areas of elevated concentration. However, it should be noted that EPA guidance on PRGs for residential land use is 1 ppm and 10 to 25 ppm for industrial use. The extent of PCB concentrations >1 ppm action limit is reduced from that above the current PRG, and if the industrial action limit of 10 ppm is applied, then elevated concentrations are sporadic at all sites.
- Several PAHs were detected above PRGs. However, benzo(a)pyrene was selected as representative of this group. Although benzo(a)pyrene was detected above PRGs, the detection limits were greater than the calculated PRGs. The fact that the PRG is lower than the quantitation limit goal should be taken into account when reviewing the data.
- Mercury was only detected at the SY-200 Yard at levels above the PRG of 82 ppm. However, the mercury was detected in isolated areas of elevated concentrations in the eastern and western section of the site. Also, visible mercury was noted in isolated areas during sampling activities.

8.1.2 Groundwater

- The historic groundwater data evaluated from the GWQARS and groundwater taken in this investigation (including the evaluation of a seep sample) identified 37 groundwater COPCs at SA-1, 33 groundwater COPCs at the SY-200 Yard, and 40 groundwater COPCs at RSA.
- Only 14 analytes at SA-1, 11 analytes at the SY-200 Yard, and 18 analytes at RSA warranted further discussion in the nature and extent based on comparison criteria.
- This focused list included metals, SVOCs, VOCs, radionuclides, and anions.
- Evaluation of metals, radionuclides, and anions indicates that these analytes can be associated with the S-3 plume or the problems associated with sampling turbid wells.
- Evaluation of the VOC data indicates that there is a TCE plume that probably originates from the vicinity of the RSA site. The S-3 plume and a possible plume that appears to be derived from the Fire Training Area (located in the upper East Fork Poplar Creek Hydrologic Regime) also contributes to the groundwater contamination in BCV OU 2.

8.1.3 Surface Water and Sediment

- The analytical surface water data evaluation identified 4 surface water COPCs at SA-1, 3 COPCs at the SY-200 Yard, and 6 COPCs at RSA. These COPCs included metals and anions. Surface water data are not being evaluated in the risk assessments; therefore the COPC list was not considered for further evaluation for the BCV OU 2 RI.
- The analytical sediment data evaluation identified 10 sediment COPCs for SA-1, 3 sediment COPCs at the SY-200 Yard, and 12 COPCs at RSA. These COPCs included metals and radionuclides. Two of the samples collected (SS-7 and -8) at the RSA were evaluated in the BERA because they were considered to be located in a perennial aquatic ecological environment. The remainder of the sediment data were not considered for further risk evaluation for the BCV OU 2 RI.

8.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

A preliminary list of available federal and state chemical- and location-specific ARARs that might be considered for the cleanup of soils at the BCV OU 2 was developed. Action-specific ARARs were not identified as part of the RI report but will be identified and analyzed when remedial alternatives are selected during the FS. In the absence of federal or state promulgated regulations, "to be considered" guidance criteria such as criteria advisories, guidance values, and proposed standards were used as guidance only for setting protective cleanup levels for the project.

- The TSCA regulations for materials contaminated with PCBs were considered. The highest concentration of PCBs at any of the sites is only 8.9 ppm; therefore, these regulations would not be ARARs because the concentration does not exceed the cleanup criteria of 50 ppm.
- Although not ARARs, "to be considered" EPA guidance for lead and PCBs was considered. Review of the lead data indicated that the concentrations in the soil (389 ppm) were below the recommended cleanup levels for soils (500 to 1000 ppm), which indicate safe levels.
- The cleanup policy on TSCA PCB spills published by EPA (52 FR 10688) recommends PCB cleanup standards of 25,000 to 50,000 ppb for sites with restricted access and 10,000 ppb for residential and unrestricted access. Also, the EPA guidance report for remedial actions at a Superfund site containing PCBs recommends a PRG of 1,000 ppb for residential land use and between 10,000 and 25,000 ppb for industrial and/or remote areas.
- Depending on the future land use determined for these sites, either the 10,000 ppb or 1,000 ppb level would apply and should be considered when FS alternatives are selected.
- The Tennessee radiation protection standards do not apply to this portion of the RI; however, they will be addressed during the FS for alternatives that consider transportation of radioactive materials for off-site disposal. The EPA regulations are not available at this time, but they will apply to the BCV OU 2 site when the Notice of Proposed Rule Making is final.

8.3 BASELINE RISK ASSESSMENT

Human health risks at BCV OU 2 were evaluated in accordance with EPA's *Risk Assessment Guidance for Superfund,* Vol. 1, Part B. Soil COPCs identified during the RI were provided to the human health risk assessment team. Two exposure scenarios—an industrial worker scenario and a residential scenario—were evaluated in the BRA. Four primary exposure pathways were evaluated, in terms of chronic daily intake, risk, and HQ for both the residential and industrial worker land uses: (1) incidental ingestion of soil, (2) inhalation of dust and VOCs, (3) dermal contact with soil, and (4) external exposure to radionuclides in the soil. Ingestion of home-grown vegetables/fruits was also evaluated for the residential scenario.

- Ten COCs were identified in BRA. For the BCV OU 2, the COC ^{226}Ra was identified as showing the highest carcinogenic risk (i.e., risk $\geq$1E-04), and risks from the external exposure pathway (for ^{226}Ra) and the inhalation pathway (for ^{226}Ra/^{222}Rn) contributed the most to the total cumulative carcinogenic risk for the SA-1 area.
- Cesium-137, ^{90}Sr, ^{99}Tc, and ^{238}U (ingestion of home-grown vegetables in RSA) and ^{234}U and ^{238}U (ingestion of home-grown vegetables in the SY-200 Yard and SA-1 areas) were identified as showing the highest carcinogenic risk (i.e., risks $\geq$1E-04) and contributed the most to the total cumulative carcinogenic risk for these areas.
- For the BCV OU 2 COCs that were identified as having the highest noncarcinogenic/ toxic effects, arsenic, cadmium, manganese, and mercury (ingestion of home-grown vegetables/fruits) contributed the most to the total cumulative HIs.
- A cumulative risk $\geq$1E-04 was found for SA-1 (the four primary pathways were included in this total); cumulative risks between 1E-05 and 1E-04 were found for the RSA and the SY-200 Yard.
- When the vegetable ingestion pathway is considered, cumulative risks >1E-04 were found for all three areas.
- Cumulative HIs $\geq$1 were not found for the three areas (with the exception of the mercury high concentration zone in the SY-200 Yard area).
- However, when the vegetable ingestion pathway is considered, cumulative HIs >1 were found for all three areas.

8.4 BASELINE ECOLOGICAL RISK ASSESSMENT

Ecological risks at BCV OU 2 were evaluated in accordance with EPA's *Framework for Ecological Risk Assessment.* This framework comprises four interrelated activities: hazard identification or problem formulation, exposure assessment, effects assessment, and risk characterization. Because the approved work plan had not called for ecological sampling, there were no data on biota body burdens or media toxicity. As a result, the BERA was done by screening data on physical media against benchmark values for toxicity.

Habitats at BCV OU 2 include an unvegetated industrial site at the SY-200 Yard, grass-covered and graveled areas at SA-1 and RSA, and some old-field and clearly successional forest bordering the fill areas at the SY-200 Yard and RSA. These habitats do not provide significant habitat values to threatened or endangered species separate from the surrounding

habitats on the ORR. No evidence was found for the presence of threatened or endangered species in BCV OU 2. Evidence of use of OU 2 areas by wildlife was observed during site surveillances. In a surveillance in mid-April 1994, there was an abundant growth of grass on both SA-1 and RSA fill areas, and there was no visible evidence of phytotoxicity in the peripheral areas at the SY-200 Yard and RSA.

- Chemicals of ecological concern were selected by a series of screens in which contaminant concentrations were compared to background and toxicity benchmark values for grasses, forbs, trees, small mammals, and sediment-dwelling biota.
- Contaminants with EQs or XQs >1 were mercury for plants at the SY-200 Yard and manganese for small mammals at SA-1. Potential sediment COCs (for which toxicity data were not available) were cobalt, magnesium, and tetrachloroethylene at RSA.
- There was no evidence of harm to threatened or endangered species at BCV OU 2 (Assessment Endpoint 1).
- Similarly, there was no visible evidence of phytotoxicity in BCV OU 2 soils (Measurement Endpoint 2a), but soil mercury concentrations in the rooting zone (upper 3 m) exceeded published toxicity endpoints (Measurement Endpoint 2b) for grasses (and possibly forbs and trees) at the SY-200 Yard. Therefore, Assessment Endpoint 2, "no adverse effects on vegetation," appears to be met at the SY-200 Yard and RSA but may not be met at SA-1.
- Soil manganese concentrations were in excess of published chronic toxicity levels for estimated intakes by small mammals (Measurement Endpoint 3) at SA-1. Therefore, Assessment Endpoint 3, "no >20% reduction of populations of small mammals residing and ingesting soil at the site," appears to be met at the SY-200 Yard and RSA but may not be met at SA-1.
- Sediment biota may be exposed to toxic levels of cobalt, magnesium, and tetrachloroethylene at RSA. Therefore, Assessment Endpoint 4, "no >20% reduction in populations of biota exposed to sediments derived exclusively from BCV OU 2," appears to be met at SA-1 and the SY-200 Yard but may not be met at RSA.

8.5 OBJECTIVES OF REMEDIATION GOAL

- Once the COCs were identified in BRA and BERA, the PRGs were modified and back-calculated based on site-specific exposure assumptions to derive RGOs. For human health considerations, RGOs were calculated for eight COCs (beryllium, mercury, Aroclor-1254, Aroclor-1260, benzo(a)pyrene, dibenzo(a,h)anthracene, ^{226}Ra, and ^{238}U, which were identified by using the four primary exposure pathways but *not* ingestion of vegetables/fruits grown in BCV OU 2 soils) for both the industrial worker scenario and the residential scenario.
- Ecologically based RGOs are chosen to protect the environment from contaminants in the physical media. Ecological RGOs for five COCs (mercury, manganese, barium, chromium, and Aroclor-1260) were calculated.
- The FS will consider the RGOs calculated for the COCs identified at each site in the analysis of remedial alternatives.

8.6 RECOMMENDATIONS FOR APPROACH TO FEASIBILITY STUDY

Modeling of the fate of contaminants at BCV OU 2 leads to the following recommendations for the FS approach to each of the sites at BCV OU 2:

- Contaminant fate and transport modeling for the next 100 years predicts that soil contamination at SA-1 and the SY-200 Yard will not impact groundwater or surface water to an extent that MCLs in groundwater will be exceeded. Groundwater contamination at the SA-1 site is probably the result of plume migrating from neighboring sites: S-3 Site and the Fire Training Area. This means that remedial alternatives for these sites can be addressed independent of the remedial alternatives suggested for the groundwater and surface water integrator OU in BCV.
- Similar modeling at RSA suggests that soil contamination at this site may be providing contamination, or will impact groundwater in the future, such that the MCL for TCE is currently exceeded and may be exceeded in the future. Remedial alternatives for the soil medium at RSA need to address the potential for contaminants (particularly TCE) to migrate to groundwater.

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