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Groundwater Strategy for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee

Volume 1. Main Text

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Groundwater Strategy for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee

Volume 1. Main Text

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Water Resources Restoration Program
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and

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ACRONYMS

ACL	alternate concentration limit
AM	Action Memorandum
ARAR	applicable or relevant and appropriate requirement
AWS	alternative well supplies
BCBG	Bear Creek Burial Ground
BCV	Bear Creek Valley
BORCE	Black Oak Ridge Conservation Easement
BSWTS	Big Spring Water Treatment System
BV	Bethel Valley
CDR	Covenant Deferral Request
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COC	contaminant/chemical of concern
CRBR	Clinch River Breeder Reactor
CSGWPP	Comprehensive State Groundwater Protection Plan
CSM	conceptual site model
CWA	Clean Water Act of 1972
D&D	decontamination and decommissioning
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
DQO	Data Quality Objective
EEVOC	East End Volatile Organic Compound
EFPC	East Fork Poplar Creek
EM	Environmental Management
EMWMF	Environmental Management Waste Management Facility
EPA	Environmental Protection Agency
ETTP	East Tennessee Technology Park
FEHM	Finite Element Heat and Mass
FFA	Federal Facility Agreement
FIR	federally controlled industrial/research
FS	feasibility study
FY	fiscal year
FYR	Five-Year Review
GRA	general response action
HRS	Hazard Ranking System
IC	institutional control
IROD	Interim Record of Decision
LEFPC	Lower East Fork Poplar Creek
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
M&O	management and operating
MCL	maximum contaminant level
MNA	monitored natural attenuation
MODFLOW	modular finite difference flow model
MOFAT	Multiphase Flow and Multicomponent Transport
MT3DMS	Modular 3-D Multi-Species transport model
MV	Melton Valley
NAPL	non-aqueous phase liquid
NNSA	National Nuclear Security Agency

NPL	National Priorities List
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORSSAB	Oak Ridge Site-specific Advisory Board
RAR	Remedial Action Report
RCRA	Resource Conservation and Recovery Act of 1976
RI	remedial investigation
ROD	Record of Decision
S&M	surveillance and maintenance
SAP	Sampling and Analysis Plan
SC	Office of Science
SCF	South Campus Facility
SDWA	Safe Drinking Water Act of 1974
SWSA	solid waste storage area
TC	time-critical
TCE	trichloroethene
TDEC	Tennessee Department of Environment and Conservation
TI	Technical Impracticability
TS	Treatability Study
UEFPC	Upper East Fork Poplar Creek
USGS	U.S. Geological Survey
VOC	volatile organic compound
WAG	Waste Area Grouping
WRRP	Water Resources Restoration Program
Y-12	Y-12 National Security Complex (Y-12 Complex)

EXECUTIVE SUMMARY

The Oak Ridge site is a complex National Priority List (NPL) cleanup site encompassing three large government facilities. As a consequence of past mission activity, groundwater beneath several areas of the Oak Ridge Reservation (ORR) has become contaminated. Extensive measures have been implemented to isolate remaining contaminant sources from groundwater, but additional efforts will be required to understand and respond to legacy groundwater challenges. The purpose of this ORR Groundwater Strategy is to document a path forward for managing these challenges.

Groundwater Strategy Team and Workshops

To build consensus around a path forward for managing ORR groundwater challenges, a Groundwater Strategy Team was convened. Six workshops with representatives from the three Federal Facility Agreement (FFA) parties (U.S. Environmental Protection Agency [EPA], Tennessee Department of Environment and Conservation [TDEC], and U.S. Department of Energy [DOE]) were held:

- Three workshops to review conceptual site models for each ORR watershed; identify plumes and related data gaps (Appendices B through G); and identify potential groundwater projects.

- Two workshops to combine and rank the plumes using a modified EPA Hazard Ranking System approach (Appendix H); combine and rank projects; and select an early action project (Appendix I).

- A final workshop to review groundwater use restrictions and policies and alternatives to engineered groundwater restoration.

Groundwater Strategy Objectives

Using the team charter (Appendix A) and findings of the workshops, the following groundwater strategy objectives have been identified to guide the path forward for groundwater remediation on the ORR:

- Identify and address potential threats to off-site public health from exposure to groundwater contaminated by ORR sources.

- Pursue selected remedial actions, as necessary, to prevent unacceptable risk and groundwater degradation and to restore groundwater to beneficial use where practicable.

- Achieve final ORR cleanup, including final groundwater decisions.

The groundwater strategy objectives provide a framework for early actions and long-term strategy implementation.

Groundwater Strategy Considerations

Potential Off-site Migration. There have been recent sporadic, low-concentration detections of radionuclides and volatile organic compounds in off-site sampling locations downgradient of the ORR that raise concern about potential off-site contaminant migration. There are no known health impacts from contaminants detected off-site to date. However, in order to minimize groundwater pumping that could draw DOE contaminants off-site, license agreements restricting groundwater use have been put in place for some residents in the area west of the Clinch River across from Melton Valley (MV). The potential off-site migration of contaminants guided selection of the early action project to perform additional

off-site sampling. The selected project, referred to as an Off-site Groundwater Quality Assessment, prioritizes early resources toward assessing this potential off-site risk. The project will be conducted in fiscal year (FY) 2014 through FY 2016.

Deep sources of contamination and fractured bedrock and karst geology in areas of the ORR create especially complex groundwater issues. There are limited existing ORR data to define potential pathways for contaminant transport through deep groundwater to off-site locations (Appendices B through G). A discussion of deep flow hydraulic and geochemical boundaries is included in this groundwater strategy (Appendix J).

Feedback from the FFA Parties. This document includes responses from EPA, TDEC, and DOE to questions about key regulatory and technical challenges relevant to ORR groundwater (Appendix K). Areas of consensus among the responses include:

- Additional near-term, off-site monitoring measures are needed to assess potential off-site risks. No immediate off-site groundwater use controls (beyond those controls already in place) are needed at this time. This assessment could change based on characterization results of the Off-site Groundwater Quality Assessment project.

- A modest change to the current ORR DOE lifecycle baseline is needed at this time to budget funding for an ongoing ORR Groundwater Program to continue to characterize groundwater conditions in support of decision-making for remedial activities. The first activity planned under the Program is an off-site sampling effort (the Off-site Groundwater Quality Assessment project). Future baseline changes may be identified as characterization of plumes proceeds under the Program.

- Further characterization is needed to determine whether groundwater restoration is practicable for some contaminated areas on the ORR. Characterization and treatability study projects to determine the appropriateness of a Technical Impracticability (TI) waiver determination for one area of the ORR can help inform future evaluations for other plumes on the Reservation. Like all Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) remedies, a TI waiver determination is subject to Five-Year Reviews of performance and protectiveness.

- Institutional controls are acceptable as a sole means of managing risks posed by groundwater contamination when active response measures are determined not to be practicable.

Groundwater Strategy Implementation

ORR Groundwater Program. Setting up an ongoing ORR Groundwater Program and budgeting annual funding for the program is recommended to implement the groundwater strategy and to support ongoing characterization efforts. The focus for the first 3 years of the Program will be implementation of an Off-site Groundwater Quality Assessment project.

The ORR Groundwater Program will be used to systematically prioritize and investigate groundwater plumes and data gaps. Prioritization decisions and resource allocation for projects to be implemented under the Program will follow FFA and Environmental Management (EM) Program budget development protocols.

- Many data gaps exist because little groundwater investigation work has been done since the 1990s time frame when most watershed-scale remedial investigations to address contaminant sources were completed. Groundwater investigation, groundwater modeling, and technology development to be

conducted under the ORR Groundwater Program will improve understanding of plume sources and migration and help achieve groundwater strategy objectives.

- A list of candidate projects was identified by the Groundwater Strategy Team to investigate groundwater pathways within and potentially beyond the DOE site boundary. The ORR Groundwater Program will prioritize these and other projects for implementation. The Program will develop project scopes for consideration and prioritization, which will improve long-term planning and potentially reduce overall cost.

- ORR Groundwater Program activities will be implemented under the CERCLA process and based in the established Water Resources Restoration Program (WRRP). This cohesive approach builds upon an existing, accepted framework and optimizes resources to achieve multiple purposes over the lifecycle of remediation efforts.

  — Groundwater investigation, modeling, and technology development to be conducted under the ORR Groundwater Program will be integrated with WRRP baseline effectiveness and trend monitoring. An iterative process will be used to reduce plume uncertainties. Results will be used to identify interim measures and actions that may be warranted and support future groundwater decisions and remediation.

Sequencing. The initial plume and project ranking approach and results presented in this document will be reevaluated based on investigation findings. An ORR Groundwater Program will be established and provide flexibility to adapt project sequencing and scopes based on plume characterization findings, cleanup progress, and changing priorities and budgets. The Program will be responsible to recommend specific changes to the timing and scope of groundwater projects in the lifecycle baseline, including final Record of Decision (ROD) projects, as work proceeds.

Near-term Steps. An Off-site Groundwater Quality Assessment will be performed as the first project under the Program as a tri-party effort. A Data Quality Objectives-based approach will be used to sample and analyze off-site groundwater. Depending on the results, follow-on actions may be needed to protect against any identified threat. After data collection is complete, results of the Off-site Groundwater Quality Assessment will be evaluated to determine the next focus areas for strategy implementation and select the next project(s).

RECOMMENDATIONS

Key recommendations center around the ORR Groundwater Program and strategy implementation described above. Other recommendations are summarized as follows:

ORR-wide Strategy Efforts: Implementing efforts that are applicable to multiple similar groundwater plumes across the ORR can streamline and improve preparedness for groundwater remediation and final groundwater decisions. Development of project scopes to implement ORR-wide strategy efforts that can be prioritized to optimize use of ORR Groundwater Program funding is recommended. Examples of ORR-wide strategy efforts are as follows:

- Reaching FFA party consensus on data and process needs for final groundwater decisions and developing guidelines that account for ORR-specific challenges and promote consistency.

- Developing and maintaining an ORR-wide regional flow model. Small-scale models can be developed and refined as needed using calibrated flows from the regional model.

- Planning and interfacing with technology demonstrations to increase certainty that selected groundwater remedies are implementable and effective and with consideration of applicability to other ORR groundwater plumes.

***Groundwater Use Restrictions and Tracking*.** Setting up a DOE interface with TDEC to allow DOE to be notified of new well installation activity in areas adjacent to and downgradient of the ORR is recommended. A portion of the annual funding to be budgeted for the ORR Groundwater Program can be utilized to improve tracking of groundwater uses and restrictions.

***Operating groundwater treatment systems*.** Operation of existing effective groundwater collection and treatment systems will continue to be key to contaminant reduction and plume mitigation at ORR sites. Maintaining awareness of changes in site infrastructure (e.g., building sumps, process water lines) that could impact system operations is recommended.

***Lessons Learned*.** Findings, successes, and lessons learned from other sites and organizations should be used to inform ORR Groundwater Program efforts. Groundwater findings from other DOE programs (e.g., DOE Office of Science research) and CERCLA decision-making completed at other NPL sites may apply to specific ORR plume evaluations. Specific lessons learned applications should be identified in project documentation as appropriate.

1. INTRODUCTION

1.1 PURPOSE OF THE GROUNDWATER STRATEGY DOCUMENT

The U.S. Department of Energy (DOE) Oak Ridge site was placed on the National Priorities List (NPL) 24 years ago in 1989. The NPL identifies sites where legacy operations resulted in the release of hazardous and radioactive contaminants that could impact current or future human health and/or the environment and must be addressed under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The ORR is the most complex NPL cleanup site in the state of Tennessee and one of the most complex in the nation, encompassing three large government facilities across nearly 33,750 acres of land. The site contains hundreds of individual hazardous and radioactive waste units. An ORR Federal Facility Agreement (FFA) [DOE 1992] describes how remediation on the Reservation is performed under CERCLA.

As a consequence of past mission activity, groundwater beneath several areas of the Oak Ridge Reservation (ORR) has become contaminated. Extensive measures have been implemented to isolate remaining contaminant sources from groundwater, but additional efforts will be required to understand and respond to legacy groundwater challenges. The purpose of this ORR Groundwater Strategy is to document a path forward for managing these challenges.

Over the years cleanup has focused on primary sources of contamination that could move off-site via surface water drainages. Another area of focus has been the dismantlement of World War II-era buildings with no current or future use. These buildings require significant stewardship resources and impact site reindustrialization and site modernization efforts. It is projected that building decontamination and decommissioning (D&D) will take many more years with large facilities such as the original Y-12 National Security Complex (Y-12 Complex) buildings still in the queue.

To build consensus around a path forward for managing ORR groundwater challenges, a Groundwater Strategy Team was convened with a charter objective to:

> *Develop an interagency strategic approach to pursue any potential on-site or off-site groundwater public health threats and to protect and restore DOE-ORR groundwater resources to beneficial use.*

The Groundwater Strategy Team includes representatives from the three signatory parties to the FFA: the U.S. Environmental Protection Agency (EPA), the Tennessee Department of Environment and Conservation (TDEC), and DOE.

1.2 GROUNDWATER STRATEGY TEAM

The ORR Groundwater Strategy Team charter, team members, workshops, and output are described below.

1.2.1 Charter

Appendix A presents the full charter developed for the Groundwater Strategy Project. The charter objective listed above and the following four primary focus areas were developed jointly by the three FFA parties to guide discussion:

1. *Delineate and possibly enhance ORR boundary monitoring.*

2. *Define groundwater flow basins and contaminant boundaries within each basin and any deep flowpaths that might impact possible off-site migration.*

3. *Establish additional groundwater use restrictions/policies and frame an alternative strategy if these restrictions/policies prove unavailable.*

4. *Pursue selected groundwater remedial actions when practicable, including:*

   - *Identify any groundwater-related DOE/TDEC "Natural Resource Damage" sites and develop a CERCLA cleanup strategy.*

   - *Identify an early action strategy to address unacceptable migration and exposure of contaminated groundwater both on- and off-site.*

   - *Develop a strategy for final groundwater response actions.*

Additionally, two FFA Appendix E milestones are identified in the charter schedule:

- Issue a D1 ORR Groundwater Strategy 09/30/13.

- Construction Start 09/30/14 (for an early action groundwater project using budgeted funds through fiscal year [FY] 2016).

1.2.2 Strategy Team

In addition to representatives from EPA, TDEC, and DOE, the ORR Groundwater Strategy Team included contractor representatives and a representative from the U.S. Geological Survey (USGS) who acted in the capacity of independent technical support and the interface and liaison between the ORR Groundwater Strategy Team and the Oak Ridge Site-specific Advisory Board (ORSSAB)[1]. Team members and their roles and responsibilities are listed in Appendix A.

1.2.3 Workshops and Output

The ORR Groundwater Strategy Team initially identified the need for four workshops, one for each of the primary focus areas. Early in the process it was determined that the workshops needed to start with review of conceptual site models (CSMs) for each of the ORR watersheds in order to better address the focus areas. A total of six workshops were held as illustrated in Fig. 1.1: three CSM workshops, two plume and project ranking workshops, and a groundwater use restrictions workshop. Table 1.1 lists the dates and major agenda items for these Groundwater Strategy Workshops held in FY 2013.

The review of CSMs was based largely on remedial investigation (RI) information from the 1980s and 1990s. Also reviewed for each watershed, in conjunction with the CSMs, were applicable recent available trend data. These watershed evaluations by the Groundwater Strategy Team culminated with the identification of groundwater plumes and related data gaps (Appendices B through G). Frequently throughout the planning sessions and workshops, the need to select an early action called for in the charter

[1] The Oak Ridge Site-specific Advisory Board (ORSSAB) is a federally appointed citizens' panel that provides independent advice and recommendations to the U.S. Department of Energy Environmental Management Program in Oak Ridge, Tennessee.

and identify future candidate groundwater projects was stressed. As a result, each CSM workshop ended with a list of potential actions within that watershed that are each linked to an identified plume.

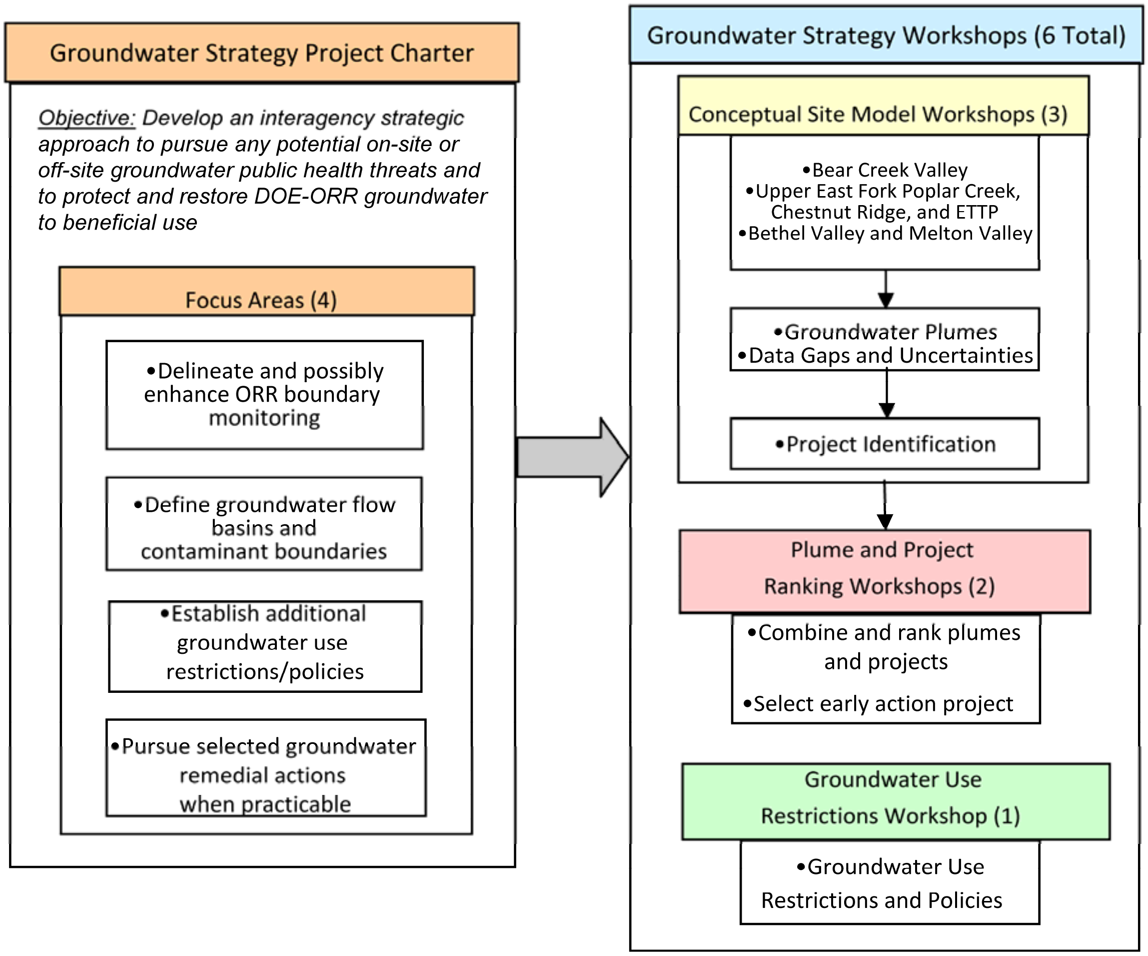

Fig. 1.1. Groundwater strategy project charter and workshops.

The outputs of the CSM workshops were then combined for overall ORR comparison and ranking of groundwater plume scores (Appendix H) in a fourth workshop that also focused heavily on selection of an early action project (Appendix I). A fifth workshop was held to select the early action project and discuss preliminary scope. A sixth workshop was held to discuss options for additional groundwater use restrictions/policies and how they may be appropriately incorporated in the Groundwater Strategy. A comprehensive set of meeting minutes was developed for each workshop for review by all participants.

Table 1.1. FY 2013 Groundwater Strategy Workshops

Workshop date	Major agenda items
Conceptual Site Model Workshops	
January 29, 2013	Overview of groundwater on the ORR BCV Watershed CSM and data gaps Initial discussion on approach to ranking plumes
March 18, 2013	UEFPC CSM and data gaps Chestnut Ridge CSM and data gaps ETTP CSM and data gaps
April 9, 2013	BV CSM and data gaps MV CSM and data gaps
Plume and Project Ranking Workshops	
May 2, 2013	Review key issues from previous workshops Present full list of ORR groundwater plumes identified from each CSM discussion Ranking for ORR groundwater plumes Ranking of early action groundwater projects
July 9, 2013	Select early action groundwater project and discuss preliminary scope GW Strategy document status update
Groundwater Use Restriction Workshop	
August 6, 2013	Groundwater use restrictions/policies

BCV = Bear Creek Valley.
BV = Bethel Valley.
CSM = conceptual site model.
ETTP = East Tennessee Technology Park.
FY = fiscal year.
GW = groundwater.
MV = Melton Valley.
ORR = Oak Ridge Reservation.
UEFPC = Upper East Fork Poplar Creek.

1.3 ORGANIZATION OF THE DOCUMENT

The remainder of this document is organized as follows:

- Chapter 2 – Groundwater Strategy Objectives.
- Chapter 3 – Background information, including the regulatory and environmental setting on the ORR.
- Chapter 4 – Current Environmental Management (EM) Program priorities.
- Chapter 5 – Technical considerations for developing the strategy.
- Chapter 6 – ORR Groundwater Strategy components, including an ORR Groundwater Program to implement the strategy; sequencing; and near-term steps.

- Chapter 7 – Recommendations for implementing the ORR Groundwater Strategy.
- Chapter 8 – References used in the preparation of this report.

Volume 2 – Appendices:

- Appendix A – ORR Groundwater Strategy Project Charter.
- Appendix B – Bear Creek Valley Site Conceptual Model.
- Appendix C – Upper East Fork Poplar Creek Site Conceptual Model.
- Appendix D – Chestnut Ridge (and South Campus Facility) Site Conceptual Model.
- Appendix E – East Tennessee Technology Park Site Conceptual Model.
- Appendix F – Bethel Valley Site Conceptual Model.
- Appendix G – Melton Valley Site Conceptual Model.
- Appendix H – Ranking System for ORR Groundwater Strategy.
- Appendix I – Project Identification and Ranking for the Oak Ridge Reservation Groundwater Strategy.
- Appendix J – Hydraulic and Geochemical Boundaries in the Deep Flow System Underlying the ORR.
- Appendix K – Feedback from the FFA Parties on Key ORR Groundwater Strategy Issues.

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2. GROUNDWATER STRATEGY OBJECTIVES

The following groundwater strategy objectives have been identified to guide the path forward for groundwater remediation on the ORR:

- Identify and address potential threats to off-site public health from exposure to groundwater contaminated by ORR sources.
- Pursue selected remedial actions, as necessary, to prevent unacceptable risk and groundwater degradation and to restore groundwater to beneficial use where practicable.
- Achieve final ORR cleanup, including final groundwater decisions.

These objectives were identified using the Groundwater Strategy Project charter and findings of the Groundwater Strategy Workshops (Fig. 2.1). Along with EM Program guiding principles and priorities (Chap. 4), the groundwater strategy objectives provide a framework for early actions and long-term strategy implementation. This document presents an ORR-wide approach for accomplishing the strategy objectives.

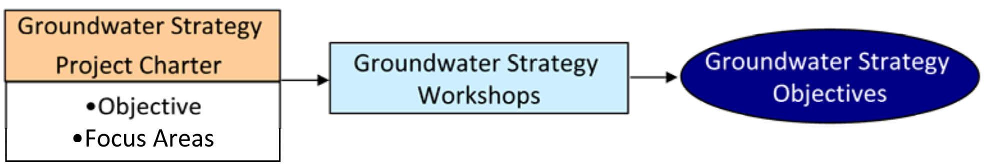

Fig. 2.1. Identification of groundwater strategy objectives.

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3. BACKGROUND INFORMATION

3.1 HISTORY OF THE ORR

Table 3.1 provides a high-level summary of operations that preceded legacy waste cleanup on the ORR.

Table 3.1. Chronology of relevant activities on the ORR

Event	Date
The U.S. Government identified the Oak Ridge National Laboratory (ORNL, X-10) and Oak Ridge Y-12 Plant as research, development, and processing facilities to support the Manhattan Project.	1940s
ORNL is built in Bethel Valley as a pilot plant for demonstrating production and separation of plutonium.	1943
The Y-12 Plant, at the headwaters of East Fork Poplar Creek (EFPC), begins engineering and production of nuclear weapons materials and systems. This plant is now referred to as the Y-12 National Security Complex.	1943
The K-25 Oak Ridge Gaseous Diffusion Plant (ORGDP) [now the East Tennessee Technology Park (ETTP)] is built; eventually K-25 expands its mission to produce enriched uranium for the commercial nuclear power industry.	1945
The Melton Valley Solid Waste Storage Areas (SWSAs) serve as the U.S. Atomic Energy Commission's Southern Regional Burial Grounds for wastes from over 50 facilities.	1955–1963
Production shuts down at the K-25 Site.	1987
The ORR is added to the National Priorities List (NPL) as a Superfund Site.	November 1, 1989
DOE establishes the Environmental Management Program to cleanup the waste legacy of WWII and the Cold War.	1989
The first CERCLA removal action in the ORR, the White Oak Creek Embayment Sediment Retention Structure, is implemented to address ^{137}Cs releases from ORNL to the Clinch River.	1991
An FFA is established between DOE, EPA, and TDEC.	January 1, 1992

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U.S. Department of Energy.
EPA = U.S. Environmental Protection Agency.
FFA = Federal Facility Agreement.
ORR = Oak Ridge Reservation.
TDEC = Tennessee Department of Environment and Conservation.
WWII = World War II.

The ORR consists of three major DOE facilities and their associated CERCLA administrative watersheds. (Fig. 3.1):

- The Oak Ridge National Laboratory (ORNL) and associated waste disposal areas that fall within the Melton Valley (MV) watershed and Bethel Valley (BV) watershed.

- The Y-12 Complex and associated waste disposal areas that fall within the Upper East Fork Poplar Creek (UEFPC) and Bear Creek Valley (BCV) watersheds, and adjacent to the Chestnut Ridge hydrogeologic regime.

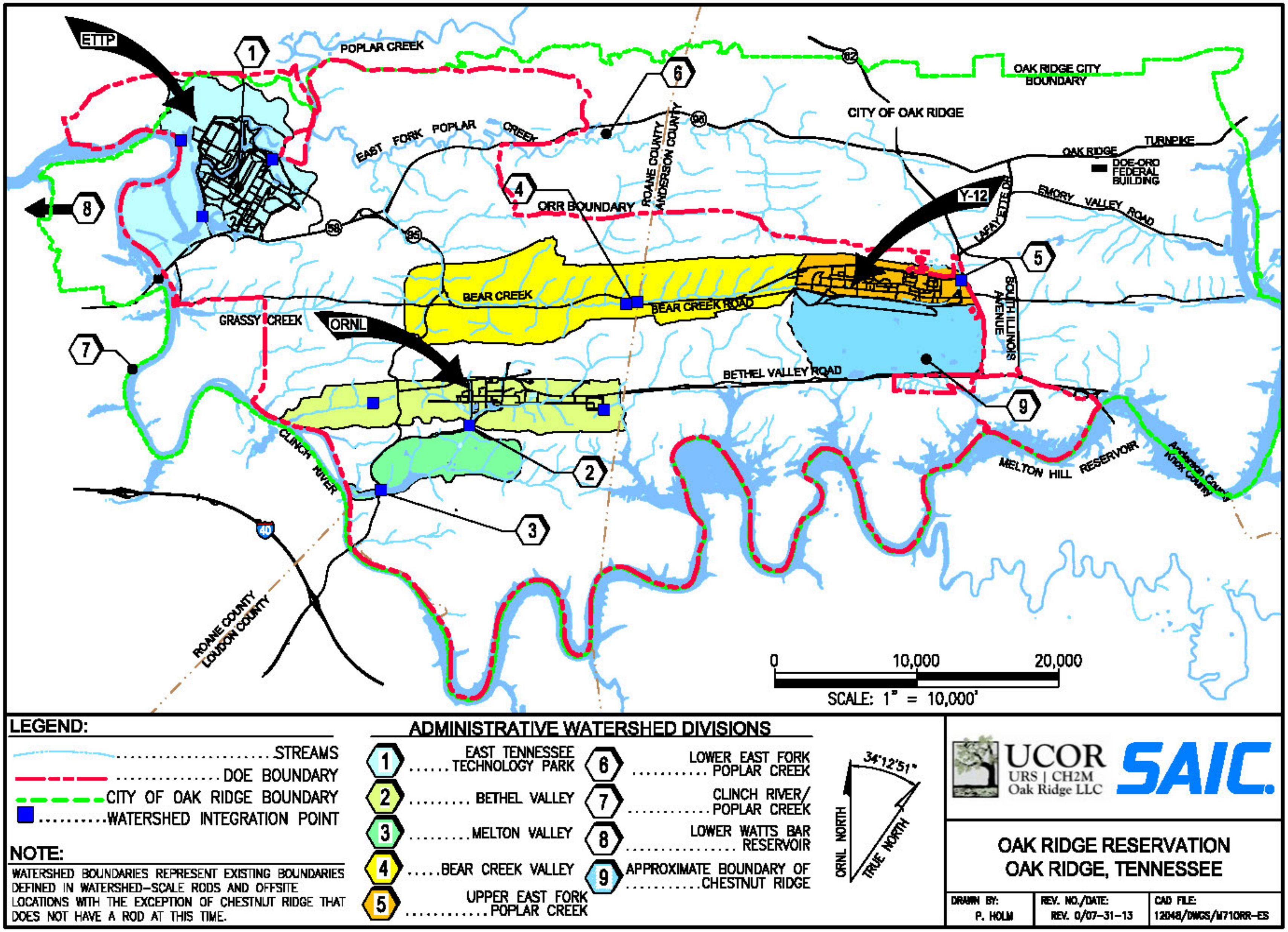

Fig. 3.1. Administrative watersheds on the Oak Ridge Reservation.

- The former Oak Ridge Gaseous Diffusion Plant (K-25 Site), now referred to as the East Tennessee Technology Park (ETTP), which is made up of several small watersheds but treated as a single administrative watershed.

- Areas that are outside of the DOE ORR boundary but which lie downgradient of the facilities and have received contamination from the facilities over the years.

The physical characteristics and contaminant sources within each of the watersheds are discussed in Appendices B through G of this report.

The mission and operations at each of the three ORR facilities have resulted in unique hazardous and radioactive wastes and waste management areas in each of the watersheds. Table 3.2 summarizes these differences and the corresponding differences in identified groundwater contamination. In general, ORNL plumes contain by-products of reactor operations (^{90}Sr, ^{137}Cs), including some fission nuclides. Plumes at the Y-12 Complex reflect uranium processing and lithium isotope separation performed (requiring large amounts of mercury). Plumes at ETTP contain traces of technetium-99 (^{99}Tc) used in the early uranium enrichment processes. One recurrent theme throughout the Reservation is the large number of releases of volatile organic compounds (VOCs) at all the sites. VOCs were used routinely as solvents for washing equipment and other purposes. As shown in Table 3.2, there are additional contaminants/chemicals of concern (COCs) at each of the sites.

Table 3.2. Production differences and resulting groundwater contamination at the ORR plant sites

Plant/Watershed	Primary production and other activities	Primary COCs	Groundwater contamination
ORNL/Bethel Valley	Nuclear research reactors, hot cells, radioisotope production facilities, and isotope separation	Cs-137, ^{90}Sr, ^{3}H, Hg, and VOCs (East End VOC Plume)	Reactor and fission isotopes in the Corehole 8 and other plumes
ORNL/Melton Valley	Research reactors; fuel reprocessing facilities; and waste treatment, storage, and disposal units (Solid Waste Storage Areas), as well as deep hydrofracture injection wells	Cs-137, ^{90}Sr, ^{3}H, and numerous LLRW radionuclides from burial grounds and VOCs	SWSAs with shallow groundwater contamination dominate the valley; unique hydrofracture challenge
Y-12/Upper East Fork Poplar Creek (Plant Site)	Original Calutron for uranium separation; lithium isotope separation; and produced components for nuclear weapon systems. Converted ^{235}U compounds to metal and casting, rolling, and machining operations.	Uranium, nitrate, Hg, and VOCs	S-3 fingerprint (uranium, nitrate) in west end; large amounts of VOC contamination
Y-12/Bear Creek Valley	Waste burial grounds for Y-12 Plant operations, including the S-3 Ponds and Bear Creek Burial Grounds	Uranium, nitrate, and VOCs	S-3 fingerprint on east end (uranium, nitrate); large amount of buried uranium; and various VOC plumes
East Tennessee Technology Park	Uranium enrichment through gaseous diffusion	Tc-99, Cr+6, and VOCs	Numerous VOC plumes throughout the plant site

COC = contaminant/chemical of concern.
Cr = chromium.
Cs = cesium.
^{3}H = tritium.
Hg = mercury.
LLRW = low-level radioactive waste.
ORNL = Oak Ridge National Laboratory.
ORR = Oak Ridge Reservation.
Sr = strontium.
SWSA = Solid Waste Storage Area.
Tc = technetium.
U = Uranium.
VOC = volatile organic compound.
Y-12 = Y-12 National Security Complex.

3.2 REGULATORY SETTING AND REQUIREMENTS

Initial groundwater cleanup efforts on the ORR were begun in the 1980s under the requirements of the Resource Conservation and Recovery Act of 1976 (RCRA). In 1989, the DOE Oak Ridge site was added to the NPL. The NPL identifies sites for the states and the public that appear to warrant remedial action due to contaminant releases. The original narrative for the proposed ORR NPL listing (http://www.epa.gov/superfund/sites/npl/nar1239.htm) pointed to releases to surface water—not groundwater—as the primary reason for the listing:

> *Additional studies revealed that some 170,000 pounds of mercury are contained in the sediments and floodplain of about a 15-mile length of East Fork Poplar Creek (EFPC), which has its headwaters at Y-12, and that some 500 pounds of mercury annually leave this watershed. Mercury and cesium-137 have been detected at higher than background levels in sediments of the Clinch River and the Tennessee River near Chattanooga, some 118 miles downstream of ORR. Seven water intakes in this 118-mile stretch provide drinking water to an estimated 43,200 people.*
>
> *Metals, organics, and radionuclides have been detected in ORR soil, ground water, and surface water. At present, ground water contamination appears confined to ORR.*

An FFA was signed by EPA, the state of Tennessee, and DOE in 1992 that provided the structure under which CERCLA would be implemented on the ORR (DOE 1992). Eventually it was agreed that all new cleanup effort would fall under the CERCLA umbrella; however, several RCRA groundwater permits remain active at the Y-12 Complex under which ongoing groundwater monitoring and reporting is conducted.

Most of the ORR CERCLA decisions reached to date have addressed primary contaminant sources; however, six of them were decisions specific to groundwater plume remediation only[2]:

- Waste Area Grouping (WAG) 1 Corehole 8 Action Memorandum (AM) [Plume Collection]: AM, 11/10/94; Addendum AM (Letter), 4/22/98; and Addendum AM, 9/30/1999 (DOE 1994; DOE 1999a).
- Oak Ridge Associated Universities (ORAU) South Campus Facility (SCF) Record of Decision (ROD): ROD, 12/28/95 (DOE 1995).
- Union Valley Interim Record of Decision (IROD) [Institutional Controls (ICs)]: IROD, 07/10/97 (DOE 1997a).
- Corehole 8 Plume Source (Tank W-1A) AM: 9/18/98, Amended in 1999 (DOE 1998a; DOE 1999b).
- Y-12 East End Volatile Organic Compound (EEVOC) Plume AM (Pump and Treat): AM, 06/25/99 (DOE 1999c).
- Mitchell Branch Hexavalent Chromium Release: time-critical (TC) AM, 12/20/2007 (DOE 2007a), and non-TC AM, 3/26/2010 (DOE 2010).

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[2] Another Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) decision specific to groundwater plume remediation only is a 1998 Action Memorandum and 2000 Addendum (DOE 1998c; DOE 2000b) under which groundwater from Pathways 1 and 2 from the S-3 Pond was collected and treated. Due to poor performance, shutdown of the system was approved in 2007.

Three of these groundwater-specific decisions resulted in active, currently operational groundwater pump-and-treat systems: the Corehole 8 ^{90}Sr plume at ORNL, the EEVOC Plume (carbon tetrachloride and other volatile organics) at the Y-12 Complex, and hexavalent chromium extraction in the ETTP Mitchell Branch area.

Existing watershed RODS include groundwater-specific actions, as well as other source control actions (e.g., hydrologic isolation, source removal). Completed groundwater-specific actions in existing watershed RODs are as follows:

- Ongoing operation of the Big Spring Water Treatment System (BSWTS) that was constructed under the UEFPC Phase I ROD (DOE 2002a) to collect and treat mercury-contaminated shallow groundwater.

- Ongoing collection and treatment of ^{90}Sr-contaminated groundwater from downgradient trenches installed under the MV IROD (DOE 2000a).

- Improvements to Corehole 8 plume collection and treatment and diversion of Bldg. 4501 mercury-contaminated sump discharges that have been completed under the BV IROD (DOE 2002b).

Groundwater-specific actions in existing watershed RODs that have yet to be completed are:

- Full-scale remediation of the ORNL 7000 Area and remaining actions to address mercury-contaminated groundwater in other ORNL building sumps under the BV IROD.

- Installation of a trench at S-3 Ponds Pathway 3[3] for passive in situ treatment of shallow groundwater under the BCV Phase I ROD (DOE 2000b).

Future groundwater decisions will be guided by the tri-party FFA process. Section XVIII, "Scoping Work Priorities," of the FFA lays out the general process for implementing the numerous cleanup projects on the Reservation. Details of the process are provided in the following FFA Appendices (http://www.ucor.com/ettp_ffa_appendices.html):

- Appendix E – Timetables and Deadlines
- Appendix G – Prioritization of Environmental Restoration Tasks
- Appendix J – FY+3 Non-Enforceable Projected Milestones

Conditions, priorities, and funding will change over the 30+-year time frame projected to complete Oak Ridge site cleanup; consequently, near-term projects and schedules are more defined. The ORR cleanup completion date, 2046, is based on current annual budget projections. Projected milestones listed in Appendix J serve as approximations of project implementation time frames for the outyears.

3.3 ENVIRONMENTAL SETTING

3.3.1 Land and Resource Use (ORR and Surrounding Areas)

Current land use and groundwater resource use conditions in areas surrounding the ORR, current and future end use assumptions for the ORR, and environmental resources on the ORR are described below.

[3] Pathway 3 is one of three pathways for S-3 Ponds contaminated groundwater in Bear Creek Valley. Current plans are to combine Pathways 1 and 2 with Pathway 3 as a remedial action under the BCV Phase I Record of Decision.

Current Land Use Conditions in Surrounding Areas

The land within the ORR is zoned as a federally controlled industrial/research (FIR) area. The nearest population center with 25,000 or more residents is the city of Oak Ridge, and the nearest boundary to this population center is the portion of the ORR boundary that separates the DOE property from the residential and commercial area of Oak Ridge.

The nearest residents and industrial areas to the ORR operations are located in three general areas (Fig. 3.2):

1. In the areas northwest and east of the Y-12 Complex are the Scarboro residential community, commercial facilities, and the Union Valley commercial and industrial area.

2. On the western side of the ORR (extending from the area across the Clinch River from MV to across the Clinch River from ETTP) are rural, residential, and industrial park areas. In this same area on the ORR side of the Clinch River is the former Clinch River Breeder Reactor (CRBR) site.

3. Located northeast of ETTP are rural, residential areas (referred to as the Blair Road Area on Fig. 3.2).

Current Groundwater Use Conditions in Surrounding Areas

The Scarboro Community is isolated from groundwater contamination on the ORR because of the along-strike, down-valley flow on the ORR. Scarboro lies across-strike of several aquitard formations. The Union Valley area east of the Y-12 Complex is currently zoned for industrial and commercial use. Actions have been taken under an existing CERCLA decision to prevent further off-site migration of a VOC plume into the Union Valley area and in another decision to restrict groundwater use off the ORR in the Union Valley area.

The rural, residential, and industrial park areas located west across the Clinch River from the ORR are downgradient of the ORR. Monitoring is being performed in some of these areas (Sect. 5.2) and there are license agreements in place with some residents to minimize pumping stresses that could draw DOE contaminants off-site (Sect. 5.4). The former CRBR Site is also downgradient of the Reservation.

Current and Future ORR End Use Assumptions

Figure 3.3 provides an overview of the different area end uses designated in existing watershed RODs. Interim land use goals do not determine groundwater and surface water classifications. Final decisions for land use, surface water, and groundwater will be made in future watershed Final RODs (Sect. 3.4).

Significant end use planning assumptions for long-term or permanent waste management areas are:

- For MV, this interim ROD assumption approved by the FFA parties left the vast majority of the solid waste storage area (SWSA) wastes in place with hydrologic isolation, including capping of the SWSAs.

- For BCV, this waste management assumption is inherent in the ROD to develop the Environmental Management Waste Management Facility (EMWMF) to dispose CERCLA waste on the ORR (DOE 1999d). This facility now has a capacity of over 2 million cubic yards and there are plans to develop a second facility in the future. A future ROD for the Bear Creek Burial Grounds (BCBG) located west of the EMWMF could also result in a selected remedy that leaves buried waste in place. The

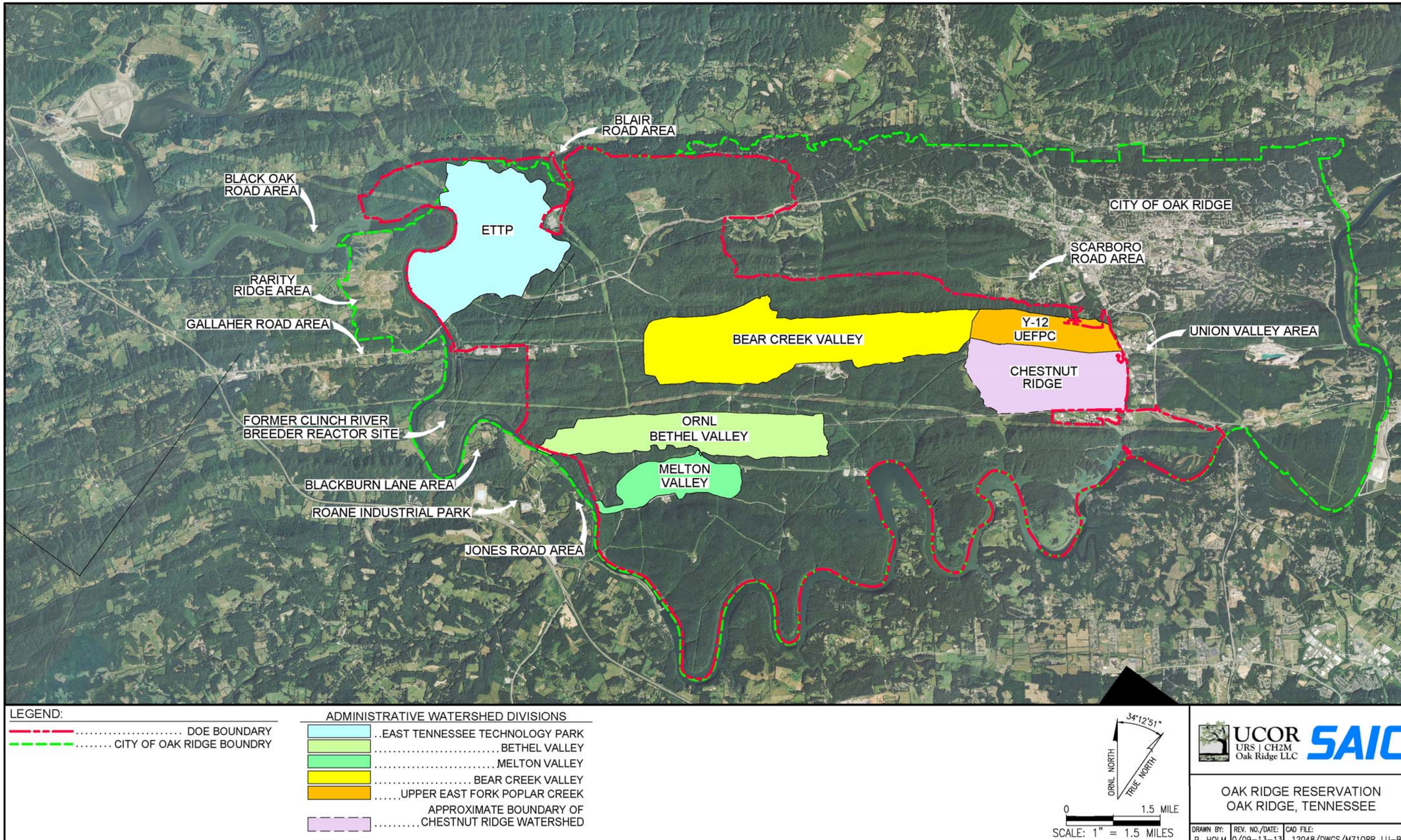

Fig. 3.2. Aerial view of the Oak Ridge Reservation and surrounding areas.

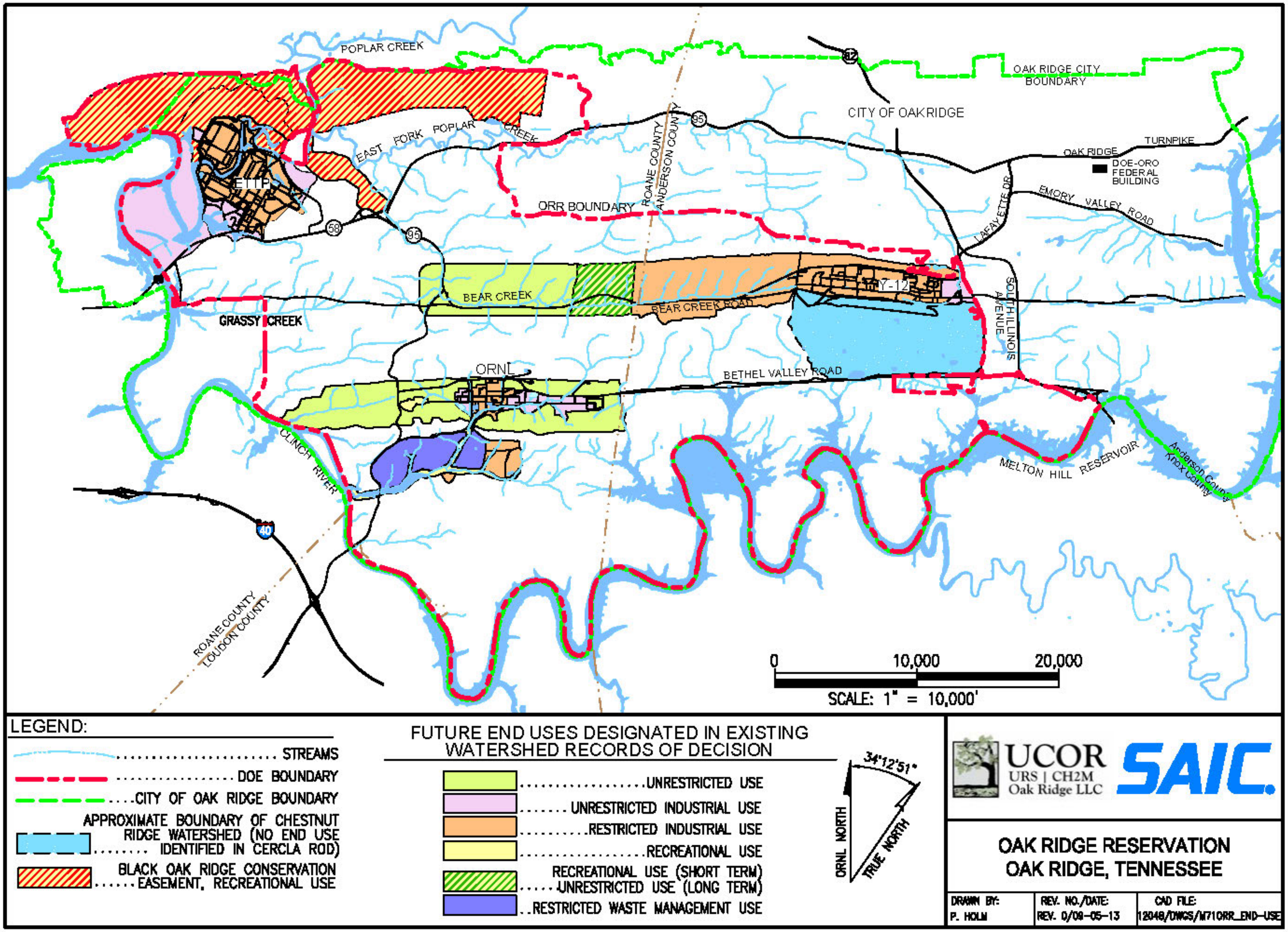

Fig. 3.3. End uses designated in existing watershed RODs.

EMWMF and BCBG are in the eastern portion of BCV located west of the Y-12 main plant and designated for long-term restricted industrial use.

- Chestnut Ridge contains several active and closed industrial landfills and some hazardous waste disposal areas closed under RCRA. There is no watershed decision in place on Chestnut Ridge; however, a future Chestnut Ridge ROD with a groundwater component is planned. Consistent with End Use Working Group recommendations (DOE 1998b), areas of Chestnut Ridge are planned for continued waste management use for the foreseeable future.

Aerial photos of closed and active waste management areas in MV, BCV, and Chestnut Ridge are shown in Fig. 3.4.

Another significant end use planning assumption in place at this time shown on Fig. 3.3 is the Black Oak Ridge Conservation Easement (BORCE) that is designated for recreational use. This area is maintained and managed by the Tennessee Wildlife Resources Agency.

Environmental Resources

The ORR includes surface water and groundwater resources. Surface water hydrology on the ORR is characterized by a network of small streams that are tributaries of the Clinch River, which is part of the Tennessee Valley Authority-managed hydrologic network (Fig. 3.5). For some of the ORR watersheds, surface water contaminant releases exit at the ORR boundary (i.e., ETTP, MV, and UEFPC). For other watersheds, the releases exit well within the Reservation boundary (Bear Creek, BV). Releases from the Y-12 Complex (UEFPC Watershed) are the only releases that flow through the city of Oak Ridge via EFPC. Surface water flow and groundwater discharge to surface water are further described in the CSM appendices (Appendices B through G).

Resources spent on early environmental restoration activities were directed toward the sediment-bound surface water releases that impacted the city of Oak Ridge (mercury) and the Clinch River (cesium). DOE's continued commitment to mercury cleanup is reflected in ongoing efforts to design a new mercury treatment facility at the Y-12 Complex to be followed by facility construction and operation.

Ecological resources must be considered in a groundwater strategy since there is significant groundwater–surface water interaction on the ORR. The ecological habitats on the ORR support a wide variety of rare, threatened, and endangered plants and animals. Information about ORR habitats and species is available at www.esd.ornl.gov/facilities/nerp.

3.3.2 Geologic and Hydrologic Setting

The DOE ORR is underlain by complex geologic conditions (Fig. 3.6). Bedrock beneath the region is predominantly Cambro-Ordovician interbedded sandstones, siltstones, limestones, and dolostones. Two regionally extensive thrust fault zones—the White Oak Mountain Fault and the Copper Creek Fault—transect the ORR trending from northeast to southwest. Movement of the bedrock along these faults occurred during the Late Paleozoic Appalachian Orogeny (some 300 million years ago), and although there is some present-day seismicity in East Tennessee, the ancient faults exposed at the land surface are not active.

The stratigraphic column of outcropping geologic formations at the ORR includes the Cambrian-age Rome Formation as the oldest bedrock formation and the Mississippian-age Fort Payne Chert as the youngest bedrock formation that occurs in a small area. The regional thrust fault zones that cross the ORR occur in the Lower Rome Formation and their configuration causes the prominent sandstones of the

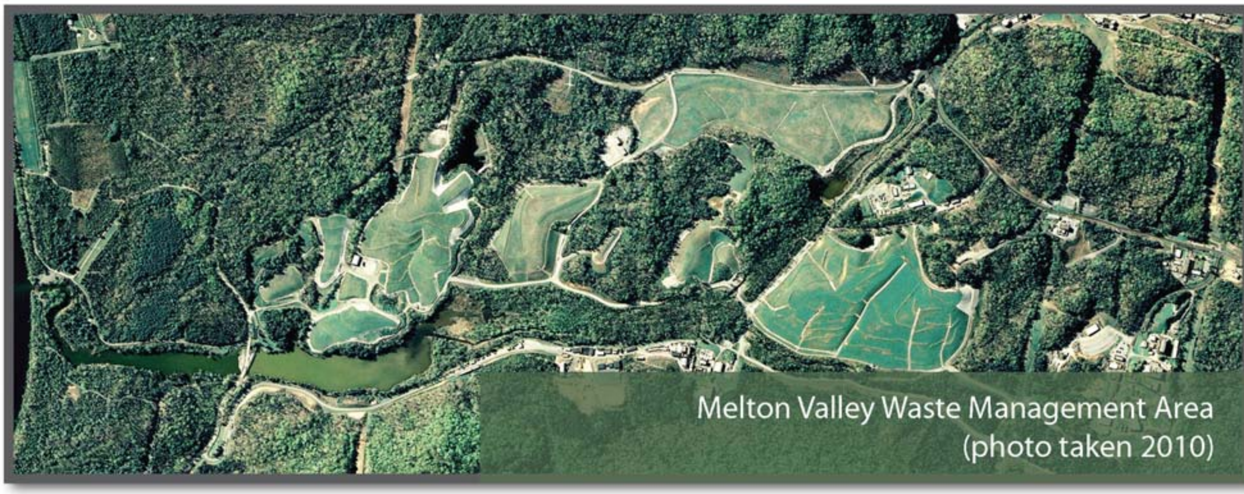

Fig. 3.4. Photos of closed and active waste management areas in Melton Valley, Bear Creek Valley, and Chestnut Ridge.

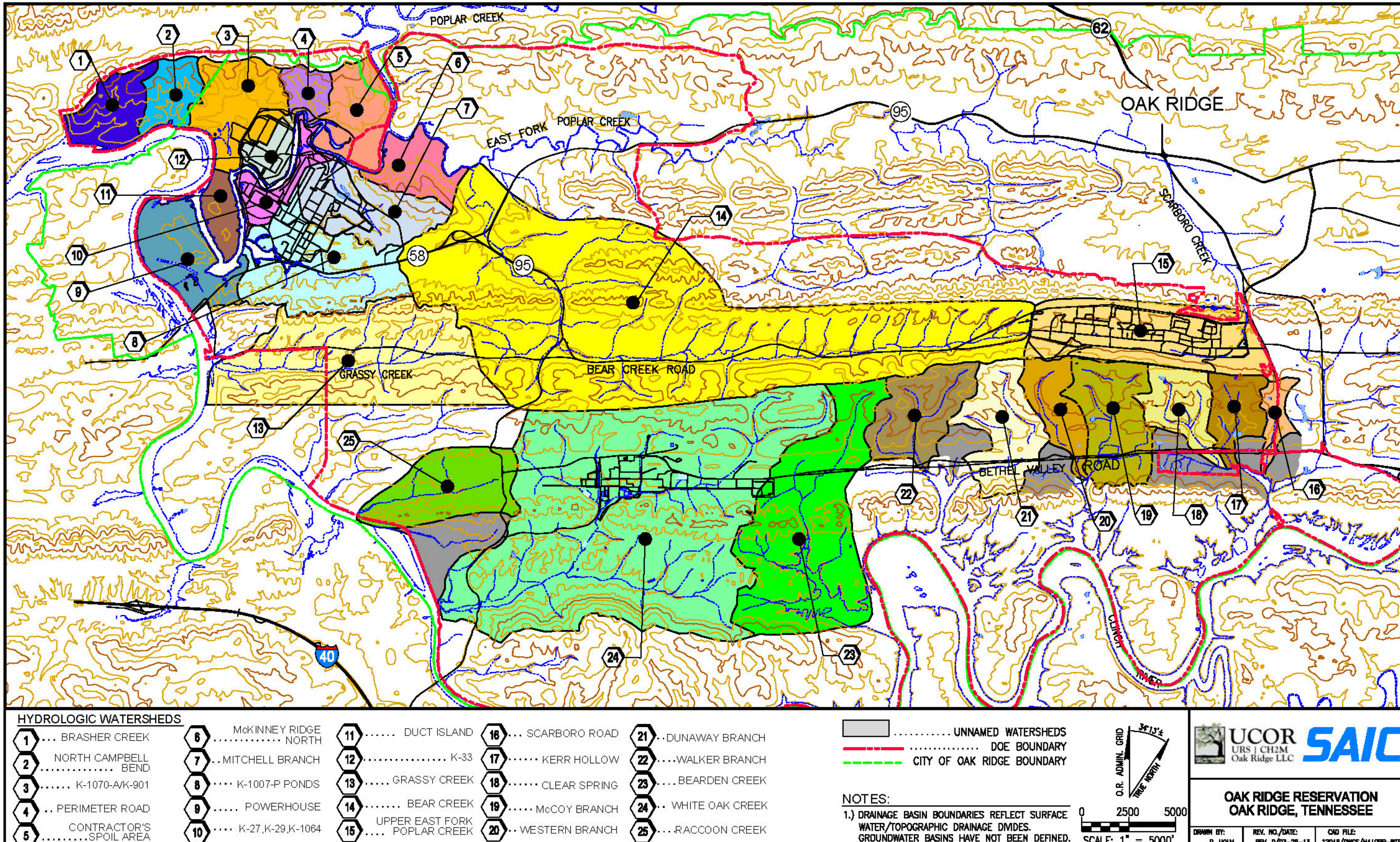

Fig. 3.5. Surface water hydrology on the ORR.

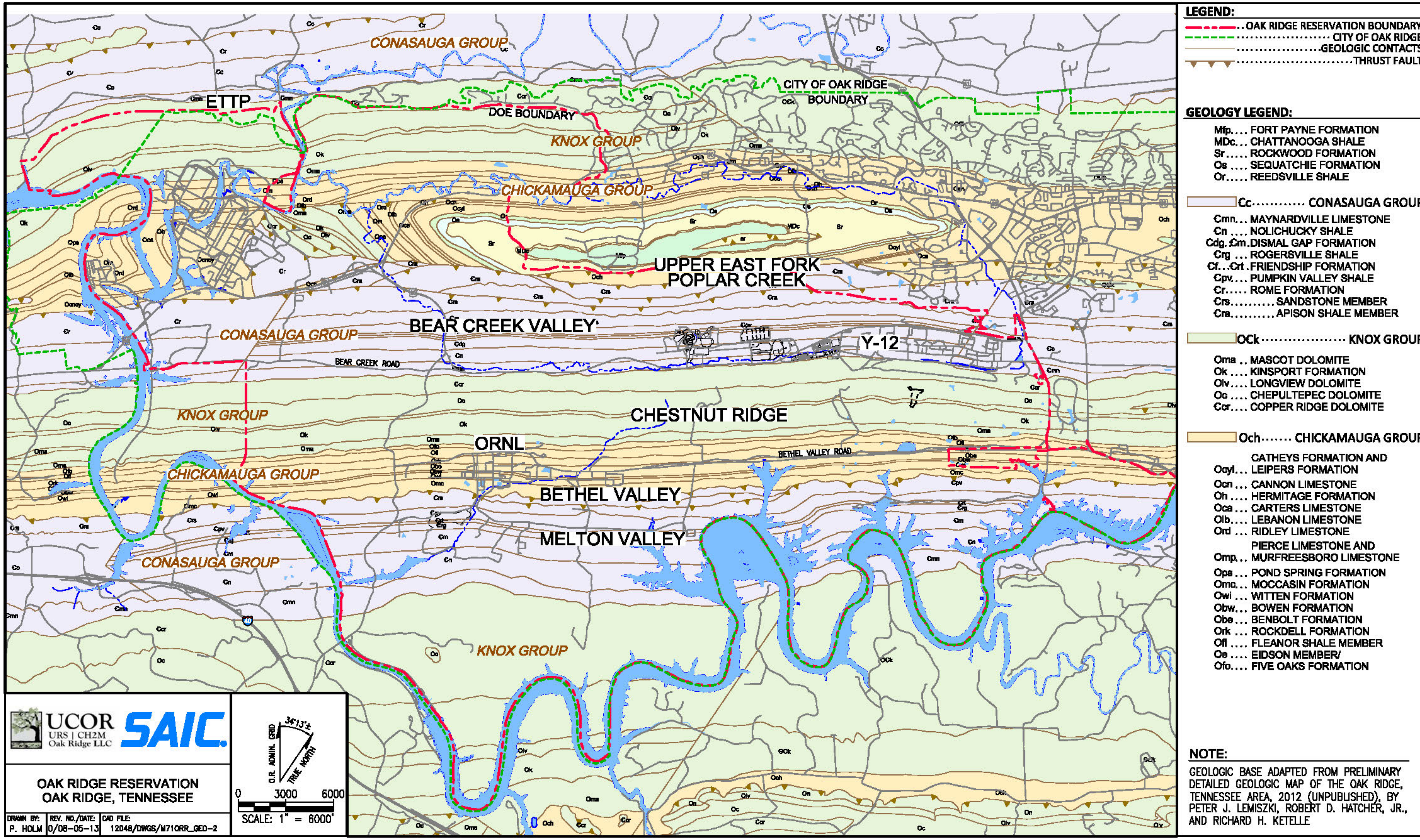

Fig. 3.6. Geologic formations in the Oak Ridge Reservation.

Upper Rome Formation to create strong ridges that trend northeast–southwest across the area. Younger bedrock units that overlie the Rome Formation include the Middle and Upper Cambrian-Age Conasauga Group, the Upper Cambrian and Lower Ordovician Knox Group, and the Ordovician-Age Chickamauga Group. The lower 75% (~400 m) of Conasauga bedrock is dominated by clastic bedrock types comprised predominantly of shale, siltstone, calcareous siltstone, silty limestones, and interbedded thin to medium beds of limestone in shale-dominated formations. The upper 25% (~100 m) of the Conasauga Group is the Maynardville Limestone, which is predominantly limestone. The Knox Group dolostones comprise ~1000 m of medium to thick to massively bedded dolomite. The juxtaposition of the Maynardville Limestone and Knox Group dolostones creates a massive (~1100-m-thick) carbonate bedrock outcrop belt of regional extent in each of the thrust belts that transect the ORR. Overlying the Knox Group in the stratigraphic sequence is the Middle Ordovician-Age Chickamauga Group. The Chickamauga group contains clastic-rich bedrock lithologies in the lower third (~150 m) while thin- to thick-bedded argillaceous limestones dominate the upper two-thirds (~440 m) of the depositional thickness. More detailed descriptions of the ORR geology are contained in the *Status Report on the Geology of the Oak Ridge Reservation* (ORNL 1992).

ORR terrain and local surface water drainage features are influenced by the underlying geology to a large degree. The on-site surface water drainage pattern is a modified trellis pattern with most on-site streams flowing parallel to the northeast–southwest geologic strike directions with infrequent instances of streams crosscutting the major ridges formed by the underlying geology. In contrast, the Clinch River, which is the largest surface water feature at the ORR, is an antecedent stream that has downcut into the landscape and crosses geologic structures in its entrenched channel.

Groundwater on the ORR occurs as a continuous, saturated zone below the groundwater table. Perched groundwater may occur locally and/or seasonally in small areas; however, its occurrence is considered to be inconsequential to the overall groundwater system and contaminant migration issues at the ORR. Geologic conditions at the ORR dictate the characteristics of groundwater occurrence, geochemistry, and movement. In a general sense, two strongly contrasting hydrogeologic settings are recognizable at the ORR—clastic bedrock-dominated systems and massive carbonate-dominated systems. The clastic bedrock-dominated systems occur in the Rome Formation/Conasauga Group formations excluding the Maynardville Limestone. The massive carbonate bedrock-dominated systems occur in the Maynardville Limestone/Knox Group. Areas underlain by the Chickamauga Group have characteristics of both the clastic- and carbonate-dominated systems. The ORR groundwater system receives areal recharge from the abundant rainfall (average 54 in./year) that occurs. Evapotranspiration is estimated to recycle approximately 50% of annual rainfall back to the atmosphere (Lu et al. 2005). On Rome and Conasauga terrains, hillslope hydrologic processes divert much of the percolating rainfall downslope to adjacent streams, which reduces the total annual recharge to the groundwater table. On the carbonate-dominated terrains—particularly the Knox Group outcrop areas—internal drainage via dolines and sinkholes increases the fraction of percolation water that reaches the groundwater zone compared to the clastic-dominated areas.

The characteristics of groundwater flow and relative groundwater abundance also vary by geologic system at the ORR. In the carbonate-dominated systems, weathering has created typical karst hydrogeologic conditions with abundant conduits that transmit groundwater rapidly. Weathering of the carbonate units has progressed to great depths with resultant occurrence of fresh water to great depth. Well yields are high in the massive carbonate units. In contrast, the clastic-dominated geologic areas exhibit low well yields and groundwater flow occurs through fractures in the bedrock. Well testing demonstrates that there is an overall decrease in hydraulic conductivity with increasing depth in the clastic-dominated bedrock. This decreasing hydraulic conductivity is also reflected in increasing dissolved solids concentration with depth and presence of increasing sodium, chloride, and bromide derived from residual connate brine fluids that are present at depths near sea level (see Appendix J).

Contaminant plumes in the Knox and Maynardville (Conasauga) carbonate-dominated formations (i.e., plumes in BCV and the UEFPC) have migrated further and deeper than the plumes in adjacent clastic-dominated formations.

Deep sources of contamination at the ORR create especially complex groundwater issues. Dense non-aqueous phase liquids (DNAPLs) are known to exist in multiple areas at the ORR. At the BCBG in BCV, a DNAPL is present at a depth of about 300 ft below the ground surface in fractured bedrock in the clastic-dominated Conasauga Group. In MV at ORNL, the disposal of radioactive liquids and sludges using the hydrofracture method of mixing waste with cement grout has created a contaminated zone in shale at depths below the top of the connate brine. Documenting and potentially managing movement of contaminants related to deep sources of contamination presents technical challenges.

Added to the complexity of the ORR geology is the complexity of the underground industrial support systems of pipelines, tank farms, and basement sumps at each plant site. Both the geological aspects (e.g., fractures and karst conduits) and the man-made aspects have resulted in some known and some unknown preferential flowpaths within BV, UEFPC, and ETTP.

One plume was confirmed to have moved off-site in the 1990s—the VOC plume emanating to the northeast from the Y-12 Complex via conduit flow in the Maynardville Limestone. The Union Valley IROD (DOE 1997a) for this area selected ICs to prevent public exposure to groundwater. Ongoing operation of a pump and treat system prevents further off-site migration of the VOC plume into the Union Valley area (DOE 1999c).

3.3.3 Overview of Groundwater Contamination on the ORR

Areas of groundwater contamination on the ORR are identified in Fig. 3.7. This contamination represents both individual plumes, areas of commingled plumes, and "hot spot" contamination that is not associated with a clear plume. One of the challenges addressed by the Groundwater Strategy Team was to better delineate a set of groundwater plumes in a manner that could be used to identify data needs and projects for long-term planning. The efforts to delineate and rank these plumes are described in Sect. 5.1 of this report. The individual watershed CSMs (Appendices B through G) and Appendix H provide additional details about groundwater plumes and ranking.

3.4 COMPLETED CERCLA PROJECTS AND THEIR RELEVANCE TO FUTURE PLANNED CERCLA ACTIONS AND DECISIONS

Completed source actions on the ORR and future planned CERCLA actions and decisions play an important role in the groundwater strategy. Table 3.3 is a chronological list of CERCLA decisions covered in the 2011 Five-Year Review (FYR) [DOE 2012a][4]. The table indicates whether CERCLA actions under the decision are complete and whether further action is required, including future planned RODs. Also listed are three CERCLA decisions not covered in the 2011 FYR because no actions in the decisions were complete at the time of the review (indicated in Table 3.3 with an "*"). Existing watershed decisions (shown in bold font in Table 3.3) encompass multiple individual actions. Many of these actions addressed the primary contaminant source (e.g., a burial ground or contaminated soil). Language in these existing watershed RODs indicates decisions for groundwater are deferred to a final watershed ROD.

[4] Explanation of why some Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) remedial and removal actions are not included in the list is provided in the 2011 Five-Year Review document.

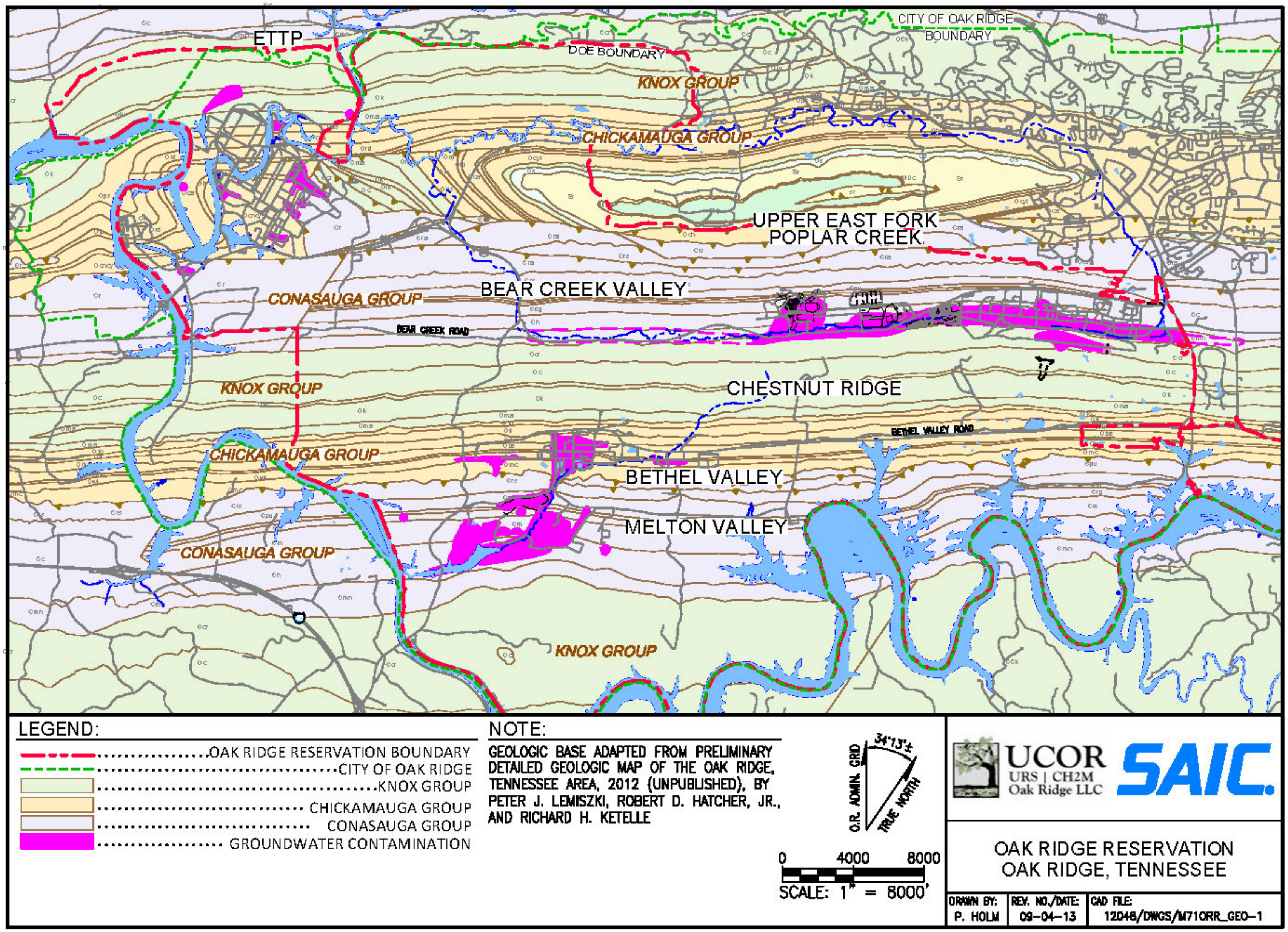

Fig. 3.7. Areas of groundwater contamination on the ORR.

Table 3.3. CERCLA decisions covered in the 2011 Five-Year Review (listed in chronological order)[a]

Site/ Watershed	CERCLA action	Primary decision document	Complete?	Ongoing groundwater system operation?	Further action required?
ORNL/MV	White Oak Creek Embayment	Time-Critical Removal Action Letter: 11/9/90	Yes		Final decision on White Oak Creek/Lake sediments in Melton Valley Final ROD
Y-12/CR	UNC Disposal Site ROD	ROD: 6/28/91	Yes		No
ETTP/ETTP	K-1070-C/D OU SW-31 Spring IROD	IROD (DOE/OR/-1050&D2): 09/30/92	Yes		Final decision in ETTP Sitewide ROD
Other/NA	White Wing Scrap Yard (WAG 11) IROD	IROD (DOE/OR/-1055&D4): 10/06/92	Yes		Final decision in future White Wing Scrapyard ROD
ORNL/MV	WAG 13 Cesium Plots IROD	IROD (DOE/OR/01-1059&D4): 10/6/92	Yes		Final decision on residual Cs in soils in Boundary Sites ROD
ETTP/ETTP	K-1407-B/C Ponds ROD	ROD (DOE/OR/02-1125&D3): 09/30/93	Yes		Source action complete. Final decision on subsurface soil in existing ETTP Zone 2 ROD; final decision on groundwater in ETTP Sitewide ROD.
ORNL/BV	WAG 1 Corehole 8 AM (Plume Collection)	AM (DOE/OR/02-1317&D2): 11/10/94	Yes	Improvements to the Corehole 8 Extraction System under the BV Interim ROD are complete; the system is operating.	Final decision in BV Groundwater ROD
Off-site/NA	**Lower East Fork Poplar Creek ROD**	ROD (DOE/OR/02-1370&D2): 08/17/95	Yes		Final decision on surface water in EFPC Surface Water ROD
Off-site/NA	**Lower Watts Bar Reservoir ROD**	ROD (DOE/OR/02-1373&D3): 09/29/95	Yes		No
Y-12/CR	Kerr Hollow Quarry ROD	NFA ROD (DOE/OR/02-1398&D2): 9/29/95	Yes		No
Other/NA	ORAU South Campus Facility ROD	ROD (DOE/OR/02-1383&D3): 12/28/95	Yes		No
Y-12/CR	FCAP/Upper McCoy Branch ROD	ROD (DOE/OR/02-1410&D3): 02/21/96	Yes		No

Table 3.3. CERCLA decisions covered in the 2011 Five-Year Review (listed in chronological order)[a] (cont.)

Site/ Watershed	CERCLA action	Primary decision document	Complete?	Ongoing groundwater system operation?	Further action required?
Off-site/NA	Union Valley IROD	IROD (DOE/OR/02-1545&D2): 07/10/97	Yes		Final decision in UEFPC Groundwater ROD
Off-site/NA	**Clinch River/Poplar Creek ROD**	ROD (DOE/OR/02-1547&D3): 09/23/97	Yes		Final decision on surface water in future Clinch River/Poplar Creek Surface Water ROD
Y-12/BCV	BCV OU 2 ROD (Spoil Area 1, SY-200 Yard)	ROD (DOE/OR/02-1435&D2): 01/23/97	Yes		Final decision on groundwater in BCV Groundwater ROD
ORNL/BV	Surface Impoundments OU ROD	ROD (DOE/OR/02-1630&D2): 9/25/97	Yes		Underlying soil to be addressed in BV Interim ROD; final decision on groundwater in BV Groundwater ROD
ETTP/ETTP	K-1070-C/D G-Pit and Concrete Pad ROD	ROD (DOE/OR/02-1486&D4): 01/23/98	Yes		Final disposition of pad to be addressed under existing ETTP Zone 2 ROD; final decision on groundwater in ETTP Sitewide ROD
ORNL/BV	Corehole 8 Plume Source (Tank W-1A) AM	AM (DOE/OR/01-1749&D1): 9/18/98	Yes		Tank W-1A removal is complete; soil to be addressed in the BV Interim ROD; final decision on groundwater in BV Groundwater ROD
Y-12/BCV	CERCLA Waste Cell (EMWMF) ROD	ROD (DOE/OR/01-1791&D3): 11/02/99	No		Additional on-site disposal capability will be required to handle all ORR CERCLA wastes
Y-12/UEFPC	Y-12 EEVOC Plume AM	AM (DOE/OR/01-1819&D2): 06/25/99	Yes	System is operating	Final decision in UEFPC Groundwater ROD
ETTP	K-1070-A Burial Ground ROD	ROD (DOE/OR/01-1734&D3): 01/13/00	Yes		Final decision on groundwater in ETTP Sitewide ROD
Y-12/BCV	**Bear Creek Valley Phase I ROD**	ROD (DOE/OR/01-1750&D4): 06/16/00	No		Remaining actions include remediation of S-3 Ponds shallow groundwater (Pathway 3)[b]; future ROD to address Bear Creek Burial Grounds; final decision on groundwater in BCV Groundwater ROD

Table 3.3. CERCLA decisions covered in the 2011 Five-Year Review (listed in chronological order)[a] (cont.)

Site/ Watershed	CERCLA action	Primary decision document	Complete?	Ongoing groundwater system operation?	Further action required?
ORNL/MV	**Melton Valley Interim Actions ROD**	ROD (DOE/OR/01-1826&D3): 9/21/00	Yes	Seep collection system is operating	Remaining building D&D to be addressed in a MV Reactors and Other Facilities ROD; final decisions on secondary media (groundwater, White Oak Creek, and lake sediments) as well as ecological to be addressed in MV Final ROD
Y-12/UEFPC	**Upper East Fork Poplar Creek Phase I Interim Source Control Actions ROD**	ROD (DOE/OR/01-1951&D3): 05/02/02	No	Big Spring Water Treatment System is operating	Soil to be addressed under existing UEFPC Phase II ROD; final decision on surface water in UEFPC Surface Water ROD; final decision on groundwater in UEFPC Groundwater ROD
ORNL/BV	**Bethel Valley Interim Actions ROD**	ROD (DOE/OR/01-1862&D4): 050/2/02	No	Upgraded Corehole 8 Plume Extraction System is operating	Final decision in BV Groundwater ROD
ETTP/ETTP	**East Tennessee Technology Park Zone 1 Selected Contaminated Areas Interim Removal Actions ROD**	ROD (DOE/OR/01-1997&D2): 11/08/02	Yes		Zone 1 ROD addressed soils only; final decision for soil in Final Zone 1 ROD; ETTP Sitewide ROD to address surface water and groundwater
ETTP/ETTP	**East Tennessee Technology Park Zone 2 Soil, Buried Waste, and Subsurface Structure Removal Actions ROD**	ROD (DOE/OR/01-2161&D2): 04/19/05	No		Zone 2 ROD addressed soils only; ETTP Sitewide ROD to address surface water, groundwater, and ecological
Y-12/UEFPC	**Upper East Fork Poplar Creek Phase II Remedial Actions for Contaminated Soils and Scrapyard ROD***	ROD (DOE/OR/01-2229&D3): 04/21/06	No		Final decision on surface water in UEFPC Surface Water ROD; final decision on groundwater in UEFPC Groundwater ROD

Table 3.3. CERCLA decisions covered in the 2011 Five-Year Review (listed in chronological order)[a] (cont.)

Site/ Watershed	CERCLA action	Primary decision document	Complete?	Ongoing groundwater system operation?	Further action required?
ETTP	Reduction of Hexavalent Chromium Releases into Mitchell Branch AM*	AM (DOE/OR/01-2448&D1): 04/13/2010	Yes	Chromium water treatment system is operating	Final decision in ETTP Sitewide ROD
ORNL/MV	Corrective Actions at White Oak Dam TCAM*	TCAM (DOE/OR/01-2460&D1): 07/23/10	Yes		Final decision on White Oak Creek/Lake sediments in Melton Valley Final ROD

[a] The list includes three CERCLA decisions that were not included in the 2011 FYR (indicated with an "*"). No actions under these decisions were complete at the time of the review.

[b] Pathway 3 is one of three pathways for S-3 Ponds contaminated groundwater in BCV. Under a 1998 Action Memorandum and 2000 Addendum (DOE 1998c; DOE 2000c), groundwater from Pathways 1 and 2 from the S-3 Pond was collected and treated. Due to poor performance, the system was shut down. Current plans are to combine Pathways 1 and 2 with Pathway 3 as a remedial action under the BCV Phase I ROD.

* = No actions under the CERCLA decision were complete at the time of the 2011 FYR.

Bold font = existing watershed ROD.

AM = Action Memorandum.
BCV = Bear Creek Valley.
BV = Bethel Valley.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
CR = Chestnut Ridge.
Cs = cesium.
D&D = decontamination and decommissioning.
DOE = U.S. Department of Energy.
EEVOC = East End Volatile Organic Compound.
EMWMF = Environmental Management Waste Management Facility.
EFPC = East Fork Poplar Creek.
ETTP = East Tennessee Technology Park.
FCAP = Filled Coal Ash Pond.
FYR = Five-Year Review.
IROD= Interim Record of Decision.
MV = Melton Valley.
NA = not applicable.
NFA = no further action.
OR = Oak Ridge.
ORAU = Oak Ridge Associated Universities.
ORNL = Oak Ridge National Laboratory.
ORR = Oak Ridge Reservation.
OU = operable unit.
ROD = Record of Decision.
TCAM = Time-Critical Action Memorandum.
UEFPC = Upper East Fork Poplar Creek.
UNC = United Nuclear Corporation.
WAG = Waste Area Grouping.
Y-12 Complex = Y-12 National Security Complex.

Source control actions under the MV IROD were completed in 2006. For BV, BCV, UEFPC, and ETTP, many primary source actions remain to be completed under the existing watershed RODs and some source actions will require additional decision documents (e.g., the BCBG).

For Chestnut Ridge, in addition to closure of waste management units under RCRA, several single-project CERCLA decisions have been completed and implemented to address contaminant sources. A final ROD is planned for Chestnut Ridge that will include a groundwater component.

Three out of the five ORR watersheds (BCV, UEFPC, and MV) have an established line of sentry wells, also referred to as “Picket Wells” or “sentinel wells,” along the downgradient exterior edge of the watershed to track any ongoing movement of contaminants from the remaining interior sources. The list of candidate projects identified by the Groundwater Strategy Team (Appendix I) includes projects to install picket wells in the other two ORR watersheds (BV and ETTP).

4. CURRENT EM PROGRAM PRIORITIES

For CERCLA actions, human and environmental risk reduction is the overall goal and a key driver for sequencing remediation and D&D projects. Additional sequencing drivers include construction logic (for example, building D&D allows access to underlying contaminated environmental media), prevention of recontamination, reduction of surveillance and maintenance (S&M) costs, and release of remediated areas to support site missions.

To date, early CERCLA remediation efforts have focused on immediate risk reduction to off-site receptors with key actions along Lower East Fork Poplar Creek (LEFPC), the Clinch River and Lower Watts Bar Reservoir, and at sources on the Reservation that were contributing to contaminant migration off-site via surface water. Following these actions, DOE implemented watershed-scale RODs to identify and remediate the remaining sources of potential off-site and industrial risk.

DOE seeks input from the public, regulatory agencies, and the ORSSAB regarding priorities for budget requests. Among EM Program priorities for CERCLA actions through FY 2015 are finishing the demolition and cleanup of the K-25 building and planning for a mercury treatment system at Y-12 Outfall 200 to reduce mercury discharges. Implementation of an early action groundwater project is budgeted in FY 2014 through FY 2016.

Planned activities through FY 2026 include completion of ETTP closure (including reaching final groundwater decisions), construction and operation of the Y-12 Outfall 200 mercury treatment system, and initiation of D&D of some of the large, former mercury-use buildings at the Y-12 Complex. The balance of Y-12 and ORNL cleanup, including final watershed decisions that address groundwater, is a longer-term focus beginning in the FY 2027 time frame.

In addition, there are near-term EM Program priorities focused on completing actions associated with removal of transuranic waste and ^{233}U from the Reservation. Maintaining necessary base operations (e.g., surveillance and maintenance and mission support activities) is an ongoing priority throughout the EM Program duration.

Ongoing operation of groundwater collection and treatment systems shown on Table 3.3 is key to contaminant reduction and plume mitigation on the Reservation. Continued operations depend on the presence and availability of site infrastructure (e.g., building sumps and process waste lines) and treatment facilities, some of which are non-EM facilities at ORNL and Y-12. Ongoing interfaces between DOE-EM and other DOE programs (DOE-SC at ORNL and National Nuclear Security Administration [NNSA] at Y-12) are needed to maintain awareness of facility changes and site modernization plans that could impact system operations.

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5. GROUNDWATER STRATEGY TECHNICAL CONSIDERATIONS

This chapter presents the technical considerations that are integral to the strategy, including:

- A listing of groundwater plumes on the ORR identified during the Groundwater Strategy Team Workshops (Sect. 5.1).
- Current understanding of potential off-site migration, along with the need for any near-term actions to address that risk (Sect. 5.2).
- Discussion of future pre-RI, RI, and feasibility study (FS) characterization and technology development needs, starting with a discussion of potential response actions for the ORR groundwater plumes (Sect. 5.3).
- Groundwater use restrictions and policies on and around the ORR (Sect. 5.4).
- Feedback from the FFA parties on key groundwater issues (Sect. 5.5).

5.1 ORR GROUNDWATER PLUMES

The first three Groundwater Strategy Workshops were held to review CSMs and recent trend data for each ORR watershed (Appendices B through G). The key output from those discussions is a comprehensive listing of the groundwater plumes on the ORR (Sect. 5.1.1) along with a listing of major data gaps and uncertainties related to each plume (Sect. 5.1.2). In addition, the plumes have been ranked based on hazard (toxicity, size, and longevity); pathway; and potential receptors to provide a basis for future prioritization of resources (Sect. 5.1.3).

5.1.1 Listing of ORR Groundwater Plumes

Table 5.1 shows the list of 35 groundwater "plumes"[5] identified by the Groundwater Strategy Team. A more detailed discussion of these plumes is presented in each watershed appendix. The list represents plumes from a single-point source (e.g., the Corehole 8 Plume at ORNL) and other areas of groundwater contamination such as commingled groundwater plumes from multiple sources (e.g., ETTP-9 Mitchell Branch Commingled Plume); contamination from multiple spills (e.g., UEFPC-6 Localized Mercury Sources to Groundwater); and contamination from undetermined sources (e.g., MV-3 Exit Pathway/Picket Wells).

5.1.2 Data Gaps and Uncertainties

The Groundwater Strategy Team identified major data gaps and uncertainties for the identified groundwater plumes. The Team observed that many data gaps existed because little groundwater investigation work has been done since the 1990s time frame when most watershed-scale RIs were completed to address

[5] The U.S. Environmental Protection Agency definition of a plume (EPA 1997) is "*A visible or measurable discharge of a contaminant from a given point of origin…*". For this Groundwater Strategy, the listing of ORR "plumes" includes plumes from a single-point source as well as other areas of groundwater contamination.

Table 5.1. Consolidated list of Oak Ridge Reservation groundwater plumes

Plume No.	Source area	Description
		Bear Creek Valley
BCV-1a	S-3 Pond	S-3 Shallow/deep contamination (nitrate, uranium, Tc-99) in Nolichucky Shale (Pathways 1, 2, 3)
BCV-1b		S-3 Deep nitrate in Maynardville Limestone
BCV-2	OLF, BYBY, SL, others	Uranium in the Maynardville Limestone
BCV-3		HCDA Shallow/deep VOCs (DNAPL) in Nolichucky Shale
BCV-4	Bear Creek Burial Grounds	BG-A Shallow/deep (DNAPL) VOCs in Nolichucky Shale
BCV-5		BG-C West Shallow VOCs in Nolichucky Shale
BCV-6		Various near surface uranium signatures in Nolichucky Shale
		Upper East Fork Poplar Creek, Y-12 Plant Site
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	S-3 Shallow/deep nitrate, uranium, and ^{99}Tc in Nolichucky Shale Nitrate, uranium, metals, and VOCs in Maynardville Limestone
UEFPC-2	Western and Central Y-12 Area VOC Plume	Plant-wide commingled VOC sources (solvents and BTEX): *Nolichucky Shale and Maryville Limestone* VOCs at Former Salvage Yard (OST, Drum Deheader, Tank 2063-U, OSDS): Former Waste Coolant Processing Area (WCPA) – (potential DNAPL); Buildings 9201-4, 9201-5, and 9204-4; Former Rust Construction Garage (BTEX); Building 9204-2 vicinity; Building 9212 vicinity; Building 9731 vicinity *Maynardville Limestone* VOCs at Former Fire Training Area; Western Carbon Tetrachloride Source (undefined); Former S-2 Site; Buildings 9201-1 and 9201-2 vicinity
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	Buildings 9201-4, 9201-5, and 9204-4 Former Salvage Yard
UEFPC-4	Former East End Fuel Station and Garage Tanks	Petroleum products plume in Nolichucky Shale – BTEX, TPH, and minor chlorinated solvents
UEFPC-5	Uranium Sources in Maynardville Limestone	Former S-2 Site: Uranium Oxide Vault; Coal Pile Trench; GW-605/GW-606 source area; Former Oil Skimmer Basin
UEFPC-6	Localized Mercury Sources to Groundwater	Buildings 9201-4, 9201-5, and 9204-4; Building 81-10; Buildings 9201-1 and 9201-2 vicinity
UEFPC-7	East End VOC Plume	Shallow/deep carbon tetrachloride source (undefined, potential DNAPL); Shallow PCE, TCE source (undefined, former Bldg. 9720-6 vicinity, potential DNAPL)
		Chestnut Ridge and South Campus
CR-1	Chestnut Ridge Security Pits	Eastern Trench Area: VOCs Western Trench Area: VOC
CR-2	United Nuclear Corporation Disposal Site	Nitrate, ^{90}Sr
CR-3	South Campus Facility	VOCs: PCE, TCE, and 1,2-DCE

Table 5.1. Consolidated list of Oak Ridge Reservation groundwater plumes (cont.)

Plume No.	Source area	Description
East Tennessee Technology Park		
ETTP-1	K-901 Area	K-1070-A Burial Ground VOCs
ETTP -2		Contractor's Spoil Area (CSA) - TCE at the spring USGS 10-895
ETTP-3	Duct Island Powerhouse Area	K-1085 Old Firehouse Burn Area VOCs
ETTP-4		Duct Island/K-1070-F - VOCs at PCO Spring
ETTP-5		K-720 Fly Ash Pile metals in groundwater
ETTP-6		K-770 Scrap Metal Yard gross alpha and beta activity adjacent to the Clinch River
ETTP-7	Administrative Areas	K-1200 Area PCE/TCE in groundwater
ETTP-8		K-1004 Area VOCs in the Chickamauga bedrock
ETTP-9		Mitchell Branch Commingled VOC Plumes: *Rome Formation*: K-1407-B Pond; K-1401 Area (DNAPL in fractured rock at depths of >100 ft bgs); K-1070-C/D G-Pit; Northwest K-1070-C/D; K-1420. *Chickamauga Supergroup (Cannon-Catheys):* K-1035; K-1413; K-1095
ETTP-10	K-31/K-33 Area	K-1064 Peninsula VOCs, primarily TCE (~5 µg/L) in an isolated plume within the lower Chickamauga/upper Knox Group bedrock
ETTP-11	K-27/K-29 Area	*Chickamauga Supergroup (Cannon-Catheys):* South K-27/K-29 VOC Plume; North K-27/K-29 VOC Plume
Bethel Valley, Oak Ridge National Laboratory		
BV-1a	Main plant area widespread, shallow ^{90}Sr, ^{3}H, and Mercury	Quadrant 1 – North Tank Farm; LLLW lines around Bldg. 3019
BV-1b		Quadrant 2 – Pipeline leaks and spills from former radioisotope production and distribution facilities
BV-1c		Quadrant 3 – Mercury-contaminated soil (Bldgs. 3592, 3503, and 4501) and mercury in Fifth Creek sediments
BV-1d		Quadrant 4 – South Tank Farm/Bldgs. 3517, 3515, and surface impoundments
BV-1e		4000 Area Hg sources
BV-2	Corehole 8 Plume ^{90}Sr, $^{233/234}$U, and ^{137}Cs	Strontium-90, uranium, and ^{137}Cs in shallow/deep Benbolt limestones and siltstones
BV-3	7000 Area VOC Plume	VOCs, primarily TCE and daughters, in Witten shaley siltstones and limestones; relatively minor VOCs in shallow/deep Benbolt limestones and siltstones
BV-4	SWSA 3 ^{90}Sr Plume	Strontium-90 in Witten shaley siltstones and limestones migrating both east (to Northwest Tributary) and west (Raccoon Creek)
Melton Valley		
MV-1	Shallow Groundwater Contamination emanating from buried waste operations overlying the Conasauga Group formations	Contamination in shallow groundwater flow zone that quickly surfaces to nearby streams in the WOC watershed

Table 5.1. Consolidated list of Oak Ridge Reservation groundwater plumes (cont.)

Plume No.	Source area	Description
MV-1a	Shallow Groundwater Contamination at SWSA 4	SWSA 4 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, ^{60}Co and VOCs surfacing to WOC floodplain.
MV-1b	Shallow Groundwater Contamination at SWSA 5	SWSA 5 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, and ^{60}Co surfacing to WOC; VOCs in shallow groundwater downgradient of specific burial trenches but not at WOD.
MV-1c	Shallow Groundwater Contamination at SWSA 6	SWSA 6 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, and ^{60}Co surfacing to WOC; VOCs in shallow groundwater downgradient of specific burial trenches but not at WOD.
MV-1d	Shallow Groundwater Contamination in the Pits and Trenches Area (also referred to as WAG 7)	WAG 7 shallow groundwater contamination including tritium and ^{90}Sr, surfacing to WOC.
MV-1e	Shallow Groundwater Contamination at WAG 9 (HRE)	WAG 9 ^{90}Sr and tritium contaminants from transfer pipeline leaks at HRE [7500 building area].
MV-2	Hydrofracture Sites	Deep injection of grout used as a carrier for intermediate level liquid radioactive wastes with ^{90}Sr and tritium contaminants being the potentially mobile constituents.
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	Western migration of contaminants from SWSAs or hydrofracture to MV picket wells

BCV = Bear Creek Valley.
BG = Burial Ground.
bgs = below ground surface.
BTEX = benzene, toluene, ethylbenzene, and xylenes.
BV = Bethel Valley.
BYBY = Boneyard/Burnyard.
CR = Chestnut Ridge.
CSA = Contractor’s Spoil Area.
DCE = dichloroethene.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
GW = groundwater.
HCDA = Hazardous Chemical Disposal Area.
Hg = mercury.
HRE = Homogenous Reactor Experiment.
LLLW = liquid low-level (radioactive) waste.
MV = Melton Valley.
μg/L = micrograms per liter.
OLF = Oil Landfarm.
OSDS = Oil Solvent/Drum Storage.
OST = oil storage tank.
PCE = tetrachloroethene.
SL = Sanitary Landfill.
SWSA = Solid Waste Storage Area.
^{99}Tc = technetium-99.
TCE = trichloroethene.
TPH = total petroleum hydrocarbons.
UEFPC = Upper East Fork Poplar Creek.
USGS = U.S. Geological Survey.
VOC = volatile organic compound.
WAG = Waste Area Grouping.
WCPA = Waste Coolant Processing Area.
WOC = White Oak Creek.
WOD = White Oak Dam.
Y-12 = Y-12 National Security Complex.

contaminant sources.[6] To achieve the strategy objectives (Chap. 2), investigations to fill these data gaps are needed to better understand plume toxicity and movement.

Table 5.2 summarizes some of the common uncertainties identified in the Workshops that prevent a full understanding of plumes and current and potential off-site migration. The full listing is presented in Appendix H. Ranking of plumes is discussed in Sect. 5.1.3. Potential projects identified by the Groundwater Strategy Team to address many of these data gaps are listed and ranked in Appendix I. Considerations for prioritizing and sequencing projects as the groundwater strategy proceeds are discussed in Sect. 6.2. In some cases, a single identified project relates to, and can reduce uncertainty about, multiple groundwater plumes.

5.1.3 Ranking of ORR Groundwater Plumes

An additional effort undertaken by the Groundwater Strategy Team was an initial attempt to rank the groundwater plumes on the ORR. The Team selected a modified Hazard Ranking System (HRS) approach using the following goals for the effort:

- Find a tool that would help score and categorize the groundwater plumes across the ORR to help prioritize and sequence actions over time.
- Identify a process that is robust enough to identify the highest risk plumes.
- Make the process simple enough for use in a group decision setting with limited data.
- Ensure that decision-makers can easily communicate the concepts used for ranking.

The EPA's HRS process (EPA 1992) incorporates the key criteria needed to identify the worst groundwater plumes; however, modifications were made to the HRS primarily due to its complexity. The ranking approach adopted for this effort is:

Overall Ranking (Total Plume Score) = Weighted Total Hazard Score + Total Pathway Score

where

Weighted Total Hazard Score = (Toxicity + Area + Longevity) × 0.57*.
Total Pathway Score = Pathway + Receptor.

*The total available points for the Hazard score are 35 and the total available points for the Pathway score are 20. The Hazard score receives the weighting factor of 0.57 (20/35) to give equal weight to the Hazard and Pathway considerations. Using this weighting factor, the highest possible Total Plume Score is 40.

A complete description of the modified HRS approach used and the results of the Overall ranking are presented in Appendix H. Table 5.3 shows the results of the ranking effort using two separate ranking methods:

- Pathway ranking based on Total Pathway Score.
- Overall ranking based on Total Plume Score.

[6] In order to determine the success of cleanup with respect to surface water and groundwater quality improvements, DOE adopted the approach in watershed decisions reached on the ORR to date to implement source actions before final groundwater decisions (DOE 2003).

Table 5.2. Summary of data gaps and uncertainties identified by the Groundwater Strategy Team

General description	Specific examples[a]
Vertical and horizontal extent of plume is not known	BCV-1b – S-3 Deep nitrate in Maynardville Limestone
	MV-2 – Hydrofracture Sites
	UEFPC-1 – S-3 Site Eastern Plume/S-2 Site Plume
	BV-2 – Corehole 8, ^{90}Sr, U, ^{137}Cs
	ETTP-9 – Mitchell Branch Commingled Plumes
Absence or presence of DNAPL	BCV-3 – HCDA Shallow/deep VOCs
	BV-3 – 7000 Area VOC Plume
	UEFPC-2 – Western and Central Y-12 Area VOC Plume
Unknown source	MV-3 – Exit Pathway/Picket Wells contamination from undetermined sources
	UEFPC-7 – East End VOC Plume
	ETTP-2 – Contractor's Spoil Area[b]
	ETTP-4 – Duct Island/K-1070-F
	ETTP-7 – K-1200 Area
Extent of contamination at Exit Pathway?	UEFPC-7 – East End VOC Plume
	CR-1 – Chestnut Ridge Security Pits
	ETTP-1 – K-1070-A Burial Ground
	BV-4 – SWSA 3 Source Area
Deep flow characteristics from plume to off-site location	MV-2 – Hydrofracture Area
	BCV-1b – S-3 Deep nitrate in Maynardville Limestone
	BCV-2 – Uranium in the Maynardville Limestone
	ETTP-1 – K-1070-A Burial Ground
	ETTP-9 – Mitchell Branch Commingled Plume
	BV-2 – Corehole 8 Plume
Presence or location of a groundwater divide	BCV-1a – S-3 Shallow/deep contamination (nitrate, uranium, ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3)
	BCV-1b – S-3 Deep nitrate in Maynardville Limestone
	UEFPC-1 – S-3 Site Eastern Plume/S-2 Site Plume
	BV-4 – SWSA 3 Source Area, ^{90}Sr plume shallow in limestones of Witten Formation

[a] This table provides examples of groundwater plumes with similar identified uncertainties. Refer to Appendix H for a complete listing of identified data gaps and uncertainties.

[b] The source of TCE at a spring downgradient of the Contractor's Spoil Area is unknown. Refer to Appendix E for additional information.

BCV = Bear Creek Valley.
BV = Bethel Valley.
CR = Chestnut Ridge.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
HCDA = Hazardous Chemical Disposal Area.
MV = Melton Valley.
SWSA = Solid Waste Storage Area.
^{99}Tc = technetium-99.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.

The list of plumes under each ranking method was divided into three general groupings: high (red), medium (yellow), and low (green). These groupings should be used with caution because several plumes scored within one point of the higher or lower grouping.

Pathway ranking. The Pathway ranking based on Total Pathway Score is used to focus on groundwater plumes with the greatest potential for off-site migration. The Pathway ranking method places greater

Table 5.3. Pathway ranking and Overall ranking of ORR groundwater plumes

Plume No.	Groundwater Plume	Hazard Score				Pathway Score			
		Toxicity	Area	Longevity	Weighted Total	Pathway	Receptor	Pathway Ranking[a] by Total Pathway Score	Overall Ranking[a] by Total Plume Score
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	7	5	2	8.0	10	10	20	28
BCV-2	Uranium in the Maynardville Limestone	5	5	10	11.4	10	7	17	28
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	4	10	1	8.6	10	7	17	26
ETTP-1	K-1070-A Burial Ground	7	3	3	7.4	7.5	9	16.5	24
ETTP-2	Contractor's Spoil Area (CSA)	4	3	3	5.7	7.5	9	16.5	22
BV-2	Corehole 8, ^{90}Sr, U, ^{137}Cs	15	5	2	12.6	7.5	7	14.5	27
ETTP-11	K-27/K-29 Area	8	1	6	8.6	7.5	7	14.5	23
ETTP-5	K-720 Fly Ash Pile	5	1	10	9.1	5	9	14	23
BV-4	SWSA 3, ^{90}Sr	6	3	2	6.3	5	9	14	20
ETTP-4	Duct Island/K-1070-F	4	3	3	5.7	5	9	14	20
UEFPC-7	East End VOC Plume	10	10	6	14.9	10	3	13	28
MV-2	Hydrofracture Sites	15	7	10	18.3	5	7.5	12.5	31
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	9	10	10	16.6	7.5	5	12.5	29
BCV-1a	S-3 Shallow Contamination in Nolichucky Shale and Bear Creek (Pathways 1, 2, 3)	12	7	10	16.6	7.5	5	12.5	29
UEFPC-6	Localized Mercury Sources to Groundwater	12	3	10	14.3	7.5	5	12.5	27
ETTP-9	Mitchell Branch Commingled Plumes	15	3	6	13.7	7.5	5	12.5	26
BV-3	7000 Area VOC Plume	12	3	6	12.0	7.5	5	12.5	25
BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky and Maynardville	9	5	6	11.4	7.5	5	12.5	24
ETTP-7	K-1200 Area	8	3	3	8.0	7.5	5	12.5	21
CR-1	Chestnut Ridge Security Pits	5	5	3	7.4	7.5	5	12.5	20
ETTP-8	K-1004 Area	4	3	3	5.7	7.5	5	12.5	18
CR-2	United Nuclear Corporation Disposal Site	5	1	2	4.6	7.5	5	12.5	17
ETTP-10	K-1064 Peninsula	2	1	3	3.4	7.5	5	12.5	16
BV-1	Main Plant, ^{90}Sr, ^{3}H, mercury	13	3	2	10.3	5	7	12	22
UEFPC-5	Uranium Sources in Maynardville Limestone	7	3	10	11.4	7.5	3	10.5	22
BCV-6	Various near surface uranium signatures in Nolichucky Shale	7	10	10	15.4	5	5	10	25
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	5	3	10	10.3	5	5	10	20
MV-1	Shallow Groundwater Contamination emanating from buried waste operations overlying the Conasauga Group formations	10	3	2	8.6	5	5	10	19
ETTP-3	K-1085 Old Firehouse Burn Area	7	3	3	7.4	5	5	10	17
ETTP-6	K-770 Scrap Metal Yard	5	1	4	5.7	1	9	10	16
BCV-4	BG-A Shallow/deep (DNAPL) VOC in Nolichucky Shale	13	3	6	12.6	5	3	8	21
UEFPC-2	Western and Central Y-12 Area VOC Plume	9	3	3	8.6	5	3	8	17
CR-3	South Campus Facility	2	3	3	4.6	5	1	6	11
UEFPC-4	Former East End Fuel Station Plume and Garage Tanks	9	1	1	6.3	1	3	4	10
BCV-5	BG-C West Shallow VOC in Nolichucky Shale	9	3	3	8.6	1	1	2	11

[a] Shading: Red = High; Yellow = Medium; and Green = Low Ranking. Total Plume Scores are rounded.

BCV = Bear Creek Valley.
BV = Bethel Valley.
BYBY = Boneyard/Burnyard.
CR = Clinch River.
^{137}Cs = cesium-137.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
^{3}H = tritiated hydrogen or tritium.
HCDA = Hazardous Chemical Disposal Area.
MV = Melton Valley.
^{90}Sr = strontium-90.
U = uranium.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.

emphasis on plume pathways and receptors than inherent plume hazards (plume toxicity, size, and longevity). With a highest possible Total Pathway Score of 20, Total Pathway Scores shown in Table 5.3 for the identified groundwater plumes ranged from 2 (for the BCV-5 Bear Creek Burial Grounds C-West Shallow VOC in Nolichucky Shale plume in Bear Creek Valley) to 20 (for MV-3 Exit Pathway/Picket Wells contamination from undetermined sources). The pathway scoring conservatively assumes the worst case in terms of whether a plume is mobile with potential for off-site migration and the distance to the receptor. Plumes with the potential to move off-site to a residential drinking water well receptor are given the highest scores, and plumes that are likely to remain on-site are given the lowest scores. For example, the Total Pathway Score components (pathway and receptor scores) for MV-3 Exit Pathway/Picket Wells contamination from undetermined sources assume that contamination is in off-site wells to account for the current uncertainty. Until uncertainties regarding exit pathways are addressed, the Pathway ranking is the more appropriate guide for the strategy focus (Sect. 6.2).

Overall ranking. After exit pathway data gaps are filled, the Overall ranking can be used to prioritize ORR interior plumes. The Overall ranking method places equal emphasis on plume pathways and receptors and inherent plume hazards (plume toxicity, size, and longevity). With a highest possible Total Plume Score of 40, the Total Plume Scores shown in Table 5.3 for the identified groundwater plumes ranged from 10 (for the UEFPC-4 Former East End Fuel Station plume at Y-12) to 31 (for MV-2 Hydrofracture Sites). Figure 5.1 illustrates the “High,” Medium,” or “Low” category of each plume based on the Overall ranking by Total Plume Score and identifies the plumes spatially in relation to ORR boundaries and geology. In general, the highest ranked groundwater plumes based on Total Plume Score are those with large contaminant masses and long half-lives and lie within the limestone aquifer formations on the Reservation, or in the case of the Hydrofracture Sites, near the ORR boundary. In most cases the high-ranking plumes are extremely complex and may require extensive characterization work and technology evaluation.

One of the high-ranked plumes by the Overall ranking method, UEFPC-6 Localized Mercury Sources in Groundwater, is contaminated groundwater in the Y-12 main plant area from former mercury use areas. Pathways for mercury migration in groundwater are localized and have been heavily influenced by dewatering sumps. Mercury-contaminated groundwater is extracted by dewatering sumps and from Big Spring discharge at Bldg. 9201-2 at Y-12 and treated prior to discharge to surface water (Central Mercury Treatment System and BSWTS). There are plans to construct and operate a new water treatment system and demolish former mercury use buildings at the Y-12 Complex. These projects are part of a Mercury Strategy to further remediate mercury contamination (DOE 2013c).

High-ranked Plumes by both ranking methods. The following groundwater plumes at ORNL and Y-12 ranked high by both the Pathway ranking and Overall ranking methods:

- MV-3 Exit Pathway/Picket Wells contamination from undetermined sources.
- BCV-2 Uranium in the Maynardville Limestone.
- BCV-1b S-3 Deep nitrate in Maynardville Limestone.
- BV-2 Corehole 8, ^{90}Sr, U, ^{137}Cs.
- UEFPC-7 East End VOC Plume.

The top-ranked plume in the Overall ranking, MV-2 Hydrofracture Sites, could be relevant to the top-ranked plume in the Pathway ranking, MV-3 Exit Pathway/Picket Wells contamination from undetermined sources.

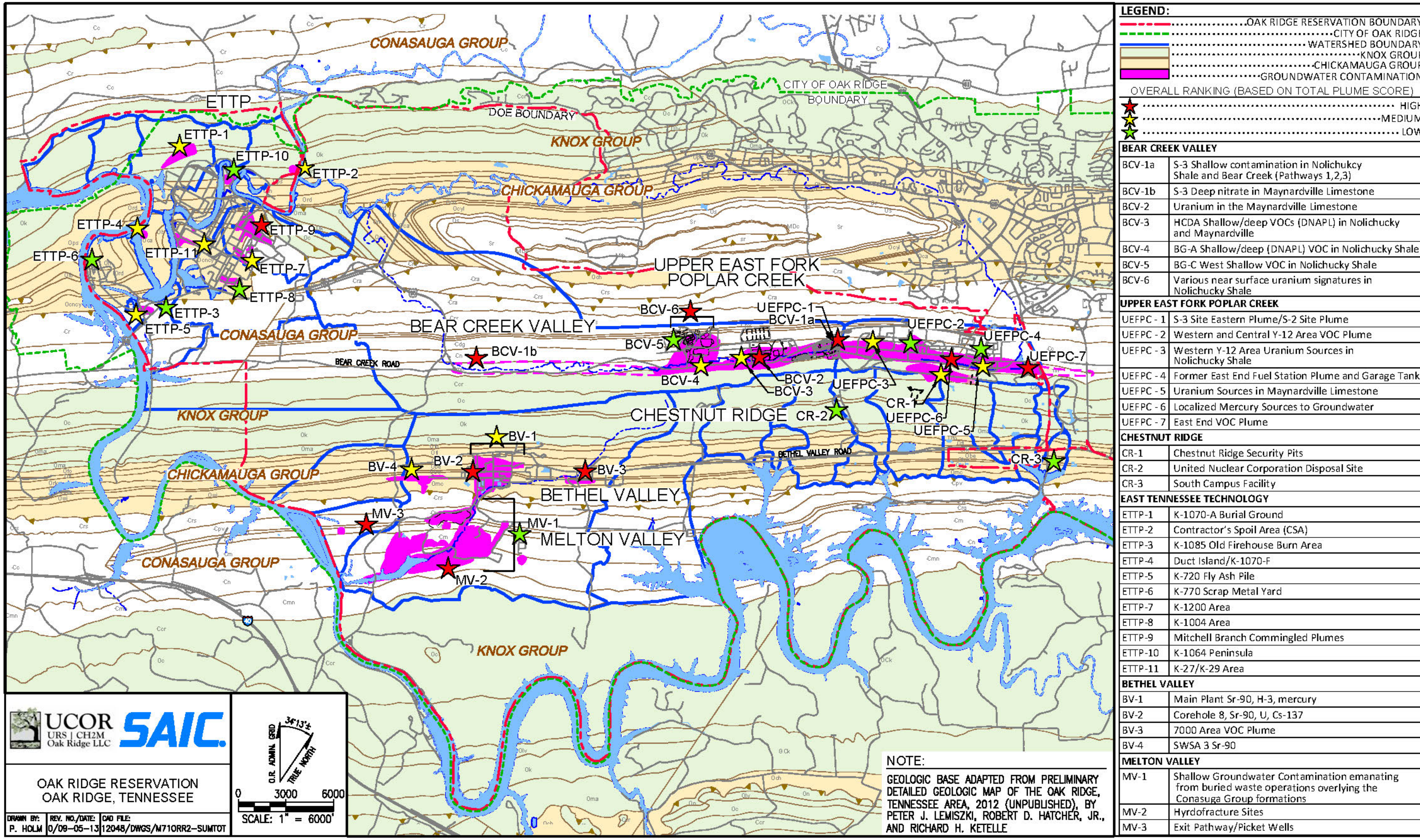


Fig. 5.1. Map showing ORR groundwater plumes and overall ranking.

5.2 UNDERSTANDING POTENTIAL OFF-SITE MIGRATION

The general conceptual risk assessment model for the ORR includes contaminant transport pathways from on-site sources to off-site environmental media. Of specific concern for a groundwater strategy are the following two pathways:

- Overland flow and shallow groundwater flow from waste sources to nearby surface waters, and transport through the surface water to off-site locations.

- Leaching from primary and secondary waste sources to underlying groundwater, and transport through deep groundwater to off-site locations.

There is substantial, available data to quantify to a high degree of confidence the amount of contamination that migrates away from sources via the first pathway – migration through surface water. With historical and ongoing monitoring information, DOE can quantify and report contaminant transport through the many creeks on the ORR and its impact to off-site locations (e.g., DOE 2012b; DOE 2013a; http://www.ornl.gov/sci/env_rpt/).

There are significantly less data to define migration through the second pathway. Although historical efforts have been successful at identifying areas on the ORR where contaminants have leached from primary waste sources to the underlying groundwater, data to describe the potential for contaminant transport from these areas through the deep groundwater to off-site locations are limited. Groundwater strategy efforts to better define potential deep pathways between major sources and the Reservation boundary in each watershed, as well as data gaps and uncertainties, are presented in Appendices B through G. Appendix J provides a discussion of deep flow hydraulic and geochemical boundaries.

Over the past decade, efforts to better understand the potential for deep groundwater flow in the limestone aquifers on the ORR to carry contaminants off-site include:

- Installation of the lines of deep multiport Picket Wells in MV, BCV, and UEFPC.

- Installation of off-site monitoring wells across the Clinch River from MV.

Concern about the probability of off-site groundwater contamination was reported as follows in TDEC's 2012 Annual Status Report about the ORR (TDEC 2012):

> *The year 2012 monitoring results showed no unacceptable risk to the public. DOE has made efforts to improve the overall health of the public and the environment. There are still significant sources of contaminants that could be released as a result of engineering and/or administrative control failure. Additionally, sources of gamma radiation exposure that still exist must be effectively isolated from the public. The probability of off-site groundwater contamination is also a concern that must be addressed. It is necessary and prudent for the state and DOE to continue monitoring efforts in order to detect and evaluate, as early as possible, potential releases and radiation that could affect the public. The state considers these factors in helping to manage cleanup with DOE and the U.S. Environmental Protection Agency (EPA).*

TDEC has placed additional emphasis on monitoring water supplies, wells, and springs, both on and off the ORR, and conducting hydrogeologic investigations such as aquifer evaluations and dye traces (TDEC 2013).

For the groundwater strategy path forward, considerations relative to off-site contaminant migration include the following:

- The Clinch River is not a complete hydraulic boundary to flow from the ORR to downgradient areas. Although groundwater flow paths converge toward the Clinch River on both sides, given the karst conditions in several geologic formations and possible influence from off-site groundwater pumping stresses, there is the potential for some conduit flow under, rather than into, the Clinch River.

- There have been sporadic, low-concentration detections of radionuclides and VOCs in off-site sampling locations downgradient of the ORR that raise concern about potential off-site contaminant migration from the ORR.

- There are no known health impacts from contaminants detected off-site to date. With the exception of a low VOC detection in one sample in one well in 2010, no results in off-site wells have exceeded Safe Drinking Water Act of 1974 (SDWA) maximum contaminant levels (MCLs).

  — This detection occurred simultaneously with detection of similar VOCs in one of the on-site MV picket wells, which also experienced an anomalous low hydraulic head measurement during the sampling episode. The off-site detection occurred early in the sampling history and is suspected to have occurred because of pumping stresses in the off-site well during construction that caused low head in a discrete fracture zone connected to the vicinity of the on-site well. Neither well has experienced subsequent detections of the VOCs detected in 2010. This detection is considered to exemplify the vulnerability of off-site wells in close proximity to areas of ground contamination.

The Pathway ranking shown in Table 5.3 emphasized plumes that are in karst formations and also highlighted plumes that are closest to the ORR boundary and off-site well users. Using the Pathway ranking, MV-3 Exit Pathway/Picket Wells contamination from undetermined sources ranked highest and guided the selection of the near-term groundwater action project to perform additional off-site groundwater quality monitoring. Another high-ranked project, a project to implement additional groundwater use restrictions/policies off-site, remains under consideration as potential off-site migration concerns are further investigated (Appendix I).

5.3 CERCLA REMEDIAL INVESTIGATION AND FEASIBILTY STUDY NEEDS

This section discusses some of the CERCLA program processes and requirements that will need to be implemented as part of ORR groundwater cleanup. Optimizing, integrating, and streamlining these processes so that resource expenditures provide the most value added is part of the groundwater strategy.

5.3.1 Groundwater General Response Actions for the ORR

Identifying General Response Actions (GRAs) is the first step in the CERCLA FS process for identifying and screening remedial alternatives (EPA 1988). GRAs are defined as broad response actions that satisfy the objectives for cleanup, such as “containment,” “removal,” or “treatment.” GRAs are often combined to develop remedial alternatives (e.g., removal and treatment). Future CERCLA decisions related to groundwater on the ORR, including Final RODs, will be based on a detailed analysis of a range of alternatives and technologies available at the time decisions are made. The following listing of potential GRAs for ORR groundwater plumes is included for consideration in the groundwater strategy and in no way pre-empts the CERCLA RI/FS process:

- Groundwater use restrictions and other ICs.
- Containment (e.g., hydraulic isolation of source area, in situ barrier wall).
- Active remediation (e.g., ex situ treatment [pump and treat], biological, chemical, or thermal remediation).
- Monitored Natural Attenuation (MNA).
- Technical Impracticability (TI) waiver.

Identifying one or more GRAs that could be applied to specific ORR plumes will:

- Help focus CERCLA characterization and decision-making efforts on the types of data needed for certain types of decisions (see discussion of RIs, modeling, technology evaluations and treatability studies [TSs], and monitoring in Sects. 5.3.2 through 5.3.5, respectively).
- Allow various groundwater projects to share technology and decision-making resources (e.g., multiple plumes may benefit from a single technology demonstration and decision approach).
- Allow the FFA parties to develop approaches and templates that will be applied consistently across plumes with similar likely remedies.

Groundwater monitoring may be a component of some final remedies and will be used to evaluate effectiveness of CERCLA actions after remedy implementation.

5.3.2 Remedial Investigations

Most final watershed decisions are currently scheduled in the last 10 to 20 years of the ORR cleanup lifecycle. Considerations for future groundwater decisions and remediation, including integrated monitoring and pre-RI efforts that may be started ahead of current RI schedules to fill data gaps for ORR plumes, are described below.

5.3.3 Groundwater Modeling

Groundwater modeling will play an instrumental role in the CERCLA RI/FS process in coming years, and for some of the more complex decisions, it may play a role in the long-term monitoring (LTM) phase of CERCLA implementation. Decisions that will require model support include:

- No further action decisions on residual sources (e.g., soil) to demonstrate that any remaining contaminant in the primary source will not migrate to groundwater resulting in unacceptable groundwater concentrations.
- MNA decisions, where a model will be needed to demonstrate that dilution, attenuation, and biodegradation will remediate a plume within a sufficient period of time.
- TI Waivers, where a significant amount of modeling support could be needed to predict the extent of future plume boundaries and to help delineate the TI Zone.
- Active remedial design efforts to support pumping or injection well placements, pumping and injection rates, and predictions of treatment times to support FS cost estimates.

- Changes in hydrological conditions due to building D&D and infrastructure changes.
- Monitoring program design to optimize LTM requirements and possibly support FYRs.

The industry standard and most widely used numerical model code is MODFLOW (modular finite difference flow model) developed by the U.S. Geological Survey (USGS) in the late 1960s. MODFLOW solves saturated flow in three dimensions using a finite-difference method. It is heavily applied, well tested and verified, and has had graphical interfaces and additional computation modules developed for it over the years by both the USGS and private parties. MODFLOW has been used across the ORR for several large- and small-scale applications, particularly to develop a large-scale flow model for the Y-12 Complex (both BCV and UEFPC) [DOE 1997b; DOE 1998d)] and to support the Sitewide Groundwater RI at ETTP (DOE 2007b).

MODFLOW has some limitation in handling complex geometries, including issues encountered with fracture flow and flow in karst systems that can be addressed by more advanced simulation codes. In 2011 to 2012, DOE convened a team of groundwater experts to review 25 relevant model codes for their applicability to the complex flow environment at ETTP. The experts selected a combination of DOE-FEHM (Finite Element Heat and Mass transfer model) [Zyvoloski 2007] for discrete flow simulation and MODFLOW/MT3DMS (Modular 3-D Multi-Species transport model) [Harbaugh at al. 1996; Zheng et al. 1999] for regional flow conditions. FEHM was tested on the ETTP K-1401 plume area in 2012 to determine its ability to model heterogenous subsurfaces (discrete fractures) and dual-porosity/dual-permeability flow conditions. The model tests indicated it was successful at all challenges with one exception, contaminant transport in dual-porosity/dual-permeability and anisotropic conditions (it was successful at simulating groundwater flow in these conditions). FEHM programmers are currently working on revisions to the code to address this finding.

A gap identified in groundwater modeling capabilities for future CERCLA decisions on the ORR is an ORR-wide regional flow model. Filling this gap would ensure that a single, regional calibrated flow model exists for all remaining decisions and that there is a consistent method for modeling regional-scale groundwater flow across the Reservation. Once a regional flow model is developed, small-scale models can be developed using the calibrated flows from the regional model as their boundary conditions. These individual models may be selected based on local site conditions and the purpose of the model (e.g., the EPA Multiphase Flow and Multicomponent Transport [MOFAT] code may be used for bioremediation system design). Significant challenges exist in the development of regional flow models, including documenting and reaching consensus on the physical bases upon which the key model parameters are based (e.g., water budget, head and flow boundary conditions, strategies for incorporating preferential groundwater flow features such as fractures and conduits, bottom elevation of model domains, etc.). A master dataset would need to be maintained, including geographical bases, to support the long-term use of groundwater models at the ORR. Similarly, the key elements of site conceptual models would require maintenance and updating through the lifecycle of groundwater characterization, decision-making, and remediation.

5.3.4 Technology Evaluations and Treatability Studies to Support FS Data Needs

Some future groundwater decisions on the ORR will require technology demonstrations, preferably prior to a final ROD, so that the action selected is known to be implementable and effective with a high degree of certainty. This section provides a discussion of technology demonstrations that could be performed at a single site but are potentially applicable to multiple groundwater plumes across the ORR. Sequencing and design of these demonstrations should consider their multiple applications to help optimize technology development resources. Evaluation needs for potential MNA and TI Waiver response actions are also

considered in this discussion since early attempts at selecting these alternatives will effectively serve as "demonstrations" for subsequent decisions.

In-situ and Ex-Situ Treatment Technologies

In situ or ex situ treatments are GRAs that will be considered for ORR plume remediation. In some cases, the combination of two GRAs (e.g., in situ or ex situ treatment combined with MNA) may be appropriate.

Two recent groundwater TSs are partially complete on the ORR – a DNAPL in fractured rock study and a biostimulation study. Completion of these two TSs will allow DOE to understand the role of the two test technologies in chlorinated VOC plume remediation.

- In 2008, DOE initiated work on a multi-phased TS to verify that DNAPL was at the core of a highly contaminated groundwater zone at the ETTP site to determine the feasibility of remediation of groundwater in a DNAPL zone in fractured bedrock. The first phase, which is complete, was to verify that DNAPL was the core of one of the most highly contaminated groundwater zones on-site. The subsequent phase will be designed to test an in situ conductive heating technology for DNAPL zone treatment. Characterization investigations did demonstrate the presence of DNAPL; however, funding has not been available to continue full site characterization, process design, and implementation of the full-scale treatability testing. This information will be necessary to determine the feasibility of remediation of relatively shallow DNAPL in weathered and fractured bedrock.

- In 2010, DOE initiated work on a TS to use biostimulation of indigenous microbes in a trichloroethene (TCE) plume at the ORNL 7000 Area to accelerate the biodegradation of the plume. The TS demonstrated the use of groundwater tracing in the karst setting to gain an understanding of groundwater flow velocities in different parts of the plume as an aid to selection of appropriate zones for biostimulant injection. A portion of the plume was selected in which biostimulant chemicals were injected into existing monitoring wells and monitoring of biological indicators and VOCs has continued for 2+ years post-treatment. Continuation of monitoring, expanded characterization, and design of additional biostimulant injections to obtain full plume treatment remains to be completed to remediate this plume.

Additional groundwater technology development needs for the ORR include: in situ methods for immobilization of uranium and fission products (principally ^{90}Sr and tritium) in groundwater, improved delivery strategies to introduce chemical and/or biological treatment media into the subsurface environment, and monitoring technologies to improve confidence and reduce costs.

Monitored Natural Attenuation

Plumes on the ORR with characteristics that will allow them to degrade in a reasonable amount of time (e.g., <100 years) are candidates for an MNA decision. MNA may be the single selected remedy for a plume or one component of a total remedy. It is often combined with treatment technologies as a final "polishing" step (e.g., after an active bioremediation effort) to meet MCLs or other cleanup goals.

EPA tools for plume characterization and screening protocols are outlined in a number of guidance documents (EPA 1998; EPA 1999; EPA 2007a; EPA 2007b; EPA 2010) that should be followed to propose an MNA decision. The process for making MNA remediation decisions on the ORR can be optimized by developing ORR-appropriate characterization guidelines that meet the requirements of EPA's MNA guidance, account for ORR-specific challenges (e.g., modeling in fractured flow), and are applied consistently across all potential ORR MNA sites.

Technical Impracticability Waivers

TI Waivers are used to remove the requirement of meeting an applicable or relevant and appropriate requirement (ARAR) when it is not technically practicable. The most common ARAR-based criteria waived in a TI Waiver are MCLs from the SDWA.

The EPA has issued a recent analysis of historical TI Waivers to help current sites evaluate whether a TI Waiver may be part of their remedial strategy (EPA 2012). The analysis shows a nationwide total of 91 TI Waivers have been granted from 1988 to 2011. Other notable findings included:

- Complex geology was cited as the rationale for the waiver at 54 of 85 sites, with "fractured bedrock" and "karst" as key factors.

- DNAPL, light non-aqueous phase liquid (LNAPL), or just non-aqueous phase liquid (NAPL) were cited as factors in many decisions.

- The possibility that as new technologies are developed, engineering "impracticability" may be more difficult to show in the future. EPA cites the emergence of thermal treatment and DNAPL identification technologies as reasons for this.

- Remedial components identified in waivers include treatment, containment, MNA, ICs, alternative water supplies (AWS), or well-head treatment.

Some of the plumes on the ORR contain typical features found in TI decisions. For example, relevant to some ORR groundwater contamination sources (e.g., Y-12 S-3 Ponds site secondary groundwater sources and the MV Hydrofracture Sites at ORNL), is the finding that 12 TI Waivers cited "a large source that could not be removed."

There are strict guidelines for obtaining a TI Waiver and a substantial amount of information is required to support a TI Waiver decision (EPA 1993; EPA 1995) including:

- A CSM that describes the geology, hydrology, contaminant sources, transport and fate of contaminants, exposure pathways, and receptors.

- Specific ARARs for which TI determinations are sought.

- Spatial area (in three dimensions) over which the ARAR waiver will apply (also known as the TI Zone).

- Evaluation of site restoration potential, including any data and analysis that indicate restoration may be technically impracticable. This should include a discussion of possible source control measures, the performance of past or ongoing remedial actions, and analysis of restoration time frame (preferably based on modeling) and an FS of other technologies.

- Cost estimate for existing or proposed remedial technologies.

- Additional information or analysis as EPA deems necessary.

In addition to the required CERCLA decision documents, a TI Waiver requires the development of a "TI Evaluation Report" that captures and analyzes the above information (Fig. 5.2). The TI Evaluation Report is typically submitted as part of the TI Waiver Application. Applications for a TI Waiver can be considered at any stage of the regulatory process, as long as data are sufficient to support the claim of technical impracticability. There are two primary types of TI Waivers: *front-end* and *post-implementation*.

Applications for ***front-end TI Waivers*** are most likely at sites where a significant amount of information is available to support the need for the waiver, including extensive site characterization data in the RI and the FS, and TS performance data or performance data from an interim remedial measure. These data allow stakeholders to assess that cleanup is impracticable. For this type of TI Waiver, the waiver is incorporated into the ROD.

Post-implementation TI Waivers are granted after a full-scale remedial strategy identified in a ROD has been in place for a period of time and performance data show that the technology is ineffective. In this scenario the treatment system may need to operate for many years and the site owner must demonstrate that the failure of the system is not due to faulty design or maintenance.

In both scenarios, a TI Waiver may not be the sole aspect of the decision. The decision may also include removal or containment requirements and will include land/water use restrictions and LTM requirements.

Figure 5.2 illustrates an approach for obtaining front-end TI Waivers by performing representative treatability and engineering studies prior to the ROD. The figure also shows how a first ROD for an ORR plume that includes a TI Waiver may be used to substantially decrease the time and resources needed to make a TI determination for other plumes using applicable findings from the first TI Waiver decision.

Alternate Concentration Limits

CERCLA Sect. 121(d)(2)(B)(ii) allows consideration of alternate concentration limits (ACLs) for CERCLA actions to remediate contaminated groundwater as long as three conditions are met:

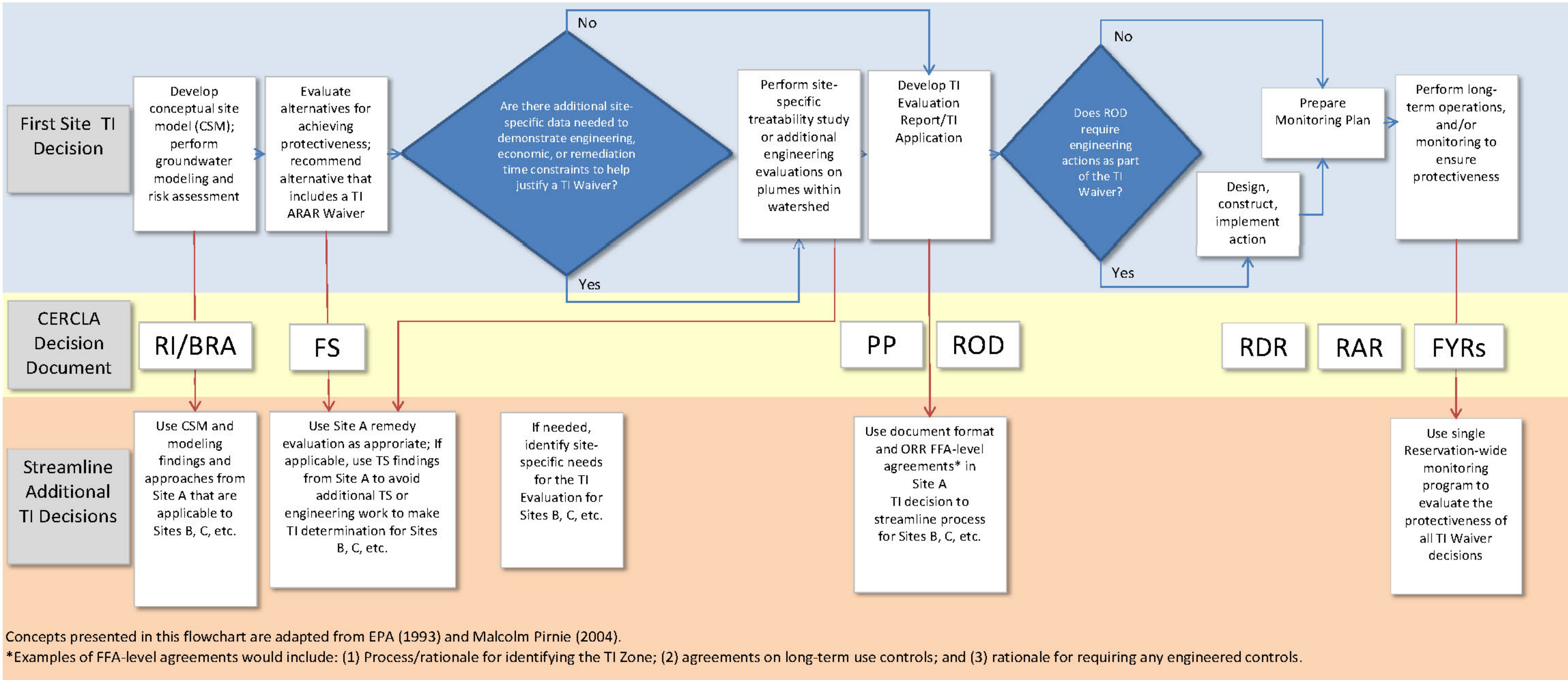
1. The points of entry of contaminated groundwater into surface water are known (or projected).

2. The ACLs will cause no statistically significant increase in hazardous constituents from contaminated groundwater into surface water.

3. The remedial action will include enforceable measures that will preclude human exposure to contaminated groundwater at any point between the facility boundary and all known and projected points of entry of contaminated groundwater into surface water.

EPA's policy regarding the use of ACLs in CERCLA remedies is presented in a 2005 memorandum (EPA 2005). The memorandum notes that the Agency, in its discretion, decides if an ACL might be appropriate based on site-specific circumstances. Most importantly, EPA notes that the CERCLA ACL provision is directed at standards that are *legally applicable* for hazardous constituents in groundwater and cannot be used in circumstances where the standards have been determined, under the CERCLA ARARs process, to be "relevant and appropriate" rather than "applicable" standards.

Tennessee is authorized by EPA to administer the federal CWA in the state and has a classification scheme for groundwater that includes use classifications and specific numeric criteria and risk standards for each use. TDEC 1200-04-03-.07(4)(b) designates all groundwater in the state as General Use Groundwater (except for groundwater that has been specially designated otherwise). Groundwater



ARAR = applicable or relevant and appropriate requirement.
BRA = Baseline Risk Assessment.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
CSM = conceptual site model.
FFA = Federal Facility Agreement.
FS = feasibility study.
FYR = Five-Year Review.
PP = Proposed Plan.
RAR = Remedial Action Report.
RDR = Remedial Design Report.
RI = remedial investigation.
ROD = Record of Decision.
TI = Technical Impracticability.
TS = Treatability Study.

Fig. 5.2. Approach for obtaining Watershed RODs that include "front-end" Technical Impracticability (TI) ARAR Waivers.

designated as General Use must meet the state's numeric water quality criteria under TDEC 1200-04-03-.03(1)(j) and (k) for surface waters classified as a Domestic Water Supply and must contain no other constituents that pose an unreasonable risk to public health or the environment. The state's groundwater rules also include a process for petitioning the Water Quality Control Board to reclassify groundwater as Site-Specific Impaired.

As part of its groundwater rules development process, TDEC developed a draft Comprehensive State Groundwater Protection Plan (CSGWPP) as required by EPA. However, the plan has not been approved. EPA stopped reviewing state CSGWPPs and no longer has any mechanism in place or plan for reviewing and approving them. Approval of the CSGWPP is necessary for the state groundwater rules to be considered EPA-approved. Absent that approval, the rules are not considered by EPA to be *legally applicable* at EPA CERCLA sites. Consequently, applying ACLs is not a viable option for ORR groundwater because the state groundwater standards are not *legally applicable* standards as that term is applied under the CERCLA ARARs process.

5.3.5 Groundwater Monitoring Considerations

Groundwater monitoring is a critical component of the ORR Groundwater Strategy both now and in the future. Currently, monitoring is performed to:

- Evaluate the effectiveness of completed CERCLA actions to determine if remediation goals are being met.
- Meet specific regulatory requirements (e.g., RCRA permit requirements and EMWMF detection monitoring requirements)
- Track contaminant trends at key integration or exit points including Picket Wells in MV, BCV, and UEFPC. There are currently no Picket Wells in BV or ETTP.
- Investigate, on occasion, specific issues that arise.

In the coming years monitoring will take on additional roles, including:

- Boundary location and off-site monitoring will be revisited to address recent issues discussed in Sect. 5.2.
- The current monitoring network and monitoring program infrastructure can be utilized and augmented to support pre-RI and RI characterization efforts.
- Monitoring will be a part of any future groundwater decisions with MNA or TI Waiver components.
- Post-final ROD monitoring will likely continue in perpetuity in support of CERCLA FYRs at sites where waste is left in place.

Monitoring data are the cornerstone of all groundwater investigations and decisions. Acquisition of reliable groundwater data representative of the monitored location, whether in situ physical measurements or results of off-site lab analysis, is of paramount importance. The Data Quality Objectives (DQOs) process is used for ORR CERCLA projects to define sampling and analysis needs. DQOs are determined on the basis of the end uses of the data and specify the quality of the data.

For example, to reduce the uncertainties surrounding the potential off-site migration issue (Sect. 5.2), several important study parameters need to be controlled to better understand if low-level detections seen to date represent complete pathways from the ORR, including (but not limited to):

- The ability to determine if detections of radionuclides that are close to the analytical measurement detection limit are real.
- The ability to determine if detections represent naturally occurring concentrations of materials (e.g., uranium and radium are naturally occurring in groundwaters) or if they are above universal radioactive fallout concentrations that resulted from weapons testing.
- The need to demonstrate the source of the detections (e.g., some chemicals could come from sources other than the ORR).

Collection and interpretation of data in fractured rock and karst settings is complicated by changes in conditions that can occur rapidly in response to precipitation-induced recharge and hydraulic head changes. Some of the monitoring projects selected to implement the groundwater strategy may be dedicated to collection and interpretation of high-frequency data signals that can be interpreted and used to plan sample collection timing relative to groundwater stressor events.

Current groundwater monitoring technology options offer a number of different approaches to conducting measurements and collecting samples from discrete fracture or conduit zones. During the late 1980s, DOE’s ORR management and operating (M&O) contractor adopted use of the Westbay® technology for deep groundwater investigations and monitoring. Although expensive to install and operate, that technology has a proven track record of durability and operability to great depths. Other technologies are available for fractured rock applications but most are limited in the depth of use and the practical sample volumes that can be obtained. Future groundwater investigations and monitoring should make use of the most cost-effective discrete zone sampling technologies available to obtain the required groundwater data.

Additional technology development needs for the ORR monitoring program include in situ monitoring technologies capable of reliable, low-level detection and recording over time of site-related contaminants in wells and development of strategies to collect and process groundwater data intensively in the near term that will provide the most reliable, LTM strategies at reduced frequency and cost. For example, collection of time series physicochemical parameter data coupled with specific ion chemical sensors may provide insight into specific hydrologic conditions that promote contaminant migration. A number of existing ion selective electrodes exist for use in laboratory environments; however, long-term deployment in field conditions for continuous recording of parameters in the groundwater environment has not been demonstrated for most. A recent report (SERDP 2012) describing development of an in situ sensor that could quantify 30 organic compounds in groundwater points to the need to move leading edge research and development for groundwater monitoring to levels of reliable field application.

5.4 GROUNDWATER USE RESTRICTIONS/POLICIES

For many years there have been conditions that have required groundwater use restrictions on and off the ORR. In areas where unacceptable potential risk is identified, groundwater use restrictions/policies can be used for interim protectiveness until final decisions are made. Table 5.4 lists areas with groundwater use restrictions on and around the ORR. These areas are shown in Fig. 5.3.

Table 5.4. Current groundwater use restrictions for the ORR and adjacent areas

Site	Watershed/Area	Groundwater use restriction[a]
On the ORR	NA	DOE groundwater use restrictions enforced
	South Campus Facility	CERCLA groundwater use restriction – final ROD
	Melton Valley	CERCLA groundwater use restriction – interim ROD RAR
	Clean Parcel Determinations	Groundwater use restriction in deed
	Covenant Deferrals	Groundwater use restriction in Covenant Deferral Request package
Off the ORR	Union Valley	CERCLA groundwater use restriction – ROD
	Property transfer areas, for example: Cheyenne Hall and other properties in the downtown Oak Ridge Area; Bethel Valley Industrial Park; Commerce Park; Parcel A; and Rarity Ridge	DOE groundwater use restriction in deed
	Off-site Wells	License agreements in place

[a] Use restrictions preclude groundwater from being used unless prior authorization is received from DOE.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U.S. Department of Energy.
NA = not applicable.
ORR = Oak Ridge Reservation.
RAR = Remedial Action Report.
ROD = Record of Decision.

Use of groundwater within the ORR boundaries is restricted. In addition to the groundwater use restrictions enforced throughout the Reservation, there are restrictions specified by ROD and post-ROD documents for the following areas on the ORR:

- A notice of contamination in the property title for ORAU SCF to alert current and potential future owners of risk (SCF ROD [DOE 1995]).

- Post-remediation and deed restrictions prohibiting certain uses of groundwater in delineated MV areas (MV IROD [DOE 2000a]).

All ORR CERCLA Covenant Deferral Requests (CDRs) [e.g., DOE 2013b] and Clean Parcel Determinations (CPDs) for property transfers include language restricting groundwater use:

- Properties which DOE can show are protective for the intended use may be transferred (leased) under a CERCLA 120(h)(3) CDR, which allows DOE to transfer properties prior to completion of CERCLA remediation activities. As of 2009, select parcels of the ORR, mostly in the ETTP area, have been transferred early via CDRs. Where CDRs are in place, DOE remains responsible for the remediation of the area in accordance with the FFA.

- A number of parcels have been transferred (deeded to a non-federal agency) as "clean parcels" pursuant to CERCLA Sect. 120 (h)(4). In these cases, there has been agreement by the FFA parties that the area requires no further cleanup under CERCLA. If, in the future, this is shown to not be the case and there is contamination from the historical Federal operations, DOE will remain responsible for any additional cleanup at the site.

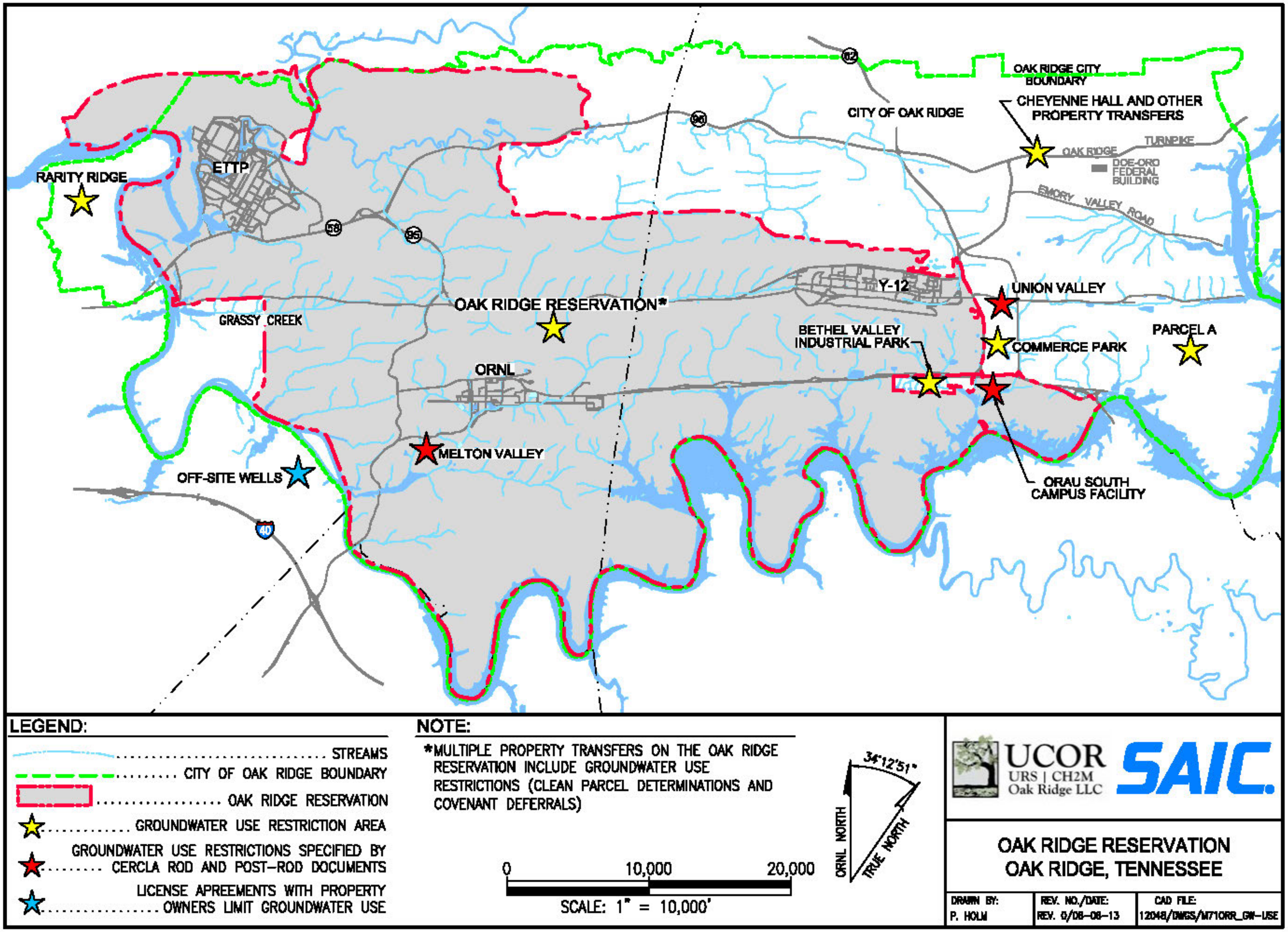


Fig. 5.3. Areas with groundwater use restrictions on and around the ORR.

Off the ORR, DOE places groundwater use restrictions in property transfer deeds for all areas where the Federal government maintained ownership when the city of Oak Ridge was incorporated in the late 1950s. For other areas, DOE reaches license agreements with land owners when potential risk is identified.

- The Union Valley ROD for an Interim Action (DOE 1997a) identified ICs as the selected alternative for a contaminated VOC plume originating from beneath Y-12 that migrated off the ORR (UEFPC-7 East End VOC Plume). Administrative actions were instituted for the term of the ROD until a final ROD is issued for the UEFPC area. License agreements were established between DOE and all affected property owners within the interim remedial action boundary.

- Numerous property transfers from DOE have included groundwater use restrictions in the deed. For example:

  - Several former properties located in the downtown Oak Ridge City area near the Oak Ridge Turnpike: Cheyenne Hall, Original Oak Ridge Hospital Site and Cancer Research Facility, and Bus Terminal. New structures and large parking lots have been constructed on most of these sites.

  - The BV Industrial Park area located near Bethel Valley Road.

  - The Commerce Park area located east of the ORR and west of South Illinois Avenue.

  - An area referred to as “Parcel A” located east of the ORR that is used for residential and recreational purposes. A golf course is located on a portion of the property.

  - The Rarity Ridge residential area located west of ETTP. The Clinch River floodplain area of this property was determined clean under an approved CPD in 1994 and was added to the deed.

- In order to minimize groundwater pumping that could draw DOE contaminants off-site, DOE has license agreements restricting groundwater use in place with some property owners across the Clinch River from ORNL. Beginning in FY 2010, DOE has worked with the public utility and provided funds for installation of utility water supply to off-site residents in this area (MV-3 Exit Pathway/Picket Wells contamination from undetermined sources).

DOE evaluation and tracking of groundwater use in areas adjacent to the Reservation is an ongoing effort. The WRRP tracks and reviews ICs for CERCLA decisions annually in the RER and in CERCLA FYRs. Tracking and documentation of groundwater uses and restrictions that are not part of a CERCLA decision can be improved. In addition to residential users, groundwater users that pump large volumes of groundwater could induce deep flow pathways for contaminant migration under the Clinch River. Setting up a DOE interface with TDEC is recommended to allow DOE to be notified of new well installation activity in areas adjacent to and downgradient of the ORR.

5.5 FEEDBACK FROM THE FFA PARTIES

A list of questions about key regulatory and technical challenges relevant to ORR groundwater was discussed at the August 2013 workshop. The FFA party participants have provided a written response to each question (Appendix K). Areas of consensus among the responses include:

- Additional near-term, off-site monitoring measures are needed to assess potential off-site risks. No immediate off-site groundwater use controls (beyond those controls already in place) are needed at

this time. This assessment could change based on characterization results of the Off-site Groundwater Quality Assessment project.

- A modest change to the current ORR DOE lifecycle baseline is needed at this time to budget funding for an ongoing ORR Groundwater Program to continue to characterize groundwater conditions in support of decision making for remedial activities. The first activity planned under the Program is an off-site sampling effort (the Off-site Groundwater Quality Assessment project). Future baseline changes may be identified as characterization of plumes proceeds under the Program.

- Further characterization is needed to determine whether groundwater restoration is practicable for some contaminated areas on the ORR. Characterization and TS projects to determine the appropriateness of a TI Waiver determination for one area of the ORR can help inform future evaluations for other plumes on the Reservation. Like all CERCLA remedies, a TI Waiver determination is subject to FYRs of performance and protectiveness.

- ICs are acceptable as a sole means of managing risks posed by groundwater contamination when active response measures are determined not to be practicable.

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6. ORR GROUNDWATER STRATEGY

The ORR Groundwater Strategy includes the following components:

- Adopt the following groundwater strategy objectives (Chap. 2) to guide strategy implementation:
  - Identify and address potential threats to off-site public health from exposure to groundwater contaminated by ORR sources.
  - Pursue selected remedial actions as necessary to prevent unacceptable risk and groundwater degradation and to restore groundwater to beneficial use where practicable.
  - Achieve final ORR cleanup, including final groundwater decisions.
- Set up an ongoing ORR Groundwater Program to implement the strategy and achieve strategy objectives (Sect. 6.1).
- Prioritize and sequence groundwater investigation and remediation activities (Sect. 6.2).
- Identify specific steps for the near term to begin implementation of the strategy (Sect. 6.3).

6.1 ORR GROUNDWATER PROGRAM

Over a decade has passed since most watershed-scale groundwater investigations were completed and it will be 30+ years until projected completion of ORR cleanup in 2046. Little RI-scale investigation is currently planned prior to final groundwater decision projects in the outyears. Setting up an ORR Groundwater Program is recommended to implement the groundwater strategy and to support ongoing characterization efforts. A modest change to the current DOE lifecycle baseline is needed to budget annual funding for the Program. The focus for the first 3 years of the Program will be implementation of an Off-site Groundwater Quality Assessment project.

The ORR Groundwater Program will be used to systematically prioritize and investigate groundwater plumes and data gaps. Prioritization decisions and resource allocation for projects to be implemented under the Program will follow FFA and EM Program budget development protocols.

- Groundwater investigation, groundwater modeling, and technology development to be conducted under the Program will improve understanding of plume sources and migration and help achieve groundwater strategy objectives.
- The Program will have an integrated schedule with implementation based upon funding. Activities will be logically sequenced taking into consideration current potential public health threats and other factors. The ORR Groundwater Program will develop groundwater project scopes for consideration and prioritization, which will improve long-term planning and potentially reduce overall cost. Candidate projects include the list of potential projects identified by the Groundwater Strategy Team (Appendix I).

- ORR Groundwater Program activities will be implemented under the CERCLA process and based in the established WRRP. The existing, accepted WRRP framework for quality assurance, sampling and analysis, and data management and WRRP programmatic resources will be used for execution of ORR Groundwater Program integrated monitoring and pre-RI efforts. Groundwater investigation, modeling, and technology development to be conducted under the Program will be integrated with WRRP baseline effectiveness and trend monitoring. An iterative process will be used to reduce plume uncertainties. Results will be used to identify interim measures and actions that may be warranted and support future groundwater decisions and actions.

A flowchart of ORR Groundwater Program strategy implementation is shown in Fig. 6.1. Program elements and interfaces shown in the figure are described below.

6.1.1 Off-site Groundwater Quality Assessment

A preliminary hazard ranking process of groundwater plumes across the ORR indicated the need to conduct investigations focusing on potential groundwater flow pathways that could lead off-site. Consequently, an Off-site Groundwater Quality Assessment has been selected as the first project to begin groundwater strategy implementation under the ORR Groundwater Program. It supports the strategy objective of identifying and addressing potential public health threats. Selection of this project aligns with results of plume and project ranking efforts (Appendices H and I). The Off-site Groundwater Quality Assessment will be used to determine if early actions for human health protection are needed and to prioritize Program focus areas.

This activity will include DQO-based sampling and analysis of off-site groundwater including residential wells and springs to determine if contaminants unique to the DOE Reservation are present and to determine if there is a potential public health risk from DOE contaminants off-site. An off-site seep/spring inventory is planned in downgradient areas (e.g., between Clinch and Tennessee Rivers) and USGS services may be utilized.

6.1.2 ORR Reservation-Wide Conceptual Model Investigations (pre-RI)

Data gaps have been identified for groundwater pathways within and potentially beyond the DOE site boundary (Table 5.2). Reaching the strategy objective of preventing unacceptable risk and groundwater degradation and restoring groundwater to beneficial use where practicable requires improved understanding of sources and their pathways. Carbonate bedrock zones were identified as the highest priority pathways of concern. The need to further characterize interior plumes was also identified. Results of the Off-site Groundwater Quality Assessment will be used to confirm or adjust ranking results presented in this strategy.

Candidate projects under this element of the ORR Groundwater Program include investigations and monitoring to improve groundwater conceptual models and reduce uncertainty regarding groundwater flow from source areas on the ORR to exit pathways leading off-site and from interior plumes.

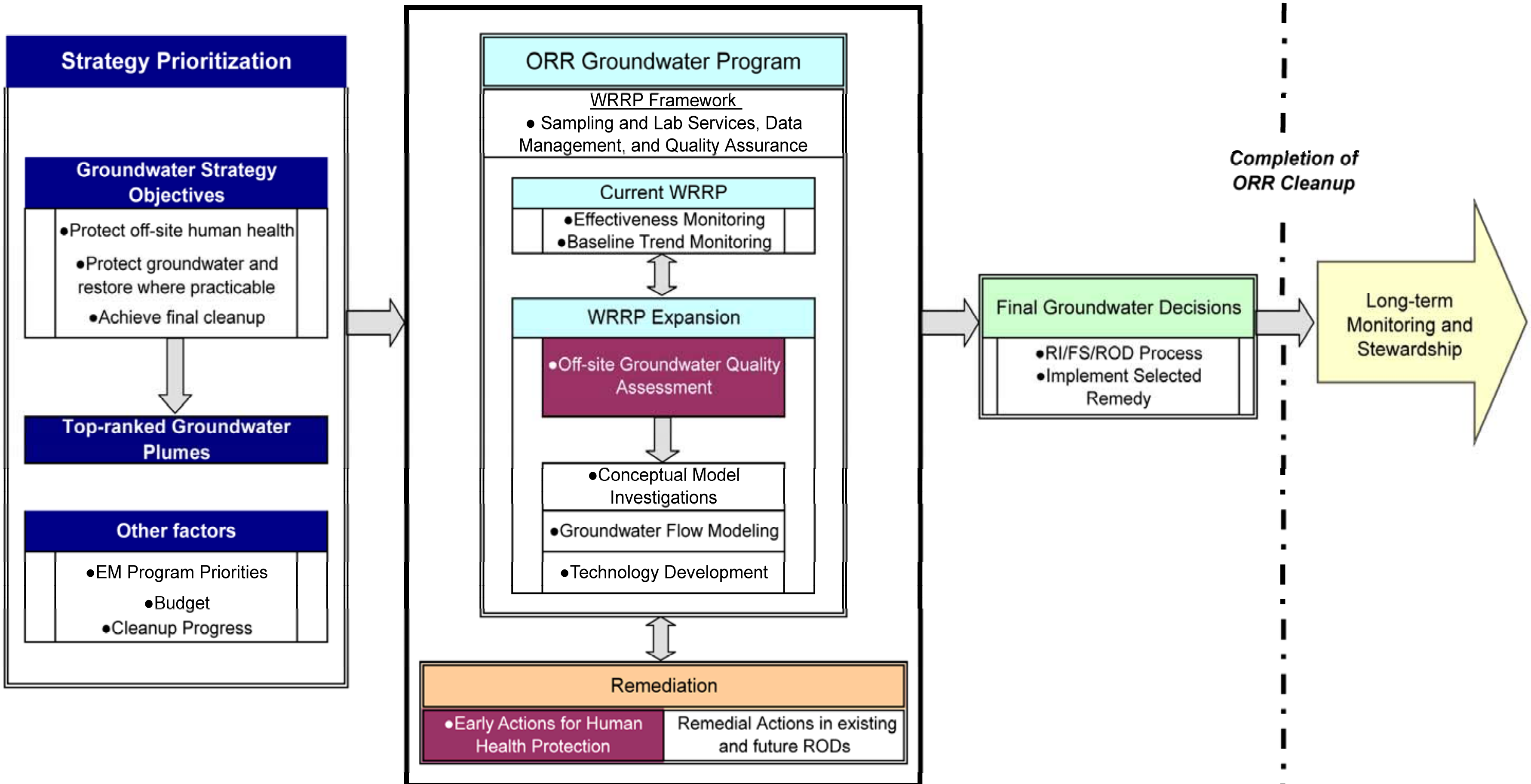

Fig. 6.1. ORR groundwater strategy implementation flowchart.

6.1.3 ORR Groundwater Flow Modeling

A candidate project under this element of the ORR Groundwater Program is assembling a groundwater modeling team consisting of local resources and recognized technical experts as advisors to begin creation of groundwater flow and contaminant transport models at scales appropriate to support ORR regional and local conceptual models. Numerous, local-scale groundwater modeling efforts have been conducted in the past and information gleaned from those models would be incorporated into the current generation models. The modeling would support and inform conceptual model enhancement, technology development, groundwater remediation, and final CERCLA decision-making.

- The task is envisioned to be a multi-year effort with iterative updates based on steadily improving input/calibration data and interfaces with other tasks. Regional extent of models would be defined and appropriate models would be selected. Input data needs would be defined to capitalize on previous RI data augmented with newer investigation results. Groundwater level information for off-site springs/seeps and wells and groundwater chemical indicators from the Off-site Groundwater Quality Assessment would be used.

- Early modeling efforts would include developing both conceptual and quantitative flow information to better define and delineate flow conditions for the various flow basins on the ORR. Creation of model domain(s) would be phased to attain overall goals [e.g., by selecting portions of the ORR with sufficient data to start model domain population (possible initial focus areas include the BV/MV/Clinch River area and BCV area from one Clinch River border to the other)]. Models would be developed with particular focus on potential off-site flow systems

6.1.4 Technology Development

Under the technology development element of the ORR Groundwater Program, candidate projects include:

- Providing a prioritization and planning interface to support planned TS projects to address chlorinated VOC plumes (ORNL 7000 Area VOC Plume Bioremediation and ETTP K-1401 Site DNAPL in fractured rock study). The ORR Groundwater Program would use results of these studies to develop criteria that may be applied to similar plumes on the ORR and support groundwater decision-making.

- Improvement of monitoring technology deployment and testing of additional in situ remedies. These projects would be incorporated with groundwater flow modeling to improve the confidence level in ongoing and long-term groundwater monitoring. This would be accomplished through use of statistical data analysis methods of existing and newly collected data combined with fate and transport models to develop probability-based monitoring criteria. The most reliable monitoring strategies would be established at LTM sites to support selected remedies. At selected locations, testing and demonstration of an LTM approach would be conducted (e.g., evaluation of MNA for chlorinated VOCs). LTM design may include focused monitoring in discrete zones at various frequencies over time tied to a calibrated model to demonstrate system response to climatic/water budget variables. A capability of system response prediction would be created based on the combination of empirical monitoring results and model calibration. Scale and contaminant transport/attenuation processes would be considered.

6.1.5 Identification of Groundwater Early Action / Remedial Actions

This element of the ORR Groundwater Program includes the identification of early groundwater actions deemed necessary to control contaminant migration from DOE sources to confirmed off-site pathways. If the Off-site Groundwater Quality Assessment and/or the results of pre-RI activities indicate contaminant migration to off-site locations is a concern, necessary follow-on actions (e.g., additional investigation, remedial action, alternative measures such as groundwater use restrictions) will be taken. This element also supports groundwater remedy planning for implementation under existing and future CERCLA decisions.

Potential remedial actions that may be identified include containment pump and treat or in situ methods for contaminant toxicity reduction or other source removal/treatment actions to minimize unacceptable further degradation of groundwater.

6.1.6 Groundwater Decision Process Interface

The final groundwater decisions at the ORR may include some remediation elements, some long-term contaminant containment elements, and LTM related to MNA. In some areas remediation of groundwater may be determined to be technically impracticable, which would require designation of areas where groundwater quality restoration is waived. Alternative measures, such as groundwater use restrictions and LTM, would be adopted. Work undertaken in the conceptual model investigations, groundwater modeling, technology development, and groundwater early actions/remedial actions will aid final groundwater ROD decision-makers. The work will also help identify interim measures and actions that may be warranted until final decisions are reached.

6.2 SEQUENCING

The initial plume and project ranking approach and results presented in this document will be reevaluated based on investigation findings. The ORR Groundwater Program will provide flexibility to adapt project sequencing and scopes based on plume characterization findings, cleanup progress, and changing priorities and budgets. Prioritization factors shown in Fig. 6.1 will be used for project sequencing:

- Groundwater strategy objectives.
- Top-ranked groundwater plumes.
- Other factors such as EM Program priorities, budget, and cleanup progress.

Figure 6.2 shows a general sequence of strategy implementation to meet groundwater strategy objectives. The Pathway ranking and Overall ranking results (Sect. 5.1.3) will be considered along with other prioritization factors to select projects.

- The initial focus of the ORR Groundwater Program will be on assessing potential off-site migration. The Pathway ranking based on Total Pathway Score will be used to rank groundwater plumes until exit pathway data gaps are filled. As uncertainties are reduced based on investigation findings, the plume scores will be adjusted and plumes and projects will be re-ranked.

- When the strategy focus switches to interior plumes, the Overall ranking based on Total Plume Score will be used to rank plumes. How resources are directed on interior plumes will be guided by groundwater investigation findings, plume conditions, ORR property end uses, and other considerations. Potential drivers for remediation of interior plumes include:

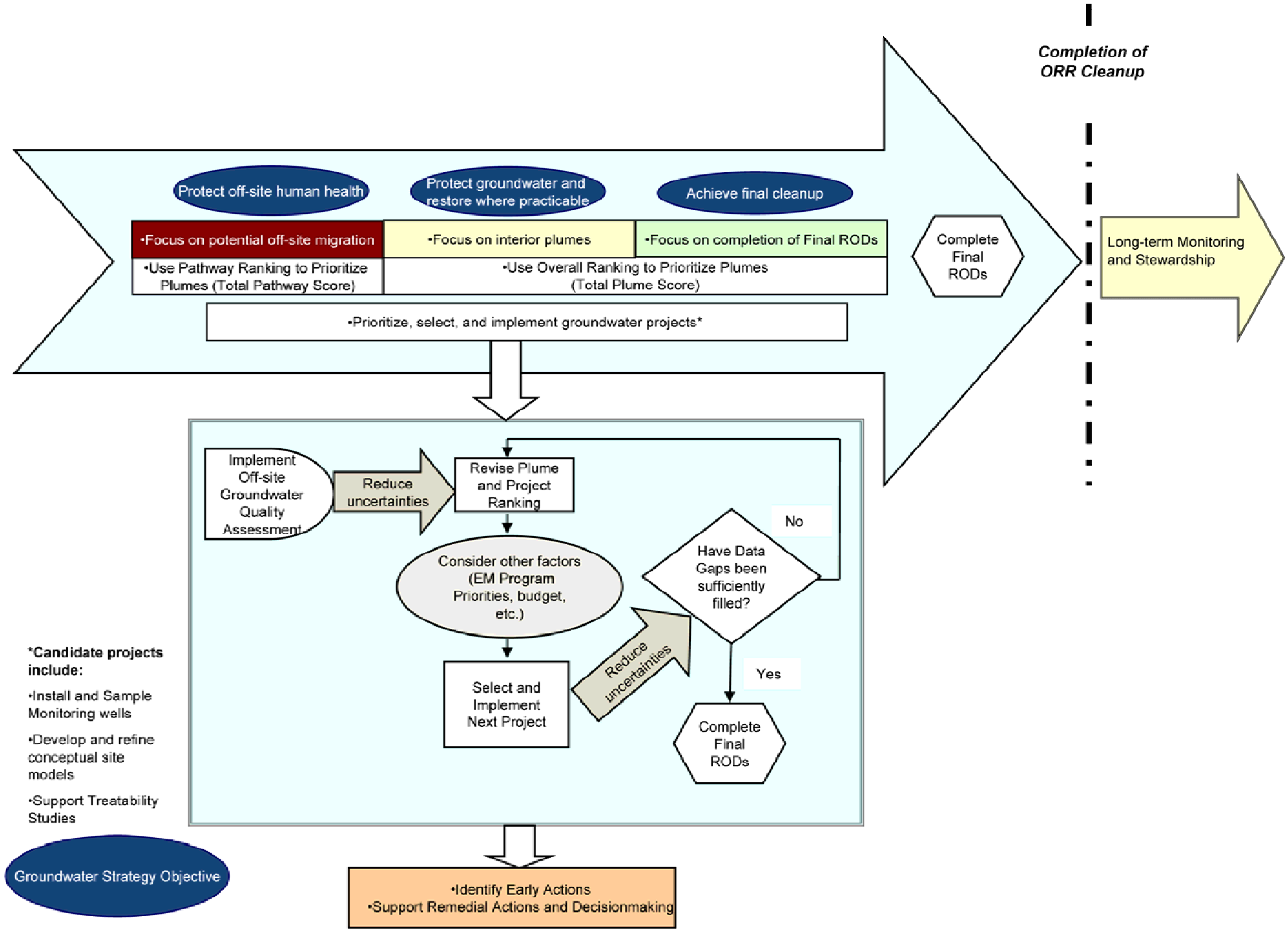

Fig. 6.2. General sequence of groundwater strategy implementation.

— Plume migration to off-site drinking water receptors.
— Plume discharge to nearby creeks.
— Plume migration into clean areas and further groundwater degradation.
— Plans for future property transfer from government ownership.
— Cost-benefits of remedial action that could reduce long-term stewardship costs.

When interior data gaps are filled, the focus will switch to filling any remaining data gaps needed to reach final groundwater decisions.

Completion of site cleanup and final RODs will be followed by LTM and stewardship. Once protective measures and remedial actions are completed, adequate monitoring of remaining contamination as well as the soundness of physical barriers and ICs must continue. The groundwater strategy focus will transition from characterization, remedy selection, pre-design support, and short-term evaluation of remedies, to long-term remedy evaluation and post-closure LTM.

Figure 6.3 shows the future CERCLA groundwater decisions in the current ORR lifecycle baseline. Annual funding for ongoing operation of groundwater collection, pump, and treat systems is budgeted in the lifecycle baseline. Consistent with initial ranking efforts of the Groundwater Strategy Team, an Off-site Groundwater Quality Assessment project is planned for FY 2014 through FY 2016 to assess potential off-site migration concerns. A project to design and construct a new water treatment system in the main plant area of Y-12 is budgeted over the next several years (Fig. 6.3) followed by system operation and the planned demolition of large former mercury use buildings at Y-12.

The ORR Groundwater Program will be responsible to recommend specific changes to the timing and scope of groundwater projects in the lifecycle baseline, including final ROD projects, as work proceeds. As characterization progress is made, potential changes will become better defined for incorporation in the lifecycle baseline and FFA milestone agreements. Examples of potential changes include:

- Deferring final ROD decisions in the main plant areas of ORNL (BV watershed) and Y-12 (UEFPC watershed) until completion of building D&D and remediation. Planned building demolition and soil removal activities at the sites will significantly change the site infrastructure. Building basements, sumps, and underground sewer and piping systems will be impacted and alter groundwater flow paths.

- Addressing contaminant flow from the S-3 Ponds area into the two adjacent CERCLA administrative watersheds (BCV and UEFPC) as a single project. Information from the field research site downgradient of the S-3 Ponds[7] can be utilized along with ORR Groundwater Program findings to collectively evaluate S-3 Ponds contamination.

[7] DOE-SC has been performing investigations at this field research site. Immobilization strategies and rates and mechanisms that control contaminant fate and transport have been studied.

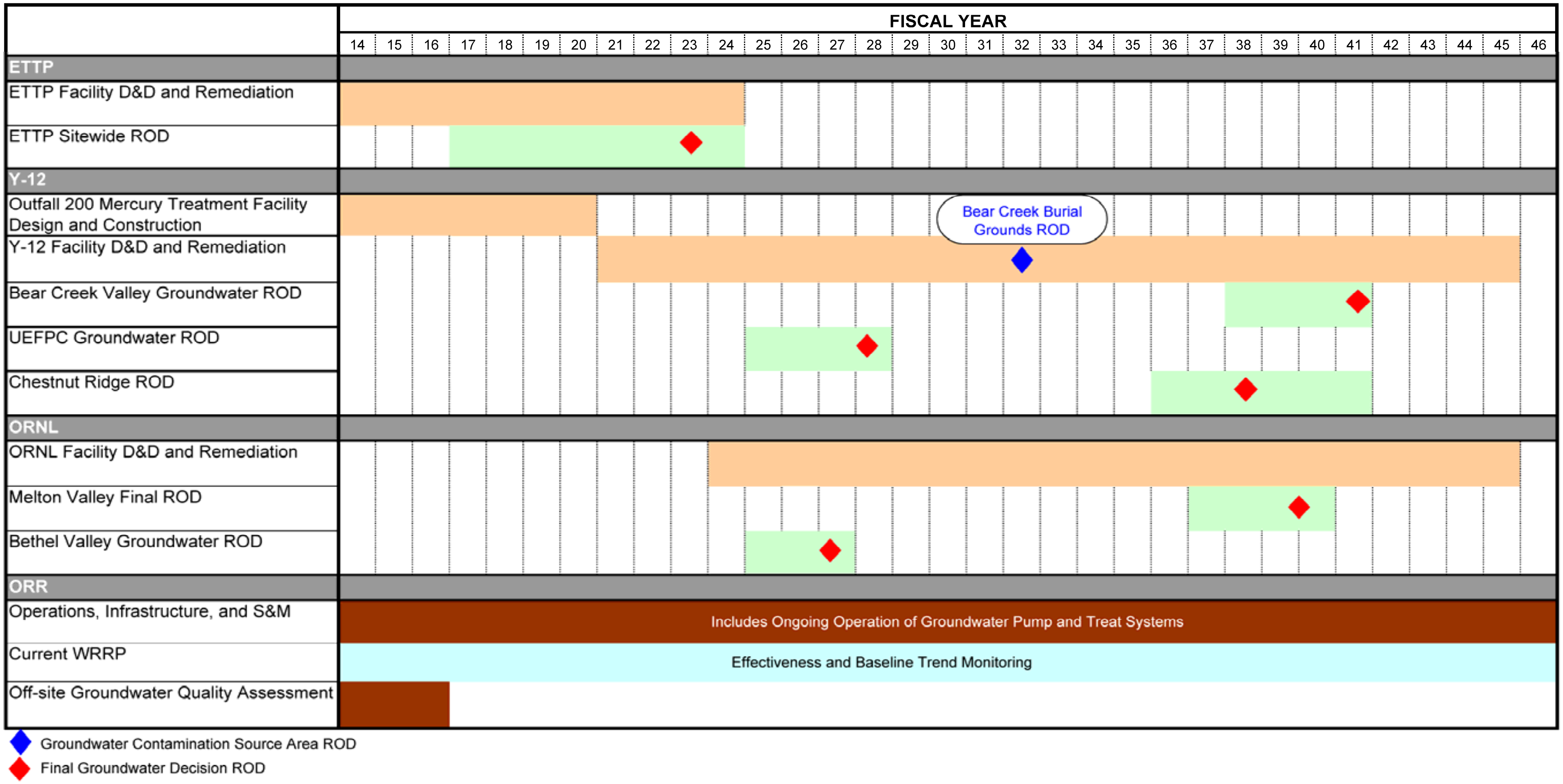

Fig. 6.3. Future CERCLA groundwater decisions in Current ORR Lifecycle Baseline.

6.2.1 Near-term Strategy Steps

Strategy steps in the near-term are as follows:

1. **Set up an ORR Groundwater Program to implement the strategy and budget annual funding for the Program.**

    - Expand the existing WRRP scope to implement the strategy, starting with the Off-site Groundwater Quality Assessment project as the focus for the first 3 years (FY 2014 through FY 2016).

    - Identify long-lead projects and estimate costs to support funding needs outside of the annual funding to be budgeted for the ORR Groundwater Program (e.g., deep monitoring well installation, in-field remediation).

2. **Implement an Off-site Groundwater Quality Assessment as the first strategy project under the Program.** As a tri-party effort, use a DQO-based approach to assess off-site groundwater quality to ensure there is no threat to human health. This effort involves the following:

    - Hold DQO Workshops:

        — Identify a qualified team and prepare a DQO Scoping Package.

        — Define the region included, sample locations, analytes, detection levels, sampling frequencies, statistical requirements, decision rules, etc. Develop a Sampling and Analysis Plan (SAP) for implementation within the WRRP framework (WRRP/Sample Management Office sampling, lab services, data validation, and archiving).

    - Obtain regulator approval of the SAP.

    - Develop a cost estimate for monitoring.

    - Perform the monitoring.

    - Evaluate the results and prepare an assessment report.

    - Take necessary follow-on actions (e.g., additional investigation, remedial action, groundwater use restrictions).

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7. RECOMMENDATIONS

Recommendations for implementing the ORR Groundwater Strategy are provided below in program, ongoing groundwater treatment, and best management practice categories.

7.1 PROGRAM

Recommendations for an ORR Groundwater Program and potential changes to DOE's lifecycle baseline are as follows.

7.1.1 ORR Groundwater Program

Recommendation 1: Set up an ORR Groundwater Program to implement the strategy and budget annual funding for the Program. The focus for the first three years of the Program will be implementation of an Off-site Groundwater Quality Assessment project (Recommendation 2). Data gaps have been identified for groundwater pathways within and potentially beyond the DOE site boundary. In order to meet groundwater strategy objectives, improved understanding of sources and their pathways is needed. Setting up an ongoing ORR Groundwater Program is recommended to implement the groundwater strategy and to support ongoing characterization efforts. A modest change to the DOE lifecycle baseline is needed to budget annual funding for the Program.

The ORR Groundwater Program will be used to systematically prioritize and investigate groundwater plumes and data gaps. Prioritization decisions and resource allocation for projects to be implemented under the Program will follow FFA and EM Program budget development protocols.

- Many data gaps exist because little groundwater investigation work has been done since the 1990s time frame when most watershed-scale RIs to address contaminant sources were completed. Groundwater investigation, groundwater modeling, and technology development to be conducted under the ORR Groundwater Program will improve understanding of plume sources and migration and help achieve groundwater strategy objectives.

- A list of candidate projects was identified by the Groundwater Strategy Team to investigate groundwater pathways within and potentially beyond the DOE site boundary. The ORR Groundwater Program will prioritize these and other projects for implementation. The Program will develop project scopes for consideration and prioritization, which will improve long-term planning and potentially reduce overall cost.

- ORR Groundwater Program activities will be implemented under the CERCLA process and based in the established WRRP. This cohesive approach builds upon an existing, accepted framework and optimizes resources to achieve multiple purposes over the lifecycle of remediation efforts.

- Groundwater investigation, modeling, and technology development to be conducted under the ORR Groundwater Program will be integrated with WRRP baseline effectiveness and trend monitoring. An iterative process will be used to reduce plume uncertainties. Results will be used to identify interim measures and actions that may be warranted and support future groundwater decisions and remediation.

Recommendation 2: Beginning in FY 2014 implement an Off-site Groundwater Quality Assessment as a tri-party effort. Take early actions as necessary to protect against any identified imminent threat. Pursuing this action as the first project under the strategy and the ORR Groundwater Program is consistent with results of Groundwater Strategy Team plume and project ranking efforts. The project prioritizes early resources toward assessing the potential threat of off-site contamination. A DQO-based approach will be used to sample and analyze off-site groundwater. Depending on the results and identified follow-on actions, additional funding may be required.

Recommendation 3: Implement ORR-wide strategy efforts that are applicable to multiple similar groundwater plumes across the ORR and can streamline and improve preparedness for groundwater remediation and final groundwater decisions. Development of project scopes to implement ORR-wide strategy efforts that can be prioritized to optimize use of ORR Groundwater Program funding is recommended. Examples of ORR-wide strategy efforts are as follows.

- Reach early tri-party consensus on data and process needs for final groundwater decisions to ensure that ongoing characterization, modeling, and technology demonstration activities are targeted and effective. Develop guidelines that account for ORR-specific challenges, promote consistency, and facilitate a streamlined decision-making process.

- Develop and maintain an ORR-wide regional flow model to ensure a single, regional, calibrated model exists to support groundwater characterization, decision-making, and remediation. Develop and refine small-scale models as needed using calibrated flows from the regional model.

- Plan and interface with technology demonstrations to increase certainty that selected groundwater remedies are implementable and effective. To optimize resources, sequence and design the demonstrations with consideration of applicability to other ORR groundwater plumes.

Recommendation 4: Utilizing a portion of the annual funding to be budgeted for the ORR Groundwater Program, continue to evaluate and track groundwater use at properties adjacent to and downgradient of the ORR. Set up a DOE interface with TDEC to allow DOE to be notified of new well installation activity. If potential unacceptable risk is identified, consider additional groundwater use restrictions/policies for interim protectiveness until final decisions are reached. The WRRP tracks and reviews ICs for CERCLA decisions annually in the RER and in CERCLA FYRs. Tracking and documentation of groundwater uses and restrictions that are not part of a CERCLA decision can be improved under the ORR Groundwater Program. In addition to residential users, groundwater users that pump large volumes of groundwater could induce deep flow pathways for contaminant migration under the Clinch River. Communications should be maintained with off-site groundwater users as necessary to remain cognizant of planned usage that may pose an unacceptable risk.

7.2 ONGOING GROUNDWATER TREATMENT

Recommendation 5: Continue implementation of effective ongoing groundwater treatment actions, including necessary EM interfaces with ORNL (Office of Science) and Y-12 (NNSA) regarding treatment facility and infrastructure availability and changes. Ongoing operation of groundwater collection and treatment systems at ORR sites will continue to be key to contaminant reduction and plume mitigation. Continued operations are dependent on the presence and availability of site infrastructure (e.g., building sumps and process waste lines) and treatment facilities. Awareness of facility changes and site modernization plans that could impact system operations needs to be maintained.

7.3 BEST MANAGEMENT PRACTICE

Recommendation 6: Utilize findings, successes, and lessons learned from other organizations and sites to inform ORR Groundwater Program efforts, such as DOE-SC investigations and groundwater decisions at other NPL sites. Identify specific applications to the ORR groundwater strategy in project documentation as appropriate. For example, findings of DOE-SC field research near the S-3 Ponds can be incorporated in DQO packages for BCV plumes. Successes and failures at other NPL sites can be used to guide the process for ORR plume evaluations.

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Groundwater Strategy for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee

Volume 2. Appendices

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CONTENTS

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APPENDIX A
ORR GROUNDWATER STRATEGY PROJECT CHARTER

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CONTENTS

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ACRONYMS

BCV	Bear Creek Valley
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
FY	fiscal year
MV	Melton Valley
ORR	Oak Ridge Reservation
RSI	Restoration Services, Inc.
SAIC	Science Applications International Corporation
TDEC	Tennessee Department of Environment and Conservation
UCOR	URS / CH2M Oak Ridge LLC

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OAK RIDGE RESERVATION GROUNDWATER STRATEGY PROJECT CHARTER

A.1 OBJECTIVE

The objective of this project is to develop an interagency strategic approach to identify, manage, and pursue any potential on-site and off-site groundwater public health threats and to protect and restore the U.S. Department of Energy (DOE)-Oak Ridge Reservation (ORR) groundwater resources to beneficial use.

A.2 OVERVIEW

A series of facilitated interagency workshops will be conducted to discuss the objective stated above. The workshops will focus on the following strategic approaches:

- Delineate and possibly enhance ORR boundary monitoring.
- Define groundwater flow basins and contaminant boundaries within each basin and any deep flowpaths that might impact possible off-site migration.
- Establish additional groundwater use restrictions/policies and frame an alternative strategy if these restrictions/policies prove unavailable.
- Pursue selected groundwater remedial actions when practicable, including:
    - Identify any groundwater-related DOE/Tennessee Department of Environment and Conservation (TDEC) “Natural Resource Damage” sites and develop a Comprehensive Environmental Response, Compensation, and Liability Act of 1980 cleanup strategy.
    - Identify an early action strategy to address unacceptable migration and exposure of contaminated groundwater both on- and off-site.
    - Develop a strategy for final groundwater response actions.

The discussions and areas of consensus will be documented in a final report that will include recommendations on near-term steps that can be taken with funds that are currently budgeted for fiscal year (FY) 2013, FY 2014, FY 2015, and FY 2016. Quarterly progress updates, including the identification of policy issues, will be provided to the ORR Supervisory Management Team.

A.3 WORK TASKS

A.3.1 PROJECT TEAM MEETINGS

A meeting will be held with the project team at the initiation of the project to review the project approach and schedule, conduct preliminary scoping for each workshop, and identify potential participants. Prior to each workshop, a project team meeting will be held to develop the workshop agenda, finalize workshop attendees, and discuss workshop materials. Quarterly project team meetings will be conducted to review progress and jointly prepare/update presentations for the supervisory team meetings. Project team meetings will also be held to support preparation and review of the final ORR Groundwater Strategy document.

A.3.2 WORKSHOP PREPARATION

The following materials will be prepared for the workshops:

- Summary of off-site DOE groundwater monitoring locations/data summaries.
- Preliminary identification of ORR boundary monitoring data gaps.
- Identification of existing data useful to define contaminant plume geometry within each watershed to establish its position and movement within the groundwater basin, both on and adjacent to DOE-ORR.
- Quantitative presentation from TDEC on their off-site groundwater monitoring.
- Summary of current DOE off-site groundwater use restrictions, including alternate water supply and private well use restrictions.
- Preliminary identification of additional potential groundwater use restrictions, including groundwater classification and well notification requirements.
- Preliminary identification/data packages to support evaluation of potential groundwater remedial actions.
- Strategies for verifying groundwater basin areas on-site/off-site and shallow/deep groundwater flowpaths. Evaluation of priorities and funding needs for basin delineation activities.
- Updated status of project costs and forecasted project budget.

A.3.3 CONDUCT WORKSHOPS

A series of small, facilitated workshops attended by a limited number of DOE, TDEC, U.S. Environmental Protection Agency (EPA), and contractor representatives will be conducted for collaborative discussions on the identified strategy approaches. Workshop materials prepared in the previous task will be distributed to workshop attendees in advance. Workshop discussions, including areas of agreement and policy issues that require elevation, will be documented in meeting notes. The

need for supplemental workshops on the same, or an additional, strategy approach will also be discussed at the workshops. One workshop will be conducted for each the following four strategic approaches:

1. **Enhance ORR boundary monitoring** – reduce uncertainties in shallow and deep flow pathways from primary source areas (Bear Creek Valley [BCV] Burial Grounds, Melton Valley [MV] Burial Grounds, etc.).

2. **Define groundwater flow basins and contaminant boundaries within each basin** – understand where groundwater contamination begins and ends to be in a better position to address risk (e.g., Bear Creek/Grassy Creek divide area, White Oak Creek/Raccoon Creek divide area, Black Oak Ridge areas adjacent to the East Tennessee Technology Park (ETTP) site, and potential Clinch River underflow areas). The project team will attempt to determine contamination within each watershed (i.e., basin) and if there is a deep flowpath that might impact possible off-site migration.

3. **Establish additional groundwater use restrictions/policies** – evaluate the potential role of additional groundwater use restrictions and policy decisions such as reclassification of groundwater use. Also, determine the magnitude and scope of groundwater restoration if these policies/restrictions are unavailable and establish a watershed priority groundwater restoration sequence in each of the DOE-ORR groundwater basins.

4. **Pursue selected groundwater remedial actions when practicable** – identify and prioritize early opportunities to contain/control and, where possible, remediate contaminated groundwater. Identify groundwater plumes currently preventing attainment of Government Performance and Results Act of 1993 goals.

An additional two workshops (to the above four) are assumed to be required as follow-on to issues or supplemental approaches identified at the initial workshops.

A.3.4 DOCUMENTATION

Discussions and areas of consensus from the workshops will be summarized in a final report that will include recommendations on an overarching strategy to address contaminated groundwater across the DOE-ORR, including any near-term steps that can be taken with funds that are currently budgeted for FYs 2013, 2014, 2015, and 2016. An initial draft report will be prepared for review by the project team. Project team comments will be incorporated into a D1 ORR Groundwater Strategy report that will be transmitted to the regulators to meet the September 30, 2013, ORR Groundwater Strategy Federal Facility Agreement Appendix E milestone. A summary presentation will also be prepared for the Supervisory Management Team to support their annual prioritization of ORR Environmental Management projects.

A.4 PROJECT TEAM

Following is a list of key project team members and their affiliations:

- Elizabeth Phillips / DOE Lead

- Bill McMillan and David Adler / DOE Sponsors

- Carl Froede, Jr. and Bill O'Steen / EPA
- Randy Young, Gareth Davies, and Wesley White / TDEC
- Dan Goode, USGS – Oak Ridge Reservation Site-Specific Advisory Board Technical Support
- Lynn Sims / Restoration Services, Inc. – URS / CH2M Oak Ridge LLC–Restoration Services Inc. (UCOR/RSI) – Project Manager
- Dick Ketelle / UCOR/RSI – Subject Matter Expert
- Craig Rightmire / UCOR/RSI – Technical Support
- Holly Clancy / UCOR/RSI – Document Lead
- Samantha Pack / UCOR–Science Applications International Corporation (UCOR/SAIC) – Workshop Facilitator
- Bob Gelinas, Kevin Jago, and Allen Motley / UCOR/SAIC – Watershed Technical Support

A.5 SCHEDULE

The schedule for project activities follows:

- Project Initiation – October 1, 2012
- Project Team Kickoff – October 23, 2012
- Preparation of Workshop Materials – November 2012 through May 2013
- Workshops: January 29, 2013 (ORR and BCV); February 26, 2013 (Upper East Fork Poplar Creek, Chestnut Ridge, and ETTP); April 9, 2013 (Bethel Valley and MV); May 2, 2013 (Groundwater Plumes and Project Ranking); July 9, 2013 (Select Early Action Project); and August 6, 2013 (Groundwater Use Restrictions).
- Supervisory Management Team Briefings – Quarterly
- D1 ORR Groundwater Strategy – September 30, 2013
- Construction Start – September 30, 2014

APPENDIX B
BEAR CREEK VALLEY SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

ACRONYMS

AWQC	Ambient Water Quality Criteria
BCBG	Bear Creek Burial Grounds
BCK	Bear Creek kilometer
BCV	Bear Creek Valley
bgs	below ground surface
BYBY	Boneyard/Burnyard
COC	chemical of concern
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
DU	depleted uranium
FYR	Five-Year Review
HCDA	Hazardous Chemical Disposal Area
IP	integration point
MCL	maximum contaminant level
μg/L	micrograms per liter
NT	Northern Tributary
OLF	Oil Landfarm
ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
pCi/L	picocuries per liter
RCRA	Resource Conservation and Recovery Act of 1976
RER	remediation effectiveness report
RI	remedial investigation
ROD	Record of Decision
SL	Sanitary Landfill
TCE	trichloroethene
VC	vinyl chloride
VOC	volatile organic compound
Y-12 Complex	Y-12 National Security Complex

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B.1 INTRODUCTION

This Appendix provides a summary of the conceptual model for the Bear Creek Valley (BCV) Watershed, located in the central portion of the Oak Ridge Reservation (ORR), based on the available data and the understanding of the hydrogeologic framework at the time of data collection. The following sections provide a chronology of events associated with the BCV Watershed, the primary groundwater contaminant sources identified in the watershed, the geology and hydrology of the watershed, and summaries of the source area conceptual models, including discussions of key data gaps in the individual source area conceptual models.

BCV was selected as the test case for the first Groundwater Strategy Workshop held in January 2013. Numerous oversize figures depicting contaminant plume configurations, time series trends, and geologic conditions were developed for the Workshop to demonstrate the amount of information and analysis that was available for the BCV conceptual model. These figures are reproduced in this document at a smaller scale (11-in. by 17-in. format) than in the Workshop but are provided at full-scale in electronic format on CDs provided at the end of this document.

B.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH THE BCV WATERSHED

Table B.1 provides a chronology of historical operations and relevant events related to groundwater contaminant plumes for the BCV Watershed.

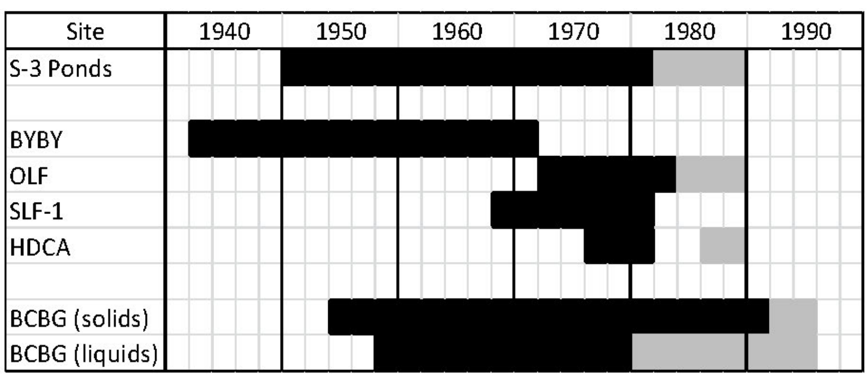
Table B.1. Chronology of events associated with the BCV Watershed

Event	Date
The Bear Creek Watershed disposal areas receive operational wastes from the Y-12 Complex and other DOE facilities (see Fig. B.1).	1943 – 1993
Sanitary Landfill 1 is closed under Tennessee Solid Waste Management Requirements.	1985
The S-3 Site is capped and closed under RCRA requirements.	1988
The OLF is capped and closed under RCRA requirements.	1990
BCBG areas, Walk-in Pits North and South, and Oil Retention Ponds 1 and 2 are closed and capped. BCBGs A-North, A-South, C-West, and Walk-in-Pits North and South are closed under RCRA requirements and are maintained under RCRA post-closure requirements.	1989 – 1994
The ORR is added to the National Priorities List as a Superfund Site.	November 21, 1989
TDEC issues RCRA Post-Closure Permit TNHW-087 for the Bear Creek Hydrogeologic Regime (Former S-3 Site).	September 30, 1991
An FFA is established between DOE, EPA, and TDEC.	January 1, 1992
An Agreed Order is signed between TDEC and DOE for corrective actions at former RCRA-regulated TSD units in the Bear Creek Watershed to be performed under CERCLA as the prime regulatory driver with post-closure care and monitoring to be conducted under RCRA (S-3 Site, BCBG, and OLF).	April 6, 1993
The OLF is added to RCRA Post-Closure Permit TNHW-087 for the Bear Creek Watershed by Class 3 Modification.	June 30, 1995

Table B.1. Chronology of events associated with the Bear Creek Watershed (cont.)

Event	Date
BCBGs (A-North, A-South, C-West, and Walk-in Pits North and South) are added to RCRA Post-Closure Permit TNHW-087 for the Bear Creek Watershed by Class 3 Modifications.	September 30, 1991 – September 12, 1995
DOE adopts the Watershed approach to CERCLA decision-making.	1996
The Final Bear Creek Watershed RI is issued.	1997
S-3 Pathways 1 and 2 action initiated (as technology demonstration project).	November 1997
The EMWMF ROD is signed by the FFA parties (separate, single-project action).	November 2, 1999
The Bear Creek Watershed Phase I ROD (DOE, 2000) is signed by the FFA parties.	June 16, 2000
The OLF Soils Containment Pad remedial action is complete.	July 16, 2001
EMWMF operations begin.	May 2002
The BCBG Unit D-East (cover repair and revegetation) action is complete.	May 9, 2003
The BYBY remedial action is complete.	January 12, 2004
The S-3 Site Tributary Interception (Pathways 1 and 2) removal action system is discontinued.	June 20, 2007
The 2011 CERCLA Five-Year Review finds that the initial actions under the Bear Creek Phase I ROD at S-3 Pathways 3 and BYBY have not been successful at reducing uranium mass flux at the Bear Creek exit point (BCK 9.2).	June 2012

BCBG = Bear Creek Burial Ground.
BCK = Bear Creek kilometer.
BYBY = Boneyard/Burnyard.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U.S. Department of Energy.
EMWMF = Environmental Management Waste Management Facility.
EPA = U.S. Environmental Protection Agency.
FFA = Federal Facility Agreement.
ORR = Oak Ridge Reservation.
OLF = Oil Landfarm.
RCRA = Resource Conservation and Recovery Act of 1976.
RI = remedial investigation.
ROD = Record of Decision.
TDEC = Tennessee Department of Environment and Conservation.
TSD = treatment, storage, and disposal.
Y-12 Complex = Y-12 National Security Complex.



Black shading = active waste operations; Gray shading = cessation of waste operations to unit closure

Fig. B.1. Schedule of historical waste operations in Bear Creek Valley.

B.1.2 PRIMARY CONTAMINANT SOURCES IN BCV

Figures B.2 through B.4 show the waste disposal sources in the BCV, moving from a large- scale view (Fig. B.2) to a more detailed scale (Fig. B.4). The sources include:

- Source Area 1 – S-3 Ponds.
- Source Area 2 – Boneyard/Burnyard (BYBY) [primary source removed in 2004 but residual remains], Oil Landfarm (OLF), Sanitary Landfill 1 (SL-1), and Hazardous Chemical Disposal Area (HCDA).
- Source Area 3 – Bear Creek Burial Grounds (BCBG).

Although the releases from the various sources have migrated away from their primary source areas and have comingled over the years, it is possible to define six key secondary groundwater sources/plumes (Table B.2 and Fig. B.5).

Detailed groundwater chemicals of concern (COCs) are listed in attached tables for the three individual source areas. The primary groundwater COCs that define plumes in the valley are:

- Nitrate.
- Uranium (alpha).
- Beta emitters (technecium-99 [^{99}Tc] and U decay products).
- Volatile organic compounds (VOCs) [tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC)].
- Cadmium (ecological).

The information contained within this conceptual model summary document relies upon several primary documents including the BCV watershed-scale remedial investigation [RI] (DOE 1996a; DOE 1996b; DOE 1996c; DOE 1996d; DOE 1996e; DOE 1996f); groundwater monitoring reports (Elvado 2009a; Elvado 2009b; Elvado 2009c; Elvado 2009d; Elvado 2009e; Elvado 2011; Elvado 2012); feasibility study for BCV (DOE 1997a); BCV Treatability Study (DOE 1997b); and the Remediation Effectiveness Report [RER] (DOE 2012; DOE 2013).

B.1.3 GEOLOGY AND HYDROLOGY

The hydrogeology of the valley dictates contaminant flowpaths. The strike of geologic units is southwest–northeast through the valley with low-conductivity, shale-dominated units of the Conasauga Group in the northern portions of the valley and the Knox Group/Maynardville Limestone in the central/southern portion of the valley underlying Bear Creek (Fig. B.2). Bedrock formations dip to the southwest at about 45 deg (Fig. B.6). The Maynardville Limestone represents the lowest topographical elevations in the valley. In the hydrogeologic framework for the ORR, the shale-dominated formations of the Conasauga Group below the Maynardville Limestone are collectively considered as aquitards. The Maynardville Limestone and Knox Group dolostone formations are considered as aquifers with much higher aggregate groundwater flow rates due to highly interconnected, solutionally enlarged fracture systems.

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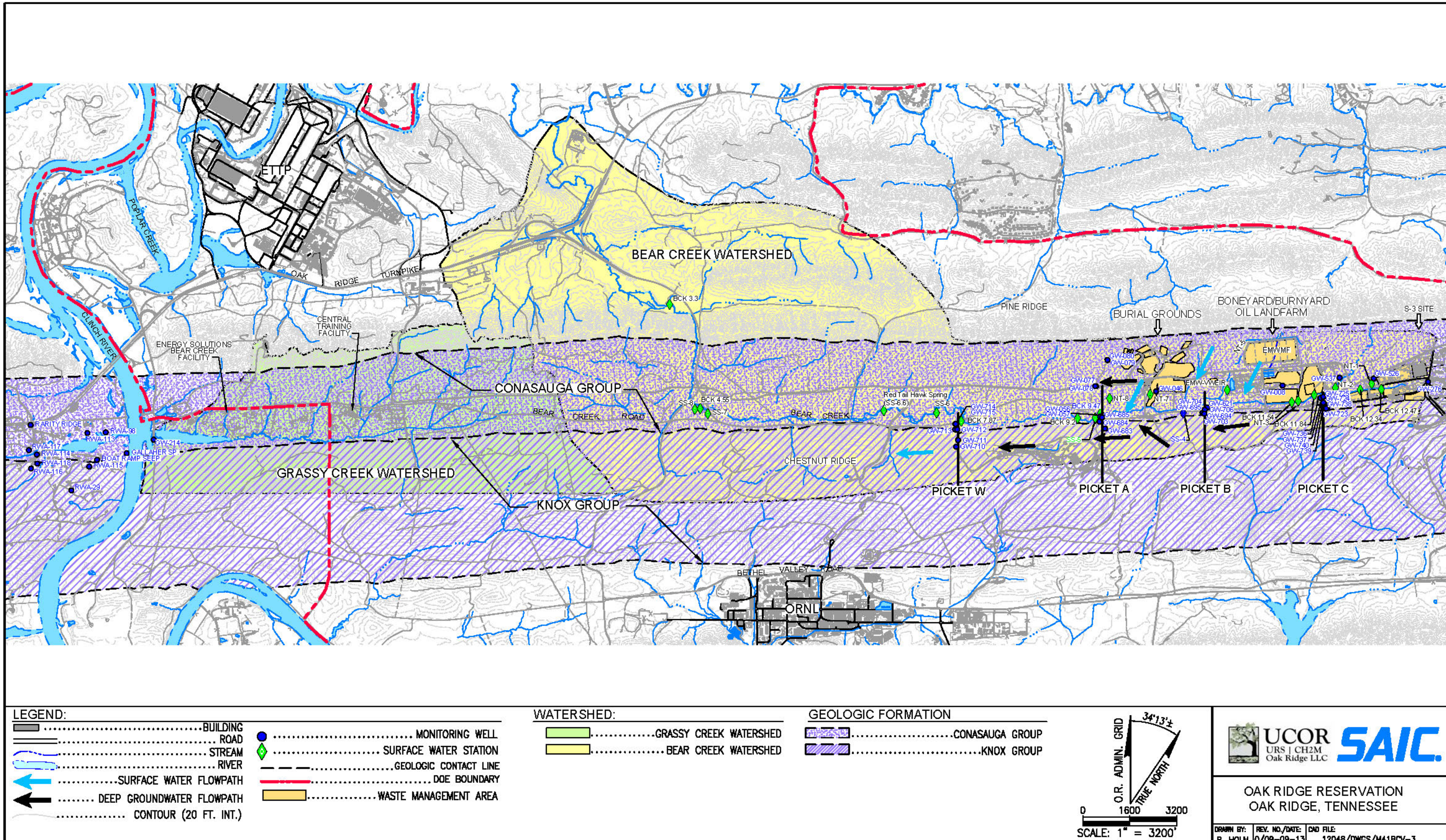

Fig. B.2. Bear Creek Valley Watershed and subsurface geology.

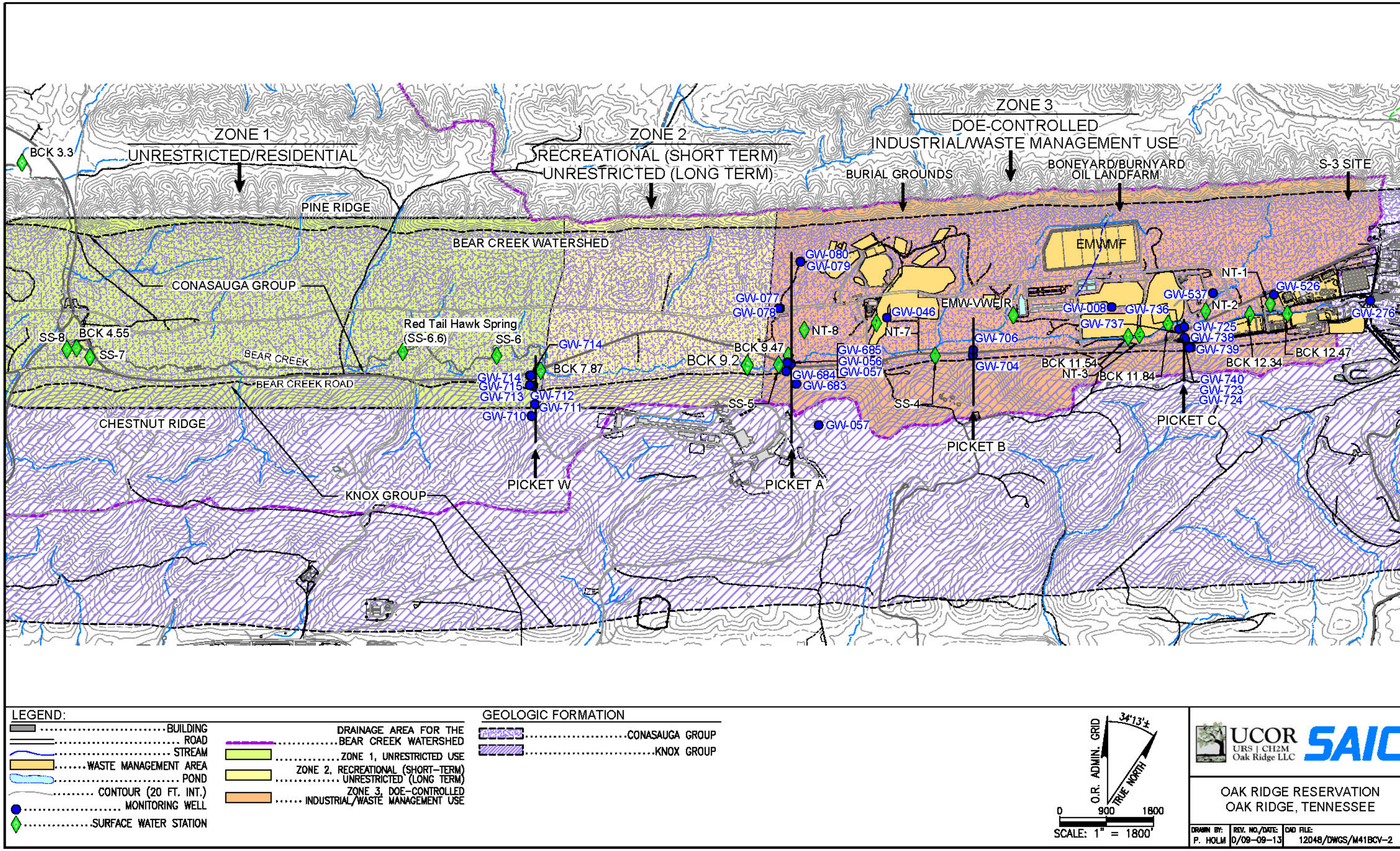

Fig. B.3. Waste management area and Record of Decision zones in Bear Creek Valley.

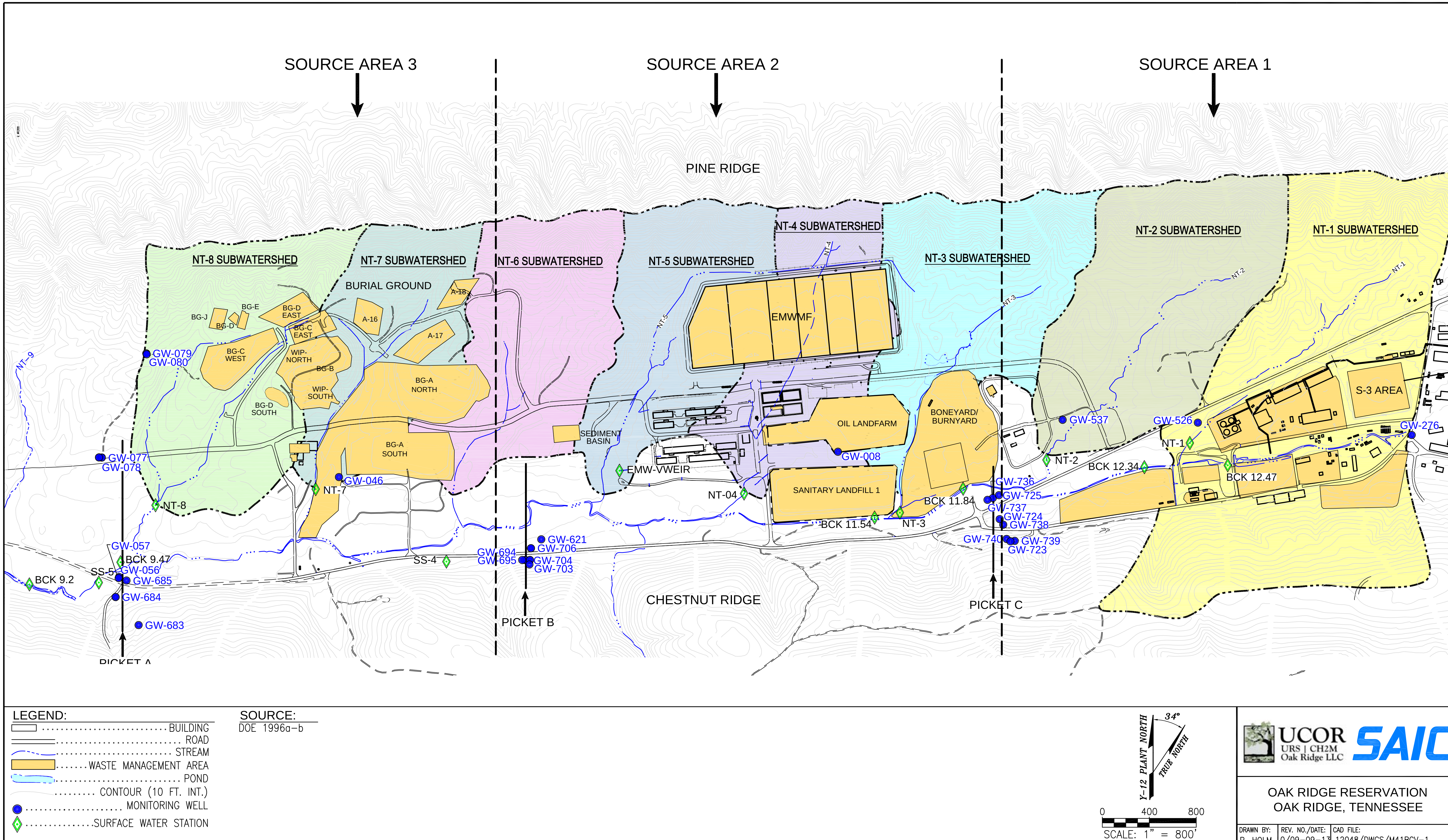

Fig. B.4. Contaminant source areas in Bear Creek Valley.

Table B.2. Groundwater plumes in Bear Creek Valley

Source area	Plume No.	Description
S-3 Pond	BCV-1a	S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3)
	BCV-1b	S-3 Deep nitrate in Maynardville Limestone
OLF, BYBY, and SL	BCV-2	Uranium in the Maynardville Limestone
	BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky Shale
Bear Creek Burial Grounds	BCV-4	BG-A Shallow/deep (DNAPL) VOCs in Nolichucky Shale
	BCV-5	BG-C West Shallow VOCs in Nolichucky Shale
	BCV-6	Various near-surface uranium signatures in Nolichucky Shale

BCV = Bear Creek Valley.
BG = Burial Ground.
BYBY = Boneyard/Burnyard.
DNAPL = dense non-aqueous phase liquid.
HCDA = Hazardous Chemical Disposal Area.
OLF = Oil Landfill.
SL = Sanitary Landfill.
VOC = volatile organic compound.

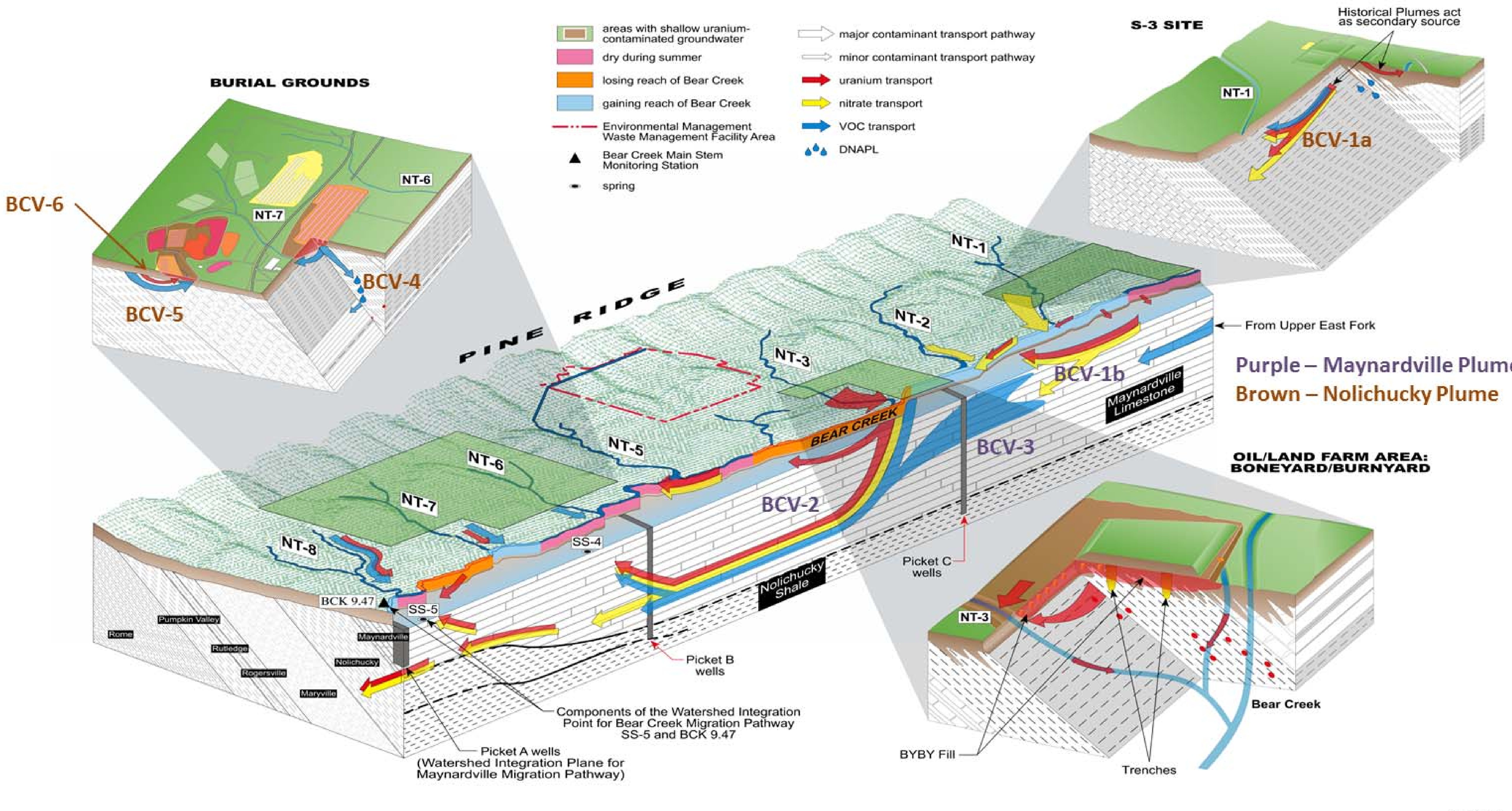

Fig. B.5. Conceptual model and plume identification for Bear Creek Valley (adapted from DOE 1996b).

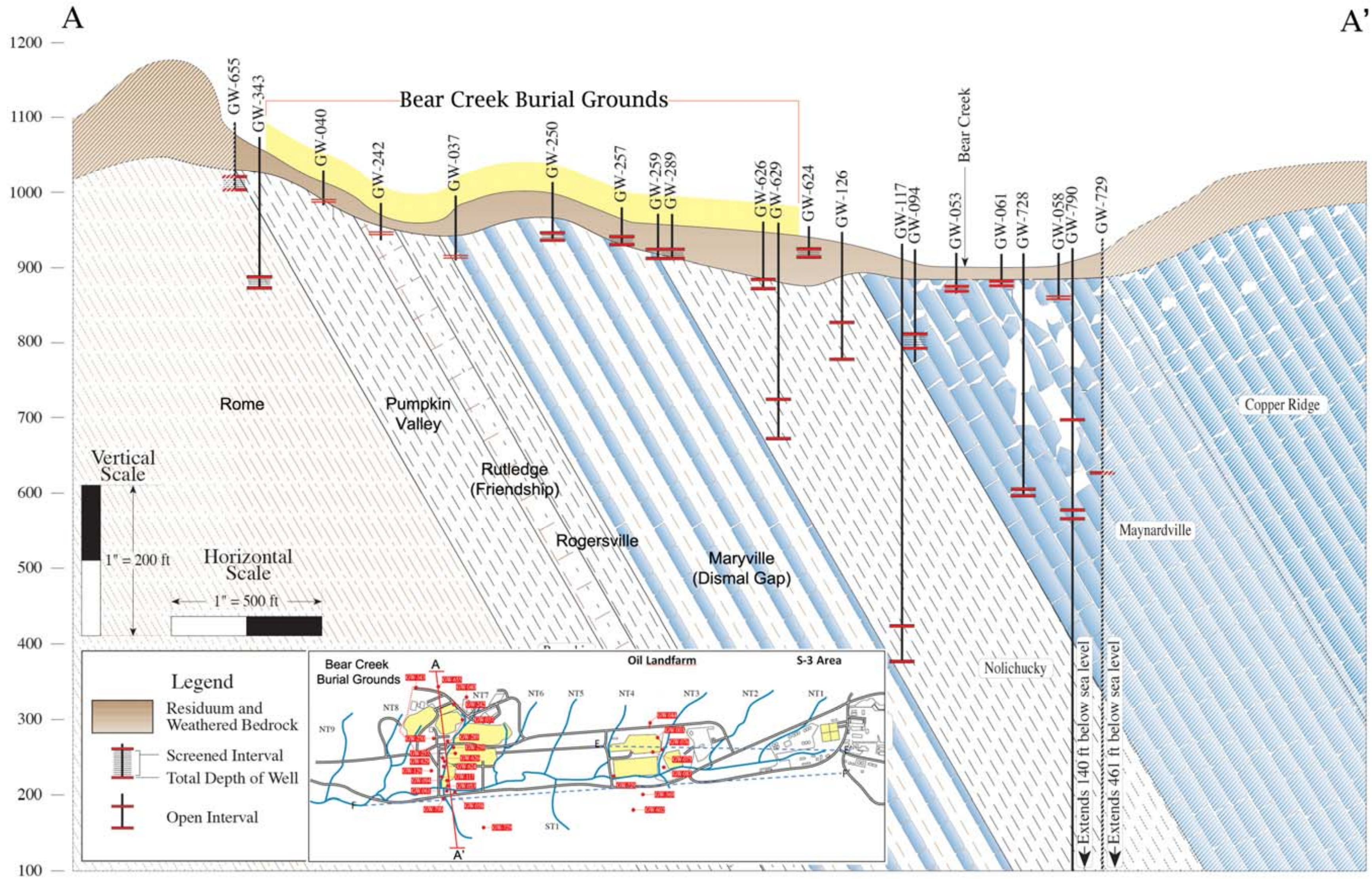

Fig. B.6. Strike-perpendicular conceptual cross-section of Bear Creek Valley geology.

The waste source areas are located in the Nolichucky Shale with a portion of the BCBG overlying the Maryville Shale. Shallow groundwater is the principal mechanism and pathway for release of contaminants from the northern portion of the valley (however, the large plumes from the S-3 Site have moved deep into the Nolichucky and there is uncertainty related to their flowpaths at depth). Contaminants travel via short pathways (primarily interconnected fracture networks) in the shallow groundwater to be discharged into tributaries of, and directly to, Bear Creek. Around 95% of rainfall recharge to the shale units flows to and through the north tributaries into Bear Creek, and exits the waste area portion of the valley at Bear Creek kilometer (BCK) 9.2, and thus BCK 9.2 is referred to as the integration point (IP). Both in the Nolichucky Shale and the Maynardville Limestone, there is a great deal of interaction between the shallow groundwater and the surface water (Fig. B.7), resulting in gaining and losing reaches along streams (Fig. B.8). Appendix C ("Characterization of Hydrogeologic Setting") of the BCV RI (DOE 1996a; DOE 1996b; DOE 1996c; DOE 1996d; DOE 1996e; DOE 1996f) presents detailed information of the hydrogeologic and hydrology framework of the BCV. There is a key uncertainty in BCV associated with uranium migration and the losing reach of Bear Creek in the BYBY area.

Historic sampling of filtered and unfiltered water samples at the IP indicated that there was essentially no difference in the uranium concentration of the turbid versus filtered samples. This indicates that the uranium is transported in Bear Creek primarily as a dissolved constituent. Table B.3 shows the annual mass of uranium that flows from (primarily) the plumes in the Nolichucky Shale to Bear Creek.

Some contaminants discharge directly into the Maynardville Limestone, a 200-ft-thick limestone formation, containing a well-developed karst network created by dissolution and enlargement of fractures and joints. Groundwater flow in the Maynardville Limestone occurs in both shallow and deep karst features, and corresponding flow rates and volumes are much higher than in the shale-dominated formations. Releases from the sources have contributed to a commingled plume of VOC, nitrate, and uranium-contaminated groundwater within the Maynardville Limestone.

Over the years this Maynardville flowpath has been monitored through a series of sentinel well transects or "pickets," as represented by Pickets C, B, A, and W, at selected locations in BCV (shown on Figs. B.2, B.3, and B.4). There is also a line of Westbay wells at the S-3 Site that have not been sampled with any regularity. The picket monitoring shows that once contaminants enter the Maynardville Limestone, they flow west down the valley and either re-enter Bear Creek through groundwater discharge to the creek channel and a series of seeps dominated by vertical, upward pressure (SS-4, SS-5), or continue to flow in the deeper zones, intersecting Picket W (as traced by nitrate detections). The fate of migration in the Maynardville downgradient of Picket W is uncertain. Downgradient of Picket W the Bear Creek surface watershed turns northwest and flows through a gap in Pine Ridge east of the Bear Creek/Grassy Creek surface water divide. Bear Creek flows north to East Fork Poplar Creek and Grassy Creek flows west to the Clinch River. There is uncertainty as to whether or not this surface divide represents a deeper groundwater flow divide in the Maynardville.

Contaminant monitoring at the pickets indicates the following:

- All primary COCs are present at Pickets C and B.
- Nitrate and uranium are present at Picket A.
- Low levels of nitrate, possibly background levels, are seen at Picket W.
- In general, a zone from 100 to 400 ft below ground surface (bgs) has the highest concentrations of contaminants; above this depth there is mixing of surface water and groundwater with corresponding dilution.

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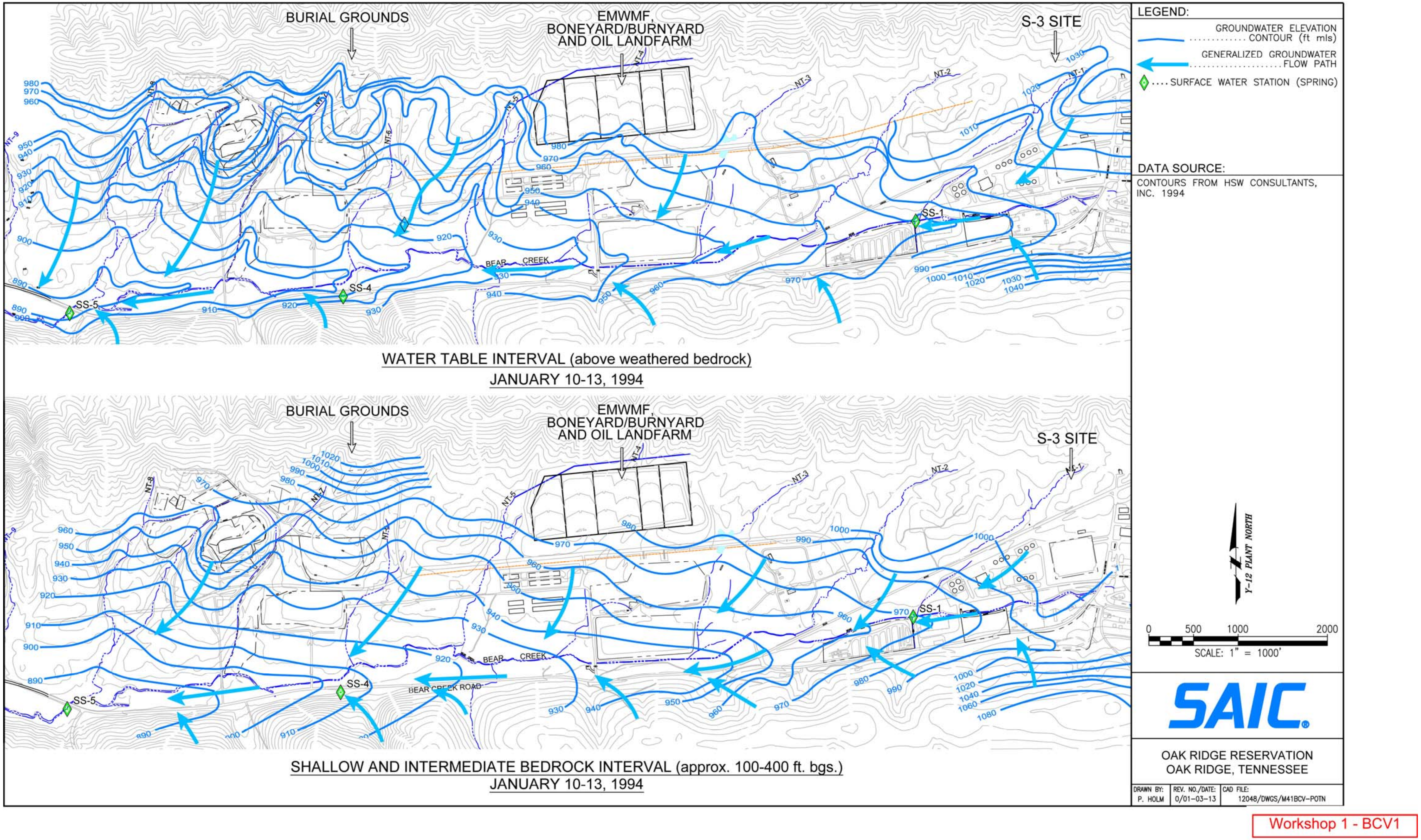

Fig. B.7. Bear Creek Valley potentiometric surface.

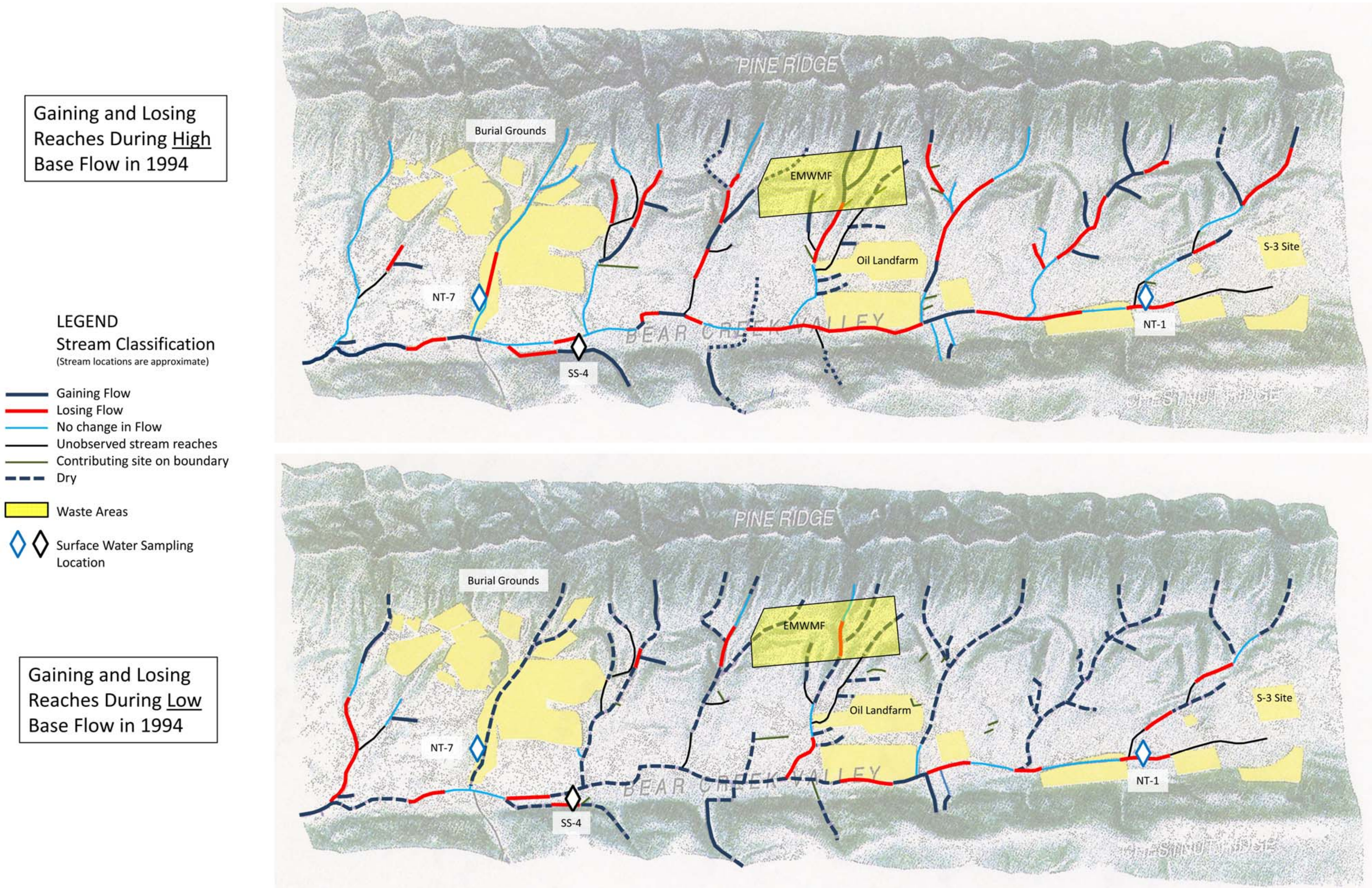

Fig. B.8. Conceptual graphic gaining and losing reaches in Bear Creek Valley (Source: DOE 1996b).

Table B.3. Uranium flux at flow-paced monitoring locations in BCV[a]

FY	BCK 9.2	SS-5	NT-8	BCK 11.54	NT-3	BCK 12.34	Average rainfall
ROD Goal	**34**	--	--	--	**4.3**	**27.2**	--
2001	**88.7**	17.2	**--**	**--**	**79.9**	24.5	45.9
2002	**120.2**	13.1	**--**	158.2	**62.8**	25.4	52.7
2003	**165.4**	12.3	**--**	87.0	**4.6**	**44.3**	73.7
2004	**115.0**	9.5	**--**	45.8	1.2	**27.3**	56.4
2005	**115.4**	11.1	**--**	39.8	4.1	**40.3**	58.9
2006	**68.5**	**--**	**--**	25.2	1.7	21.3	46.4
2007	**59.5**	**--**	**--**	12.6	--	15.8	36.8
2008	**73.2**	**--**	27.9	15.9	--	23.0	49.3
2009	**147.7**	11.6	43.3	27.2	--	**32.9**	62.5
2010	**118.9**	9.9	61.0	32.5	**14.5**	**33.9**	55.8
2011	**108.7**	9.1	40	36.7	**16.3**	**37.8**	59.2
2012	**114.9**	9.2	43.3	45.4	**13.6**	**32.9**	61.8
Contribution to BCK 9.2 (2012)[b]		8%	38%		12%	29%	

[a] Flux values for 2001 – 2010 are from DOE 2012. Flux values for 2011 and 2012 are from DOE 2013. **Bold** values indicate the Phase I ROD goal for uranium flux has not been met **"-- - no data."** All flux values are in kilograms per year (kg/year).

[b] In 2012, approximately 14% of the flux at BCK 9.2 came from a source or sources that are not gauged.

BCK = Bear Creek kilometer, BCV = Bear Creek Valley, FY = fiscal year, NT = North Tributary, and ROD = Record of Decision.

At the watershed scale, a series of figures have been developed to provide distribution and trending information for BCV. This includes Figs. B.9 through B.12, which present time series contaminant trends for nitrate, beta, alpha, and VOCs associated with Pickets C, B, A and W. Figures B.13 through B.16 present shallow (<100-ft depth) and intermediate/deep (>100-ft depth) contaminant distribution and time series trends for nitrate, beta, alpha, and VOCs (at the watershed scale) for BCV. Figures B.17 and B.18 present longitudinal and perpendicular sections along BCV showing nitrate, beta, alpha, and VOCs (TCE) contaminant distributions with depth.

As shown on Figs. B.13 through B.16, there is a groundwater divide that is located just east of the S-3 Ponds. This divide separates the Bear Creek hydrogeologic regime from that of the Upper East Fork Poplar Creek (UEFPC). During S-3 operations, the groundwater divide passed underneath the S-3 Ponds; this is made evident by the presence of the nitrate plume in groundwater below the S-3 Ponds that occurs in both the Bear Creek and UEFPC hydrogeologic regimes (Turner et al. 1991). Dreier et al. (1993) identified an isolated pressure bulge within the Nolichucky Shale down-dip of the S-3 Ponds that was attributable to slow dissipation of elevated hydraulic head caused by the operations at the former ponds. Time series data show that $^{234/238}U$ ratios for water samples collected in the S-3 Pond/SS-1 are significantly different than those located east of the divide in the S-2 Pond Area (Table B.4). This may suggest different contaminant source(s) or complexity/uncertainty in flow paths during operational history of waste units.

Risk:

The three future land use zones from the Phase I Record of Decision (ROD) (Fig B.3) include:

(1) Zone 1: Western half of BCV – unrestricted land use.

(2) Zone 2: One-mile-wide buffer zone between Zones 1 and 3 – recreational (short-term goal) and unrestricted (long-term goal) land use.

(3) Zone 3: Eastern half of BCV – controlled industrial land use.

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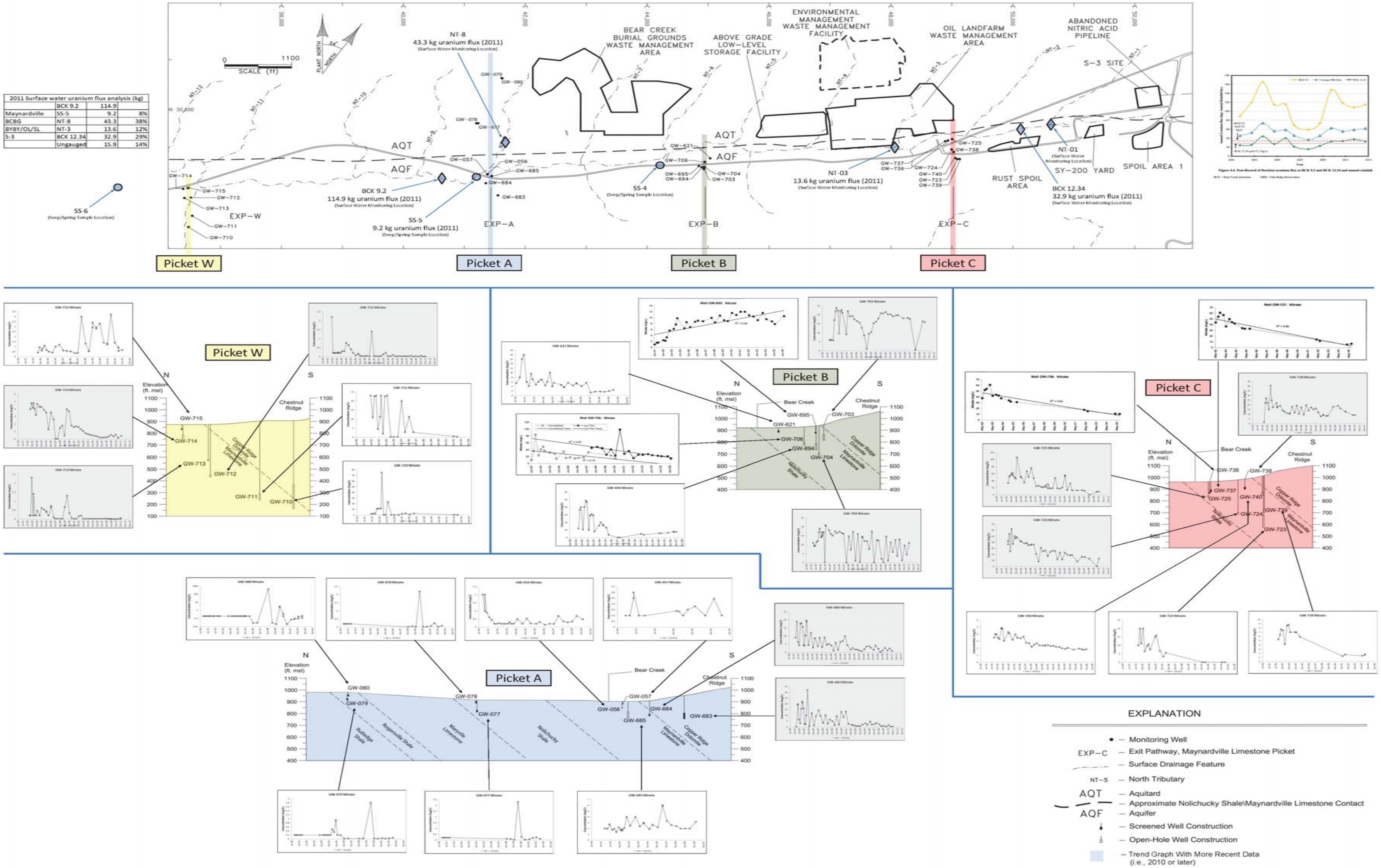


2011 Surface water uranium flux analysis (kg)			
	BCK 9.2	114.9	
Maynardville	SS-5	9.2	8%
BCBG	NT-8	43.3	38%
BYBY/OL/SL	NT-3	13.6	12%
S-3	BCK 12.34	32.9	29%
	Ungauged	15.9	14%

Fig. B.9. Nitrate characteristics in Maynardville Limestone picket wells (adapted from DOE 1996a–d; Elvado 2009a–e).

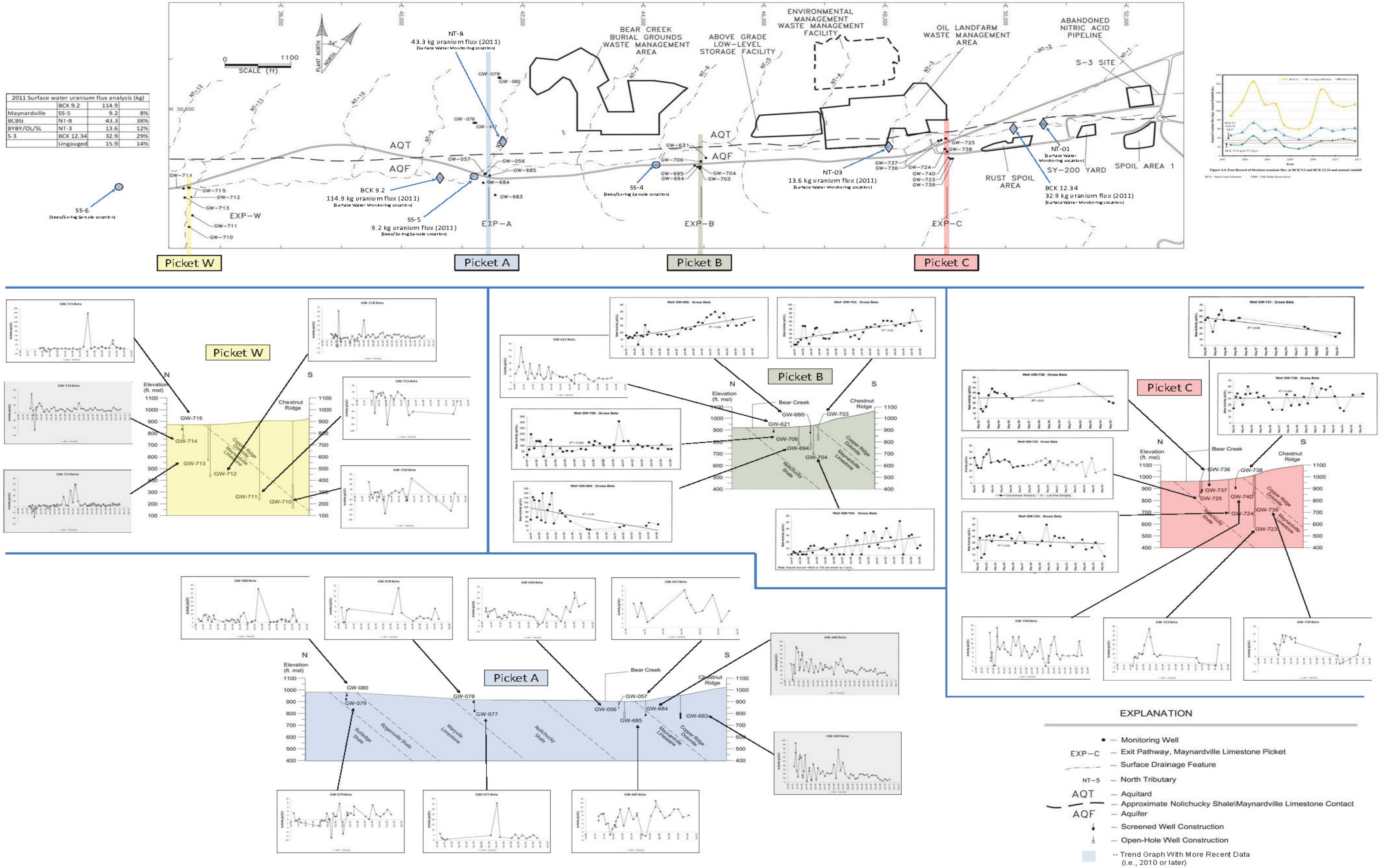
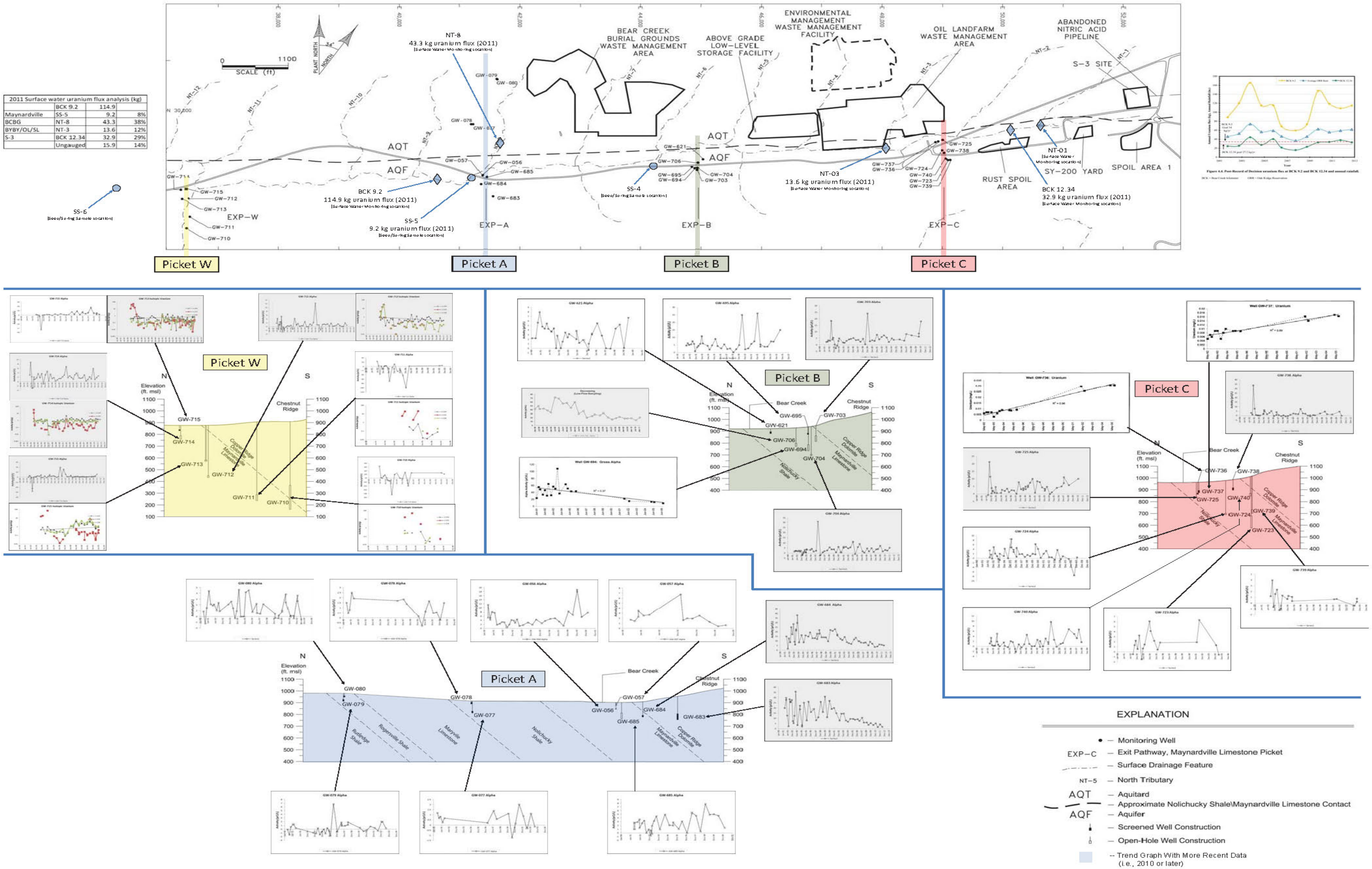
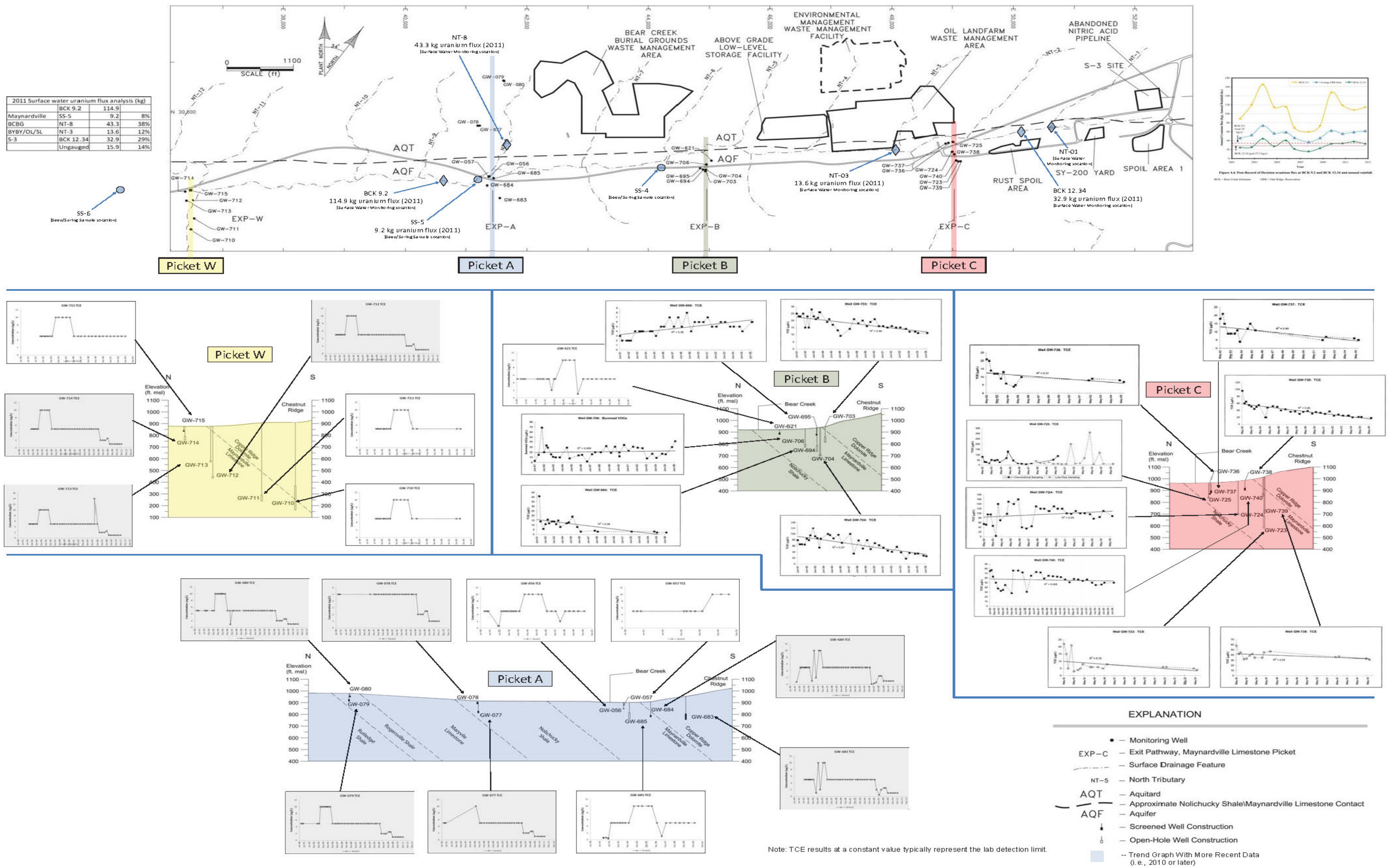


Fig. B.10. Beta characteristics in Maynardville Limestone picket wells (adapted from DOE 1996a–d; Elvado 2009a–e).



2011 Surface water uranium flux analysis (kg)			
	BCK 9.2	114.9	
Maynardville	SS-5	9.2	8%
BCBG	NT-8	43.3	38%
BYBY/OL/SL	NT-3	13.6	12%
S-3	BCK 12.34	32.9	29%
	Ungauged	15.9	14%

Fig. B.11. Alpha characteristics in Maynardville Limestone picket wells (adapted from DOE 1996a–d; Elvado 2009a–e).



2011 Surface water uranium flux analysis (kg)			
	BCK 9.2	114.9	
Maynardville	SS-5	9.2	8%
BCBG	NT-8	43.3	38%
BYBY/OL/SL	NT-3	13.6	12%
S-3	BCK 12.34	32.9	29%
	Ungauged	15.9	14%

Fig. B.12. VOA (TCE) characteristics in Maynardville Limestone picket wells (adapted from DOE 1996a–d; Elvado 2009a–e).

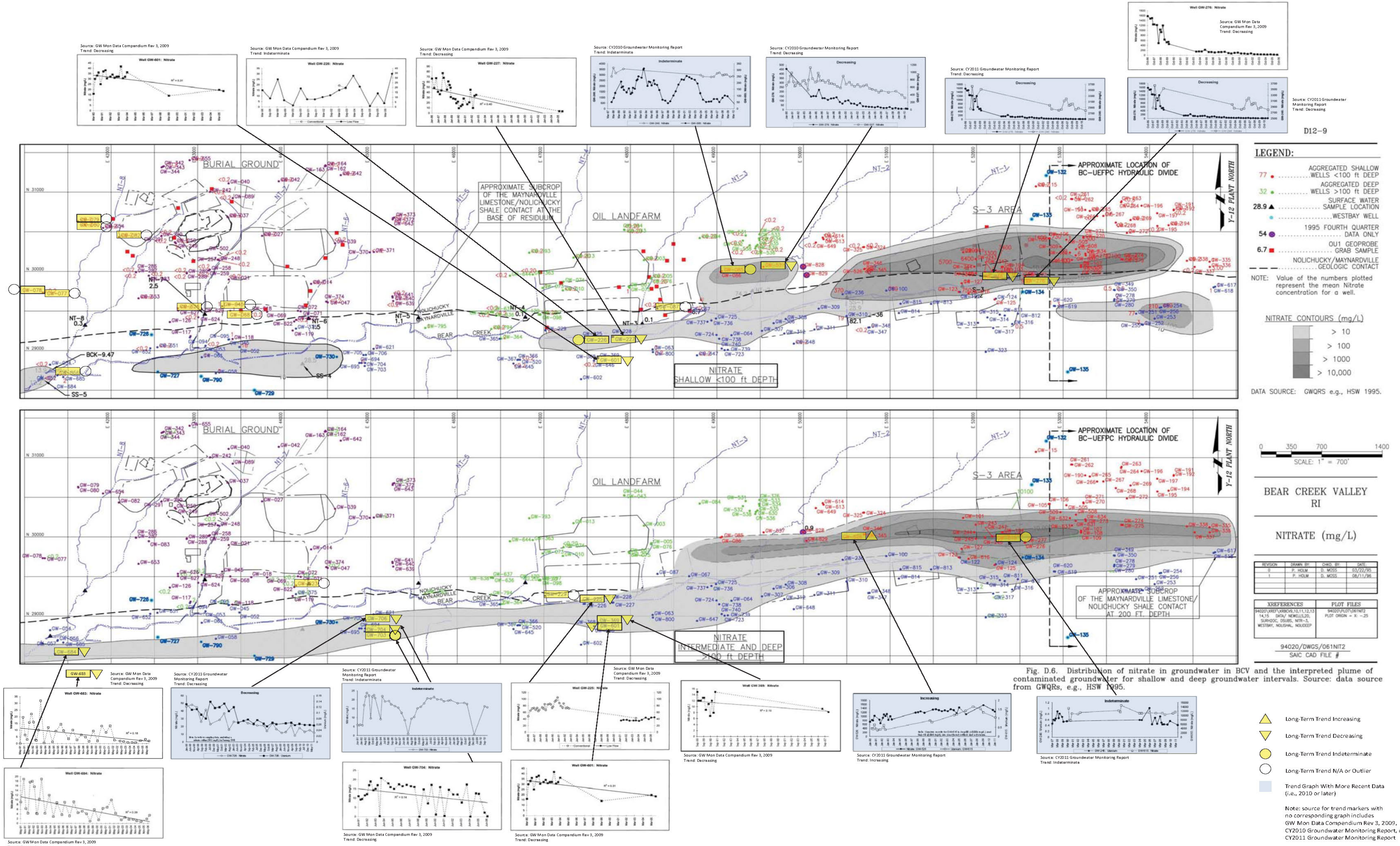


Fig. B.13. BCV Watershed-scale nitrate distribution including shallow (<100-ft depth; top) and intermediate/deep (>100-ft depth; lower), including time series at select wells (adapted from DOE 1996a–d; Elvado 2009a–e).

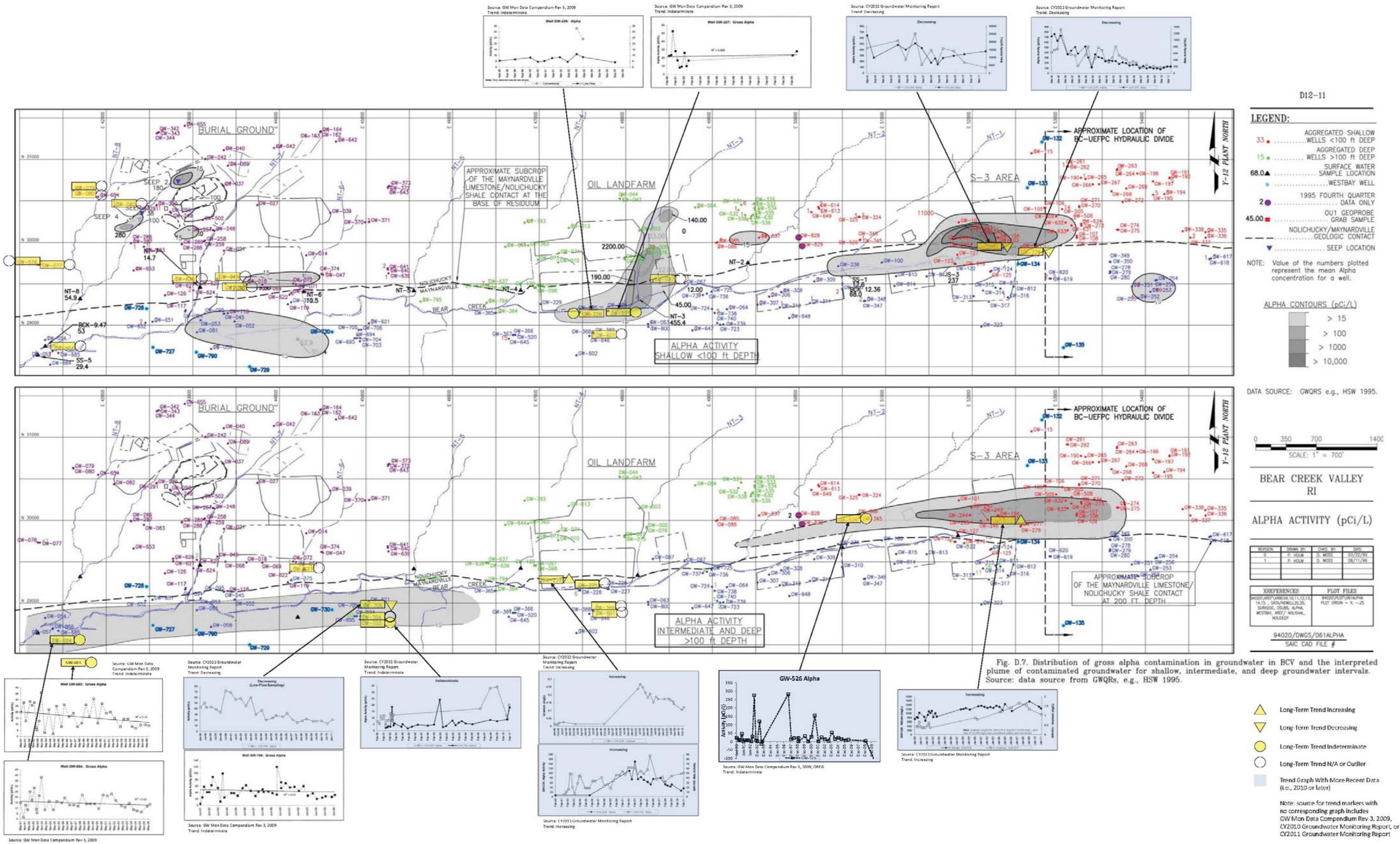


Fig. B.14. BCV Watershed-scale alpha distribution including shallow (<100-ft depth; top) and intermediate/deep (>100-ft depth; lower), including time series at select wells (adapted from DOE 1996a–d; Elvado 2009a–e).

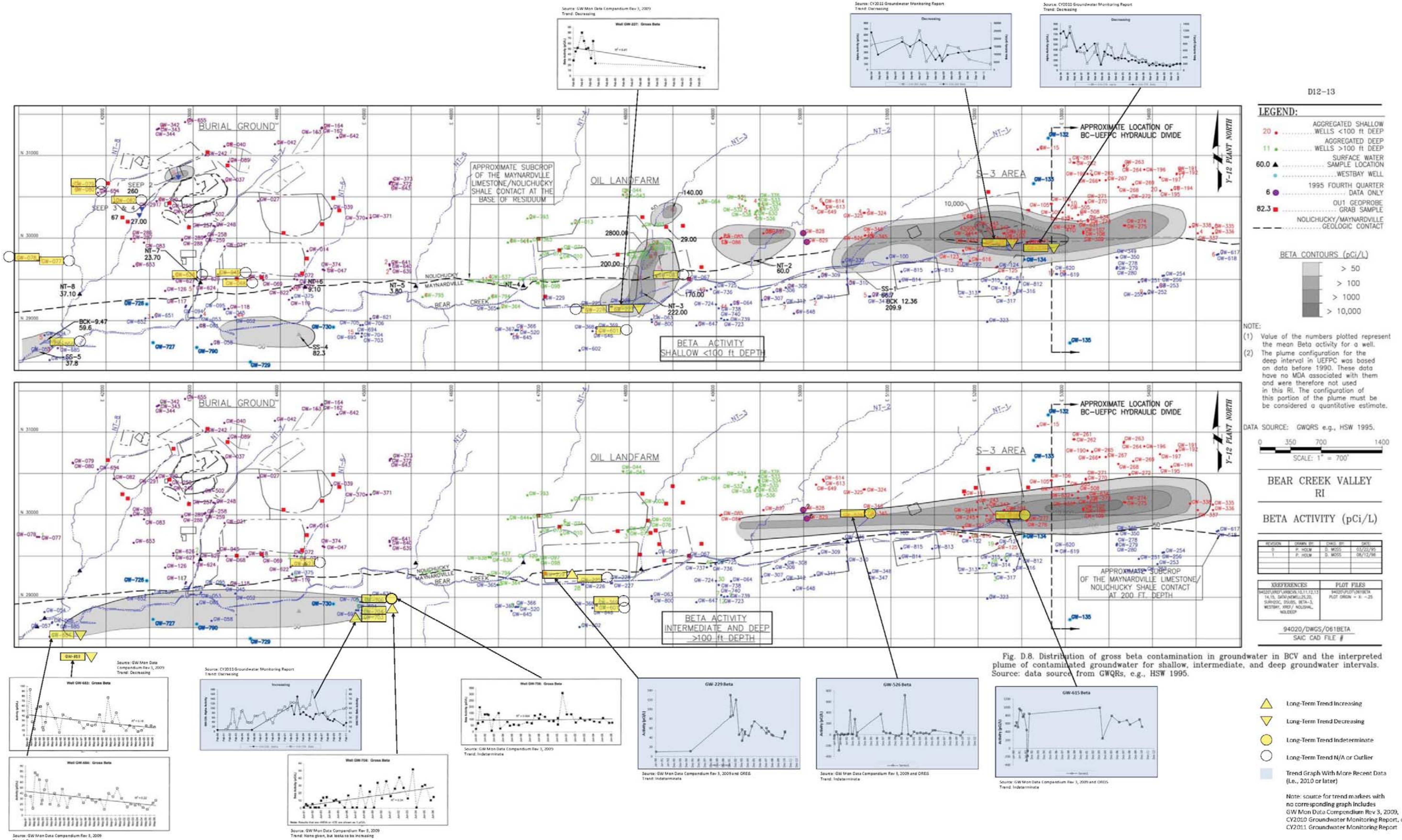


Fig. B.15. BCV Watershed-scale beta distribution including shallow (<100-ft depth; top) and intermediate/deep (>100-ft depth; lower), including time series at select wells (adapted from DOE 1996a–d; Elvado 2009a–e).

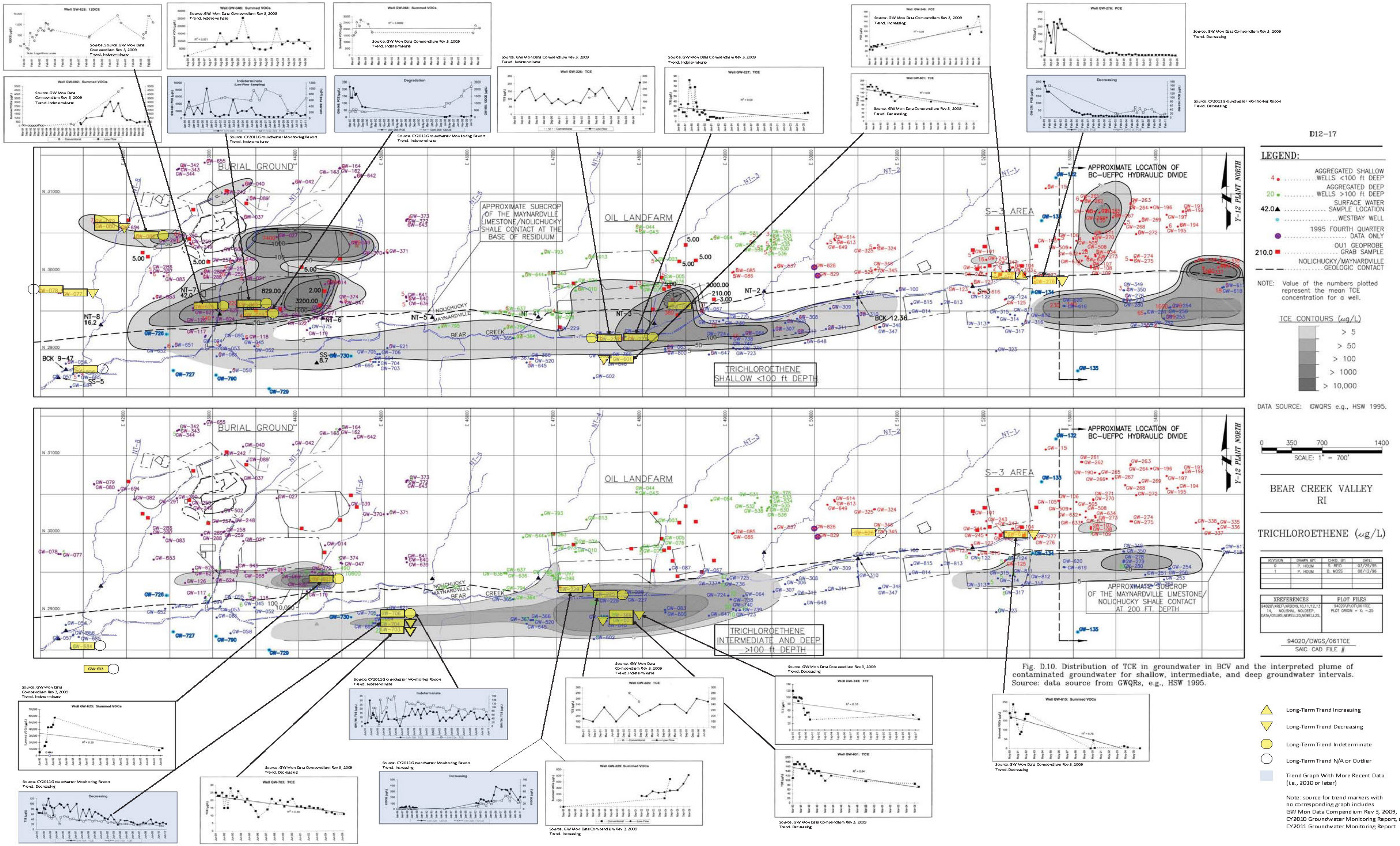


Fig. B.16. BCV Watershed-scale VOA (TCE) distribution including shallow (<100-ft depth; top) and intermediate/deep (>100-ft depth; lower), including time series at select wells (adapted from DOE 1996a–d; Elvado 2009a–e).

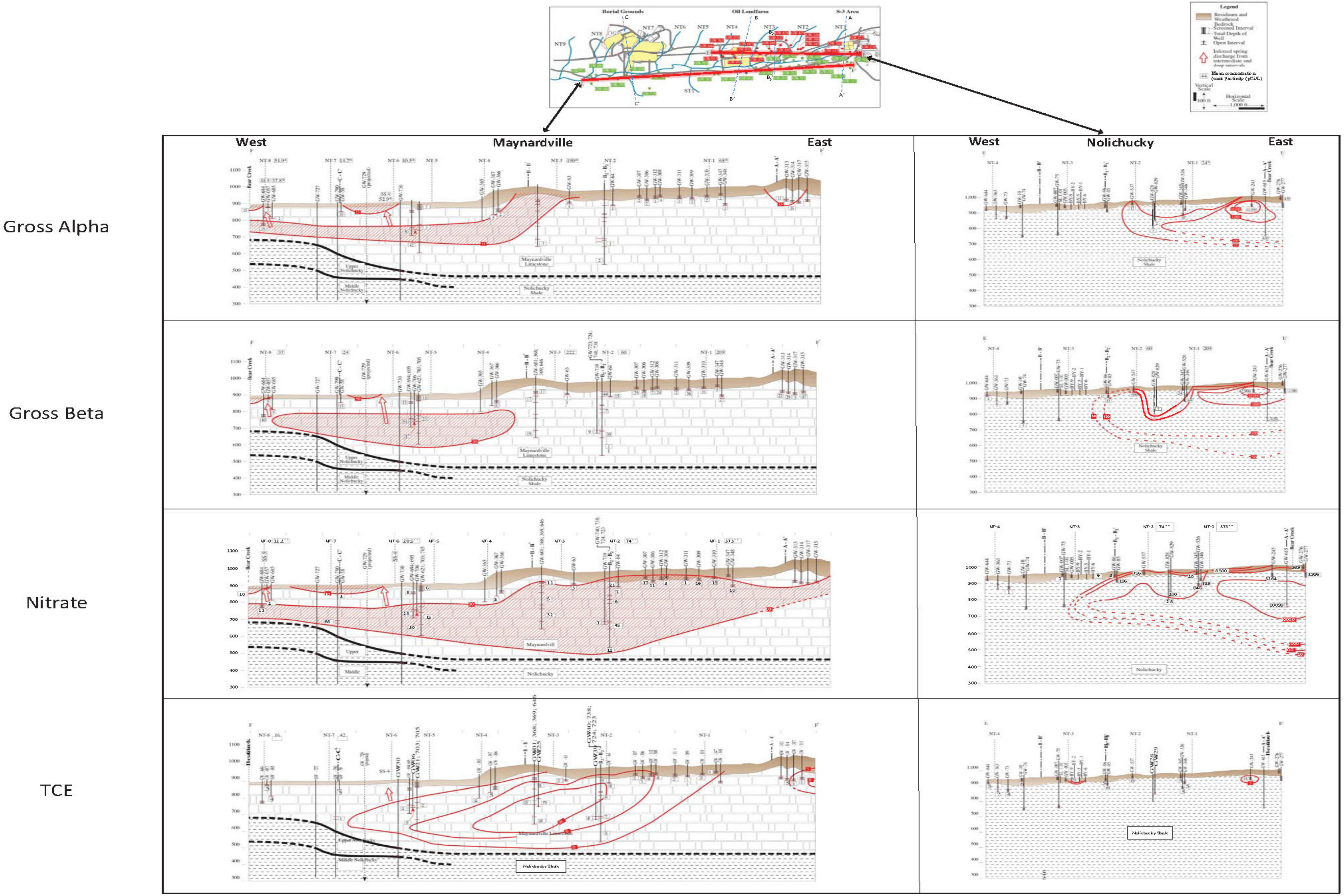


Fig. B.17. BCV Watershed-scale longitudinal cross-sections showing nitrate, beta, alpha, and VOCs (TCE) distribution with depth (DOE 1996c).

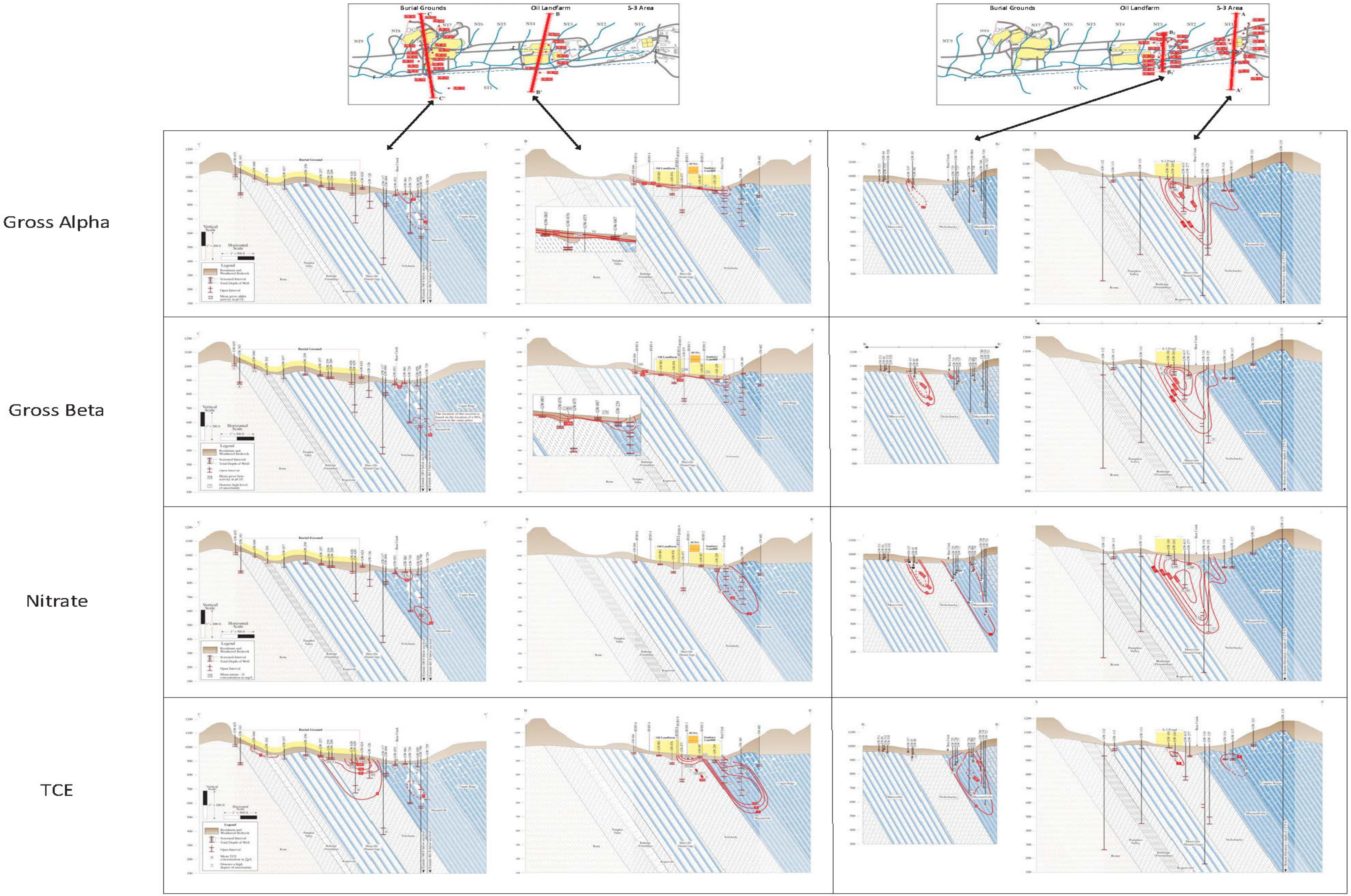


Fig. B.18. BCV Watershed-scale transverse cross-sections showing nitrate, beta, alpha, and VOCs (TCE) distribution with depth (DOE 1996c).

Table B.4. Uranium ratios west and east of the Bear Creek/UEFPC groundwater divide

Location		Date	U-234/U-238 Ratio	Location average U-234/U-238 ratio
S-2 Pond Area	GW-251 (Screen Midpoint = 43 ft bgs)	2/21/1996	2.86	3.58
		3/3/1998	4.66	
		7/16/1998	3.23	
	GW-253 (Screen Midpoint = 43.1 ft bgs)	2/21/1996	3.68	3.87
		6/10/1996	3.33	
		6/23/1998	3.98	
		7/27/1998	4.54	
		2/8/1999	3.58	
		8/24/1999	4.08	
		11/8/1999	3.58	
		5/23/2000	4.30	
		11/2/2000	4.17	
		5/2/2001	2.86	
		10/29/2001	4.40	
		5/7/2002	5.26	
S-3 Pond Representative	GW-615 (Screen Midpoint = 233.8 ft bgs)	5/15/1992	0.33	0.38
		8/18/1992	0.29	
		11/9/1999	0.44	
		2/15/2000	0.38	
		6/8/2000	0.40	
		8/30/2000	0.39	
		3/10/2004	0.41	
		8/19/2004	0.38	
		2/21/2006	0.36	
		5/14/2007	0.38	
		8/11/2008	0.37	
SS-1		8/30/1990	0.68	0.75
		11/1/1990	0.50	
		1/18/1991	0.71	
		4/10/1991	0.10	
		7/29/1991	0.75	
		12/4/1991	0.98	
		3/10/1992	0.25	
		6/1/1992	0.68	
		12/16/1992	1.33	
		2/19/1998	0.91	
		8/20/1998	0.82	
		1/10/2001	0.93	
		7/12/2001	1.09	

bgs = below ground surface.
GW = groundwater.
UEFPC = Upper East Fork Poplar Creek.

These zones establish the future uses against which to identify potential human health risk. The intent of the ROD was that groundwater would continue to meet unrestricted use goals (e.g., MCLs) in Zone 1 and eventually in Zone 2. Risk-based remediation levels were established in the Phase I ROD for only surface water exposures at the Bear Creek surface water-groundwater IP (i.e., BCK 9.2 at the Zone 2/Zone 3 boundary) [Table B.5]. The ROD also included compliance with Ambient Water Quality Criteria (AWQC), particularly for protection of fish and aquatic life.

Table B.5. Risk-based remediation levels for primary chemicals of concern in surface water at the Bear Creek IP

COC	Units	Residential	Industrial	Recreational	BCK 9.2 Range 2010 – 2012
		Carcinogens at 1.0E-5			
U-234	pCi/L	7.48	12.6	2095	6.3 – 7.9
U-238(+D)	pCi/L	6.07	10.2	1701	16.1 – 17.6
		Noncarcinogens at HI = 1			
Nitrate	mg/L	58.2	90.6	16,310	4.8 – 6.1
Uranium total	mg/L	0.109	0.170	30.6	NA

BCK = Bear Creek kilometer.
COC = chemical of concern.
HI = hazard index.
IP = integration point.
mg/L = milligrams per liter.
NA = not available.
pCi/L = picocuries per liter.

B.2 CONCEPTUAL MODEL, SOURCE AREA SCALE

B.2.1 S-3 SOURCE AREA (PLUMES BCV-1A, BCV-1B)

The former S-3 Site, a principal waste source area in BCV, is described as follows:

- The former S-3 Site was constructed in 1951 and operated until 1983. Uranium-contaminated nitric acid solutions and other liquid waste streams were piped or trucked from process areas of the Y-12 National Security Complex (Y-12 Complex) and disposed in four unlined ponds. Periodic disposal of ^{99}Tc-bearing liquid wastes at the S-3 Site is also documented.

- The acidity and density of liquid wastes resulted in dissolution of carbonate in bedrock strata beneath the site and density-driven vertical migration of wastes, which emplaced a large mass of nitrate contamination to depths of at least 500 ft in the Nolichucky.

- The former S-3 Site was closed under the Resource Conservation and Recovery Act of 1976 (RCRA) in 1988 by neutralizing sediment within the ponds, stabilizing the ponds with aggregate, and placing a multi-layer cap and asphalt cover over the unit. The site is currently used as a parking lot.

- The BCV Phase I ROD (DOE 2000) selected an S-3 Pond remedy that included a trench installed at Pathway 3 for passive in situ treatment of shallow groundwater that resurfaces at Northern Tributary 1 (NT-1). The S-3 Site Pathway 3 action has not been implemented to date. The ROD also identified that an iron filing treatability study on Pathways 1 and 2 would be maintained to treat contaminants in NT-1. This system became clogged and was shut down in 2007.

Table B.6 provides a summary of the S-3 Ponds secondary plume sources in the Nolichucky and Maynardville. Figures B.19, B.20, and B.21 present plan and sectional views of the nitrate, uranium, and ^{99}Tc contaminant distribution, respectively, in the Nolichucky Shale and Maynardville Limestone. In addition to the information on the table, key considerations include:

- The S-3 Site contaminants also included solvents. VOCs from S-3 migrated east toward Upper East Fork Poplar Creek during operations, and the plumes currently show an eastward flowpath.

- The uranium and ^{99}Tc secondary plume masses are primarily in the Nolichucky. A small mass discharges directly to the Maynardville near the former ponds but appears to resurface in the creek around BCK 12.34. In addition, shallow uranium releases to NT-1 and NT-2 release to Bear Creek. This surface water contamination may flow to a losing reach of Bear Creek and re-enter the Maynardville near BCK 11.84 (the BYBY Area).

The groundwater and surface water COCs in the area are listed in the RI and include:

- Groundwater: Metals (cadmium), nitrate, uranium, ^{99}Tc, and VOCs.
- Surface water: Cadmium, nitrate, and uranium.

Table B.6. S-3 Ponds source area groundwater plumes

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
BCV-1a	S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3)	3500 (Nitrate); 2500 (Uranium); and 3000 (^{99}Tc)	600	Nitrate: 10 to 10,000 mg/L; Uranium: 15 to 10,000 pCi/L; and ^{99}Tc: 50 to 10,000 pCi/L	Along-strike flow in the Nolichucky	Upper Bear Creek (BCK 12.34); NT-1, NT-2; Maynardville[b]?	• Ongoing releases from nitrate plume/secondary source in Nolichucky • Quantified estimates of total uranium mass that left S-3 compared to mass in current plumes • What is the extent of the uranium plume (bottom in Maynardville) • How much of the plume is currently being monitored • Water chemistry as related to potential actions • Few deep wells in Maynardville downgradient of S-3
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	3 miles	450	1 to 50 mg/L	Along-strike flow in the Maynardville	SS-4, SS-5 down valley (Picket W)	• Uncertain nitrate mass as secondary source in Maynardville • Nitrate degradation processes and rates; ammonia data • Bottom of Maynardville plume

[a] Values are approximate based on remedial investigation plume maps.
[b] Uranium from S-3 that resurfaces at BCK 12.34 may flow to a losing reach of the creek and enter the Maynardville near BCK 11.84.
Note: VOCs from S-3 migrate toward Upper East Fork Poplar Creek.
BCK = Bear Creek kilometer.
BCV = Bear Creek Valley.
bgs = below ground surface.
mg/L = milligrams per liter.
NT = Northern Tributary.
pCi/L = picocuries per liter.

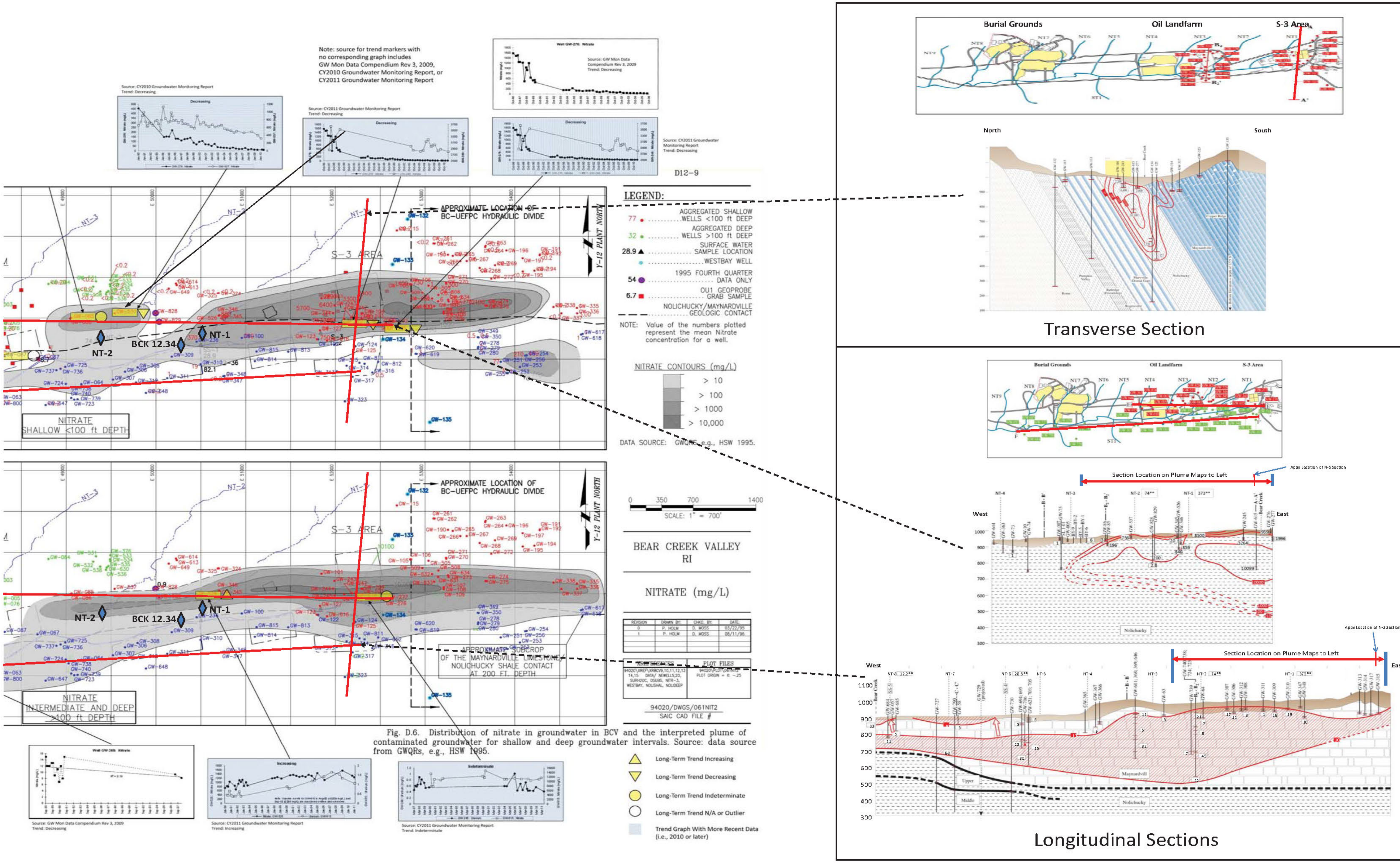


Fig. B.19. S-3 Pond source, Plumes BCV-1a and BCV-1b – distribution of shallow and deep nitrate in Nolichucky Shale and Maynardville Limestone (adapted from DOE 1996a–d; Elvado 2009a–e).

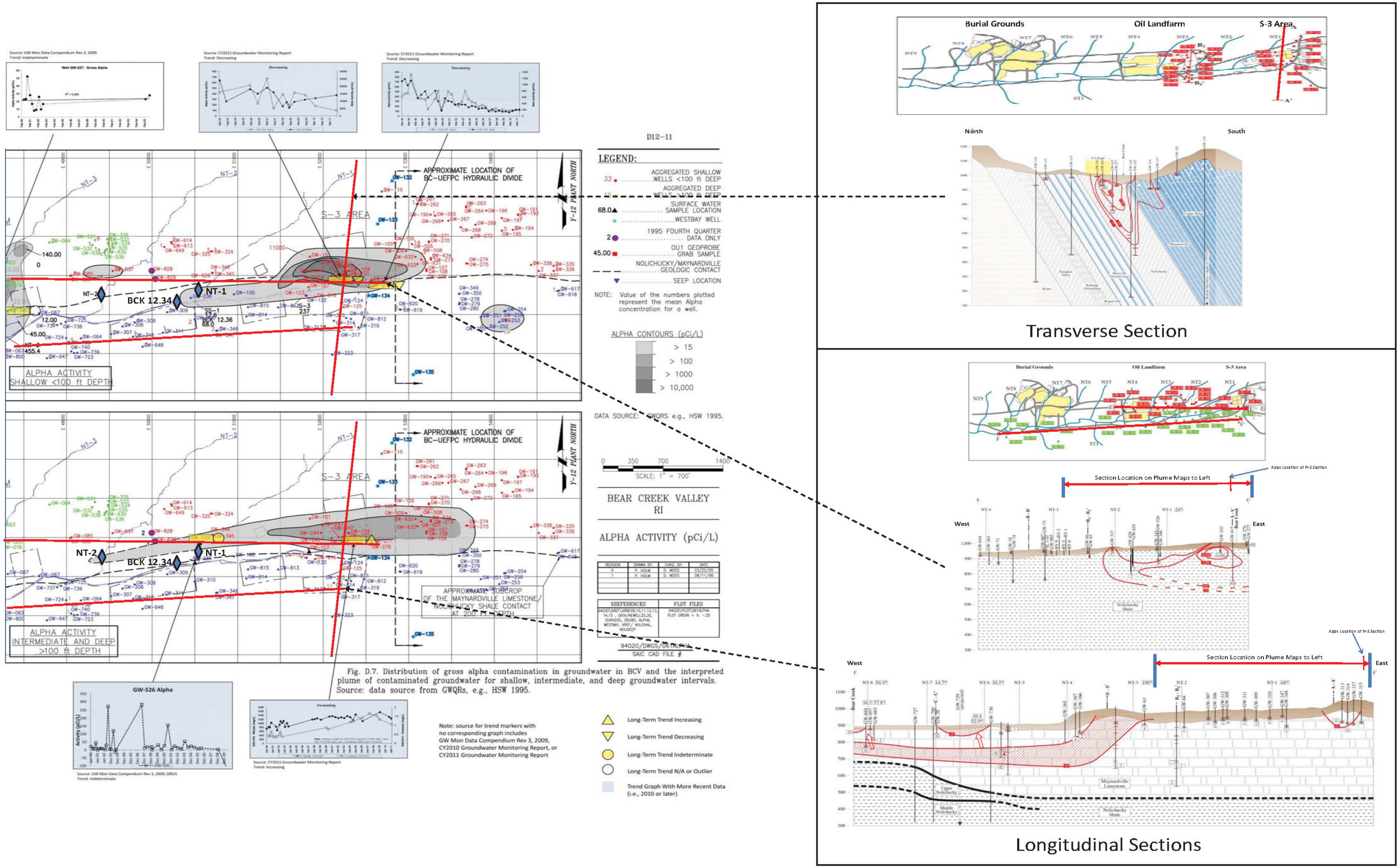


Fig. B.20. S-3 Pond source, Plumes BCV-1a and BCV-1b – distribution of shallow and deep uranium in Nolichucky Shale (adapted from DOE 1996a–d; Elvado 2009a–e).

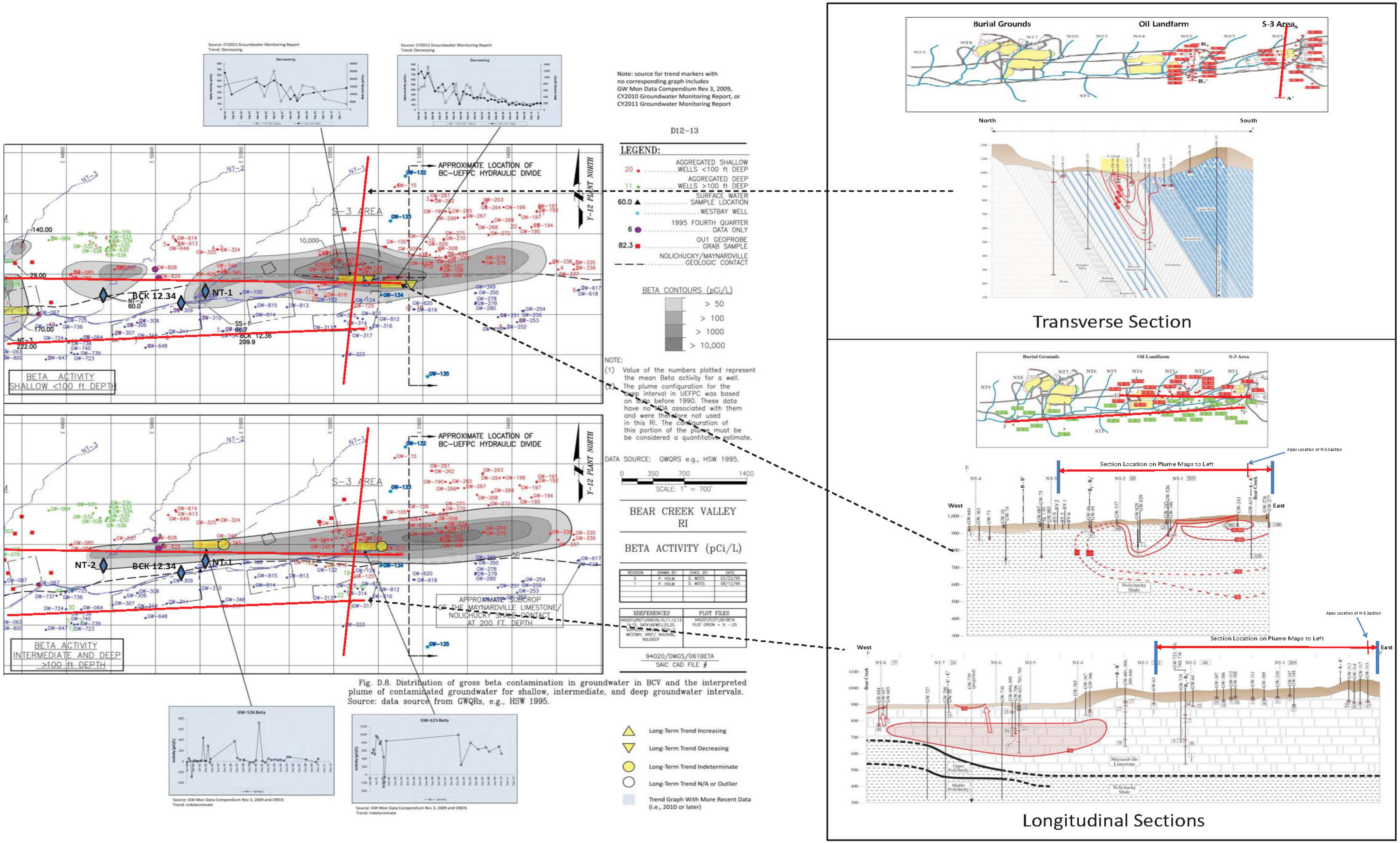


Fig. B.21. S-3 Pond Source, Plumes BCV-1a and BCV-1b – distribution of shallow and deep ^{99}Tc in Nolichucky Shale (adapted from DOE 1996a–d; Elvado 2009a–e).

The 2011 Five-Year Review (FYR) identified the following issues and data interpretations:

- NT-1 currently exceeds AWQC applicable or relevant and appropriate requirements for cadmium (0.25 micrograms per liter [µg/L]) and the action is not protective of aquatic life. The S-3 Pond removal action to address S-3 Pond Pathways 1 and 2 was ineffective and, therefore, terminated. The S-3 Pond remedial action for Pathway 3 has not been implemented. Note: Pathways 1 and 2 are planned to be combined with Pathway 3 as a remedial action under the BCV Phase I ROD in order to develop a comprehensive remediation strategy (DOE 2013, Action Plan 9 in Appendix C).

- Uranium activity at BCK 9.2 remains above acceptable levels for a residential and industrial receptor; however, there is no current unacceptable human exposure. Approximately 51% of the uranium flux to BCK 9.2 comes from the significant amount of flux at BCK 12.34, which drains the S-3 Ponds.

B.2.2 BONEYARD/BURNYARD/HAZARDOUS CHEMICAL DISPOSAL AREA, OIL LANDFARM, AND SANITARY LANDFILL 1 SOURCE AREA

A second BCV waste source area, the BYBY, is described as follows:

- The BYBY consists of two former waste disposal units, the Boneyard and Burnyard. The Boneyard was used between 1943 and 1970 primarily for the disposal of noncombustibles such as metal (depleted uranium [DU]), debris, and organics; burning of magnesium chips; and construction spoils. The Burnyard operated in the 1960s and was used for open burning of solids, liquid solvents and oils, and sludges in two unlined trenches.

- Remedial actions at BYBY were completed in 2004. Major elements included: (1) excavation and disposal of about 64,000 yd^3 of highest uranium concentration wastes (Units 4 and 5); (2) excavation of about 22,000 yd^3 of less contaminated waste with consolidation in the northeastern portion with construction of a low-permeability cap, hydrogeologic controls (French drain), and surface water run-on and run-off controls. Contaminated materials from Units 4 and 5 were disposed in the Environmental Management Waste Management Facility.

- The HCDA lies immediately adjacent to, and east of, the BYBY and operated from 1975 to 1981; the disposal area received ignitable, reactive, corrosive and/or toxic wastes, which were allowed to react in a concrete vessel, after which residues were disposed on-site or drained into soil. The HCDA was capped with a RCRA-type cap in 1989 but is not regulated as a closed RCRA treatment, storage, or disposal unit. This unit was not remediated during the BYBY remediation effort.

- The OLF was capped under RCRA. In 1985, SL-1 was closed and capped. The selected CERCLA remedy under the BCV Phase I ROD is maintenance of the existing soil cap and SL-1.

Table B.7 provides a summary for groundwater plumes in the BYBY/OLF/SL source area. Figures B.22 and B.23 present plan and sectional views of the shallow and deep uranium distribution in the Nolichucky Shale and Maynardville Limestone, and dense non-aqueous phase liquid (DNAPL) [VOCs] within the Nolichucky Shale and Maynardville Limestone.

The groundwater and surface water COCs in the area are listed in the RI and include:

- Groundwater: Uranium, VOCs.
- Surface Water: Cadmium, nitrate (both from S-3), and uranium.

Table B.7. BYBY/Oil Landfarm/Sanitary Landfill source area plumes

Plume No.	Name	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
BCV-2	Uranium in the Maynardville Limestone	7500	200	Shallow: Up to 2200 pCi/L; Deep: 1 to 50 pCi/L	Direct release into the Maynardville near BCK 11.54 Along-strike flow in the Maynardville	NT-3, SS-4, SS-5, and SS-7 Picket A	• Shallow plume source since BYBY action • What has happened to uranium in Maynardville since BYBY action • Is the BYBY the primary source of uranium in Maynardville downgradient of BYBY (or S-3)
BCV-3	HCDA/Old SY200 Yard[a] Shallow/deep VOCs (DNAPL) in Nolichucky and Maynardville	7500	VOCs at approximately 200-ft depth; unknown	5 to 2000 µg/L	Direct release into the Maynardville near BCK 11.54	SS-4, SS-5 Maynardville - Picket B	• Is there a DNAPL source at the HCDA; if so, how deep • Is the conceptual model for transfer from Nolichucky to Maynardville well understood • VOC degradation rates in BCV • What is the nature of the primary HCDA source

[a] SY200 Yard is to the east near the S-3 Site and is suspected of contributing to the VOC plume in Zone 3.
BCV = Bear Creek Valley.
bgs = below ground surface.
BYBY = Boneyard/Burnyard.
DNAPL = dense non-aqueous phase liquid.
HCDA = Hazardous Chemical Disposal Area.
pCi/L = picocuries per liter.
µg/L = micrograms per liter.
VOC = volatile organic compound.

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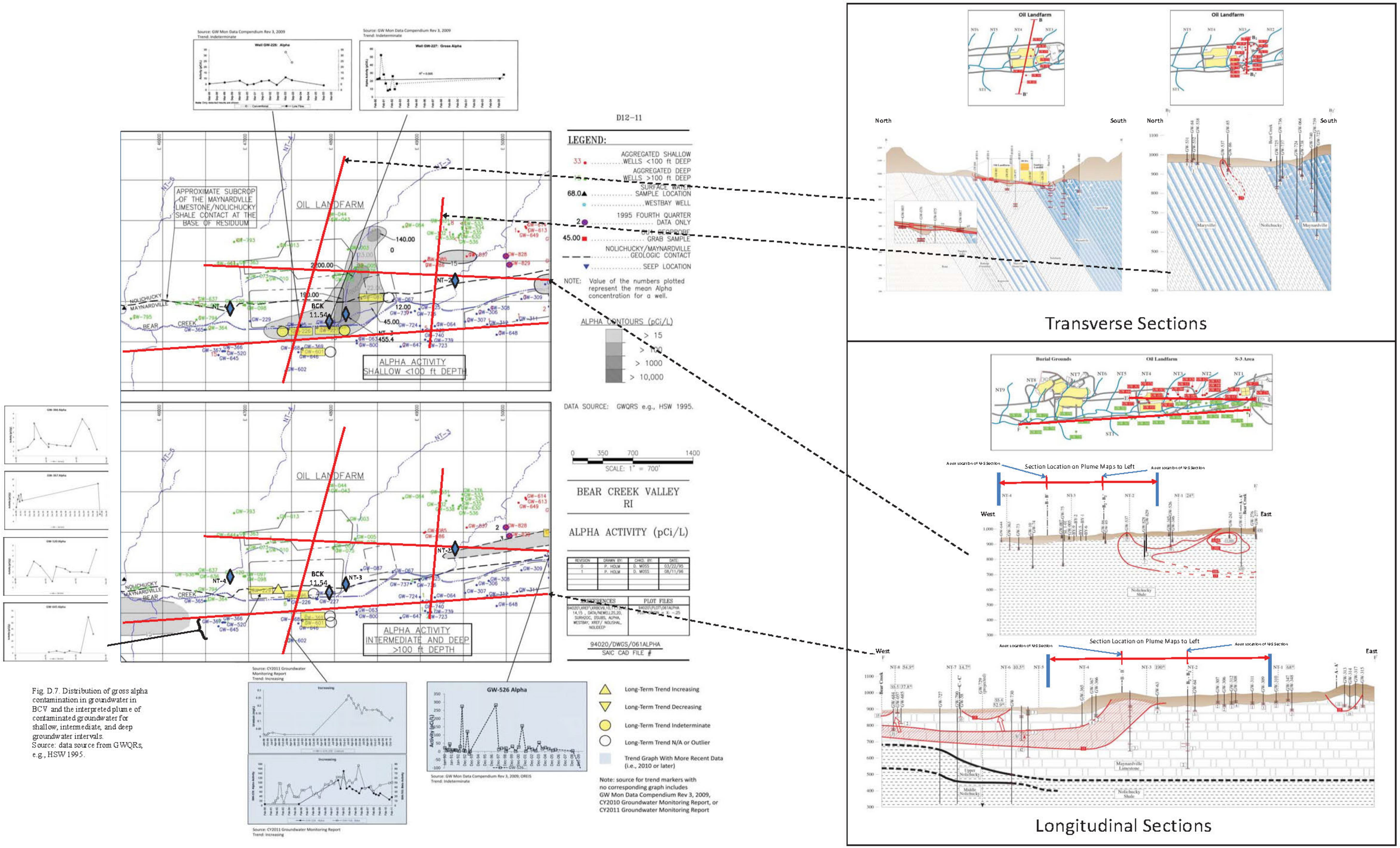

Fig. B.22. OLF/BYBY/SL Source, Plume BCV-2 – distribution of shallow uranium in BYBY to deep uranium in Maynardville Limestone (adapted from DOE 1996a–d; Elvado 2009a–e).

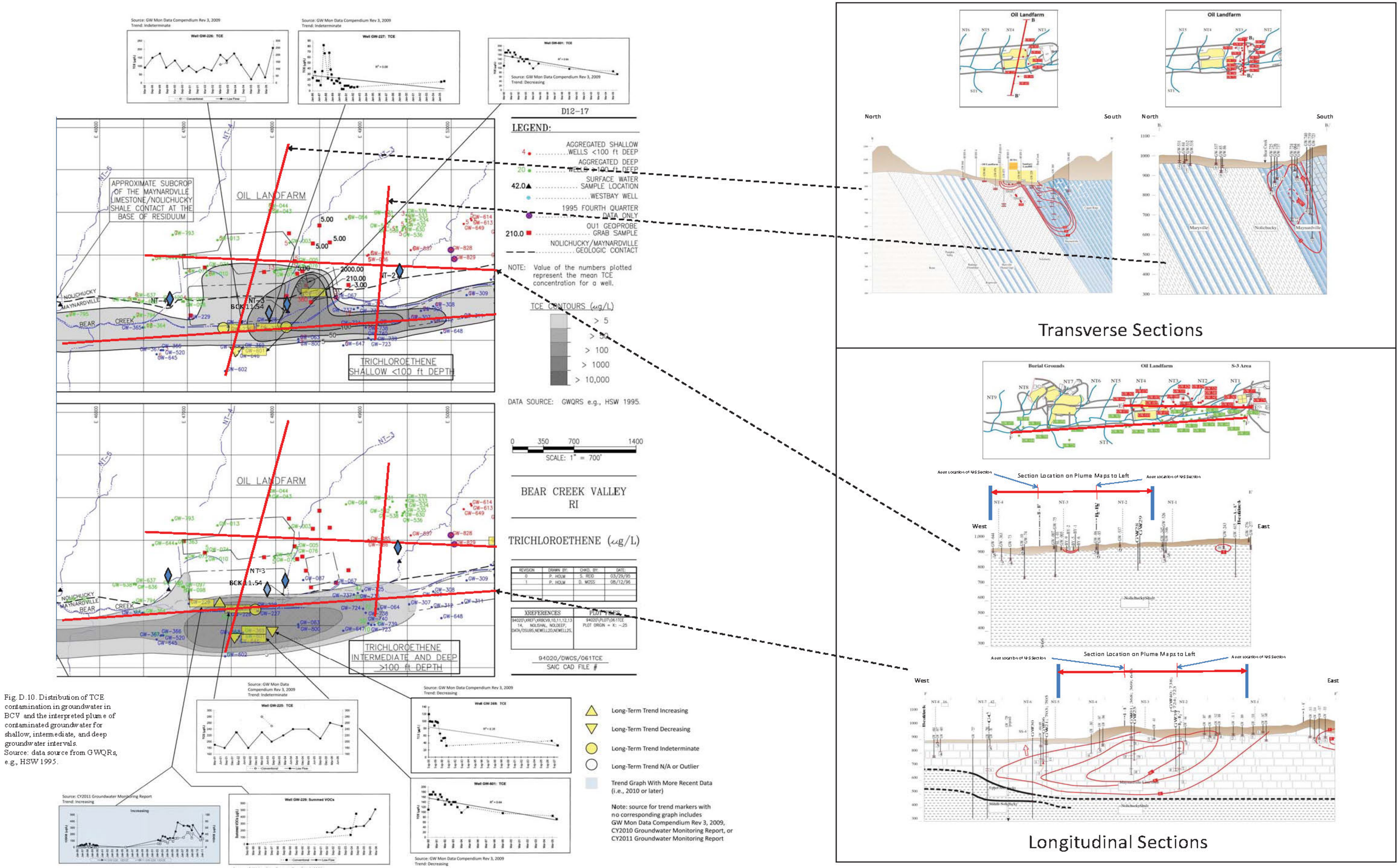

Fig. B.23. OLF/BYBY/SL Source, Plume BCV-3 – HDCA distribution of shallow and deep DNAPL (VOCs) in Nolichucky Shale(adapted from DOE 1996a–d; Elvado 2009a–e).

This COC analysis was based on data collected in the mid-1990s. Future Comprehensive Environmental Response, Compensation, and Liability Act of 1980 decisions will need to reassess the groundwater COCs in the valley following up-to-date risk processes.

The 2011 FYR identified no issues for this area.

B.2.3 BEAR CREEK BURIAL GROUND SOURCE AREA (PLUMES BCV-4, BCV-5 AND BCV-6)

The BCBG, another source area for BCV, is described as follows:

- The BCBG complex operated from about 1955 to 1993 and included several principal waste disposal units (BCBG-A North and -A South, -B, -C, -D, -E, and -J) and Walk-in Pits North and South. Each unit consists of a series of trenches used for disposal of liquid and solid wastes, including DU, DU-contaminated industrial wastes, liquid wastes, mop waters, waste oils, and machine coolants.

- The Walk-in Pits received potentially reactive and explosive wastes (e.g., picric acid).

- Oil Retention Ponds 1 and 2 were constructed to receive polychlorinated biphenyl (PCB)- and oil-contaminated drainage from BCBG-A North and -A South. The Oil Retention Ponds were closed under RCRA in 1989, and approximately 3842 yd^3 of contaminated soil excavated during the closure was placed in the Disposal Area Remedial Action Solids Storage Facility. BCBG-A North and -A South, -B, -C West, -C East, -D, -E, -J, and the Walk-in Pits North and South were closed and capped between 1989 and 1994 in accordance with RCRA post-closure requirements. There is a passive leachate collection system in portions of the BCBG for collection and treatment of leachate. The BCBG was not addressed as part of the BCV Phase I ROD, but is planned to be addressed in a future BCV Phase II ROD.

Table B.8 provides a summary for groundwater plumes in the BCBG source area. Figures B.24 and B.25 present plan and sectional views of the shallow and deep uranium distribution in the Nolichucky Shale and Maynardville Limestone, and DNAPL (VOCs) within the Nolichucky Shale and Maynardville Limestone.

The groundwater and surface water COCs in the BCBG source area are listed in the RI and include:

- Groundwater: VOCs and uranium.

- Surface Water: VOCs and uranium (total uranium comparison to MCL not available but ^{238}U exceeds total U MCL).

The 2011 FYR identified the following issue:

- Uranium activity at BCK 9.2 remains above acceptable levels for a residential and industrial receptor; however, there is no current unacceptable human exposure. Approximately 38% of the uranium flux to BCK 9.2 can be attributed to NT-8, which drains BCBG, which is not under an existing ROD.

Table B.8. Bear Creek Burial Ground source area plumes

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
BCV-4	BG-A North/South Shallow/deep (DNAPL) VOCs in Nolichucky Shale	3000 east–west 1500 north–south	200 (DNAPL)	50 to 60,000 μg/L	Along-strike shallow flow in Nolichucky, density-driven vertical flow in Nolichucky	NT-7, NT-8 Picket A	• What do existing West Bay wells tell us about VOC (and other COC migration); are they in the right place • Poorly defined bottom and west end of plume • Is DNAPL at Burial Ground A the source of contamination "moving" toward NT-8 • What is DNAPL mass at Burial Ground A
BCV-5	BG-C West Shallow VOCs in Nolichucky Shale	1000		5 to 1000 μg/L	Along-strike flow in Nolichucky	NT-8 Picket A	• How far west has the VOC plume moved
BCV-6	Various near-surface uranium signatures in Nolichucky Shale	Direct discharge to NT-8; no wells to determine if plumes move along-strike, but uranium has low solubility in neutral to high pH groundwater	Storm flow zone	Not known	Immediate discharge to north tributaries	NT-7, NT-8	• Gaining/losing reaches of Bear Creek

BCV = Bear Creek Valley.
BG = Burial Ground.
bgs = below ground surface.
COC = chemical of concern.
DNAPL = dense non-aqueous phase liquid.
GW = groundwater.
NT = Northern Tributary.
VOC = volatile organic compound.
μg/L = micrograms per liter.

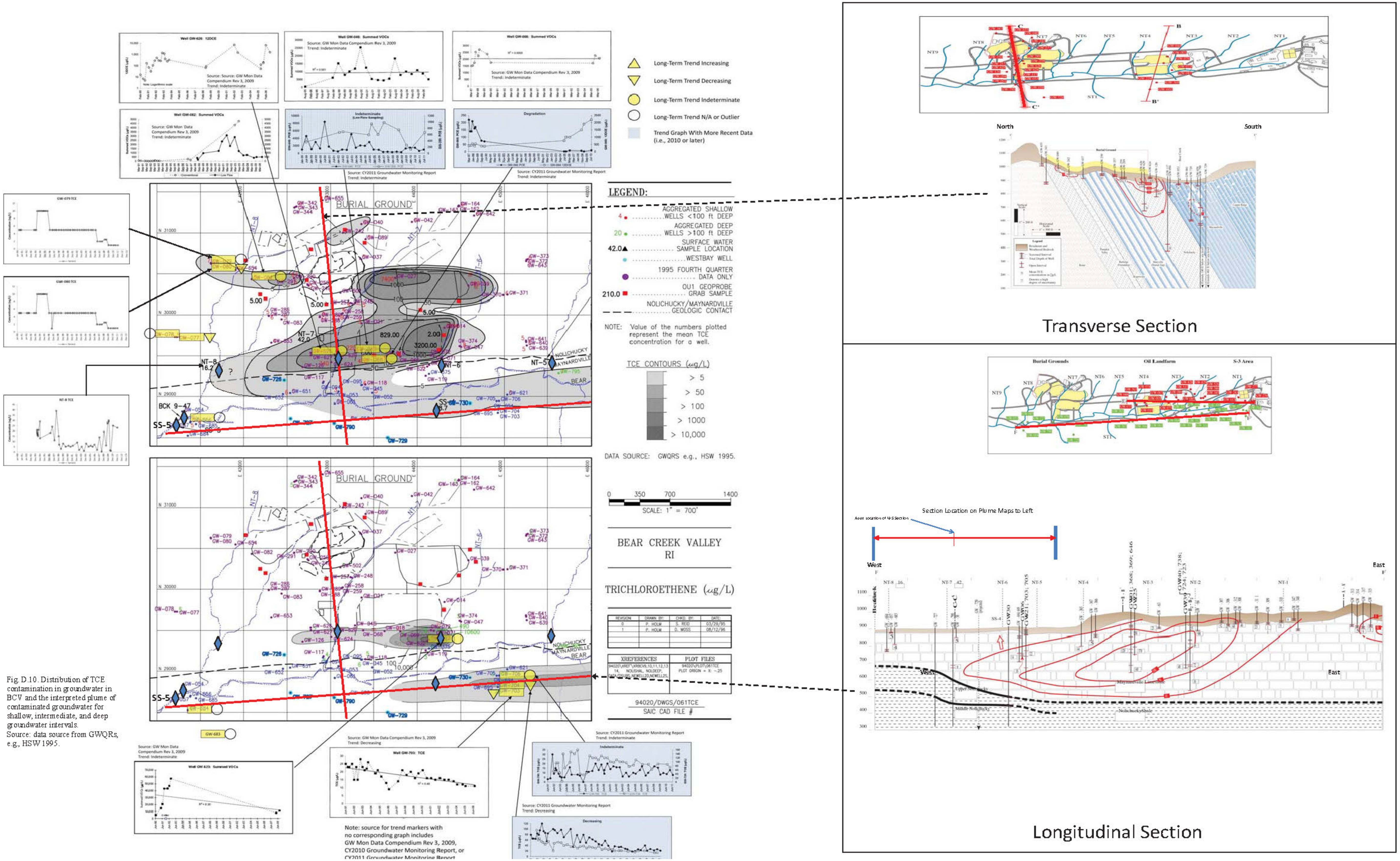

Fig. B.24. BG-A Shallow/deep DNAPL (VOCs) in Nolichucky Shale (Plume BCV-4) and BG-C West shallow VOCs in Nolichucky Shale (BCV-5) [adapted from DOE 1996a–d; Elvado 2009a–e].

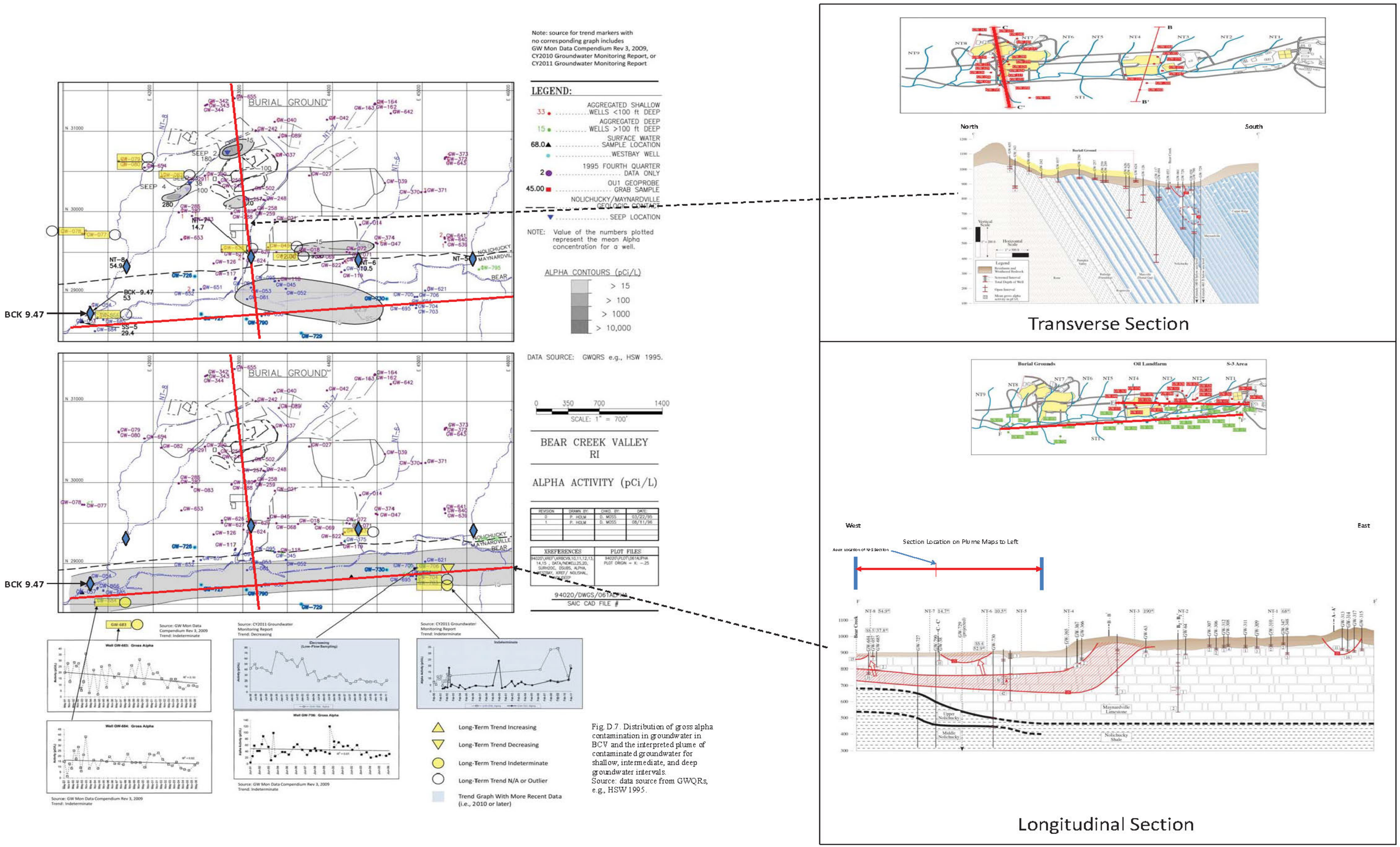

Fig. B.25. Various near-surface uranium signatures in Nolichucky Shale (Plume BCV-6) [adapted from DOE 1996a–d; Elvado 2009a–e].

The following are issues identified in the RER (DOE 2013):

- Documented discharge of contaminants from upstream sources in NT-8.
- A scarcity of groundwater monitoring wells in Zone 2 makes it impossible to precisely map and track groundwater contaminant transport pathways from a DNAPL area in the BCBG and potentially into Zone 1.

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APPENDIX C
UPPER EAST FORK POPLAR CREEK SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

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ACRONYMS

BCV	Bear Creek Valley
bgs	below ground surface
BSWTS	Big Spring Water Treatment System
BTEX	benzene, toluene, ethylbenzene, and xylene
CMTS	Central Mercury Treatment System
COC	chemical of concern
CT	carbon tetrachloride
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
EEMTS	East End Mercury Treatment System
EEVOC	East End Volatile Organic Compound
EFPC	East Fork Poplar Creek
FY	fiscal year
kg	kilogram
MCL	maximum contaminant level
μg/L	micrograms per liter
Mgd	million gallons per day
NPDES	National Pollutant Discharge Elimination System
ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
RCRA	Resource Conservation and Recovery Act of 1976
RI	remedial investigation
^{99}Tc	technetium-99
TCA	trichloroethane
TCE	trichloroethene
TPH	total petroleum hydrocarbons
TR	total risk
UEFPC	Upper East Fork Poplar Creek
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WCPA	Waste Coolant Processing Area
WEMA	West End Mercury Area
Y-12 Complex	Y-12 National Security Complex

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C.1 INTRODUCTION

This Appendix provides a summary of the conceptual model for the Upper East Fork Poplar Creek (UEFPC) Watershed, located in the eastern portion of the Oak Ridge Reservation (ORR), based on the available data and the understanding of the hydrogeologic framework at the time of data collection. The following sections provide a chronology of events associated with the UEFPC Watershed, the primary groundwater contaminant sources identified in the watershed, the geology and hydrology of the watershed, and summaries of the source area conceptual models, including discussions of key data gaps in the individual source area conceptual models. Much of the background information provided herein is from the UEFPC Characterization Area Remedial Investigation (RI) report (DOE 1998). Updated contaminant concentrations and concentration trends have been obtained from recent ORR Remediation Effectiveness Reports (DOE 2012; DOE 2013). The sources for the illustrations presented in this Appendix are indicated on the individual figures.

C.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH THE UEFPC WATERSHED

Table C.1 provides a chronology of historical operations and relevant events related to groundwater contaminant plumes for the UEFPC Watershed.

Table C.1. Chronology of events associated with the UEFPC Watershed

Event	Date
Principal carbon tetrachloride use operations (east end Y-12 area).	1943 – 1948
Former S-2 Site operations.	1943 – 1951
Former S-3 Site and Abandoned Nitric Acid Pipeline operations.	1951 – 1983
Principal mercury use operations (Bldgs. 81-10, 9201-1, 9201-2, 9201-4, 9201-5, and 9204-4).	1950 – 1962
Former Salvage Yard operations: Oil Storage Tanks, Drum Deheader, Tank 2063-U, and Oil Solvent/Drum Storage (OSDS) Area.	1950 – 1989
Former Waste Coolant Processing Area (WCPA) operations.	1977 – 1988
Former Rust Construction Garage petroleum operations.	1964 – 1988
Coal Pile Trench operations.	1965 – 1966
Former East End Fuel Station/Garage Underground Tanks operations.	1945 – 1989
Building 9401-1 Old Steam Building Storage Area RCRA clean closure.	1986
Former S-3 Site RCRA closure.	1988
Former New Hope Pond RCRA closure.	1988
Former Waste Machine Coolant Biodegradation Facility RCRA clean closure (WCPA).	1988
Former Salvage Yard OSDS RCRA closure.	1986 (west unit) 1991 (east unit)
Garage Underground Tanks RCRA clean closure.	1989
The ORR is added to the National Priorities List as a Superfund Site.	11/21/89
Building 9409-5 Storage Facility RCRA clean closure.	1989
Mercury Tanks (2100-U, 2010-U, and 2104-U) Interim Remedial Action.	IROD – 9/26/91 RAR – 12/20/93

Table C.1. Chronology of events associated with the UEFPC Watershed (cont.)

Event	Date
An FFA is established between DOE, EPA, and TDEC.	1/1/92
Final ROD (NFA) for the Plating Shop Container Areas is signed by the FFA parties.	9/30/92
An Agreed Order is signed between TDEC and DOE for corrective actions at the former RCRA-regulated TSDs in the UEFPC Watershed to be performed under CERCLA as the prime regulatory driver with post-closure care and monitoring to be conducted under RCRA (S-3 Site, New Hope Pond).	4/6/93
Final ROD (NFA) for the Abandoned Nitric Acid Pipeline (UEFPC OU 2) is signed by the FFA parties.	9/12/94
DOE adopts the Watershed approach to CERCLA decision-making.	1996
TDEC issues RCRA Post-Closure Permit TNHW-089 for the UEFPC Hydrogeologic Regime (Former S-3 Site east plume, New Hope Pond).	8/30/96
Building 9201-4 Exterior Process Piping Removal Action.	AM – 4/22/97 RmAR – 9/30/99
Union Valley IROD is signed by the FFA parties.	7/10/97
The Final UEFPC Watershed RI is issued.	August 1998
Lead Source Removal of Former YS-860 Firing Range Removal Action.	AM – 3/10/98 RmAR – 2/24/99
Building 9822 Sediment Basin and Building 81-10 Sump Removal Action.	AM – 6/19/98 RmAR – 2/24/99
East End VOC Plume Removal Action.	AM – 6/25/99 RmAR – 6/7/06
Final Phase I Interim ROD for Mercury Source Control Actions is signed by the FFA parties.	5/2/02
Big Spring Water Treatment System Action is complete (PCCR).	7/1/05
Phase II Interim ROD for Contaminated Soils and Scrapyard is signed by FFA parties.	4/21/06
West End Mercury Area remediation: Contaminated storm sewer sediment remedial action is complete (PCCR).	December 2011
Y-12 Old Salvage Yard Remediation Project is complete (PCCR)	August 2012

AM = Action Memorandum.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U.S. Department of Energy.
EPA = U.S. Environmental Protection Agency.
FFA = Federal Facility Agreement.
IROD = Interim Record of Decision.
NFA = no further action.
ORR = Oak Ridge Reservation.
OU = Operable Unit.
PCCR = Phased Construction Completion Report.
RI = remedial investigation.
RAR = Remedial Action Report.
RCRA = Resource Conservation and Recovery Act of 1976.
RmAR = Removal Action Report.
ROD = Record of Decision.
TDEC = Tennessee Department of Environment and Conservation.
TSD = treatment, storage, and disposal.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
Y-12 = Y-12 National Security Complex.

C.1.2 PRIMARY CONTAMINANT SOURCES IN THE UEFPC WATERSHED

The *Report on the Remedial Investigation of the Upper East Fork Poplar Creek Characterization Area at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (DOE 1998) provides comprehensive information on hydrogeology, contaminant sources, and extent of groundwater contamination in the watershed based on data available at that time. Multiple sources of groundwater contamination occur in the UEFPC Watershed, primarily associated with former industrial operations at the Y-12 National Security Complex (Y-12 Complex). Sources include hazardous and nonhazardous waste treatment, storage, or disposal (TSD) sites; bulk product transfer, storage, and use areas; former petroleum-fuel underground storage tanks (USTs) and associated dispensing facilities; industrial process buildings and associated infrastructure; waste and product spill areas; and utilities (e.g., storm sewers). Figure C.1 provides an illustrated conceptual model for the UEFPC Watershed.

Commingling of contaminants from numerous source areas has produced an extensive groundwater contaminant plume of varying composition that extends from the western groundwater divide in the Y-12 Complex area through the southern part of the central and eastern Y-12 areas and into Union Valley east of the ORR. Groundwater contaminant sources include a wide variety of former operations facilities, fuel and petroleum facilities, and waste disposal units. Contributions from various sources are indicated by the presence of "signature" contaminants resulting from particular industrial or waste management operations. In the UEFPC Watershed, the key groundwater contaminant types or "signatures" include:

- Chlorinated solvents [tetrachloroethene (PCE), trichloroethene (TCE), and degradation products; 111-trichloroethane (TCA) and degradation products; and carbon tetrachloride [CT]).
- Petroleum hydrocarbons.
- Uranium (elemental and isotopes).
- Nitrate.
- Technetium-99 (^{99}Tc).

For purposes of U.S. Department of Energy (DOE) ORR groundwater strategy discussions, the multiple sources and groundwater contaminant signatures have been consolidated into seven key groundwater plumes (Tables C.2 and C.3) based on major contaminant type or a dominant source (e.g., Former S-3 Site). Figure C.2 illustrates the generalized extent of groundwater contamination in the UEFPC Watershed and the seven key groundwater plumes.

C.1.3 GEOLOGY AND HYDROLOGY

Surface Water

The UEFPC RI (DOE 1998) provides a description of the surface water system and a watershed-scale water balance. Portions of the UEFPC Watershed are heavily industrialized; a total of 30 to 35% of the watershed area is covered by buildings or paved. During Y-12 construction, an extensive storm sewer network was placed to capture and control flow in filled tributaries to UEFPC, as well as the UEFPC main channel in the western half of the complex. Consequently, all surface water in the western portion of Y-12 is directed through these storm sewer networks and emerges into an above-grade channel at Outfall 200 (North–South Pipe; Fig. C.3). Consequently, approximately 96% of available water for flow (precipitation-evapotranspiration) is directed as runoff to the storm sewer system and drainage ditches,

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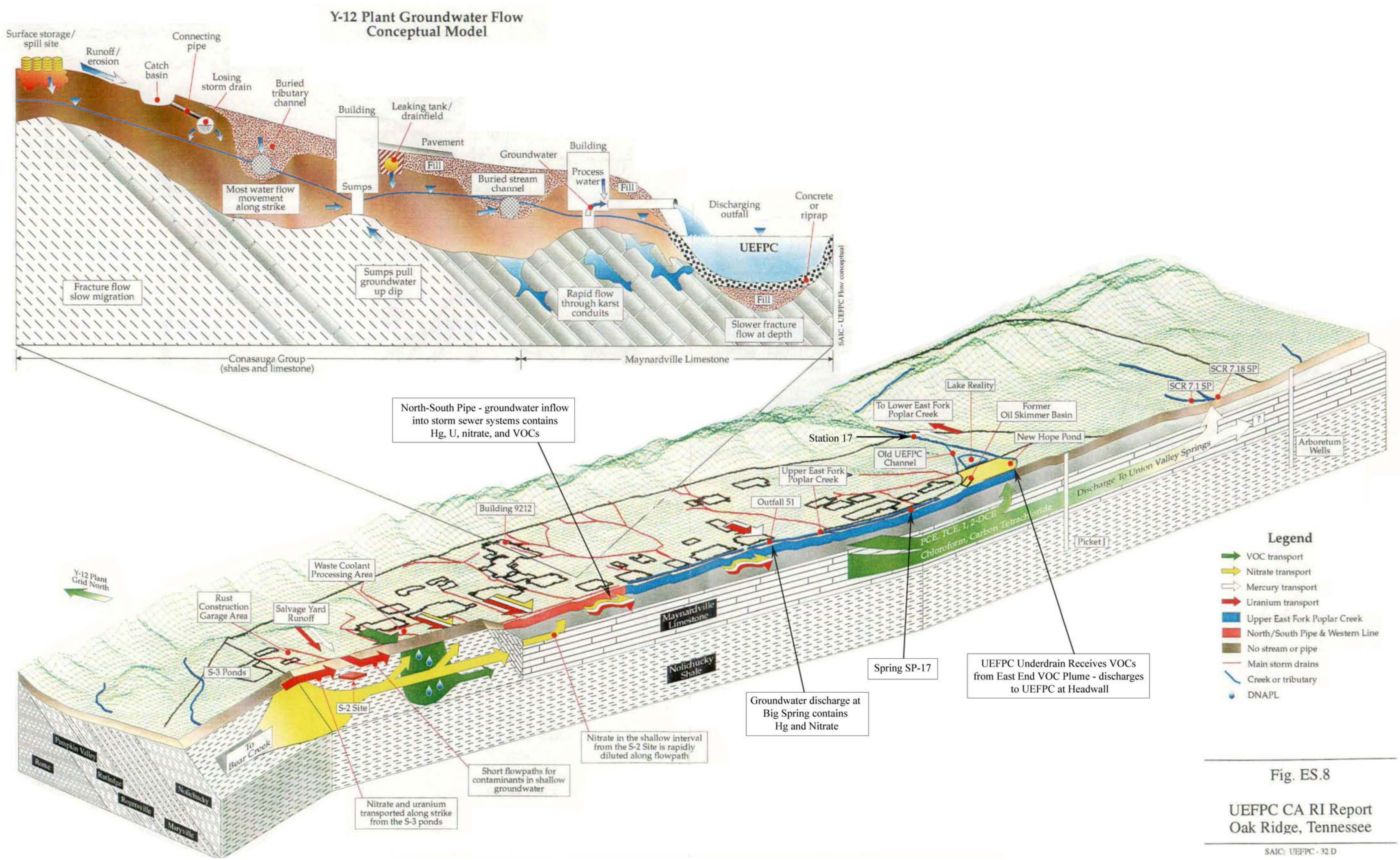


Source: DOE 1998

Fig. C.1. Generalized conceptual model for contaminant transport in the UEFPC Watershed.

Table C.2. Groundwater contaminant plumes in the UEFPC Watershed

Plume description	Plume No.	Source/contaminant signature
S-3 Site Eastern Plume/S-2 Site Plume	UEFPC-1	S-3 Shallow/deep nitrate, uranium, and ^{99}Tc in Nolichucky Shale Nitrate, uranium, metals, and VOCs in Maynardville Limestone
Western and Central Y-12 Area VOC Plume	UEFPC-2	Plant-wide commingled VOC sources (solvents and BTEX): *Nolichucky Shale and Maryville Limestone* Former Salvage Yard (OST, Drum Deheader, Tank 2063-U, OSDS) – PCE, TCE Former Waste Coolant Processing Area (WCPA) – PCE, TCE (potential DNAPL) Buildings 9201-4, 9201-5, and 9204-4 – PCE, TCE Former Rust Construction Garage – BTEX Building 9204-2 vicinity – PCE, TCE Building 9212 vicinity – PCE, TCE Building 9731 vicinity – PCE, TCE *Maynardville Limestone* Former Fire Training Area – PCE, TCE Western Carbon Tetrachloride [CT] Source (undefined) Former S-2 Site – PCE, TCE Buildings 9201-1 and 9201-2 vicinity – BTEX, PCE, and TCE
Western Y-12 Area Uranium Sources in Nolichucky Shale	UEFPC-3	Buildings 9201-4, 9201-5, and 9204-4 Former Salvage Yard
Former East End Fuel Station and Garage Tanks	UEFPC-4	Petroleum products plume in Nolichucky Shale – BTEX, TPH, and minor chlorinated solvents
Uranium Sources in Maynardville Limestone	UEFPC-5	Former S-2 Site Uranium Oxide Vault Coal Pile Trench GW-605/GW-606 source area Former Oil Skimmer Basin
Localized Mercury Sources to Groundwater	UEFPC-6	Buildings 9201-4, 9201-5, and 9204-4 Building 81-10 Buildings 9201-1 and 9201-2 vicinity
East End VOC Plume	UEFPC-7	Shallow/deep CT source (undefined, potential DNAPL) Shallow PCE, TCE source (undefined, former Bldg. 9720-6 vicinity, potential DNAPL)

BTEX = benzene, toluene, ethylbenzene, and xylene.
CT = carbon tetrachloride.
DNAPL = dense non-aqueous phase liquid.
GW = groundwater.
OSDS = Oil Solvent/Drum Storage.
OST = oil storage tank.
PCE = tetrachloroethene.
TCE = trichloroethene.
TPH = total petroleum hydrocarbons.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
Y-12 = Y-12 National Security Complex.

Table C.3. Conceptual model elements for UEFPC groundwater plumes

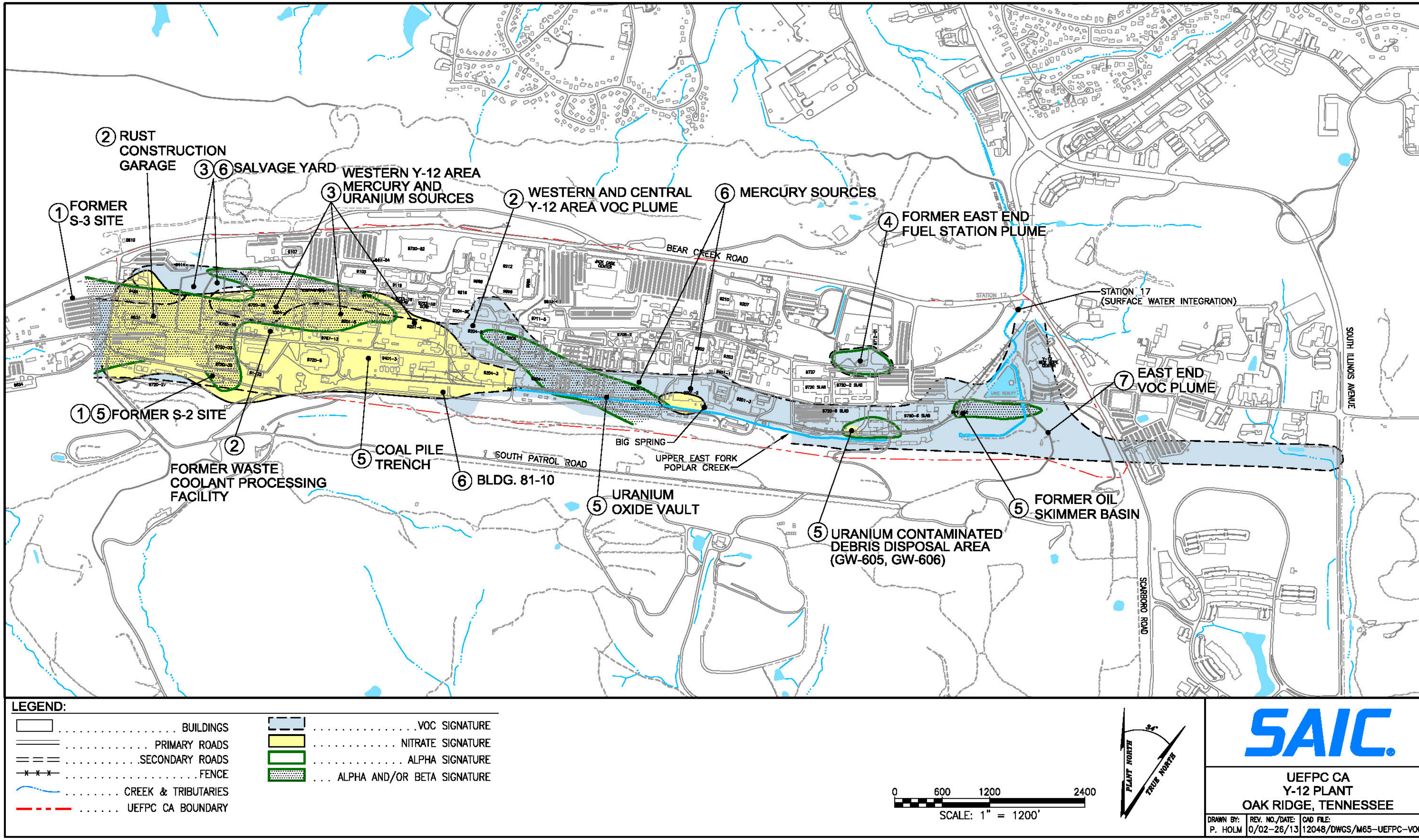
Plume No.	Groundwater plume	Contaminant signature description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Approximate extent (ft down-gradient)	Depth (ft bgs)	Maximum concentration			
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	7500 (nitrate) 4000 (^{99}Tc) 4000 (U, alpha) 4500 (S-2 Site VOCs)	>400	Nitrate: >10,000 mg/L ^{99}Tc: >10,000 pCi/L (gross beta) Uranium (alpha): ~1800 pCi/L Total VOCs (S-2 Site): ~4500 µg/L	Along-strike flow in the Nolichucky; induced flow by building dewatering sumps; S-2 Site: direct leaching to along-strike karst pathways	Storm sewer systems/ buried tributaries Basement sumps in Bldgs. 9204-4, 9201-4, and 9201-5 Discharge to UEFPC and Big Spring at Bldg. 9201-1 (nitrate)	See Table C.4
UEFPC-2	Western and Central Y-12 Area VOC Plume	9000	<100 (typical)	Total VOCs >20,000 µg/L	Along-strike flow in the Nolichucky; buried tributaries; utilities/storm sewers	Storm sewer systems/ buried tributaries Baseflow discharge to UEFPC	See Table C.4
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	2000 (variable)	<50 (sources)	>200 pCi/L (gross alpha)	Along-strike flow in the Nolichucky; buried tributaries; utilities/storm sewers	Storm sewer systems/ buried tributaries Basement sumps in Bldgs. 9204-4, 9201-4, and 9201-5 Discharge to UEFPC above North–South Pipe accounts for ~80% of U flux at Station 17	See Table C.4
UEFPC-4	Former East End Fuel Station and Garage Tanks	300	<50		Along-strike flow in the Nolichucky; utilities/storm sewers	Utility traces/storm sewers east of Portal 5; outfalls 135 and 617	See Table C.4

Table C.3. Conceptual model elements for UEFPC groundwater plumes (cont.)

Plume No.	Groundwater plume	Contaminant signature description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Approximate extent (ft down-gradient)	Depth (ft bgs)	Maximum concentration			
UEFPC-5	Uranium Sources in Maynardville Limestone	1000 (variable)	<50 (sources)	>500 pCi/L (gross alpha)	Leaching/direct contact with groundwater; along-strike karst pathways	Baseflow discharge to UEFPC	See Table C.4
UEFPC-6	Localized Mercury Sources to Groundwater	<1000 (variable)	<50 (sources)	Up to 1.0 mg/L	Buried tributaries; utilities/storm sewers; induced flow by building dewatering sumps; along-strike karst pathways	Storm sewers Discharge to UEFPC Big Spring at Bldg. 9201-2	See Table C.4
UEFPC-7	East End VOC Plume	8000 (CT signature)	>400	Total VOCs >4000 µg/L	Along-strike karst pathways; Former UEFPC channel; UEFPC by-pass underdrain system	Off-Reservation pathways, springs along Scarboro Creek east of ORR UEFPC by-pass underdrain headwall UEFPC baseflow discharge EEVOC plume capture system (GW-845)	See Table C.4

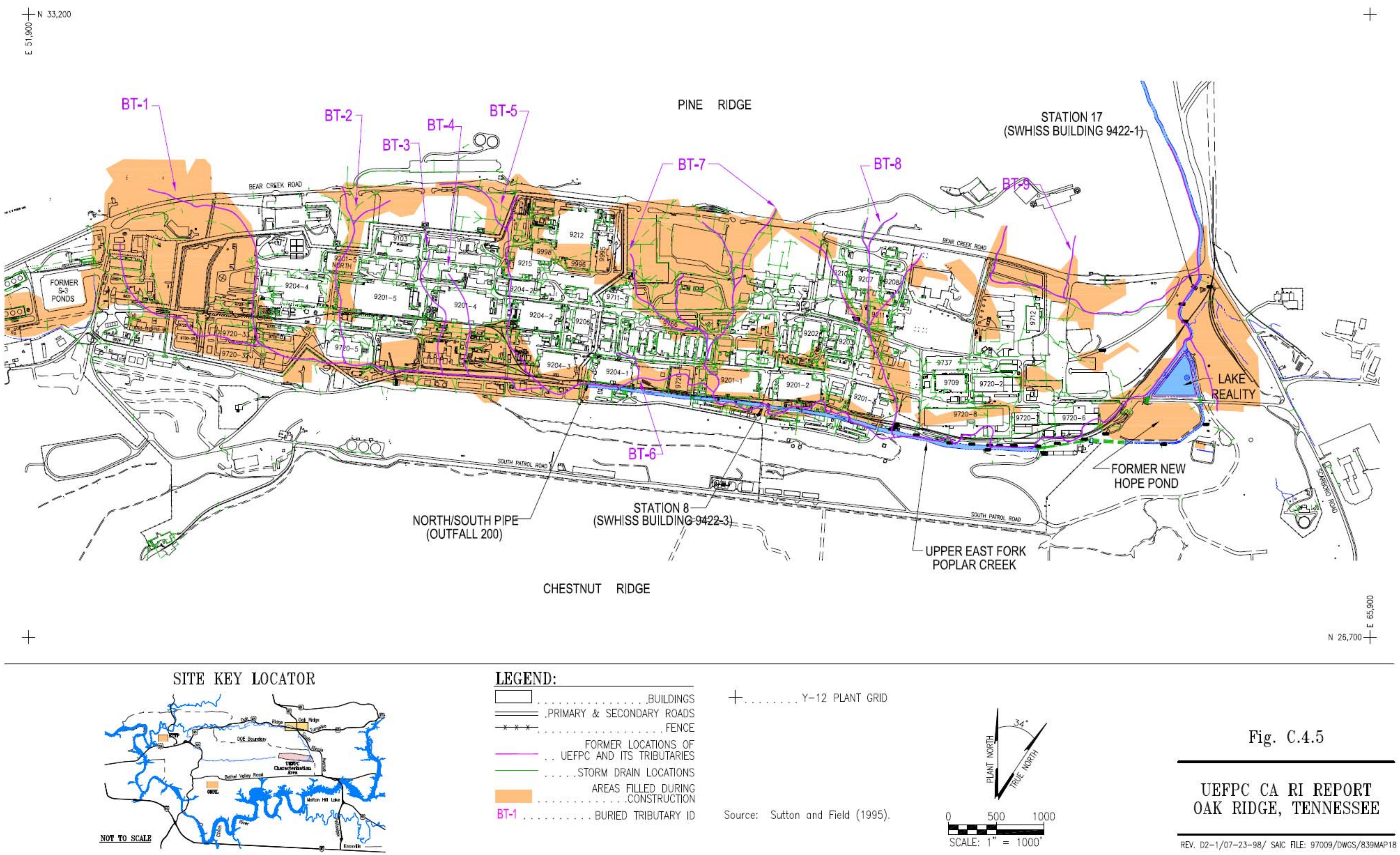
[a] Values are approximate based on available UEFPC Remedial Investigation data and recent groundwater monitoring results.

bgs = below ground surface.
CT = carbon tetrachloride.
EEVOC = East End Volatile Organic Compound.
GW = groundwater.
ORR = Oak Ridge Reservation.
µg/L = micrograms per liter.
mg/L = milligrams per liter.
pCi/L = picocuries per liter.
^{99}Tc = technetium-99.
U = uranium.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
Y-12 = Y-12 National Security Complex.



Source: adapted from DOE 2013

Fig. C.2. Groundwater contaminant plumes and generalized distribution of principal contaminants in the UEFPC Watershed.



Source: DOE 1998

Fig. C.3. Original UEFPC channel and tributaries showing areas of fill.

enters the above-ground channelized portion of UEFPC, and exits the watershed as surface flow at Station 17.

An estimated 3 to 3.5% of available water infiltrates to groundwater and discharges as baseflow to UEFPC through the creek channel or from storm sewers discharging to the creek. This baseflow discharge comprises an estimated 30% of the surface water flow in UEFPC. The remaining estimated 70% of surface water flow in UEFPC is derived from process discharges and precipitation. An estimated 0.5 to 1% flows along strike of the Maynardville Limestone exit pathway to the east and discharges to the Scarboro Creek drainage system and possibly springs along Scarboro Creek. Because surface water is the primary migration pathway for contaminants from the UEFPC Watershed, remedial actions and environmental monitoring have focused on surface water (primarily mercury reductions) with emphasis on the UEFPC exit point from the ORR (Station 17) and on the major surface water monitoring sites within the watershed (e.g., North–South Pipe). An exception is the East End Volatile Organic Compound (EEVOC) Plume removal action. Under the 1995 National Pollutant Discharge Elimination System (NPDES), augmentation of flow (flow management) in UEFPC was begun to offset long-term decreases in flow resulting from reductions in non-contaminated cooling and process water discharges via outfalls. Flow management objectives were to increase and stabilize flow in order to improve and protect stream water quality and aquatic biota, which has been in recovery. A pipeline to provide raw water from the Clinch River was constructed and the input point to UEFPC was established immediately downstream of the North–South Pipe (Fig. C.1).

Groundwater

The majority of sources in UEFPC overly the Nolichucky Shale (aquitard) or Maynardville Limestone (aquifer) of the Conasauga Group (Fig. C.4). These sources released contaminants to shallow groundwater via surface or near-surface releases with subsequent vertical and lateral migration through strike and dip parallel fracture networks, along utility systems and buried tributaries to UEFPC, and in karst flowpaths in the Maynardville Limestone.

Aquitard (Nolichucky Shale)

Shallow groundwater flowpaths in the Nolichucky Shale are typically along-strike, comparatively short relative to those in the Maynardville Limestone, and terminate at infrastructure end points. The operation of basement dewatering sumps and the network of subsurface storm drains and utilities throughout much of the western and central Y-12 areas strongly influence the movement and discharge of shallow groundwater and entrained contaminants. In the western half of the Y-12 Complex, storm sewer lines were laid within a number of former tributaries to UEFPC, as well as the former UEFPC channel, and the tributaries infilled during Y-12 construction (Fig. C.3). Some of these storm sewers have seasonal or year-round base flow, indicating groundwater influx, and UEFPC discharges to an above-grade channel at the North–South Pipe (Outfall 200). Decades of basement dewatering sump operations in Bldgs. 9201-5, 9201-4, and 9204-2 have produced a long-term capture zone for shallow groundwater in the western Y-12 area and influenced eastward migration of nitrate and ^{99}Tc from the former S-3 Ponds.

Aquifer (Maynardville Limestone)

Groundwater flow in the Maynardville Limestone is to the east along geologic strike toward Union Valley east of the ORR boundary. Groundwater flow occurs through a highly interconnected network of solutionally enlarged fractures and cavities, which has a high degree of interconnectedness with UEFPC surface water in the eastern half of the Y-12 Complex below the North–South Pipe. Two springs

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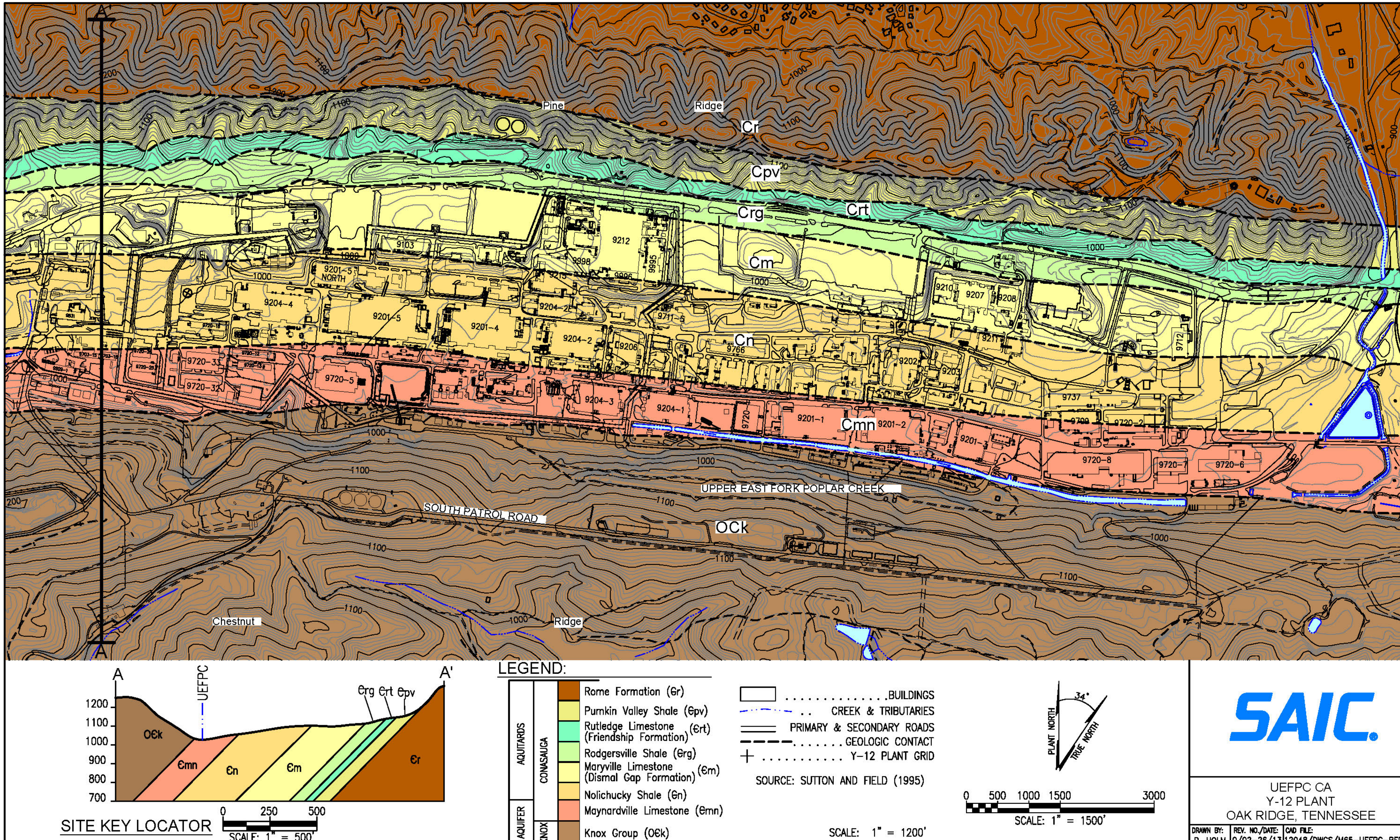


Source: DOE 1998

Fig. C.4. Bedrock geology of the UEFPC Watershed.

discharge groundwater directly to UEFPC in the eastern Y-12 areas (Big Spring, with estimated baseflow of 50 to 80 gallons per minute, and a small spring, SP-17, located on the south side of the creek [Fig. C.1]). Big Spring is a mercury source to UEFPC and a treatment system was completed in 2005 to treat discharge from Outfall 51, including that from Big Spring, prior to entering UEFPC.

A distribution channel constructed in 1989 to divert UEPFC around the former New Hope Pond to Lake Reality contains a perforated pipe and gravel underdrain system that apparently functions as a highly permeable groundwater flowpath that strongly influences local flow directions. Lake Reality has been by-passed since 1998 and the distribution channel and underdrain terminate in a headwall and discharge point at the north end of Lake Reality. Shallow groundwater flow in the Maynardville Limestone in the eastern Y-12 area is directed to the north along the UEFPC channel and underdrain system, while intermediate and deep groundwater flow is off of the ORR to the east into Union Valley, as indicated by monitoring data and pumping and dye-tracer tests conducted in 1998. The pumping and dye-tracer tests also provided evidence of a high degree of hydraulic connection between the UEFPC distribution channel underdrain and groundwater in the deeper intervals of the Maynardville Limestone.

Groundwater/Surface Interaction

Groundwater/surface water interactions in the UEFPC Watershed are highly complex and affected by the extensive storm sewer infrastructure systems noted above. Specific point discharges of groundwater to the UEFPC surface water system are difficult to identify due to the fact that all tributaries and the western half of the UEFPC main stem are contained within underground piping systems. As of the 1995 NPDES permit, 179 outfalls were connected to UEFPC (60 outfalls west of the North–South Pipe) and groundwater influx via cracked or broken pipes may serve as points for influx of groundwater in many of these outfalls. Known major groundwater contributions to the UEFPC surface water system in the western portion of the complex include the large-scale basement dewatering sump operations in Bldgs. 9201-5, 9201-4, and 9204-2, which are part of the West End Mercury Area (WEMA). The flows from these buildings are treated through the Central Mercury Treatment System (CMTS) prior to discharge into the storm sewer network. Dewatering sumps in Bldg. 9201-5 were shut down in November 2005.

The extensive epikarst system within the Maynardville Limestone promotes interaction between groundwater and surface water along the length of the above-grade section of UEFPC. The two major point discharges of groundwater to surface water in this portion of UEFPC include Big Spring and the UEFPC Lake Reality by-pass channel underdrain system (Fig. C.1). Available data indicate Big Spring is an exit point for nitrate associated with the former S-3 Site and S-2 Site (plume UEFPC-1), low levels of volatile organic compounds [VOCs] (plume UEFPC-2), and mercury (plume UEFPC-6). As noted earlier, the Lake Reality by-pass underdrain system is an exit point for shallow and deep upwelling groundwater containing VOCs associated with the EEVOC Plume (e.g., CT, PCE, and TCE). Operating basement dewatering sumps in Bldg. 9201-2 capture shallow mercury-contaminated groundwater, which is treated via the Big Spring Water Treatment System (BSWTS) prior to discharge to UEFPC. Groundwater in deeper strike-parallel flowpaths exits the ORR to the east with discharge at springs SCR7.1SP, SCR7.18SP, and possibly a spring located at the University of Tennessee Arboretum (see Sect. 2.7).

Downstream of Station 17, East Fork Poplar Creek (EFPC) gains flow through baseflow discharge. Strong upward, vertical hydraulic gradients exist in the EFPC water gap through Pine Ridge northeast of Y-12, as evidenced by artesian monitoring wells located in the this area.

C.1.4 SUMMARY OF GROUNDWATER CHEMICALS OF CONCERN AND RISK

The primary groundwater chemicals of concern (COCs) identified in the UEFPC RI (DOE 1998) include the following:

- VOCs, primarily chlorinated solvents and benzene, which occur in various locations in shallow (less than 70 ft below ground surface [bgs]) and intermediate (70 to approximately 300 ft bgs) groundwater intervals in the Nolichucky Shale, as well as in the Maynardville Limestone to depths greater than 400 ft bgs associated with the EEVOC Plume.

- Localized metals, including arsenic, beryllium, cadmium, chromium, and manganese in the Nolichucky Shale, as well as cadmium in the Maynardville Limestone.

- Nitrate associated with releases from the former S-3 Ponds.

- Radiological contaminants in association with the former S-3 Ponds (uranium isotopes, ^{99}Tc, ^{237}Np, and ^{90}Sr) and other localized areas near wells GW-605 and GW-606 (Maynardville Limestone, eastern Y-12 area); the former S-2 Site (Maynardville Limestone, western Y-12 area); and Bldg. 9731 (Nolichucky Shale).

Based on the UEFPC RI (DOE 1998), multiple individual source areas within UEFPC have associated groundwater contamination at concentrations resulting in elevated total risk (TR) $>10^{-4}$ or chemical toxicity with hazard index >3 for a residential receptor. The primary groundwater COCs with elevated risks ($>10^{-4}$) for a residential receptor in UEFPC are:

- VOCs, including chlorinated solvents and degradation products and benzene, in shallow and intermediate depth groundwater in both the Nolichucky Shale and Maynardville Limestone.

- Arsenic, beryllium, cadmium, chromium, and manganese in the Nolichucky Shale, as well as cadmium in the Maynardville Limestone. The UEFPC RI noted the number of beryllium detections in the historical groundwater database was small (22 of 87 total measurements); however, conservative toxicity factors resulted in a TR $>10^{-4}$. Elevated risk due to total chromium is associated with groundwater in the Nolichucky Shale in the vicinity of the former S-3 Ponds.

- Nitrate in shallow and intermediate groundwater in the Nolichucky Shale near the former S-3 Ponds.

- Uranium isotopes, ^{99}Tc, ^{237}Np, and ^{90}Sr in groundwater near the former S-3 Ponds. In addition, uranium presented elevated risk in other localized areas near wells GW-605 and GW-606 (Maynardville Limestone, eastern Y-12 area), the former S-2 Site (Maynardville Limestone, western Y-12 area), and Bldg. 9731 (Nolichucky Shale).

C.2 CONCEPTUAL MODEL, SOURCE AREA SCALE

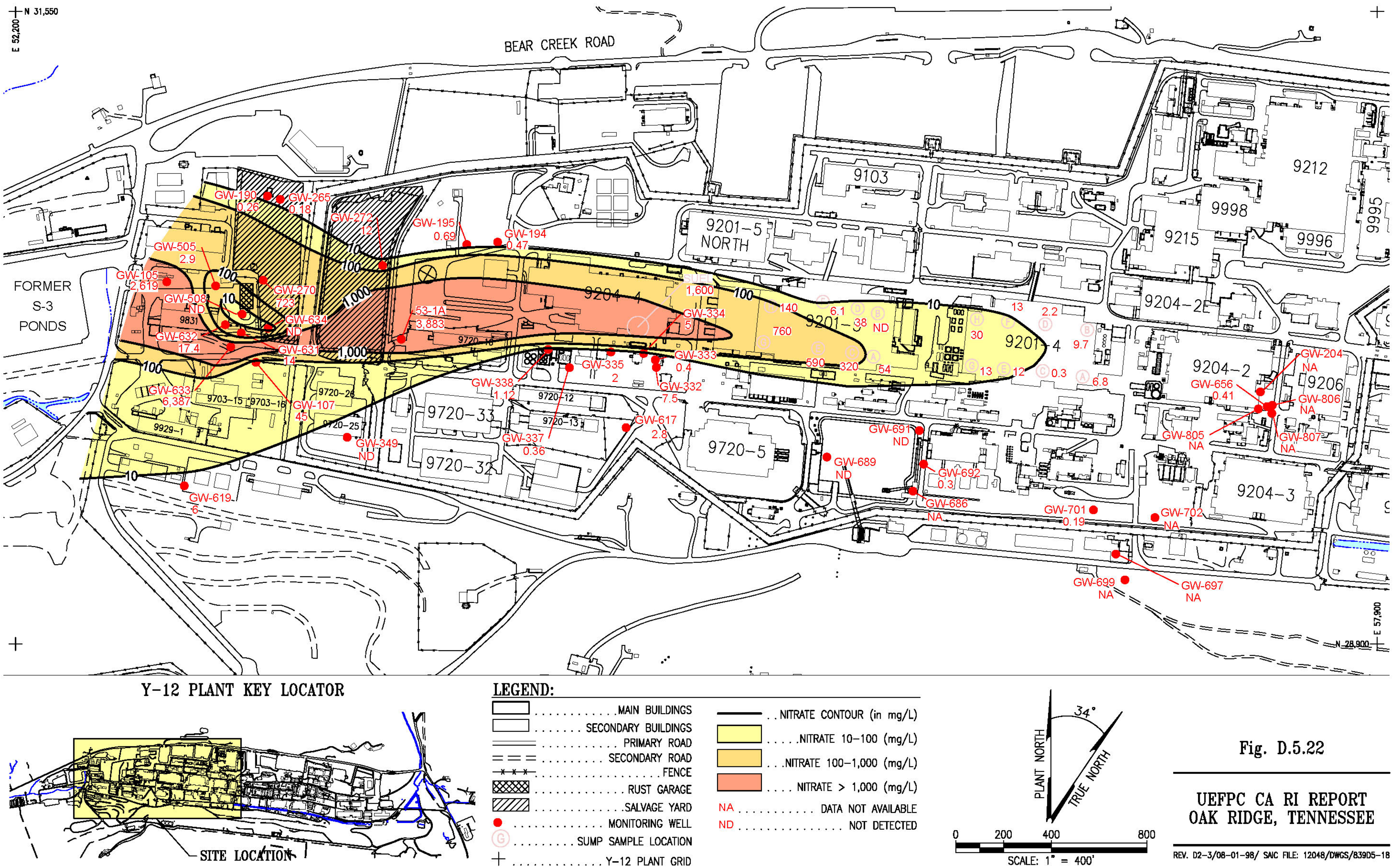
C.2.1 UEFPC-1 S-3 SITE EASTERN PLUME/S-2 SITE PLUME

The former S-3 Site was constructed in 1951 and operated until 1983 (Figs. C.1 and C.2). Uranium-contaminated nitric acid solutions and other liquid waste streams were piped or trucked from process areas of the Y-12 Complex and disposed in four unlined ponds. Periodic disposal of ^{99}Tc-bearing liquid wastes at the S-3 Site is also documented. The former S-3 Site was closed under the Resource Conservation and Recovery Act of 1976 (RCRA) in 1988 by neutralizing sediment within the ponds, stabilizing the ponds with aggregate, and placing a multi-layer cap and asphalt cover over the unit. The site is currently used as a parking lot.

The acidity and density of liquid wastes placed in the former S-3 Site resulted in dissolution of carbonate in bedrock strata beneath the site and density-driven vertical migration of wastes, which emplaced a large mass of nitrate and ^{99}Tc contamination to depths of at least 500 ft in the Nolichucky. The former S-3 Site is located near the topographic, surface water, and shallow groundwater divide between Bear Creek Valley (BCV) and the UEFPC Watershed. During operation of the impoundment, a constant hydraulic head was maintained, which resulted in a westward shift of the shallow groundwater divide and induced flow into both BCV and the UEFPC Watershed. Due to this hydraulic mechanism, contaminant plumes in both shallow and deep groundwater extended west into the Bear Creek Watershed and east into the western Y-12 area. The plume of nitrate contamination originating from the former S-3 Ponds extends vertically in the aquitard at least 150 ft bgs and laterally at least 5000 ft into the western Y-12 area (Figs. C.5 through C.7). Nitrate contamination in the Maynardville Limestone extends downgradient and along-strike approximately 7500 ft east of the former ponds (Fig. C.2).

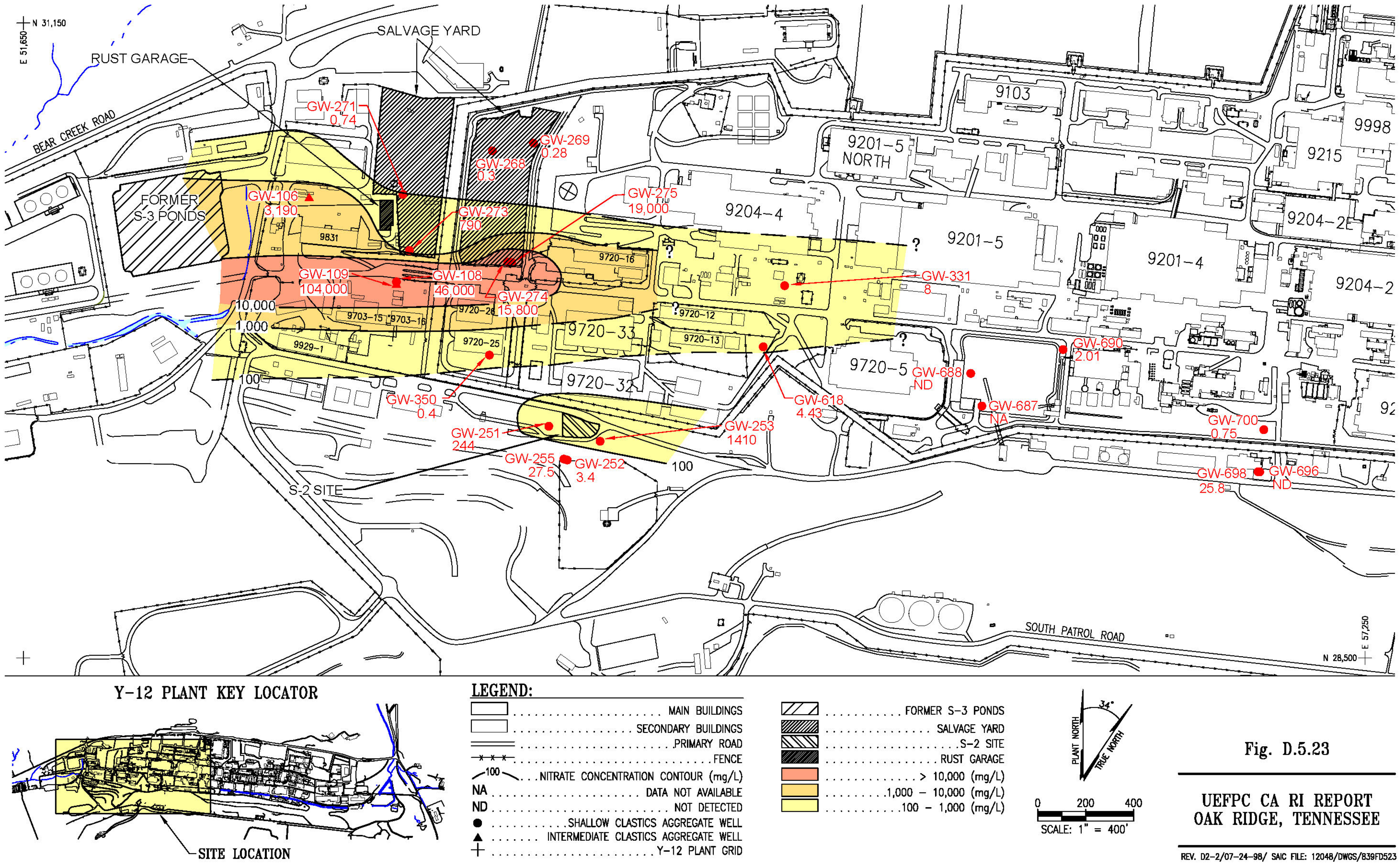
The former S-3 Ponds are a principal source of uranium isotopes (primarily ^{234}U and ^{238}U) and the only known source of ^{99}Tc in the western Y-12 area; the migration of ^{99}Tc generally mirrors that of nitrate. Low pH groundwater in the vicinity of the former S-3 Ponds also contains a diverse mix of metal ions and/or ion-complexes that are usually not mobile in less acidic groundwater, as well as metals that are mobile under a wider range of groundwater pH conditions (barium, boron, strontium, and uranium). Average isotopic ratios for ^{234}U/^{238}U in groundwater in the vicinity of the former S-3 Site range are less than 1.0 (well GW-615, spring SS-1).

The former S-2 Site operated from 1943 until 1951 and consisted of an unlined disposal pit excavated into the lowermost slope of Chestnut Ridge (45 ft wide × 128 ft long × 20 ft deep). No records of the volume or types of waste disposed at the former S-2 Site exist; however, available operational information indicates that the unit was used primarily for disposal of deteriorated chemical reagents and spent extraction raffinates. These wastes are believed to be primarily acidic solutions (nitric, sulfuric, and hydrochloric acids) containing uranium, heavy metal nitrates, and possibly cyanide. Numerous other types of wastes are noted in the UEFPC RI (DOE 1998). Spent solvents were not noted as a potential waste stream in the UEFPC RI; however, groundwater monitoring data indicate a PCE and TCE signature attributable to the site (historical PCE/TCE combined maximum up to 24,000 μg/L). The former S-2 Site was closed at some time in the mid-1950s (after 1954); wastes were chemically neutralized and the pit was backfilled with soil and seeded with grass. Groundwater monitoring data further document that the former S-2 Site is a source of uranium (metallic and isotopes), nitrate (up to 1400 mg/L), and localized metals (e.g., beryllium, cadmium, copper, and lead) above maximum contaminant levels (MCLs). Average isotopic ratios for ^{234}U/^{238}U in groundwater in the vicinity of the former S-2 Site range exceed 3.5 (wells GW-251 and GW-253), indicating a different waste composition and contaminant signature than that observed for the former S-3 Site.



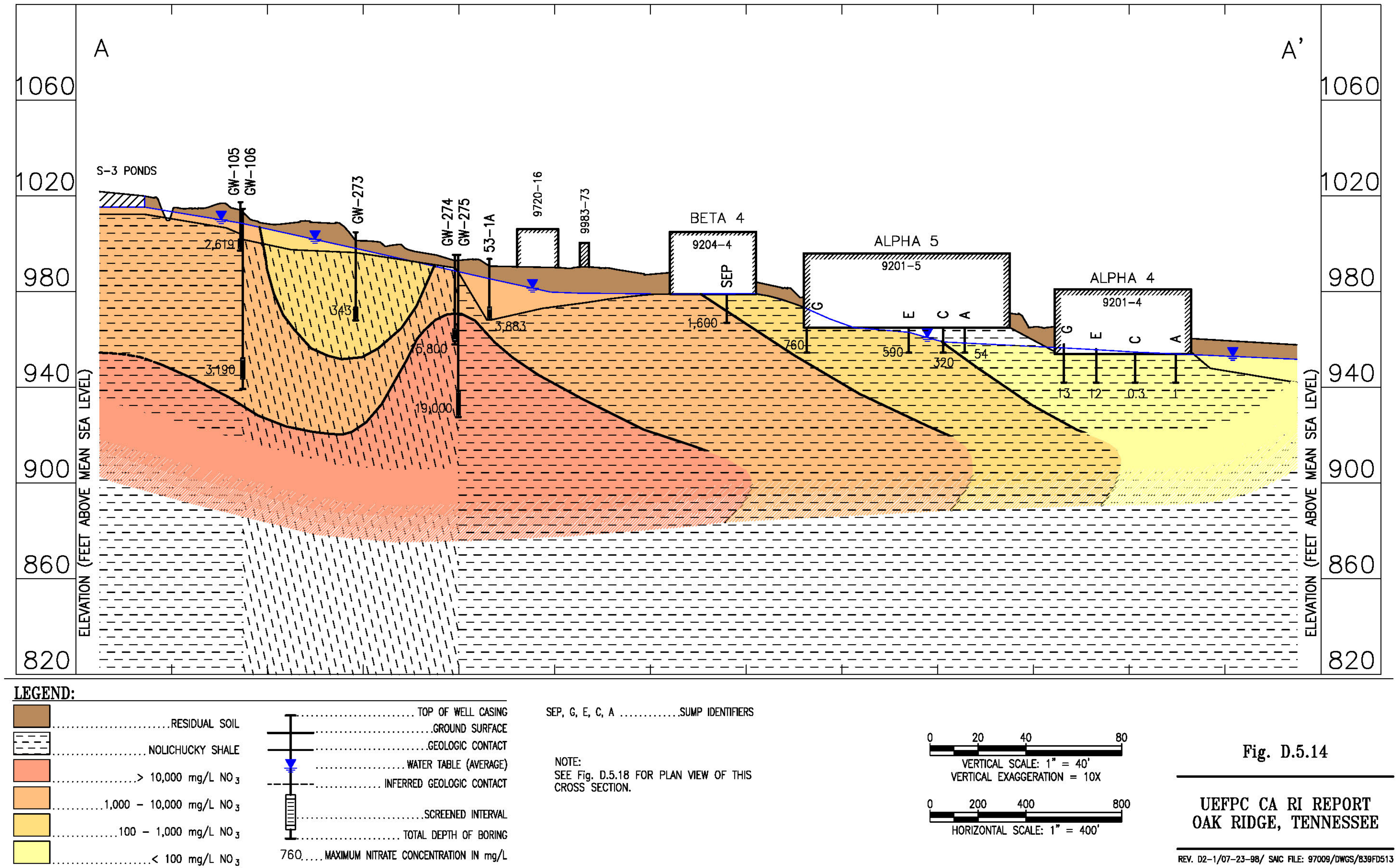
Source: DOE 1998

Fig. C.5. Nitrate distribution in the western Y-12 area – water table interval (wells <30 ft depth).



Source: DOE 1998

Fig. C.6. Nitrate distribution in the western Y-12 area – shallow and intermediate depths (wells 30 to 150 ft depth).



Source: DOE 1998

Fig. C.7. Cross-section of the Former S-3 Site nitrate plume – western Y-12 area.

C.2.2 UEFPC-2 WESTERN AND CENTRAL Y-12 AREA VOC PLUME

VOCs are the most pervasive groundwater contaminants in the UEPFC Watershed (Fig. C.2). Principal "signature" components of dissolved VOC plumes in the western and central portions of the Y-12 Complex include PCE, TCE, *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC). Chloroethanes (e.g., 1,1,1-TCA and 1,1-dichloroethane [DCA]) are also major components of the plume in the central portion of the Y-12 area. The full vertical and horizontal extent of the VOC plume in these areas of Y-12 is not well defined.

Multiple sources exist in these areas of Y-12; however, the UEFPC RI identified the Former Salvage Yard, several western Y-12 production buildings, and the former Waste Coolant Processing Area (WCPA) as key contributors. Petroleum products (e.g., benzene, toluene, ethylbenzene, and xylene [BTEX] and total petroleum hydrocarbons [TPH]) occur in groundwater in the vicinity of the former Rust Construction Garage and several former UST locations.

Significant mass and concentrations of PCE, TCE, and degradation products occur in the shallow and intermediate groundwater intervals of the Nolichucky Shale in the vicinity of the Former WCPA, indicating the presence of dense non-aqueous phase liquid (DNAPL) [recent summed chloroethene concentrations greater than 7000 micrograms per liter (μg/L)]. Migration pathways for VOCs in the Nolichucky Shale are primarily strike-parallel, shallow fracture pathways terminating at utility systems (e.g., storm sewers); buried tributaries; and building dewater sumps. Sampling of storm sewer systems and UEFPC surface waters shows that VOCs rapidly attenuate upon entering these pathways. Some transfer of VOCs into the Maynardville Limestone likely occurs; however, rapid dilution and attenuation in the karst system appear to occur based on available data from this pathway.

C.2.3 UEFPC-3 WESTERN Y-12 AREA URANIUM SOURCES IN THE NOLICHUCKY SHALE

Multiple localized sources of uranium to shallow groundwater in the Nolichucky Shale exist in the western Y-12 area (Fig. C.2). The primary historical sources are former waste management activities in the Y-12 Salvage Yard and historical operations in production facilities, including Bldgs. 9201-4, 9201-5, and 9204-4, which generated uranium-contaminated liquid waste streams, such as machine coolants and oils and mop waters. Scrap metal removal from the Salvage Yard was completed in January 2011 (DOE 2011), and soil removal and site stabilization were completed in May 2012 (DOE 2012a).

Migration pathways for uranium from these sources are primarily strike-parallel, shallow fracture pathways terminating at utility systems (e.g., storm sewers); buried tributary systems; and building dewatering sumps. Uranium mass balance data from the UEFPC RI and subsequent data indicate a significant transfer of uranium mass from storm sewer sediments and shallow groundwater to surface water in UEFPC. The UEFPC RI mass balance showed the North–South Pipe (Outfall 200) accounted for approximately 80% of uranium flux at the watershed exit point at Station 17. More recent watershed flux data suggest that the North–South Pipe accounts for most baseflow uranium flux to UEFPC; however, downstream sources in the UEFPC channel (sediment, bank soil, and groundwater) contribute uranium mass during storm flow periods.

C.2.4 UEFPC-4 FORMER EAST END FUEL STATION AND GARAGE TANKS

Two fuel stations (Bldgs. 9754 and 9754-2) and associated infrastructure operated in the eastern portion of the Y-12 Complex between 1945 and 1989. A total of eight USTs from leaded, unleaded, and diesel fuel operations were installed at various points in time; all were removed from operation, excavated, and closed under Tennessee UST regulations as of 1993.

Between 1980 and 1989, two of three tanks installed north of the former fuel station Bldg. 9754 (Garage Tanks) were used for RCRA waste oil storage (polychlorinated biphenyl [PCB], PCE, and Freon-113 contaminated oil) and were clean closed in 1994, during which time 40 drums of cadmium-contaminated soil were removed. The third Garage Tank was used for non-RCRA waste oil storage and closed under the Toxic Substances Control Act of 1976.

Petroleum operations resulted in free product and dissolved-phase BTEX contamination in shallow groundwater. Free product removal actions were completed under Tennessee UST regulations. Based on site characterization studies, contaminants migrated through the unconsolidated zone, fractures in shallow bedrock, and along preferential pathways, such as utility traces and storm sewers to the south and east of the former fuel station.

C.2.5 UEFPC-5 URANIUM SOURCES IN THE MAYNARDVILLE LIMESTONE

Multiple sources of uranium to shallow groundwater (Fig. C.2) in the Maynardville Limestone include former disposal units (e.g., former S-2 Site, Coal Pile Trench, and Uranium Oxide Vault) and miscellaneous sources (e.g., Oil Skimmer Basin, debris disposal near wells GW-605 and GW-606).

Potentiometric data indicate these sources are partially inundated and potentially leach uranium directly to shallow groundwater. In the case of the former S-2 Site, liquid wastes containing uranium were placed into the unlined impoundment and allowed to percolate into shallow karst pathways. The Coal Pile Trench contains approximately 3.8 million pounds of depleted uranium and alloys and the base of the trench (approximately 15 ft bgs) likely intersects the water table, especially during wet season conditions. Similarly, the Uranium Oxide Vault contains approximately 224 tons of uranium oxide dross and intersects the water table. Contaminated debris disposal in the vicinity of wells GW-605 and GW-606 and contaminated UEFPC sediment accumulation in the former Oil Skimmer Basin contribute uranium through direct contact with shallow groundwater.

Strike-parallel (eastward) migration of uranium occurs through karst conduits in the Maynardville Limestone with discharge occurring to UEFPC surface water and surface water exit points in the eastern Y-12 area.

C.2.6 UEFPC-6 LOCALIZED MERCURY SOURCES TO GROUNDWATER

Historical mercury releases at the Y-12 Complex have resulted in significant residual contaminant mass in soil surrounding former mercury use buildings, as well as storm sewer and UEFPC channel sediments. Mercury concentrations above MCLs in groundwater are limited to the immediate vicinity of a few former operational areas and sites (e.g., Bldgs. 9204-4, 9201-4, 9201-5, 9201-2, and 81-10).

Pathways for mercury migration in groundwater are localized and have been heavily influenced by dewatering sumps in WEMA Bldgs. 9201-4 and 9201-5 and in Bldg. 9201-2. At Bldg. 9201-2,

mercury-contaminated groundwater migrates via short karst flowpaths to discharge at Big Spring. Contaminated groundwater extracted by dewatering sumps, and from Big Spring discharge, has been subject to treatment prior to discharge to surface water since the late 1980s (CMTS, East End Mercury Treatment System[1]/BSWTS).

C.2.7 UEFPC-7 EAST END VOC (EEVOC) PLUME

In the eastern portion of the Y-12 Complex, chloromethanes (CT, chloroform, and methylene chloride) are “signature” components of a VOC plume extending from approximately Bldg. 9201-1 off of the ORR into Union Valley to the east. CT was used in large quantities at Y-12 in the early and mid-1940s as part of electromagnetic separation operations to enrich uranium.

Chlorinated solvents (PCE, TCE) are commingled with CT and appear to primarily originate from an undefined source (historical spill) east of former Bldg. 9720-6. Historical maximum concentrations of PCE (2600 μg/L) approach 1% pure-phase solubility indicating potential DNAPL as a secondary source for dissolved-phase VOCs.

Migration pathways for the EEVOC Plume include shallow groundwater pathways to the northeast associated with the former UEFPC channel (infilled) and the Lake Reality by-pass underdrain system. Deep groundwater migration pathways include strike-parallel karst conduits in the Maynardville Limestone extending to the east off of the ORR into Union Valley.

Significant mass and concentrations of CT occur in the Maynardville Limestone in the eastern portion of the Y-12 Complex, with recently detected concentrations greater than 4000 μg/L at depths of 380 ft bgs (Figs. C.8 and C.9). Dissolved concentrations of CT indicate residual DNAPL acts as a secondary source.

A plume capture system was constructed as part of the EEVOC Plume Removal Action and went operational in October 2000 (Fig. C.10). The plume capture systems includes a deep, open-hole pumping well (GW-845, 280-ft open interval extending down to an elevation of approximately 500 ft above mean sea level) spanning a large section of the Maynardville Limestone. Plume capture system operational data show that continuous operation has generally maintained 15 to 17 ft of drawdown in the immediate vicinity of the deep pumping well (GW-845, Fig. C.10) and has established an elongated zone of influence that spans the Maynardville Limestone subcrop and extends parallel with geologic strike for at least 900 ft to the east (downgradient) and 600 ft to the west (upgradient). Approximately 74 kilograms (kg) of CT mass and 8.7 kg of PCE mass were removed by the system between the start of operations and end of fiscal year (FY) 2011 (DOE 2012b). Performance monitoring data collected downgradient of the pumping well show the plume capture system has effectively intercepted contaminants migrating to the east along karst and fracture pathways (Fig. C.11). The average isotopic activities in treatment system effluent equate to about 4 μg/L of uranium metal, which is equal to the project-specified detection limit for uranium as a metal, and is much less than the 30 μg/L MCL reference concentration. Based on the average groundwater withdrawal rate throughout FY 2011, the uranium mass discharged from the EEVOC system was approximately 0.16 kg for the year (DOE 2012b).

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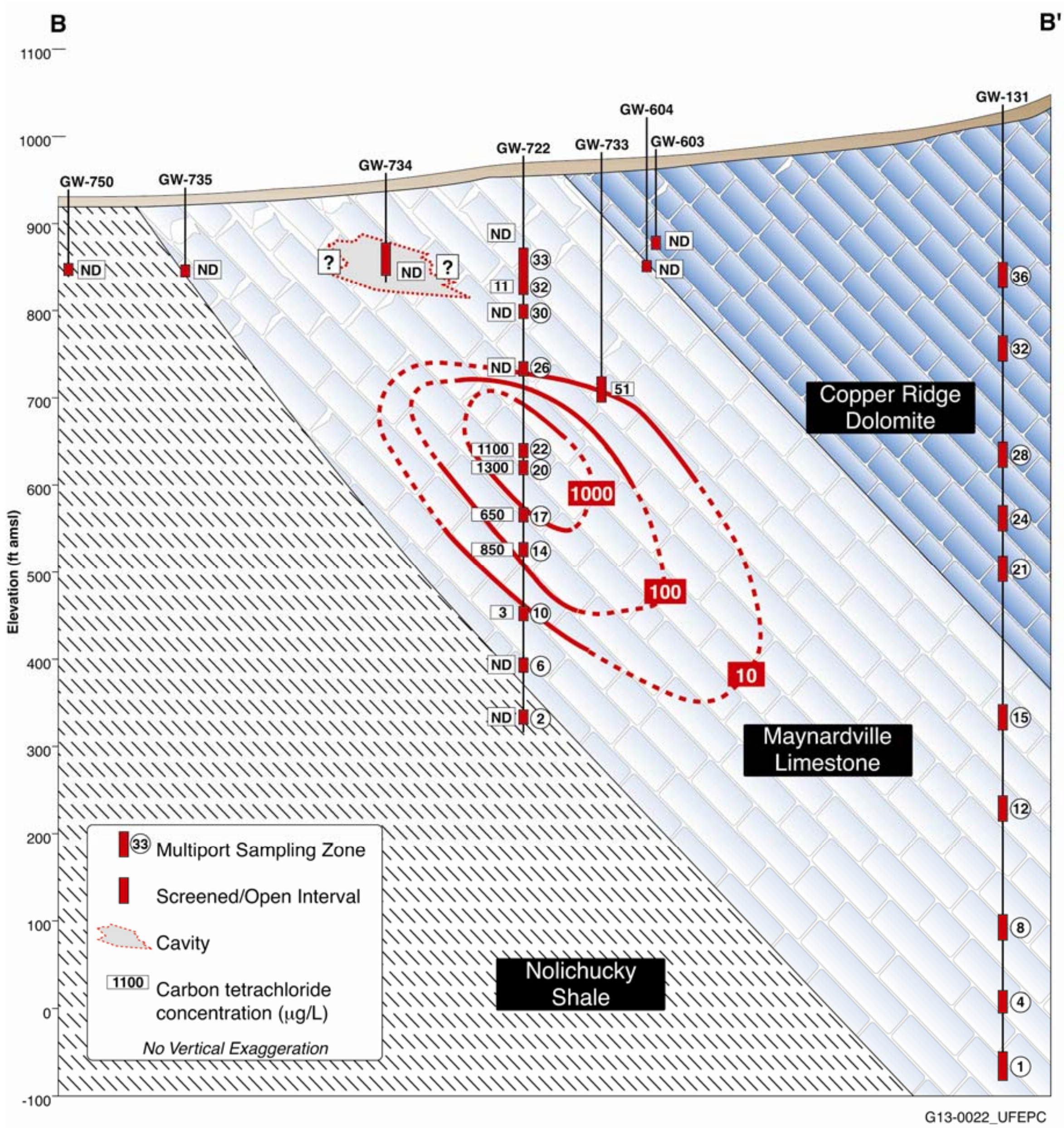
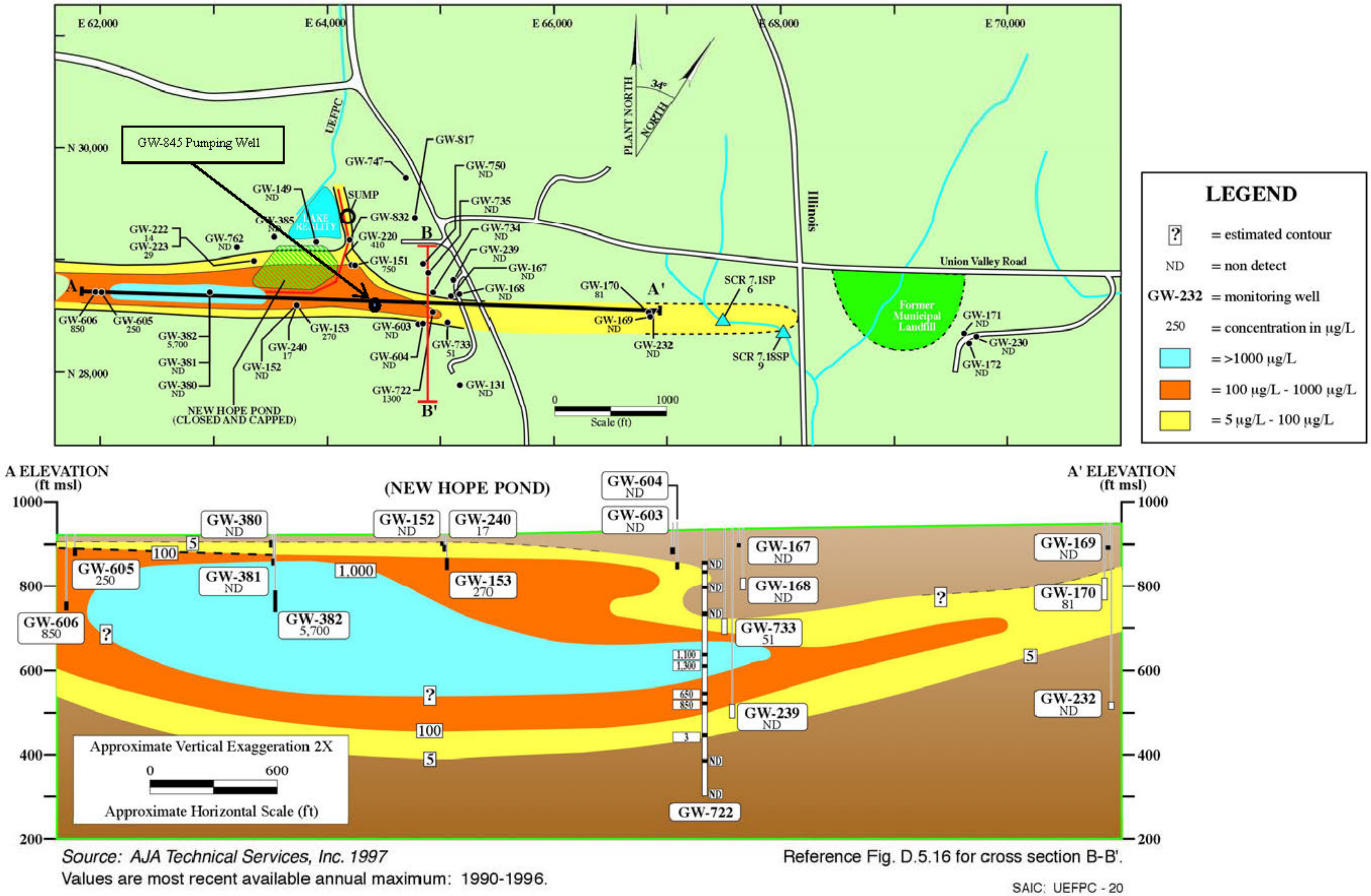
[1] Mercury-contaminated water was rerouted from the Bldg. 9201-2 sumps and the East End Mercury Treatment System (EEMTS) to the Big Spring Water Treatment System in December 2006. The EEMTS is no longer in operation.



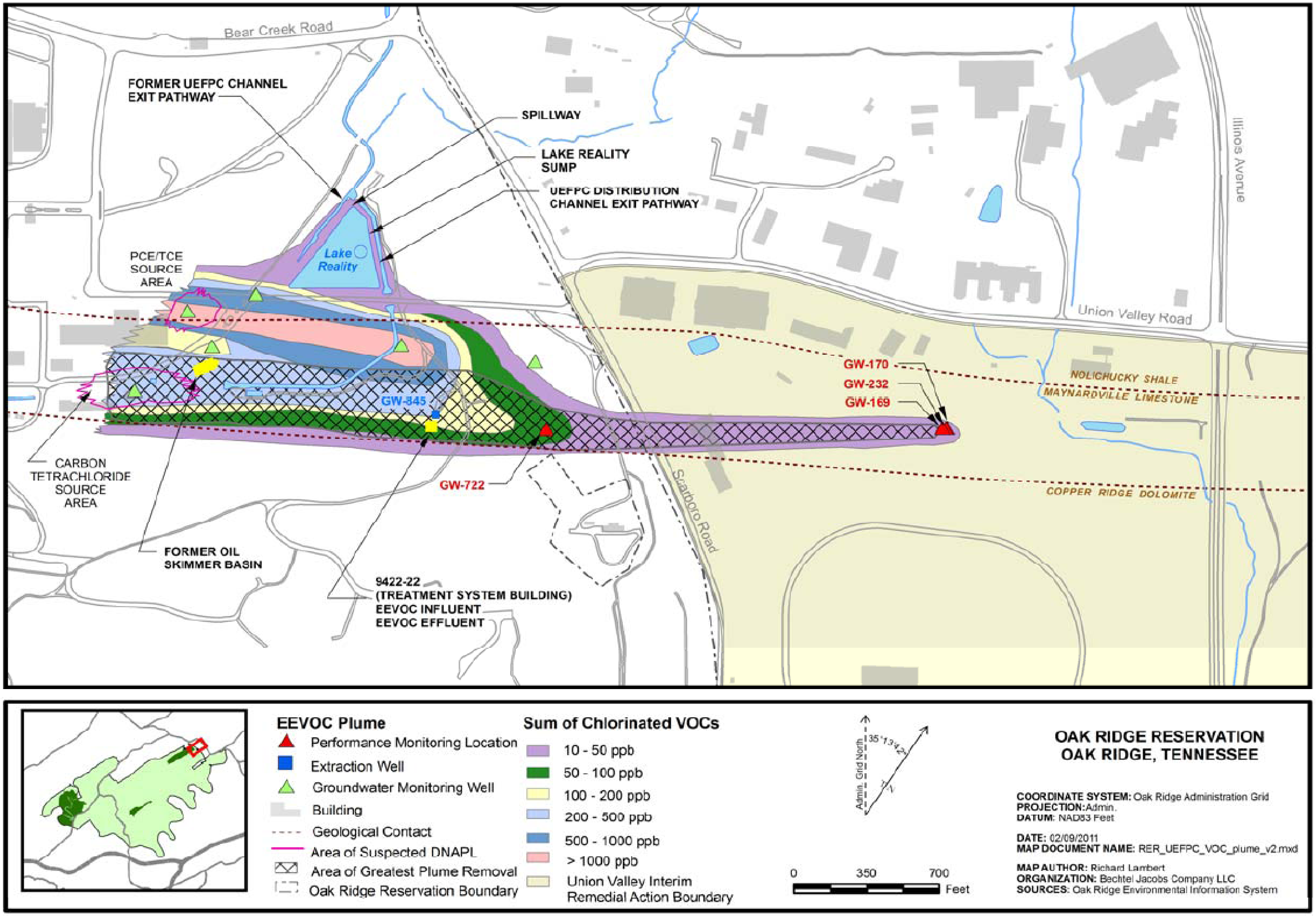
Source: DOE 1998

Fig. C.8. Strike perpendicular cross-section of East End Volatile Organic Compound Plume carbon tetrachloride signature (pre-removal action).



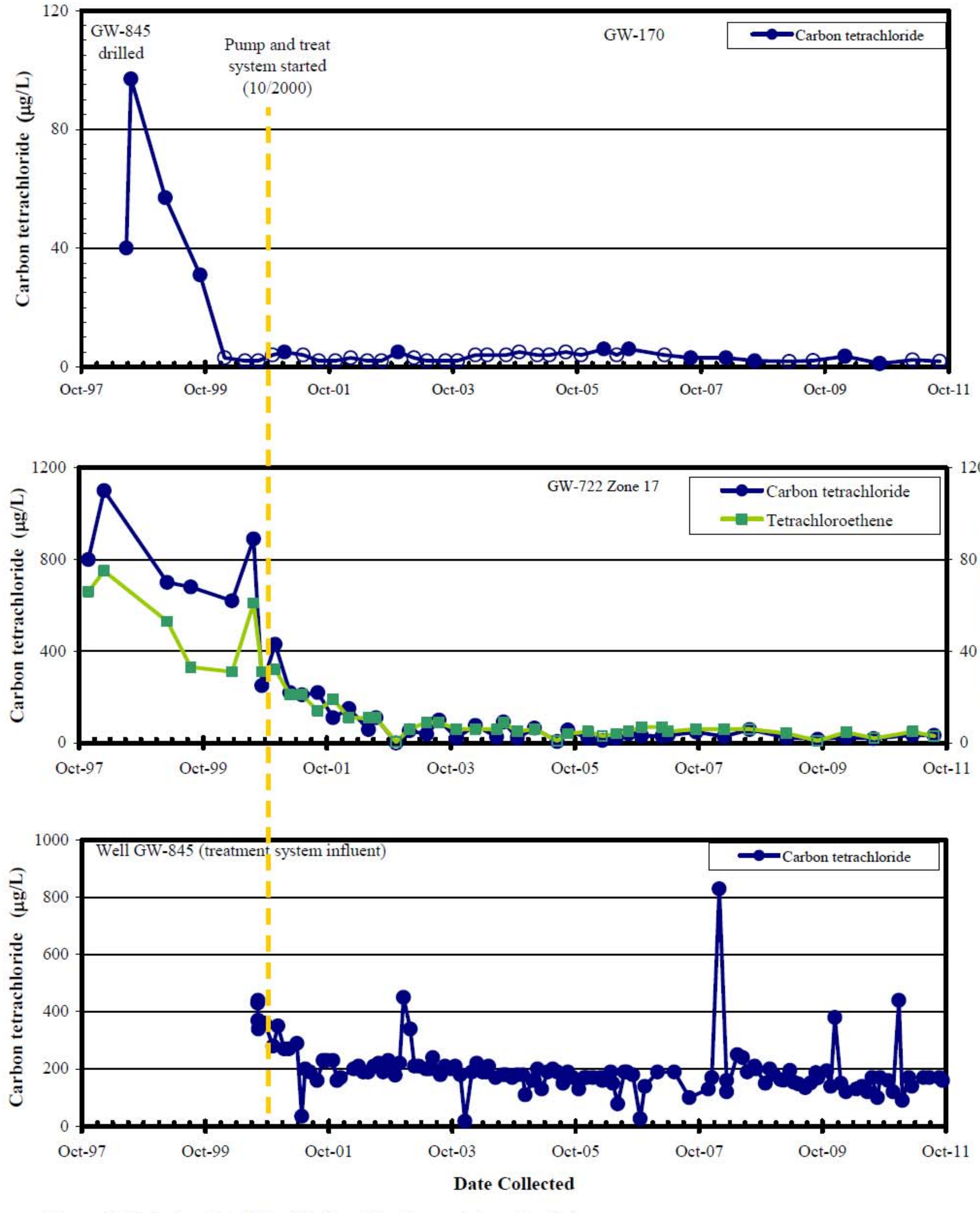
Source: DOE 1998

Fig. C.9. Strike-parallel cross-section of East End Volatile Organic Compound Plume carbon tetrachloride signature (pre-removal action).



Source: DOE 2013

Fig. C.10. East End Volatile Organic Compound Plume in FY 2011 showing region of maximum chlorinated volatile organic compound removal.



Source: DOE 2012b

Fig. C.11. Carbon tetrachloride concentrations in the East End Volatile Organic Compound Plume removal action pumping well (GW-845) and downgradient wells in the Maynardville Limestone.

C.2.8 MAJOR DATA GAPS

Table C.4 lists relevant groundwater plumes and key data gaps for the UEFPC Watershed.

Table C.4. UEFPC Watershed groundwater plumes and associated key data gaps

Plume No.	Data gap(s)
UEFPC-1, UEFPC-2, UEFPC-5, and UEFPC-6	Central Y-12 Maynardville Limestone Exit Pathway: A limited number of wells exist in the central portion of the complex within the Maynardville Limestone, particularly in the intermediate and deep groundwater intervals. Lateral and vertical extent of contamination in the exit pathway in the western and central portions of the Y-12 Complex is not well understood.
UEFPC-2	Vertical and horizontal delineation of VOCs and potential DNAPL sources in the Nolichucky Shale near former production facilities in the western Y-12 area (e.g., Bldgs. 9201-5, 9201-4, and WCPA).
UEFPC-7	East End Y-12 Nolichucky Shale strike-parallel transport pathways: A limited number of wells exist in the intermediate and deep groundwater intervals of the Nolichucky Shale at the ORR boundary and no wells exist in these intervals off of the ORR in Union Valley to the east. The potential for EEVOC Plume migration along strike-parallel fracture pathways is not well understood.
UEFPC-7	Delineation of VOCs and potential DNAPL sources in the EEVOC Plume: Existing wells in the eastern portion of the Y-12 Complex do not define the full vertical extent of VOC contamination (particularly CT) within the Maynardville Limestone and provide only partial definition of the lateral extent of the VOC plume within the eastern portion of the complex.

CT = carbon tetrachloride.
DNAPL = dense non-aqueous phase liquid.
EEVOC = East End Volatile Organic Compound.
ORR = Oak Ridge Reservation.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
WCPA = Waste Coolant Processing Area.
Y-12 Complex = Y-12 National Security Complex.

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C.3 REFERENCES

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APPENDIX D
CHESTNUT RIDGE (AND SOUTH CAMPUS FACILITY) SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

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ACRONYMS

bgs	below ground surface
CDL	construction/demolition landfill
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COC	contaminant/chemical of concern
CRSP	Chestnut Ridge Security Pits
DCA	dichloroethane
DCE	dichloroethene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FCAP	Filled Coal Ash Pond
ft/d	feet per day
FY	fiscal year
FYR	five-year review
KHQ	Kerr Hollow Quarry
MCL	maximum contaminant level
µg/L	micrograms per liter
mg/L	milligrams per liter
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCE	tetrachloroethene
pCi/L	picocuries per liter
RCRA	Resource Conservation and Recovery Act of 1976
RI	remedial investigation
ROD	Record of Decision
SCF	South Campus Facility
TCA	trichloroethane
TCE	trichloroethene
TDEC	Tennessee Department of Environment and Conservation
UNC	United Nuclear Corporation
VOC	volatile organic compound
WMU	waste management unit
Y-12 Complex	Y-12 Nuclear Security Complex

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D.1 INTRODUCTION

This Appendix provides a summary of the conceptual model for the Chestnut Ridge Watershed and South Campus Facility (SCF), located in the southeastern portion of the Oak Ridge Reservation (ORR). The following sections provide a chronology of events associated with the Chestnut Ridge Watershed, the geology and hydrology of the watershed, the primary groundwater contaminant sources in the watershed, a summary of the contaminants/chemicals of concern (COCs), and summarize the key data gaps in the understanding of the conceptual model. Much of the background information provided herein is from the Upper East Fork Poplar Creek Characterization Area Remedial Investigation (RI) report (DOE 1998), the Record of Decision (ROD) for the United Nuclear Corporation (UNC) Disposal Site (DOE 1991a), and other historical documents (see Sect. D.2). Updated contaminant concentrations and concentration trends have been obtained from the most recent ORR Remediation Effectiveness Report (RER) [DOE 2013] and the latest Reservation-wide Five-Year Review (FYR) [DOE 2012]. The sources for the illustrations presented in this Appendix are indicated on the individual figures.

D.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH CHESTNUT RIDGE

Table D.1 provides a chronology of historical operations and relevant events related to Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and Resource Conservation and Recovery Act of 1976 (RCRA) groundwater plumes for the Chestnut Ridge Watershed, including the Chestnut Ridge Security Pits (CRSP) and UNC Site. Figure D.1 provides locations of the CRSP and UNC sites and the other waste management units (WMUs) within the watershed, including the Kerr Hollow Quarry (KHQ), Sediment Disposal Basin, Filled Coal Ash Pond (FCAP), Roger’s Quarry, and the various sanitary and industrial landfills.

D.1.2 CHRONOLOGY OF EVENTS ASSOCIATED WITH THE SOUTH CAMPUS FACILITY

The SCF is located southeast of the Oak Ridge Y-12 National Security Complex (Y-12 Complex) at the intersection of Pumphouse Road and Bethel Valley Road on the eastern edge of the ORR [Fig. D.2]. The facility was originally an experimental station where radionuclide effects on animals were studied. Activities and buildings at SCF either supported research on exposed animals or managed those animals before and after exposing them to radiation. The SCF included pasture, barns, laboratories, mechanical buildings, surgical and necropsy rooms, carpentry shops, a steam power plant, storage areas, and wastewater treatment facilities and ponds. Potential contamination at SCF was investigated because operations at these facilities may have resulted in the release of chemical and/or radioactive substances to the environment. Table D.2 provides a chronology of environmental actions at the SCF.

D.1.3 GEOLOGY AND HYDROLOGY

Chestnut Ridge Hydrologic Regime

Figure D.3 illustrates the bedrock geology underlying Chestnut Ridge. The Knox Group formations underlying Chestnut Ridge comprise three vertically gradational hydrogeologic subsystems: (1) the stormflow zone, (2) the vadose zone, and (3) the groundwater zone. The subsystems are distinguished by groundwater flux, which decreases with depth (Solomon et al. 1992). Investigations show that groundwater occurs intermittently above the water table in a shallow “stormflow zone” that extends to a depth of about 8 ft below ground surface (bgs) [Wilson et al. 1990]. Macropores and mesopores provide

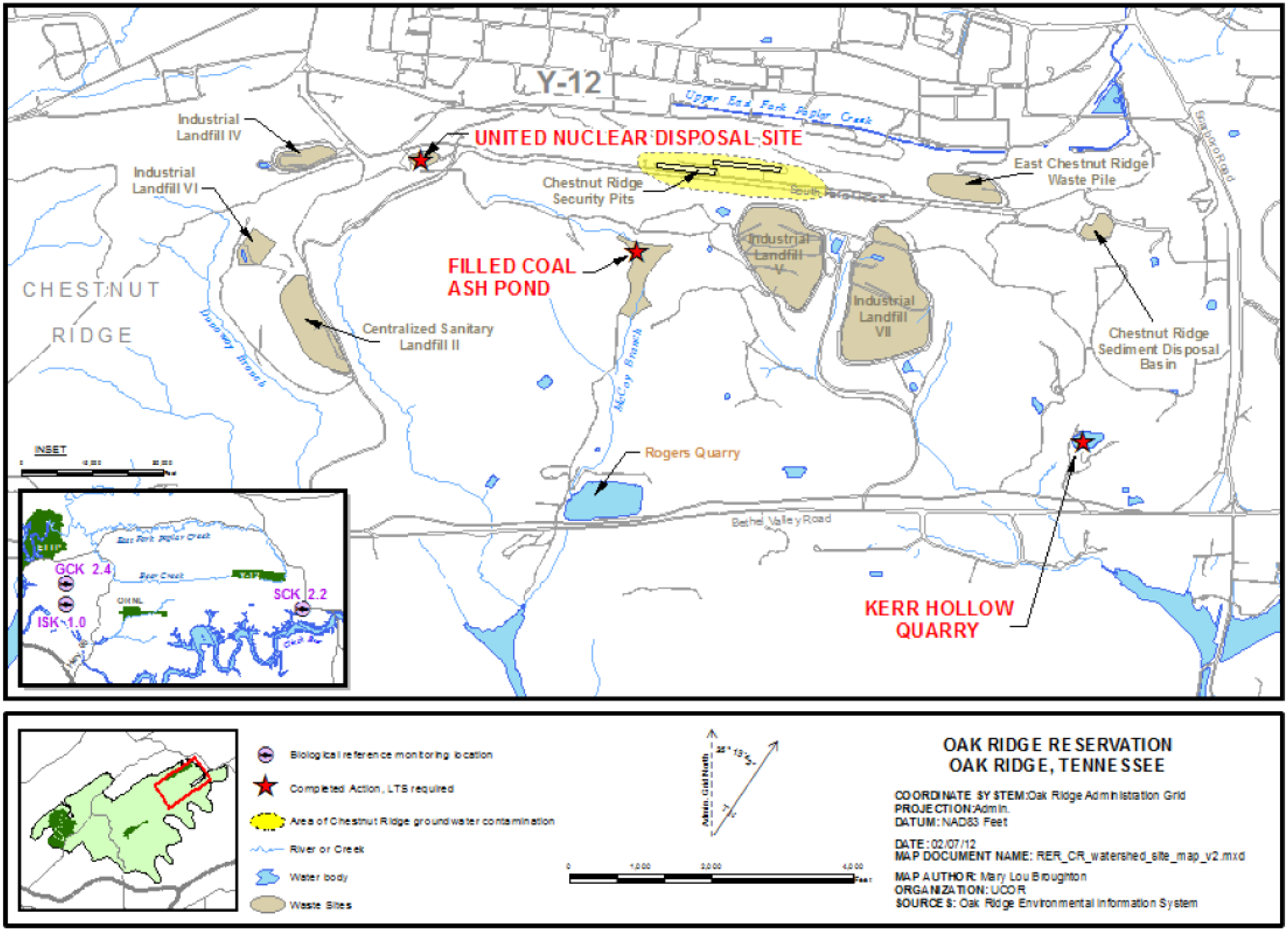
Table D.1. Chronology of events associated with Chestnut Ridge

Event	Date
United Nuclear Corporation (UNC) Site operations.	1943 – 1951
Chestnut Ridge Security Pits (CRSP) operations.	1973 – 1988
CRSP RCRA closure.	June 1989
The ORR is added to the National Priorities List as a Superfund Site.	11/21/89
Final ROD (NFA) for the UNC Site is signed by DOE, EPA, and TDEC.	6/28/91
An FFA is established between DOE, EPA, and TDEC.	1/1/92
An Agreed Order is signed between TDEC and DOE for corrective actions at former RCRA-regulated TSDs in the UEFPC Watershed to be performed under CERCLA as the prime regulatory driver with post-closure care and monitoring to be conducted under RCRA.	4/6/93
Remedial actions are completed for the UNC Site. Post-Closure Completion Report is approved.	9/6/94
TDEC issues RCRA Post-Closure Permit TNHW-088 for the Chestnut Ridge Hydrogeologic Regime.	9/18/95
DOE adopts the Watershed approach to CERCLA decision-making. Chestnut Ridge is considered a separate watershed at Y-12.	1996
TDEC issues modified RCRA Post-Closure Permit TNHW-088 for the Chestnut Ridge Hydrogeologic Regime incorporating the Chestnut Ridge Security Pits.	3/8/96

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
CRSP = Chestnut Ridge Security Pits.
DOE = U.S. Department of Energy.
EPA = U.S. Environmental Protection Agency.
FFA = Federal Facility Agreement.
NFA = no further action.
ORR = Oak Ridge Reservation.
RCRA = Resource Conservation and Recovery Act of 1976.
ROD = Record of Decision.
TDEC = Tennessee Department of Environment and Conservation.
TSD = treatment, storage, and disposal.
UEFPC = Upper East Fork Poplar Creek.
UNC = United Nuclear Corporation.
Y-12 = Y-12 National Security Complex.

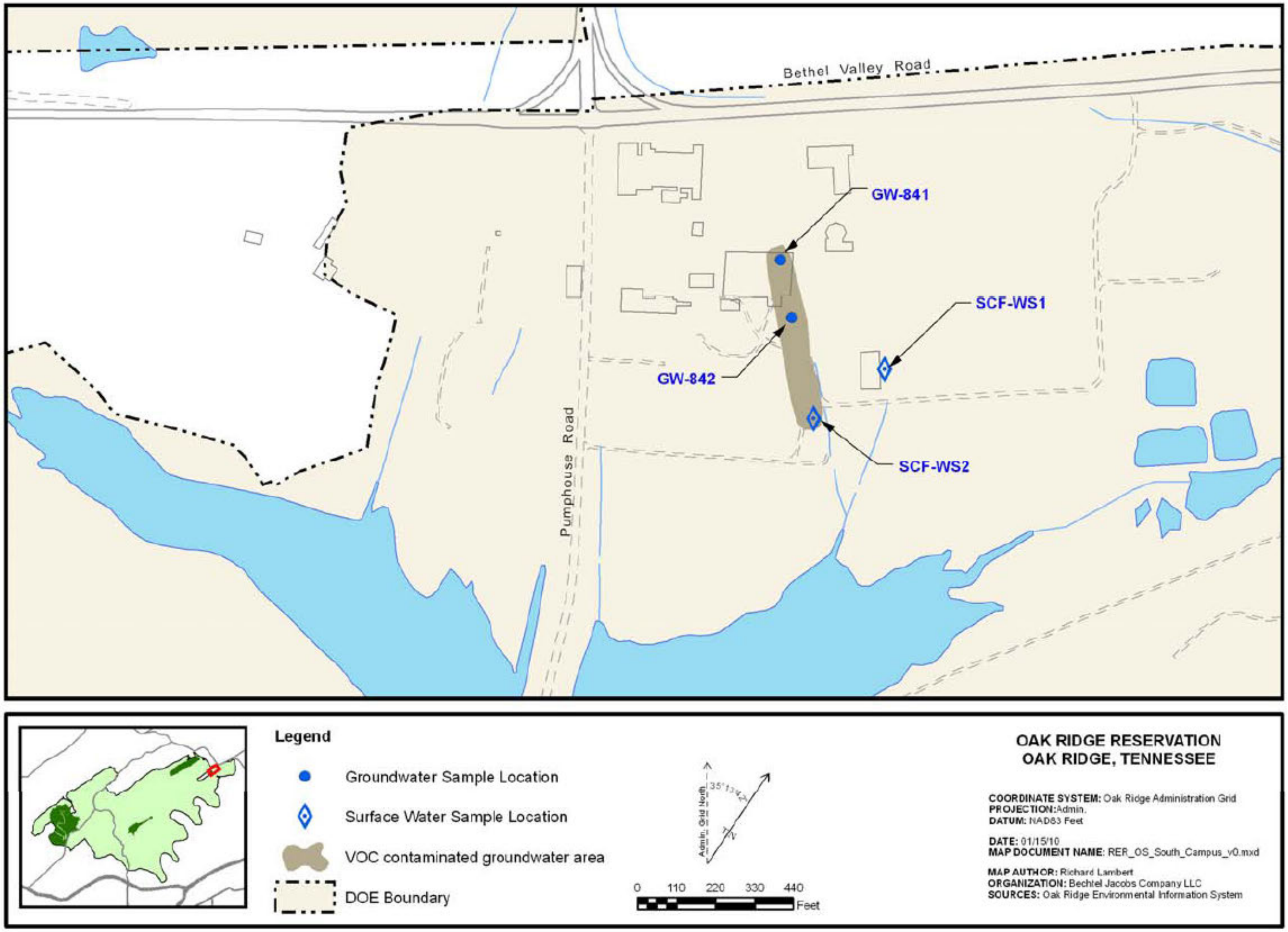
the primary channels for lateral flow in the stormflow zone, which lasts only a few days (5 to 10 d) after rainfall. Most groundwater within the stormflow zone is either lost to evapotranspiration or recharge to the water table, and the remaining water discharges at nearby seeps, springs, or streams (Moore 1989).

The vadose zone occurs between the stormflow zone and the water table, which typically occurs near the bedrock/residuum interface. Most groundwater recharge through the vadose zone is episodic and occurs along discrete permeable fractures that become saturated, although surrounding micropores remain unsaturated (Solomon et al. 1992). The residuum on Chestnut Ridge is typically clay-rich, reaches thicknesses of 80 ft in some areas, and is hydrologically heterogeneous. Recharge through the vadose zone is primarily by quickflow via dolines to karst conduits in bedrock in the subsurface. Residuum on Chestnut Ridge near the Oak Ridge National Laboratory (ORNL) has a mean hydraulic conductivity of about 0.006 feet per day (ft/d) [Moore 1988].



Source: DOE 2012

Fig. D.1. Locations of waste management units in the Chestnut Ridge administrative watershed.



Source: DOE 2012

Fig. D.2. Location of South Campus Facility and extent of contaminated groundwater.

Table D.2. Site chronology for the Oak Ridge Associated Universities South Campus Facility

Five USTs and associated contaminated soil removed and treated	1988
Groundwater monitoring wells installed and sampled	1988 – 1989
CERCLA site inspection conducted	1991
CERCLA RI performed	1993
RI/FS and Proposed Plan	1995
ROD	1995
RAR	1996

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
RI = remedial investigation.
RI/FS = Remedial Investigation/Feasibility Study.
ROD = Record of Decision.
RAR = Remedial Action Report.
UST = underground storage tank.

Groundwater below the vadose zone occurs within bedrock in orthogonal sets of permeable, planar fractures that form water-producing zones within an essentially impermeable matrix. Dissolution of bedrock carbonates has enlarged fractures and produced an interconnected conduit-flow system characteristic of karst aquifers. Because the occurrence of solution features and the frequency, aperture, and connectivity of permeable fractures decrease with depth, the bulk hydraulic conductivity of the groundwater zone is vertically gradational. Most groundwater flow occurs within the transitional horizon between residuum and unweathered bedrock (water table interval); lower flow rates occur at successively greater depths in the bedrock (Solomon et al. 1992).

Groundwater elevations on Chestnut Ridge generally mirror surface topography (Fig. D.4). Along the crest of the ridge, which is a recharge area and a flow divide, groundwater generally flows from west to east (parallel to geologic strike), with radial components of flow north into Bear Creek Valley and south toward tributary headwaters on the southern flank of the ridge (across geologic strike). The central part of the regime is characterized by radial flow directions from local groundwater flow divides along hilltops between tributaries. Groundwater flow directions in the southern part of the regime are generally south toward Melton Hill Lake. The overall directions of groundwater flow throughout the Chestnut Ridge Regime do not significantly change during seasonal groundwater flow conditions. Horizontal hydraulic gradients throughout the year are highest along the steep northern flank of Chestnut Ridge (i.e., across geologic strike) and in the upper reaches of tributaries on the southern ridge flank, and they are nearly flat along the southern boundary of the regime.

Available data show that hydraulic conductivity in the Knox Group varies over multiple orders of magnitude, which is typical of karst aquifers. Results of straddle packer tests in core holes indicate hydraulic conductivity ranging from 0.0002 to 3.1 ft/d at depths generally less than 600 ft bgs in the lower Knox Group (King and Haase 1988). Hydraulic conductivity values calculated from results of falling-head slug tests performed in monitoring wells completed at shallow depths (60 to 195 ft bgs) in the middle Knox Group range from about 0.003 to 14 ft/d (Jones 1998). Also, results of dye-tracer tests at the CRSP indicate flow rates of about 100 to 300 ft/d (MMES 1990). Although not confirmed by a second test using different tracers (MMES 1992), these findings are supported by the range of flow rates (490 to 1250 ft/d) indicated by results of a dye-tracer test performed on Chestnut Ridge near ORNL (Ketelle and Huff 1984). Dye trace tests conducted by the Tennessee Department of Environment and Conservation (TDEC) and low concentrations of volatile organic compounds (VOCs) in samples from a spring located

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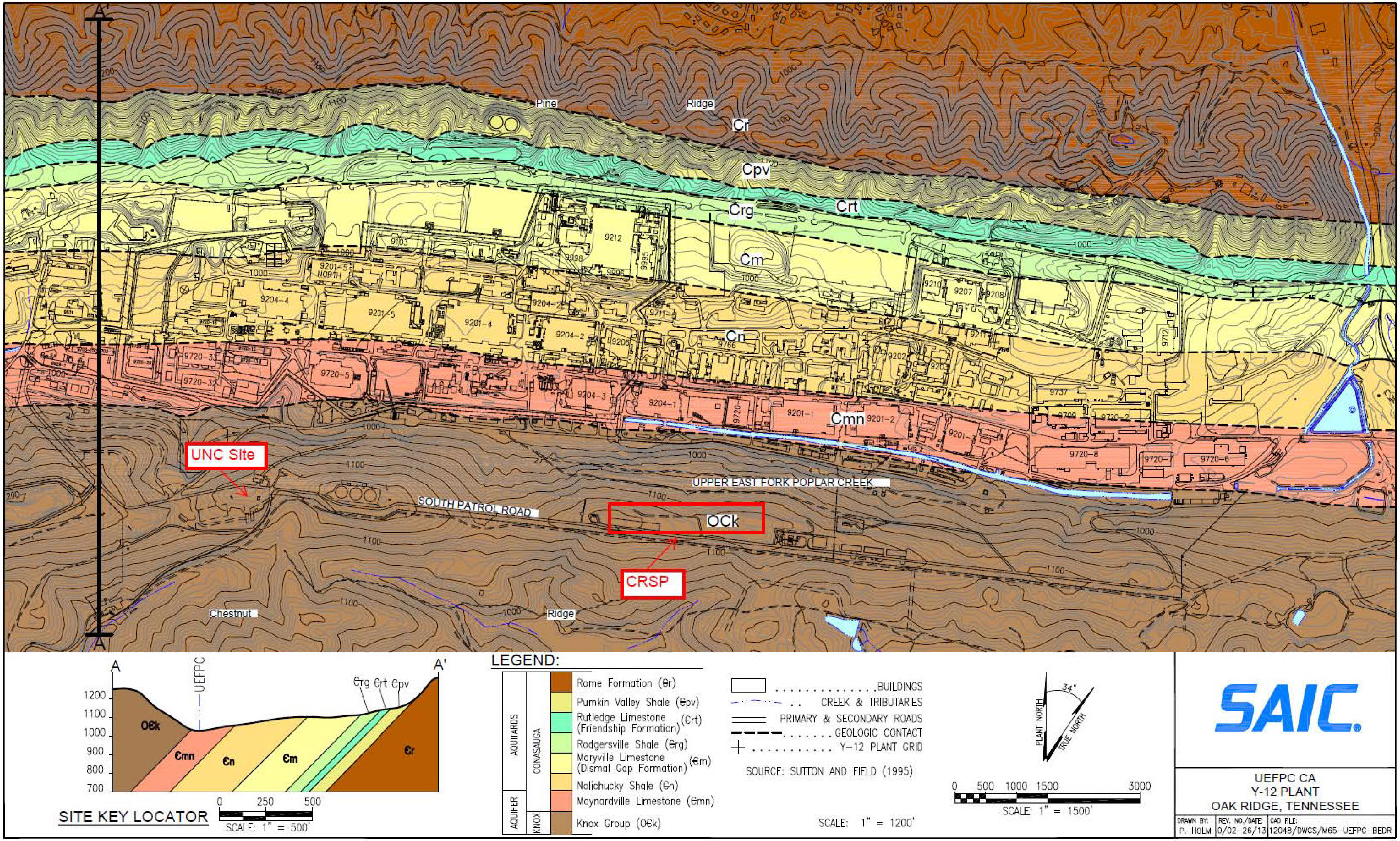
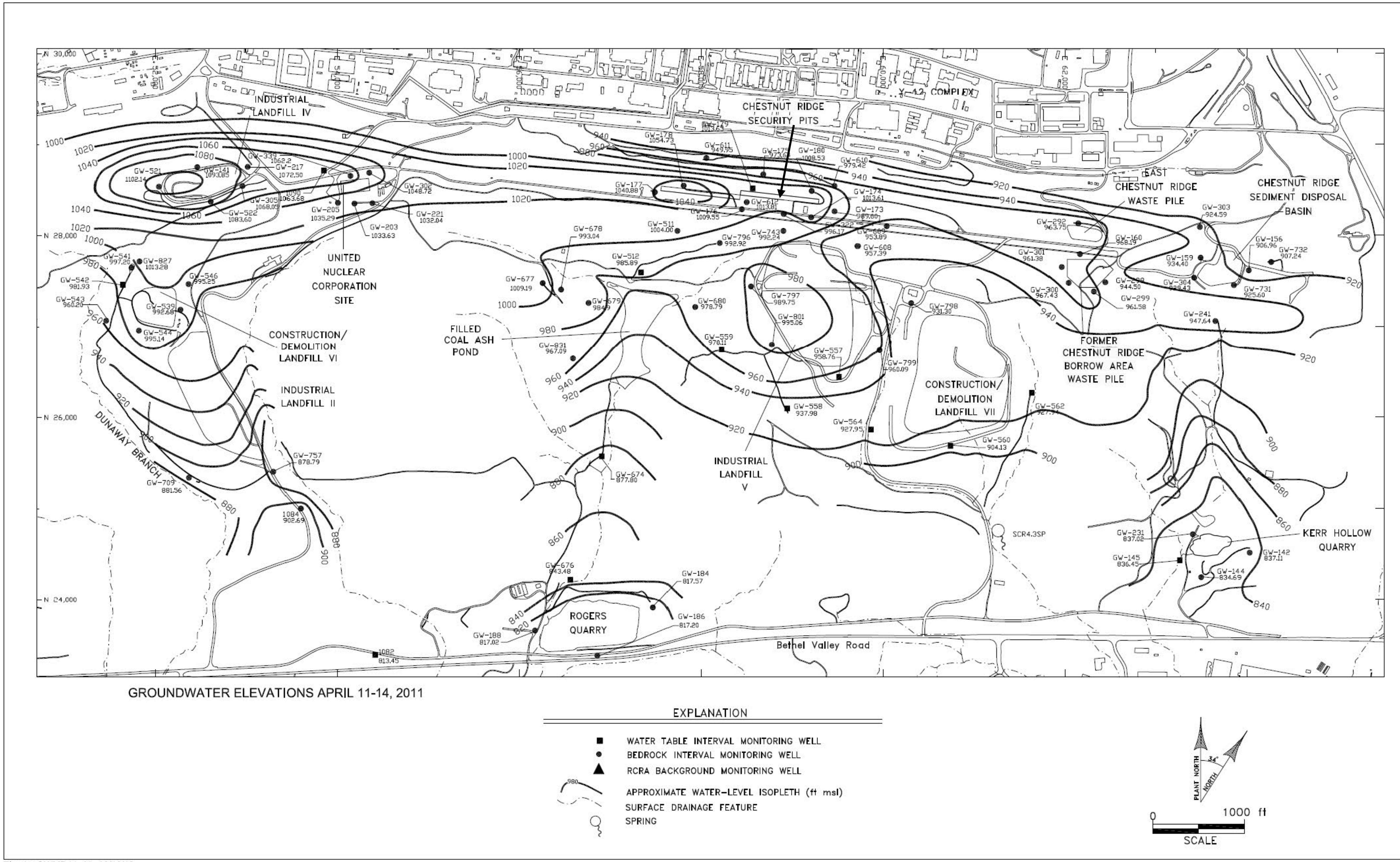


Source: DOE 1998

Fig. D.3. Bedrock geology in the Chestnut Ridge Watershed.



Elvado: GWMR11_05 08/10/12

Source: B&W 2012

Fig. D.4. Generalized groundwater potentiometric map for the Chestnut Ridge watershed.

along Illinois Avenue east of the CSRP (Arboretum Spring) suggest groundwater flow via karst conduits is a mechanism for eastward migration of plume constituents.

South Campus Facility

The SCF is underlain by carbonates of the Chickamauga Group. Surface water at the site consists of Scarboro Creek, intermittent streams, drainage ditches, storm sewers, swine water ponds, and Scarboro Creek embayment of Melton Hill Lake. All of the features drain into Scarboro Creek embayment and eventually into Melton Hill Lake. Shallow groundwater emerges as wet-weather springs near the embayment.

D.1.4 PRIMARY GROUNDWATER CONTAMINANT SOURCES: CHESTNUT RIDGE SECURITY PITS, UNITED NUCLEAR CORPORATION SITE, AND SOUTH CAMPUS FACILITY

The CRSP is the only unit in the Chestnut Ridge Watershed with a defined contaminant plume. The UNC Site has had sporadic detections of contaminants associated with wastes placed in the unit (e.g., nitrate, ^{90}Sr). Other WMUs are located in the Chestnut Ridge Watershed, but they are either: (1) closed RCRA units under post-closure detection monitoring (e.g., KHQ, Sediment Disposal Basin); (2) CERCLA-regulated units with no confirmed groundwater contaminant releases (e.g., FCAP, Roger's Quarry); or (3) industrial and construction/demolition landfills (CDLs) regulated and managed under Tennessee Solid Waste rules. The SCF groundwater contamination has been undergoing monitored natural attenuation for several years. Table D.3 presents major contaminant types and source characteristics associated with the CRSP and UNC Site. Table D.4 provides information on the conceptual model characteristics for each groundwater plume.

Table D.3. Groundwater contaminant plumes associated with the Chestnut Ridge Security Pits, United Nuclear Corporation Disposal Site, and South Campus Facility

Plume description	Plume No.	Source/contaminant signature
Chestnut Ridge Security Pits	CR-1	Eastern Trench Area: VOCs (1,1,1-TCA; 1,2-DCA) Western Trench Area: VOCs (PCE; TCE; and 1,2-DCE)
United Nuclear Corporation Disposal Site	CR-2	Nitrate, ^{90}Sr
South Campus Facility	CR-3	VOCs: PCE, TCE, and 1,2-DCE

CR = Chestnut Ridge.
DCA = dichloroethane.
DCE = dichloroethene.
PCE = tetrachloroethene.
TCA = trichloroethane
TCE = trichloroethene.
VOC = volatile organic compound.

Table D.4. Conceptual model elements for the Chestnut Ridge Security Pits, United Nuclear Corporation Site, and South Campus Facility

		Contaminant signature description[a]					
Plume No.	**Groundwater plume**	**Approximate extent (ft downgradient)**	**Depth (ft bgs)**	**Maximum concentration**	**Flowpaths**	**Groundwater exit points**	**Data gaps and uncertainties**
CR-1	Chestnut Ridge Security Pits	3800 ft east–west 1300 ft north–south	270	Historical summed VOCs: 1000 µg/L Current summed VOCs: <200 µg/L	Primarily along-strike flow in the Knox Group via karst pathways; some cross-strike flow from crest of Chestnut Ridge	Springs and tributaries on flanks of Chestnut Ridge and east of CRSP along Scarboro Creek	See Table D.6
CR-2	United Nuclear Corporation Site	No plume identified	NA	Historical maximum Sr-90: 17.8 pCi/L Nitrate: <10 mg/L	Primarily along-strike flow in the Knox Group via karst pathways; some cross-strike flow from crest of Chestnut Ridge	Springs and tributaries on flanks of Chestnut Ridge	See Table D.6
CR-3	South Campus Facility	450	<50 (sources)	Current TCE and 1,2-DCE: <5 µg/L	Shallow flow in the unconsolidated and fracture flow in shallow bedrock intervals	Scarboro Creek Embayment, Melton Hill Lake	See Table D.6

[a] Values are approximate based on available Upper East Fork Poplar Creek Remedial Investigation data and recent groundwater monitoring results.
bgs = below ground surface.
CR = Chestnut Ridge.
CRSP = Chestnut Ridge Security Pits.
DCE = dichloroethene.
NA = not applicable.
µg/L = micrograms per liter.
mg/L = milligrams per liter.
pCi/L = picocuries per liter.
TCE = trichloroethene.
VOC = volatile organic compound.

CR-1 Chestnut Ridge Security Pits

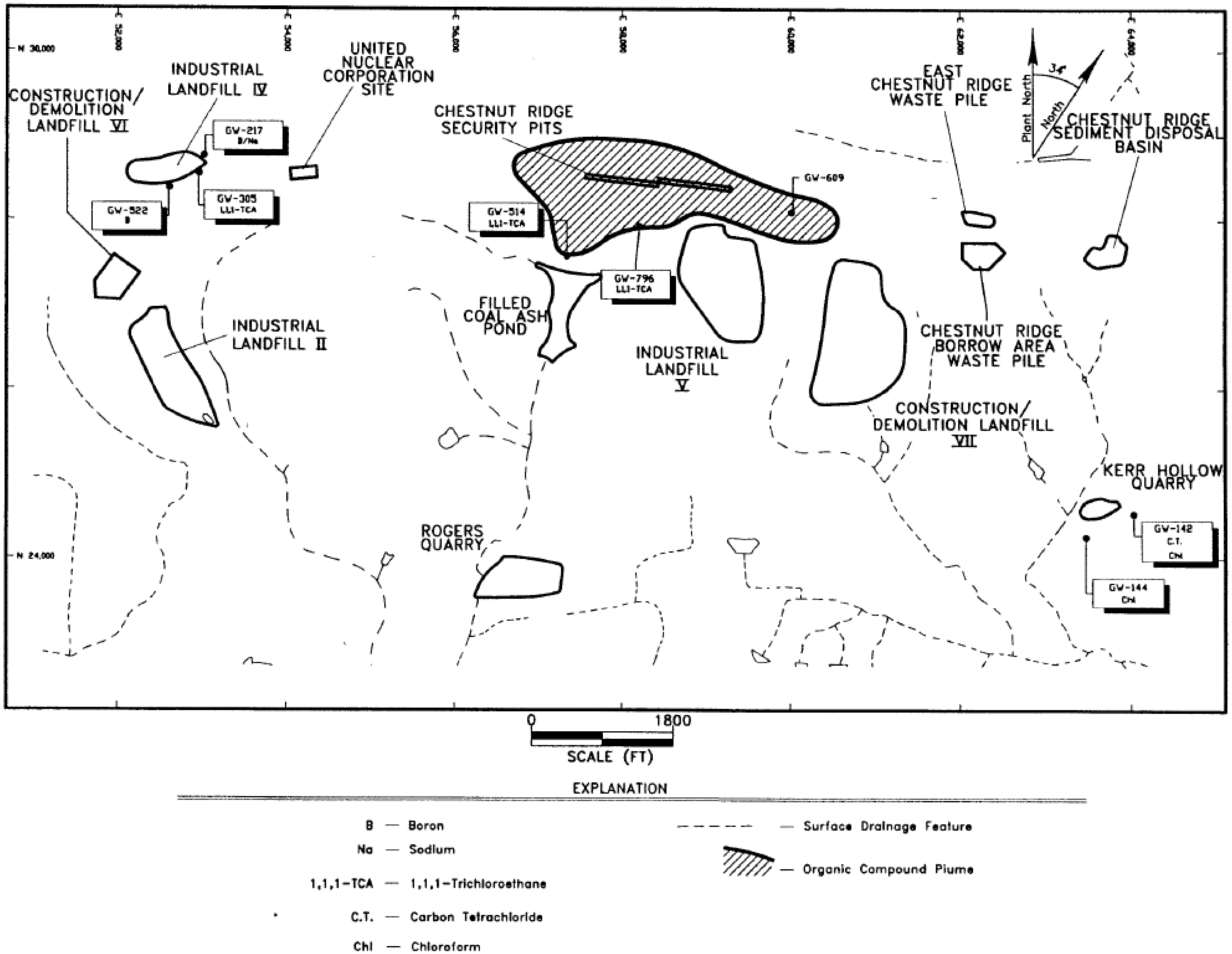
The CRSP are located on the crest of Chestnut Ridge south of the Y-12 Complex (Fig. D.1). The CRSP were used from 1973 to 1988 to dispose of classified and nonclassified hazardous and nonhazardous wastes. Some materials disposed in the CRSP have origins other than the Y-12 Complex. The CRSP consists of an eastern and western trench area. The eastern trench area contained three unlined trenches approximately 8 ft wide, 10 ft deep, and 690 to 720 ft in length. Six auger holes were located at the eastern end of the eastern trench area (2-ft diameter, 10-ft depth), which were used to dispose of reactive materials. The western trench area contained four unlined trenches approximately 14 ft wide, 15 ft deep, and 720 to 780 ft in length. Waste inventory at the CRSP included metals (e.g., lead, beryllium, uranium, and thorium) and metallic components; contaminated solid wastes (badges, bottles, cloth, and paper); reactive materials (e.g., lithium compounds); acids; alcohols; and chlorinated solvents, such as 1,1,1-trichloroethane (1,1,1-TCA). Disposal of liquid wastes represents a comparatively small volume of the overall waste inventory. The CRSP were closed with an engineered RCRA multi-layer cap as of June 1989 and have been under post-closure corrective action monitoring since issuance of a post-closure permit modification in March 1996.

Groundwater monitoring at the CRSP has been conducted under auspices of the RCRA post-closure permit for the Chestnut Ridge Hydrologic Regime and U.S. Department of Energy (DOE) Orders. A CERCLA remedial investigation (RI) has not been conducted, to date, for the CRSP. Figure D.5 shows the generalized extent of VOC groundwater contamination in association with the CRSP in the mid-1990s. Data obtained from monitoring wells at the site indicate that a narrow, elongated plume of dissolved VOCs extends parallel with geologic strike for at least 700 ft to the east (downgradient), as well as perpendicular to geologic strike for at least 300 ft downgradient to the north and south (B&W Y-12, LLC 2012). The primary components of the plume include:

- Western trench area: 1,1,1-TCA, 1,1-dichloroethane (DCA), and 1,1-dichloroethene (DCE).
- Eastern trench area and auger holes: tetrachloroethene (PCE), trichloroethene (TCE), and 1,2-DCE isomers.

The distribution of VOCs relative to the source areas and elongation of the plume along the axis of Chestnut Ridge suggests primarily strike-parallel horizontal transport (west to east as shown in the potentiometric surface in Fig. D.4) in the groundwater despite steeper hydraulic gradients toward the ridge flanks (Fig. D.4). The maximum depth of vertical migration of the VOCs has not been conclusively determined but is at least 150 ft bgs in the western trench area, 250 ft bgs near the middle of the site, and 270 ft bgs downgradient of the eastern trench area. Historical maximum concentrations of VOCs exceed 1000 micrograms per liter (μg/L).

Data obtained since the early 1990s also show that low concentrations of VOCs were present in the groundwater at two wells south–southeast and hydraulically downgradient of the CRSP: well GW-796 (<1 μg/L), which is located at Industrial Landfill V about 400 ft directly south of the site, and well GW-798, which is located at CDL VII about 1600 ft south–southeast of the site (Fig. D.4). Subsequent monitoring results indicate that VOC levels in both wells remain relatively low, with the more recent data showing that PCE concentrations in well GW-798 occasionally exceed the maximum contaminant level (MCL) of 5 μg/L (Table D.5). The repeated detection of these compounds in the groundwater at both wells probably reflects southward transport from the CRSP because this site is the only known source of VOCs that is hydraulically upgradient of either well. Long-term concentration trends for VOCs in a majority of CRSP monitoring wells have shown decreasing trends; in some wells trends have been indeterminate (Fig. D.6).



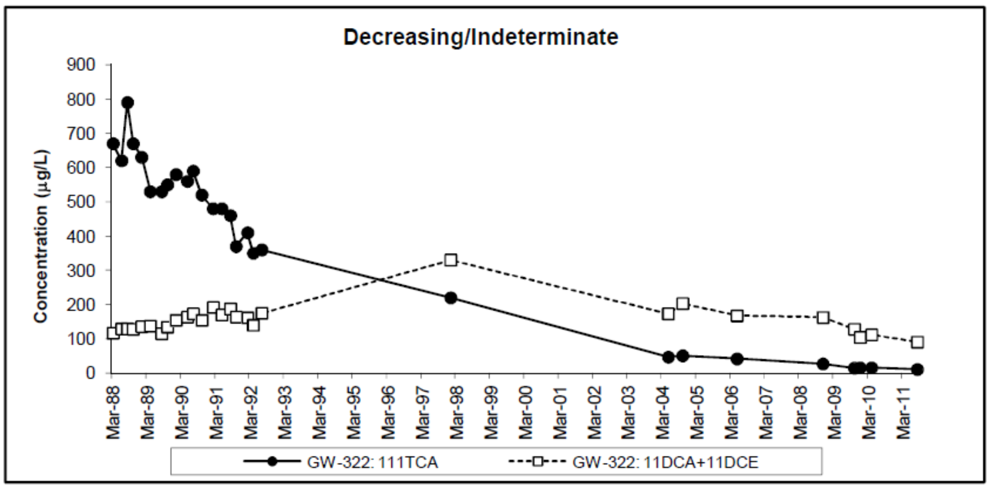
Source: AJA Technical Services 1997

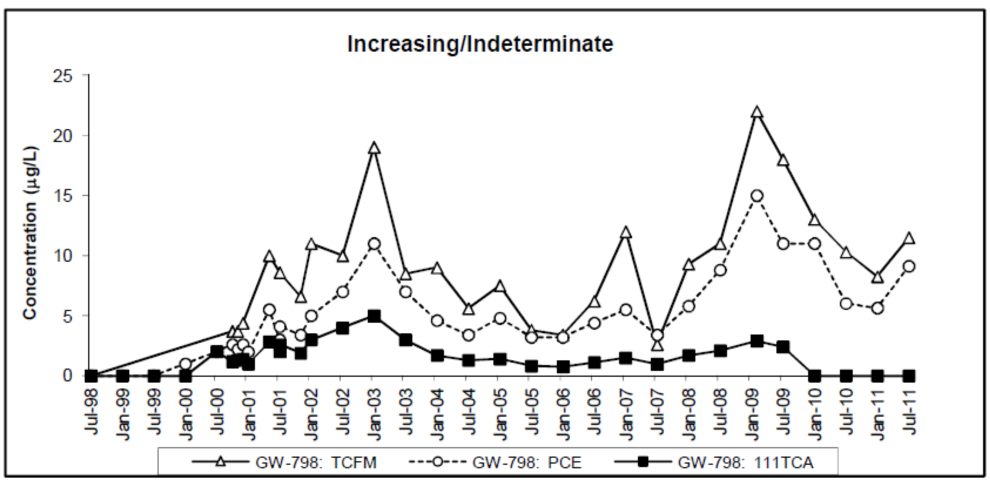
Fig. D.5. General extent of volatile organic compounds associated with the Chestnut Ridge Security Pits.

Table D.5. Maximum concentrations of VOCs in CRSP wells, calendar year 2011

Well	Maximum concentration (µg/L)					
	PCE	*cis*-1,2-DCE	1,1-DCE	1,1,1-TCA	1,1-DCA	TCFM
GW-174	ND	ND	ND	ND	ND	5J
GW-175	2J	ND	ND	ND	ND	3J
GW-176	ND	ND	23	20	43	ND
GW-177	ND	ND	7.2	5.8	31	ND
GW-180	13	ND	ND	ND	ND	3J
GW-322	3J	ND	34	11	57	19
GW-798	9.12	9.38	4.44	ND	ND	11.5

1,1,1-TCA = 1,1,1-trichloroethane.
1,1-DCA = 1,1-dichloroethane.
1,1-DCE = 1,1-dichloroethene.
cis-1,2-DCE = *cis*-1,2-dichloroethene.
CRSP = Chestnut Ridge Security Pits.
GW = groundwater.
J = Estimated value less than reporting limits.
µg/L = micrograms per liter.
ND = not detected.
PCE = tetrachloroethene.
TCFM = Trichlorofluoromethane (Freon).
VOC = volatile organic compound.





Source: B&W 2012

Fig. D.6. Volatile organic compound concentration trends in wells GW-322 and GW-798 at the Chestnut Ridge Security Pits.

CR-2 United Nuclear Corporation Site

The UNC Disposal Site is a 1.3-acre landfill located near the crest of Chestnut Ridge south of the Y-12 Complex (Fig. D.1). The unit consists of an unlined excavation containing approximately 11,000 55-gal drums of cement-fixed sludge; 18,000 drums of contaminated soil; and 288 wooden boxes of contaminated building and process equipment demolition debris from the UNC Disposal Site uranium recovery facility in Wood River Junction, Rhode Island. The *Record of Decision for the United Nuclear Corporation Disposal Site* (DOE 1991a) was approved in June 1991. Remedial actions under the ROD included a multilayer cover system, access controls, and groundwater monitoring using existing wells. Formerly Utilized Sites Remedial Action Program wastes from the Elza Gate site in Oak Ridge and non-recyclable wastes from KHQ closure activities were placed in the site before a final, multilayer RCRA cap was constructed to limit percolation of rainwater into the waste. Chemical constituents of wastes placed in the UNC Site include primarily nitrate and ^{90}Sr.

The *Feasibility Study for the United Nuclear Corporation Disposal Site* (DOE 1991b) included results of contaminant transport modeling that indicated possible impacts to groundwater, including potential nitrate leaching concentrations up to 193 milligrams per liter (mg/L) and ^{90}Sr leaching activity concentrations up to 50 picocuries per liter (pCi/L). The expected performance of the remedy in the *Record of Decision United Nuclear Corporation Disposal Site* (DOE 1991a) was to control contaminant migration in groundwater so that nitrate concentrations remained less than the Safe Drinking Water Act of 1976 limit (10 mg/L) and ^{90}Sr activity concentrations would not exceed 2 pCi/L, which is within the CERCLA risk range of 10^{-4} to 10^{-6}. The *Post-Construction Report for the United Nuclear Corporation Disposal Site* (DOE 1993) specifies implementation of a groundwater monitoring program. Although specific frequencies, locations, and analytes are not mandated by the post-construction report, groundwater is monitored for COCs [nitrate and ^{90}Sr] on which performance assessment is based.

As discussed in RERs for prior fiscal years (FYs) [see DOE 2013], nitrate concentrations in UNC Site monitoring wells have remained below the U.S. Environmental Protection Agency (EPA) Primary Drinking Water MCL since implementation of post-remediation groundwater monitoring. Strontium-90 has been detected sporadically at low concentrations in groundwater adjacent to the UNC Site with a maximum detection of 17.8 pCi/L in well GW-205 in July 2006, which exceeded a 4 millirem per year dose equivalent for gross beta, but was below the estimated maximum leaching concentration (50 pCi/L) modeled in the feasibility study (DOE 1991b). Strontium-90 was not detected at any UNC Site monitoring locations during FY 2010 and was detected in FY 2011 at well GW-205 (3.06 $\pm$ 0.941 pCi/L) and well GW-221 (2.34 $\pm$ 0.872 pCi/L). Elevated gross beta activity has been observed in downgradient well GW-205, suggesting a potential contaminant release from the site. In response to anomalous gross beta activity, ^{40}K analyses were added to the monitoring program. Monitoring results indicated gross beta activity appears to track closely to ^{40}K. A downgradient spring (UNC SW-1) was added to the monitoring network in FY 2008 to assess the potential impacts of groundwater seepage on surface water quality. Data from this spring exhibit findings consistent with results from other downgradient monitoring wells at the site that do not detect any COC above an action level.

CR-3 South Campus Facility

The RI (DOE 1995a) for SCF identified that most groundwater contaminants were near background or below regulatory levels of concern. Benzene was detected at low levels in groundwater from one monitoring well directly down-dip from the former location of underground storage tanks that were removed in 1988. TCE and degradation products were observed in groundwater near a former maintenance garage. Detected groundwater concentrations for VOCs ranged from 380 μg/L to 1400 μg/L.

Groundwater at SCF is not used at the facility or at any nearby locations, and there is little potential for future residential use of SCF groundwater. Municipal water serves the site, further reducing the need for future residential groundwater use. The ROD (DOE 1995b) for SCF determined no remedial action was necessary to ensure protection of human health and the environment. The no action alternative prescribed in the ROD included periodic sampling to ensure that evaluations completed in support of the RI are accurate and natural attenuation in the zone of contamination continues as expected. A notice of the contamination is recorded with respect to the contaminated parcel in Anderson County property records. The monitoring and title statement provides, at a minimal cost, an additional level of assurance that the site poses no unacceptable risk. The ROD also specifies FYRs under CERCLA Sect. 121(c) until natural attenuation in the zone of contamination decreases TCE concentrations below regulatory levels of concern.

Four monitoring wells (GW-841, -842, -843, and -844) and a surface water ditch location (SCF-WS2) approximately 55 m (180 ft) downgradient of the GW-842 well cluster were originally specified for monitoring in the ROD. The *2006 FYR* (DOE 2007) recommended continued annual sampling of two wells (GW-841 and GW-842) and two surface water locations (SCF-WS1 and SCF-WS2), as shown on Fig. D.2. The *2011 FYR* (DOE 2012) recommended continued annual sampling and the plugging and abandonment of the remaining wells except GW-841 and GW-842. Concentrations of VOCs in wells GW-841 and GW-842 have shown long-term decreasing concentrations (Fig. D.7). VOCs were not detected in surface water locations SCF-WS1 and SCF-WS2 in FY 2011.

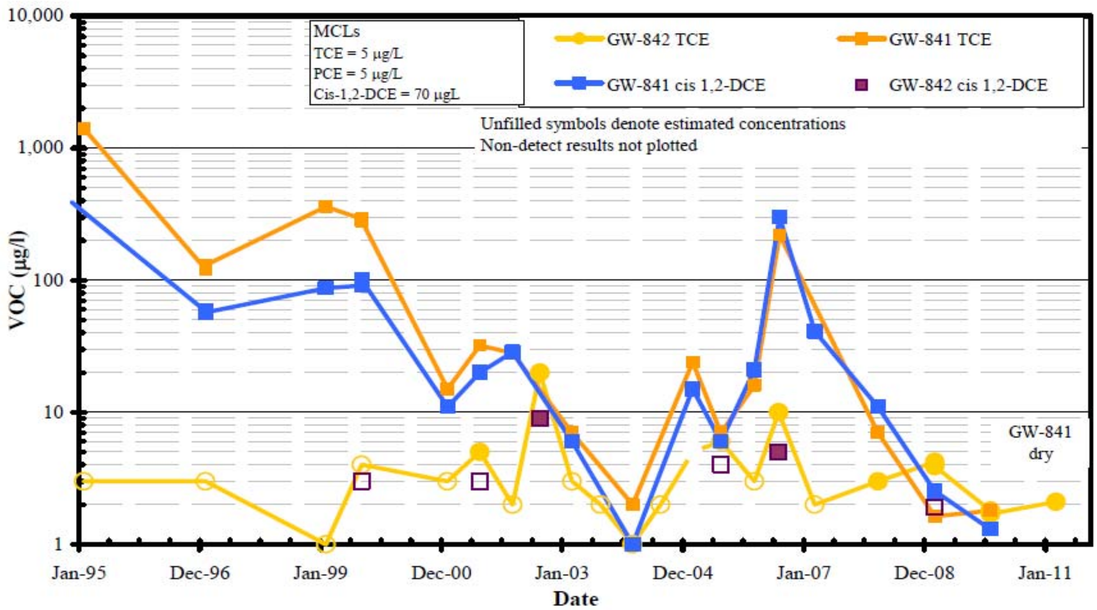


Fig. D.7. Volatile organic compound concentrations in wells GW-841 and GW-842 at South Campus Facility.

D.1.5 SUMMARY OF GROUNDWATER CHEMICALS OF CONCERN AND RISK

A human health risk assessment has not been conducted for the CRSP. Consequently COCs have not been identified for this site. As discussed above, potential COCs evaluated for the UNC Site include nitrate and ^{90}Sr.

For the SCF, domestic use of groundwater on-site was considered to be an incomplete exposure pathway in the RI (DOE 1995a). The baseline risk assessment conducted as part of the RI concluded that groundwater in the TCE area would result in a carcinogenic risk of 4×10^{-3} and a hazard index of 19. However, groundwater in the TCE area was not a drinking water source. Therefore, the RI baseline risk assessment concluded that no unacceptable risk to human health or the environment is posed by contaminants identified in groundwater so long as it is not used as a drinking water source. The Ecological Risk Assessment (DOE 1995a) also determined that the COCs do not present an unacceptable risk to wildlife or plants.

D.1.6 MAJOR DATA GAPS

Table D.6 lists relevant groundwater plumes and key data gaps for the Chestnut Ridge Watershed and SCF.

Table D.6. Chestnut Ridge Watershed and South Campus Facility groundwater plumes and associated key data gaps

Plume No.	Plume	Data gap(s)
General	There has been no comprehensive CERCLA groundwater characterization effort on Chestnut Ridge	There is no current groundwater monitoring east of the UNC site (see Fig. D.4). There are no deep monitoring wells on Chestnut Ridge. Groundwater flowpaths and exit pathways are uncertain.
CR-1	Chestnut Ridge Security Pits	Lateral and vertical extent, and mass of VOC contamination and exit pathways in the Knox Group, are not well understood.
CR-2	United Nuclear Corporation Site	No significant, documented groundwater contamination; however, potential exit pathways in the Knox Group are not well understood.
CR-3	South Campus Facility	No significant data gaps are identified.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
CR = Chestnut Ridge.
UNC = United Nuclear Corporation.
VOC = volatile organic compound.

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APPENDIX E
EAST TENNESSEE TECHNOLOGY PARK SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

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ACRONYMS

ARAR	applicable or relevant and appropriate requirement
amsl	above mean sea level
AWQC	ambient water quality criteria
bgs	below ground surface
BORCE	Black Oak Ridge Conservation Easement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CNF	Central Neutralization Facility
COC	contaminant of concern
CSA	Contractor's Spoil Area
D&D	decontamination and decommissioning
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
DVS	dynamic verification strategy
EFPC	East Fork Poplar Creek
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
EU	exposure unit
F&T	fate and transport
FLUTe™	Flexible Liner Underground Technologies, LLC
FS	feasibility study
FY	fiscal year
gpm	gallons per minute
HI	hazard index
ILCR	incremental lifetime cancer risk
LNAPL	light non-aqueous phase liquid
LOAEL	lowest observed adverse effect level
LUC	land use control
MCL	maximum contaminant level
μg/L	micrograms per liter
mg/L	milligrams per liter
MIK	Mitchell Branch kilometer
M-K	Mann-Kendall
NPDES	National Pollutant Discharge Elimination System
ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
PCCR	Phased Construction Completion Report
PCE	tetrachloroethene
pCi/L	picocuries per liter
R&D	research and development
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act of 1976
RCW	recirculating cooling water
RI	remedial investigation
ROD	Record of Decision

^{99}Tc	technetium-99
TC RmA	time-critical removal action
TCA	trichloroethane
TCE	trichloroethene
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound

E.1 INTRODUCTION

This Appendix provides a summary of the conceptual model for the East Tennessee Technology Park (ETTP), located in the northwestern portion of the Oak Ridge Reservation (ORR). The following sections provide a chronology of events associated with the ETTP, a description of the primary groundwater contaminant sources, the geology and hydrology of the ETTP, and a summary of the source area conceptual models, including a discussion of key data gaps in the conceptual models. Much of the background information provided herein is from the ETTP Sitewide Remedial Investigation (RI) and Feasibility Study (FS) [DOE 2007]. Updated contaminant concentrations and concentration trends have been obtained from the D2 version of the ETTP Final Zone 1 RI and FS (DOE 2013a) and the most recent ORR Remediation Effectiveness Report (DOE 2013b). The sources for the illustrations presented in this Appendix are indicated on the individual figures.

E.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH CERCLA GROUNDWATER ACTIONS AT THE ETTP

Table E.1 provides a chronology of historical operations and relevant events related to Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) groundwater actions and contaminant plumes for the ETTP.

Table E.1. Chronology of events associated with the ETTP

Event	Date
The ETTP (called the Oak Ridge Gaseous Diffusion Plant [ORGDP]) is built by the U.S. Army Corps of Engineers as part of the Manhattan Project.	1942
Gaseous diffusion technology is used to enrich uranium for use in nuclear weapons.	1942 – 1964
The K-25 and K-27 Process Buildings are shut down, and military production of highly enriched uranium (HEU) is ended.	1964
ORGDP produces low enriched uranium (LEU) for use in commercial, research nuclear reactors.	1964 – 1984
DOE places ORGDP on stand-by mode due to reduced demand for LEU.	1985
The decision is made to permanently shut down the ORGDP facility.	1987
The ORR is placed on the NPL.	November 1989
The FFA for ORR is signed by EPA, TDEC, and DOE.	January 1992
The K-1070 OU SW-31 Spring Remedial Action is completed.	September 1992
The K-1407-B/C Ponds Remedial Action is completed.	September 1993
Sitewide radiological walkovers are performed.	1994 and 1995
The Groundwater Remedial Site Evaluation Report for K-25 Site is issued.	May 1996
The ETTP Sitewide RI to address potential contamination throughout ETTP is conducted.	1997 – 1998
The ETTP Sitewide RI Report is issued.	January 1999
The K-1401 and K-1420 Sumps Removal Action for collection of groundwater entering building sumps is complete.	February 1999
The K-1070-C/D and Mitchell Branch Removal Action for collection of groundwater is complete.	March 1999
The FFA parties establish Zone 1 and Zone 2 at ETTP for decision-making.	1999 – 2000
The ETTP ROD for Interim Actions in Zone 1 is signed.	November 2002

Table E.1. Chronology of events associated with the ETTP (cont.)

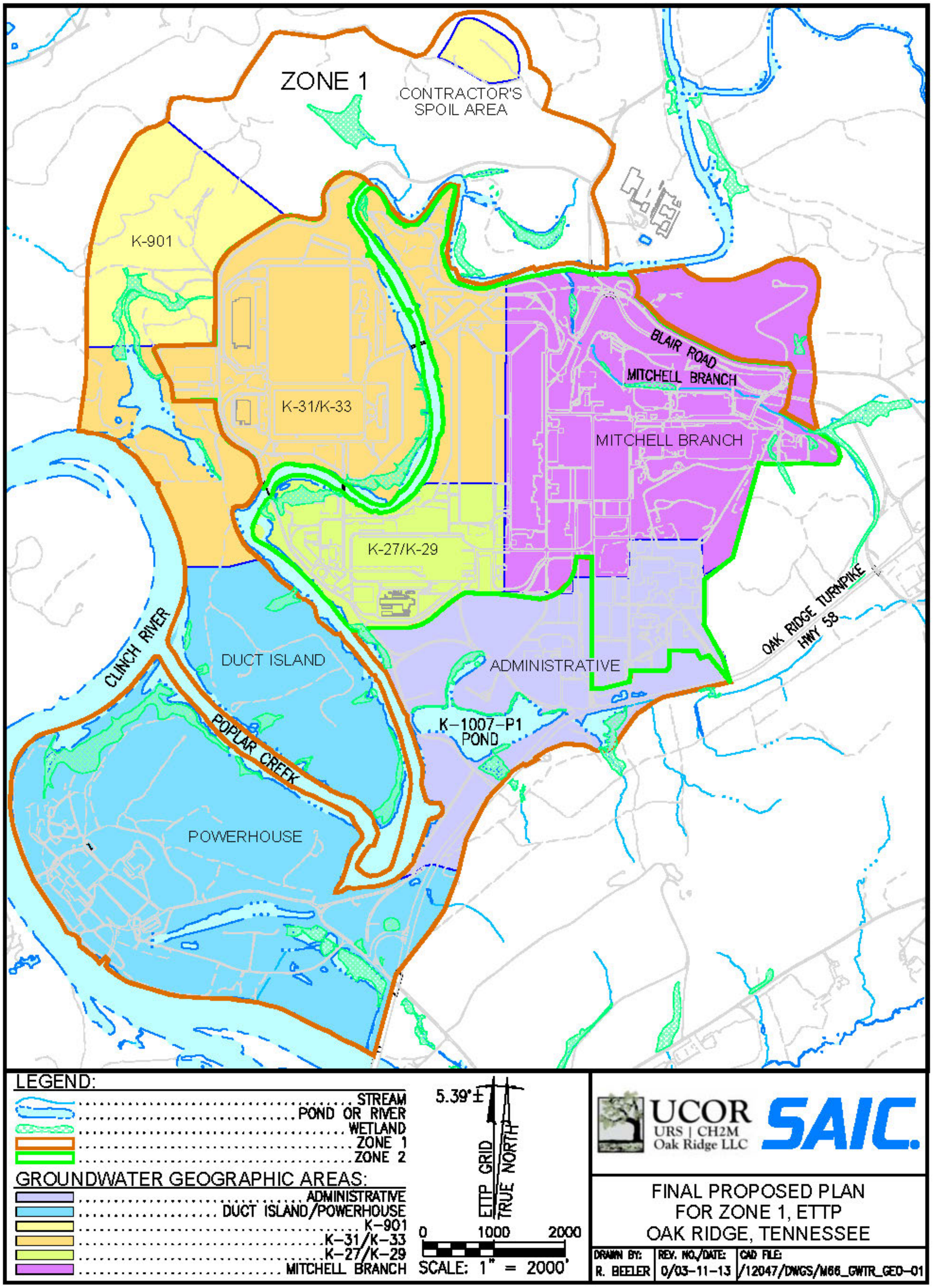
Event	Date
The K-1070-C/D G-Pit and Concrete Pad Remedial Action is complete.	February 2003
The K-1085 Old Firehouse Burn Area Drum Burial Site Removal Action is complete.	February 2003
The K-1070-A Burial Ground Remedial Action is complete.	November 2003
The ETTP Sitewide RI addressing residual contamination is conducted.	2004 – 2005
The K-1070-C/D and Mitchell Branch Removal Action groundwater collection system is terminated.	December 2004
The ETTP ROD for Soil, Buried Waste, and Subsurface Structure in Zone 2, which includes soil remediation levels for protection of groundwater, is signed.	April 2005
The RAWP for DVS in Zone 1 adopts remediation levels included in the Zone 2 ROD for protection of groundwater for Zone 1 soils.	June 2005
The K-1401 and K-1420 Sumps Removal Action collection system is terminated.	April 2006
The K-1070 OU SW-31 Spring Remedial Action collection system is terminated.	February 2007
The Final ETTP Sitewide RI/FS is submitted.	May 2007
The time-critical removal action for hexavalent chromium release via groundwater to Mitchell Branch is complete.	March 2008
PCCRs addressing Zone 1 and Zone 2 ROD requirements are approved.	2006 – present
The Final Zone 1 RI/FS is submitted.	January 2013

DOE = U.S. Department of Energy.
DVS = Dynamic Verification Strategy.
EPA = U.S. Environmental Protection Agency.
ETTP = East Tennessee Technology Park.
FFA = Federal Facility Agreement.
FS = feasibility study.
NPL = National Priorities List.
ORGDP = Oak Ridge Gaseous Diffusion Plant.
ORR = Oak Ridge Reservation.
OU = operable unit.
PCCR = Phased Construction Completion Report.
RAWP = Remedial Action Work Plan.
RI = remedial investigation.
ROD = Record of Decision.
TDEC = Tennessee Department of Environment and Conservation.

E.2 PRIMARY CONTAMINANT SOURCES AT ETTP

Figure E.1 shows the geographic groundwater areas at ETTP. These areas have been defined based on potentiometric maps, groundwater divides, storm drain networks, and surface water subwatersheds. The key source areas within these geographic areas are:

- K-901 Area – K-1070-A; Contractor's Spoil Area [CSA] (included as extension of K-901 Area).
- Duct Island/Powerhouse Area – K-1085 Old Firehouse Burn Area; Duct Island/K-1070-F; K-770; and K-720.
- Mitchell Branch Area – K-1401 Acid Line; K-1035; K-1413; K-1070-C/D and G-Pit; K-1420; and K-1095.
- K-27/29 Area – K-27/K-29.
- K-31/K-33 Area – Recirculating Cooling Water (RCW) Line leaks and K-1064 Area.
- Administrative Area – K-1200 and K-1004.



Source: DOE 2007

Fig. E.1. East Tennessee Technology Park groundwater geographic areas.

Although releases have migrated away from the original source areas and the groundwater plumes have commingled in some areas, there are 19 secondary groundwater source/plume areas and 11 corresponding groundwater plumes identified (Table E.2 and Fig. E.2). Groundwater plume ETTP-9 represents eight commingled plumes that discharge to Mitchell Branch, and groundwater plume ETTP-11 represents both the south and north K-27/K-29 plumes.

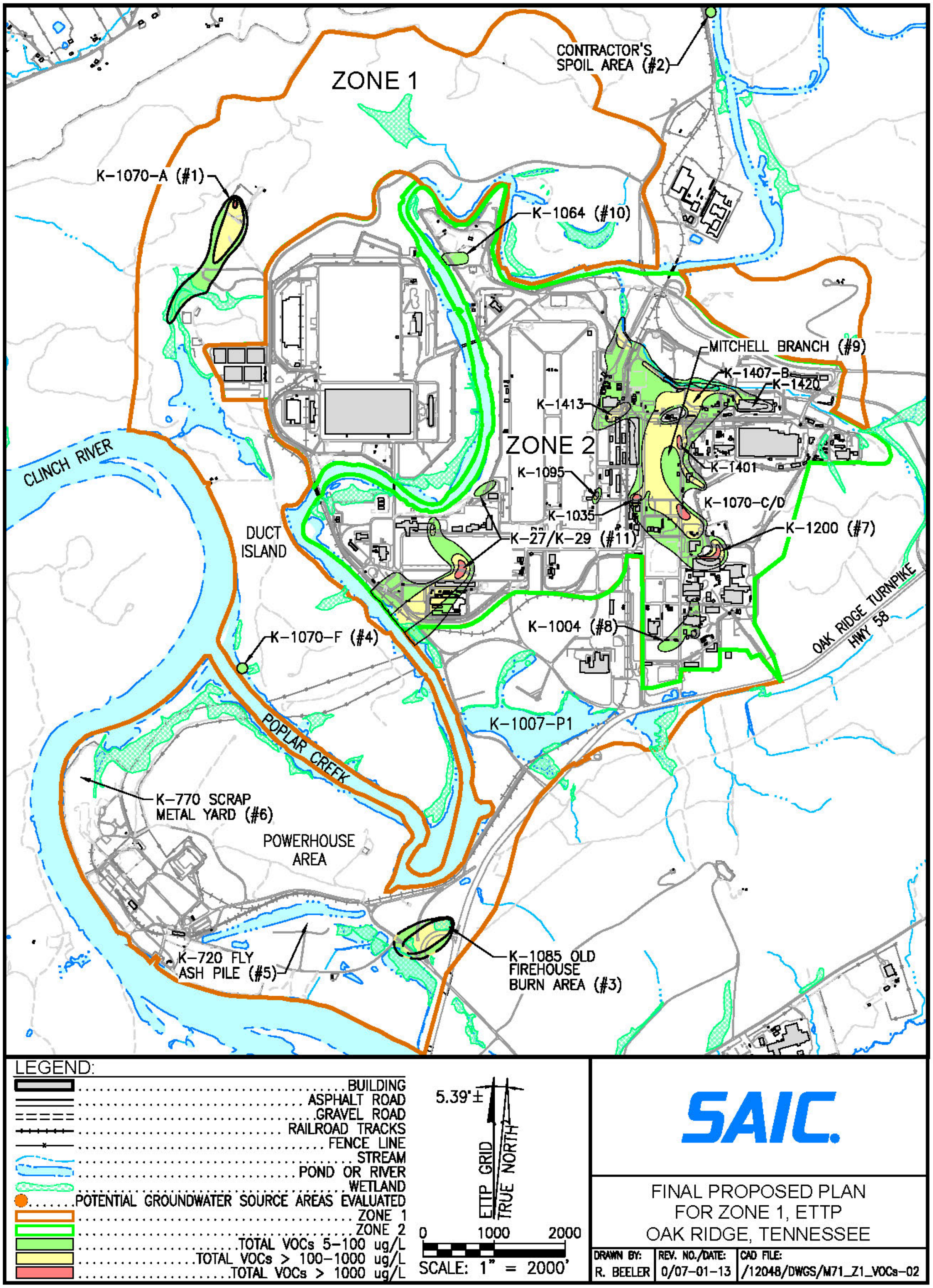
Table E.2. Groundwater plumes at ETTP

Plume description	Plume No.	Source/contaminant signature
		K-901 Area
K-1070-A Burial Ground	ETTP-1	A continuing secondary source of VOCs to groundwater exists; stable and increasing contaminant trends are observed in the karst bedrock of the Knox Group. Plume discharges occur at Spring 21-002 in the headwater of the K-901 Pond.
Contractor's Spoil Area (CSA)	ETTP-2	TCE from an uncertain source discharges at the spring (USGS 10-895) located in the bank of Poplar Creek; the spring is downgradient of the CSA, which is underlain by Knox Group bedrock, but no groundwater monitoring wells exist at the CSA to evaluate its potential as a source.
		Duct Island/Powerhouse Area
K-1085 Old Firehouse Burn Area	ETTP-3	VOC plume (TCE > 300 μg/L) discharges to nearby surface water (Beaver Dam Ponds); the site is underlain by the Rome Formation on the hanging wall of the Whiteoak Mountain Fault. The vertical extent of the VOC plume is uncertain.
Duct Island/K-1070-F	ETTP-4	VOCs from an uncertain source are present in discharge from the PCO Spring located in the streambed of Poplar Creek. Waste remains in-place at K-1070-F, which is located upgradient of the spring and underlain by Chickamauga bedrock; there are insufficient data available to determine the source of the VOCs.
K-720 Fly Ash Pile	ETTP-5	Infiltration through Fly Ash Pile produces low pH water that mobilizes metals to groundwater. Historical metal MCL exceedances are limited recently to only sporadic unfiltered groundwater samples.
K-770 Scrap Metal Yard	ETTP-6	Isolated occurrences of elevated gross alpha and beta activity are observed in two wells adjacent to the Clinch River. There have been generally stable concentration trends over the last 6 to 10 years. The area is underlain by alluvium over Chickamauga bedrock.
		Administrative Area
K-1200 Area	ETTP-7	A continuing secondary source of PCE/TCE to groundwater exists; source and vertical extent is uncertain. High concentrations (>1 mg/L) of PCE occur in the unconsolidated zone, and *cis*-1,2-DCE occurs in bedrock.
K-1004 Area	ETTP-8	Low concentrations of VOCs are observed in the Chickamauga bedrock; this may be the downgradient portion of the K-1200 Plume, but the source is uncertain.

Table E.2. Groundwater plumes at ETTP (cont.)

Plume description	Plume No.	Source/contaminant signature
Mitchell Branch Commingled Plumes	ETTP-9	**Rome Formation:** K-1407-B Pond – 1,1,1-TCA; 1,1-DCA; 1,1-DCE; *cis*-1,2-DCE; PCE; TCE; and VC (deep bedrock contamination; potential DNAPL) K-1401 Area – 1,1-DCA; 1,1-DCE; *cis*-1,2-DCE; Freon; PCE; TCE; VC; and DNAPL in fractured rock at depths of >100 ft bgs K-1070-C/D G-Pit – 1,1,1-TCA; 1,1-DCA; 1,1-DCE; *cis*-1,2-DCE; PCE; TCE; and VC (continuing secondary source of VOCs, vertical extent uncertain) Northwest K-1070-C/D – *cis*-1,2-DCE; PCE; TCE; and VC (source uncertain) K-1420 – hexavalent chromium; *cis*-1,2-DCE; PCE; and TCE **Chickamauga Supergroup (Cannon-Catheys):** K-1035 – 1,1,1-TCA; *cis*-1,2-DCE; PCE; and TCE (potential DNAPL) K-1413 – *cis*-1,2-DCE and TCE (continuing secondary source of TCE, vertical extent uncertain) K-1095 – TCE and *cis*-1,2-DCE (source and extent uncertain)
K-31/K-33 Area		
K-1064 Peninsula	ETTP-10	Low concentrations of VOCs, primarily TCE (~5 µg/L), are present in an isolated plume within the lower Chickamauga/upper Knox Group bedrock adjacent to Poplar Creek; the source is uncertain.
K-27/K-29 Area		
K-27/K-29 Area	ETTP-11	**Chickamauga Supergroup (Cannon-Catheys):** South K-27/K-29 Plume – TCE and *cis*-1,2-DCE (continuing secondary source of TCE to groundwater; source and extent uncertain) North K-27/K-29 Plume – TCE; *cis*-1,2-DCE; and VC (source and extent uncertain)

bgs = below ground surface.
DCA = dichloroethane.
DCE = dichloroethene.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
MCL = maximum contaminant level.
mg/L = milligrams per liter.
PCE = tetrachloroethene.
TCA = trichloroethane.
TCE = trichloroethene.
USGS = U.S. Geological Survey.
VC = vinyl chloride.
VOC = volatile organic compound.
µg/L = micrograms per liter.



Source: DOE 2007

Fig. E.2. Groundwater plumes at ETTP.

Constituents determined to be groundwater contaminants (defined as consistently above maximum contaminant levels [MCLs]) at ETTP include predominantly volatile organic compounds (VOCs), with minor metal and radiological constituents. MCL exceedances by metal and radiological constituents are generally isolated, infrequent, and commonly are associated with turbid samples. The predominant VOC present in groundwater is trichloroethene (TCE), with 1,1,1-trichloroethane (TCA) and tetrachloroethene (PCE) being less widespread throughout the site. Degradation products of these parent compounds, primarily *cis*-1,2-dichloroethene (DCE), 1,1-DCE, and vinyl chloride (VC), are also present in substantial concentrations in some areas. The size and shape of most parent and daughter plumes have remained relatively stable in their spatial geometry over time.

Free-phase dense non-aqueous phase liquid (DNAPL) has been observed in bedrock at the K-1401 Acid Line area. Dissolved-phase concentrations and operational history suggest DNAPLs may also exist in other areas, such as in the vicinity of the K-1070-C/D Burial Ground, the former K-1035 building, the K-1407-B Holding Pond, the K-1200 building, and possibly the K-27/K-29 area. Also, although the current concentrations do not suggest the presence of DNAPL, historical disposal operations and groundwater concentrations indicate DNAPL may have been present previously at the K-1070-A Burial Ground and the former K-1413 building. Light non-aqueous phase liquids (LNAPLs) have been observed historically in the K-1414 and K-1004 areas.

E.3 GEOLOGY AND HYDROLOGY

The developed portions of ETTP lie in East Fork Valley between Blackoak Ridge to the north, Pine Ridge to the southeast, and the smaller McKinney Ridge to the northeast. The Clinch River bounds ETTP on the southwest, and Poplar Creek bisects the main plant area. Topographic relief within the developed portion of ETTP ranges from around 740 ft above mean sea level (amsl) along the Clinch River (Watts Bar Lake) and Poplar Creek to approximately 900 ft amsl at the highest point in the K-1070-C/D Burial Ground.

Bedrock at ETTP is composed of highly indurated, folded, fractured, and faulted carbonates, shales, and sandstones with karst hydrogeology predominant in the carbonates (see Fig. E.3). The subsurface geology is dominated by complex faulting and folding. The primary thrust fault occupying the site, the K-25 Fault, places clastic rocks of the Rome Formation onto carbonates of the Chickamauga Supergroup and the Knox Group. These carbonate units underlie the majority of ETTP, including the K-901 Area, Duct Island Area, K-31/K-33 Area, K-27/K-29 Area, Administrative Area, a majority of the Powerhouse Area, and a portion of the Mitchell Branch Area. The clastics of the Rome Formation are limited to the southern and southeastern portions of the site.

The Rome Formation occupies the hanging wall of the Whiteoak Mountain Fault, which roughly parallels Highway 58 along the base of Pine Ridge, and the K-25 fault, which occupies the southeastern portion of the ETTP. Outcrops of the Rome Formation shales, siltstones, and sandstones have been observed in the vicinity of ETTP but are generally sparse and highly weathered. Mesoscopic faults, folds, and fractures are pervasive throughout the unit. Much of the Rome Formation at ETTP is expected to be complexly fractured and folded due to its position on the hanging walls of these two major thrust faults.

The predominantly carbonate rocks of the Knox Group and Chickamauga Supergroup, which together make up a 4900-ft-thick sequence of dolostone and limestone, underlie the majority of the site.

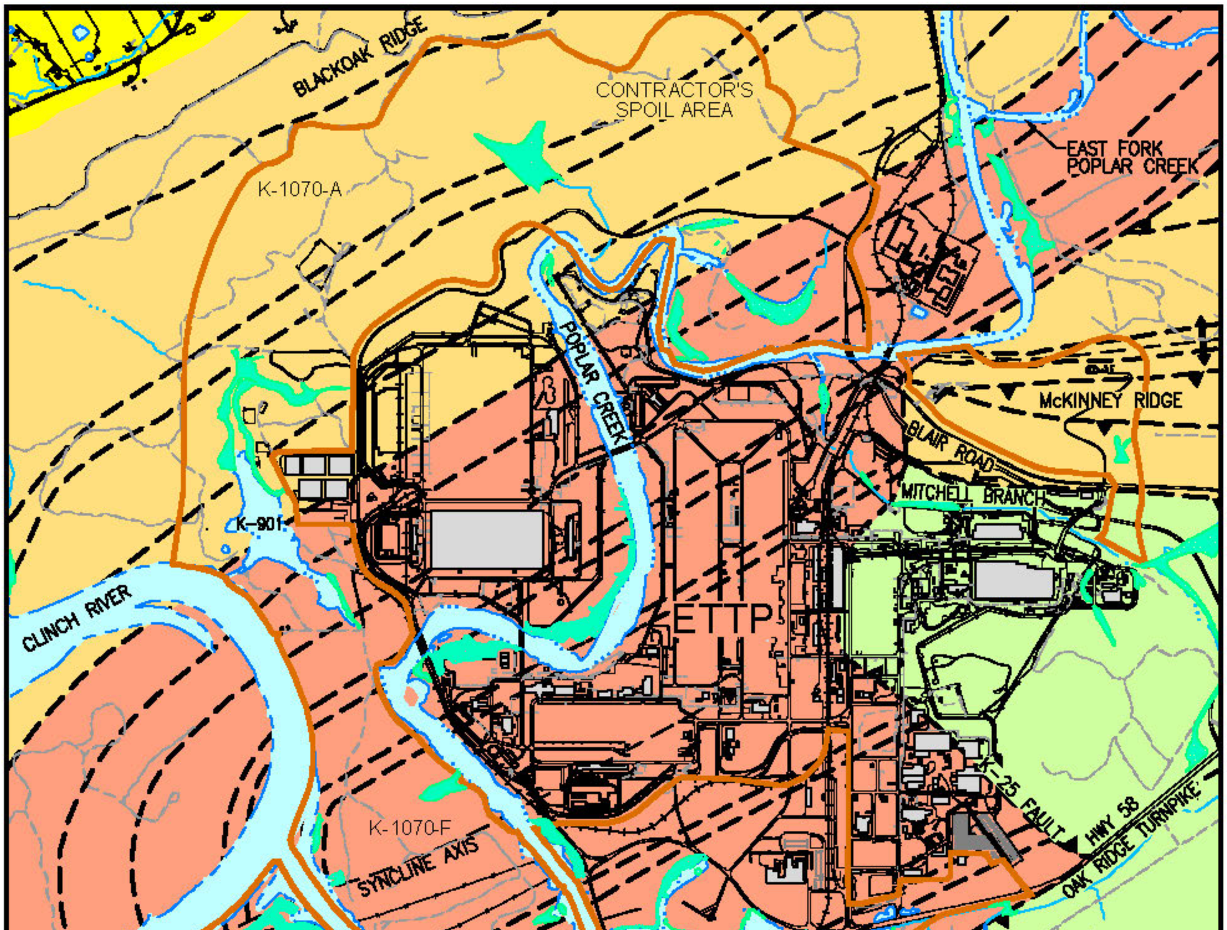


Fig. E.3. Geologic map of the ETTP.

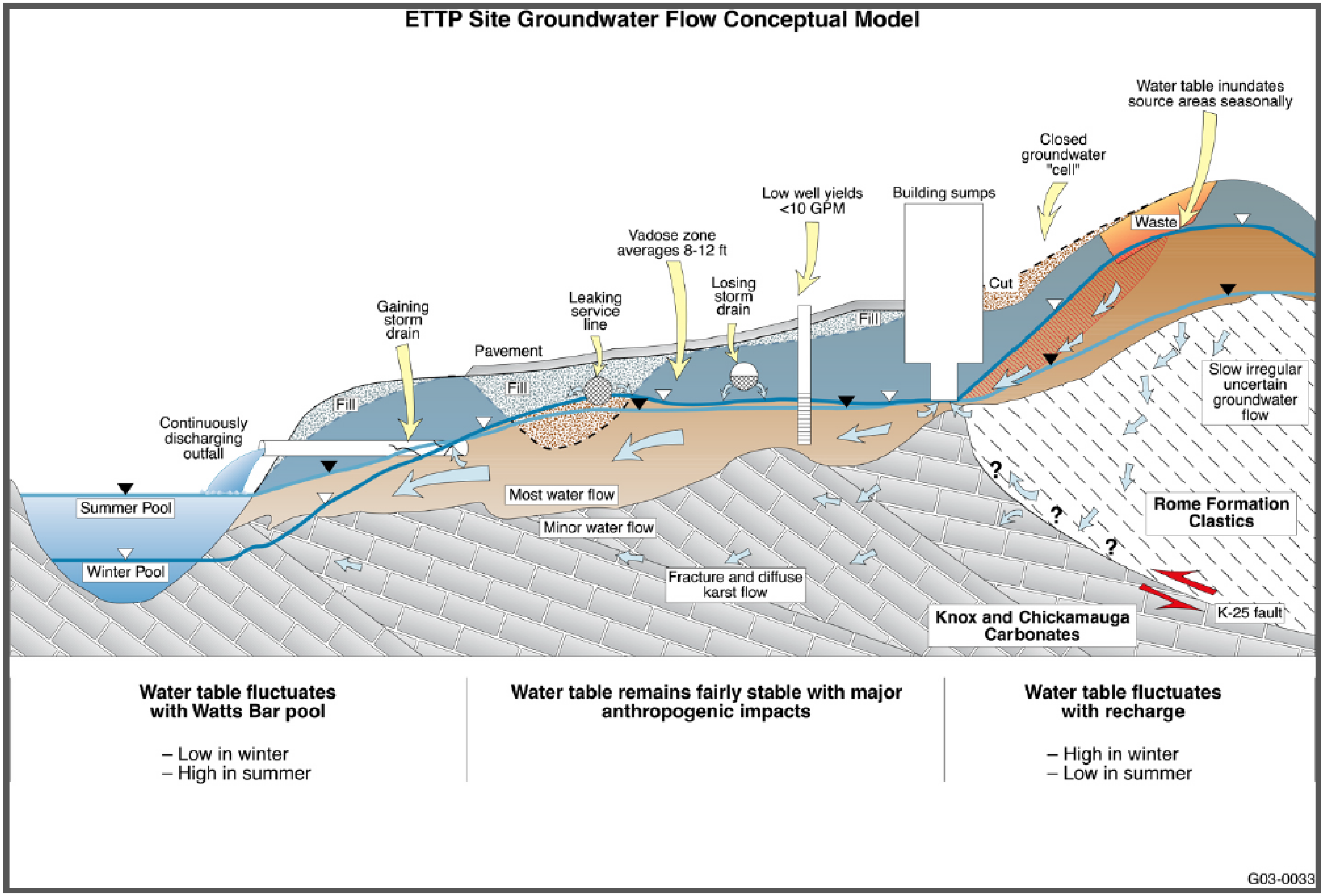
The Knox Group carbonates subcrop in the northern portion of ETTP from about the mid-point of the K-901-A Holding Pond northeast to the confluence of East Fork Poplar Creek (EFPC) and Poplar Creek and extend northward from there (Fig. E.3). Additionally, the Knox Group underlies McKinney Ridge in the northeastern portion of the site. The top of the Knox is represented by an unconformity surface that represents a period of subaerial exposure of the Knox Group prior to deposition of the overlying Chickamauga. The Knox Group is predominantly made up of dolostone that is highly siliceous, which makes it a ridge former in this region (Blackoak Ridge and McKinney Ridge).

The Chickamauga Supergroup is primarily composed of limestones and underlies valleys in which topographic relief is minimal. Within the formations that make up the Chickamauga, there are also distinct calcareous shale beds, mud-rich limestones, and thin mud seams and stringers. One common transition that is observed in the limestones of the Chickamauga Supergroup is a change from massive (6- to 12-ft-thick) fairly regularly bedded carbonates to irregular and uneven (cobbly) beds with thin clay seams. Prominent structural features in the Chickamauga are the large-scale, syncline-anticline folds present beneath the K-27/K-29, Duct Island, and Administrative Areas (Fig. E.3). At the surface, these structural features involve rocks of the Chickamauga Supergroup, producing a wide subcrop area of the Chickamauga, and undulating bedding orientations across these structures.

There is abundant evidence of karst within both the Knox and Chickamauga rocks, but the degree and style of karstification varies between these two units, at least in part as a function of the lithologic, depositional, and structural characteristics of each unit. Site data suggest these distinctions could be significant from a hydrologic perspective. Evidence of karst development in the Knox Group includes numerous sinkholes, the presence of caves, cavities encountered in boreholes, and the occurrence of numerous springs, especially along the banks of the Clinch River and Poplar Creek. These features are less common in the Chickamauga at ETTP, but are still present.

Because of the proximity to surface water features, groundwater surface water interactions are significant. Thus, transport of contaminants takes place between groundwater and surface water. Clinch River stage fluctuates on daily, weekly, and seasonal cycles as well as in response to storms during the low-pool/wet-season months in winter, creating transient boundary conditions throughout the year. These effects are seen in Poplar Creek as well, with backwater effects extending upstream along Poplar Creek above the ETTP. Further, the transition from low-pool to high-pool stage appears to have an impact on the mapped hydraulic gradient at low elevations within the site, resulting in a decrease in hydraulic gradient as wells near the river/creek equilibrate to high-pool stage. Streamflow surveys of Mitchell Branch have identified transient losing and gaining reaches illustrating the intimate interaction of groundwater and surface water at ETTP. Figure E.4 provides a generalized conceptual model for groundwater flow within the main plant area at ETTP.

Over most of the area, the water table occurs within the unconsolidated zone above bedrock. However, in some areas (e.g., Duct Island), typically in areas of thin overburden where bedrock relief is high and/or the depth to water is greater, the water table occurs below the top of bedrock. Available data suggest the bedrock and unconsolidated zone are hydraulically connected. Depth to groundwater ranges from 2 to 70 ft below ground surface (bgs), largely depending on topographic position, occurring at greater depths at higher elevations. Recharge to the groundwater generally occurs in areas of higher elevation (ridges). The Clinch River is generally considered the ultimate discharge point for shallow groundwater because, over most of the area, it truncates the unconsolidated zone flowpaths, intersects strike-parallel bedrock flowpaths, and represents the lowest observed hydraulic head in the valley. However, flowpaths in the deeper bedrock portion of the aquifer are difficult to determine, and the possibility exists that these deeper flowpaths may provide groundwater transport beneath the river. Shallow groundwater flowpaths also result in discharge to smaller order streams such as Mitchell Branch and Poplar Creek, and to the K-1007-P Ponds and the K-901-A Pond.



Source: DOE 2007

Fig. E.4. Conceptual model of groundwater flow at ETTP.

Groundwater flow at ETTP is influenced by complex geology, transient interactions with bounding surface water bodies, and numerous anthropogenic features. At the time of construction of the ETTP, extensive land modification occurred to convert rolling, hilly terrain to the nearly level industrial site configuration that exists today. Site grading required extensive cut and fill activities, which lowered the elevations of knobs and raised the elevations of valleys. Much of the main plant area, in particular, has been extensively reworked as part of the original site construction activities, yielding thick, filled areas, which, in some cases, were occupied by former surface water drainage channels that now may serve as primary migration pathways. Storm drains serve a dual role as either sinks for discharge of groundwater or sources of recharge water to groundwater. A number of storm drains flow continuously even in dry weather, suggesting they are discharging captured groundwater.

Maps of the water table surface (Fig. E.5) show that the water table appears to be a subdued replica of topography, with elevated heads associated with elevated topography and lower heads defined by bounding surface water features. Consequently, the potentiometric maps imply radial flow from elevated areas within the plant, such as occurs in the vicinity of the K-1070-C/D Burial Ground, to the adjacent surface water features, including Mitchell Branch, the K-1007-P1 Holding Pond, the K-901-A Holding Pond, Poplar Creek, and the Clinch River.

The extent of surface cover provided by the massive buildings, paved areas, or otherwise impervious areas reduces the overall infiltration of rainfall in some areas of the site, and thus recharge to groundwater in these areas, producing a potentiometric surface that is relatively flat over the main plant area.

As mentioned above, much of the bedrock contains karst features that serve as conduits for groundwater flow. Thus, groundwater flow in bedrock is very complex because flowpaths are controlled by the orientation and interconnections of fractures and solution channels.

Groundwater tracer tests in the Mitchell Branch area indicate a range in groundwater seepage velocities of 1 to 12 ft/d through saprolite, residual soils, and fractured bedrock of the Rome Formation and Chickamauga Group limestones based on the observed tracer velocities. Historical dye tracer tests at the K-1070-A Old Contaminated Burial Ground have indicated tracer seepage velocities of greater than 2800 ft/d through karst bedrock of the Knox Group. Due to the proximity of surface water to the disposal/release sites at ETTP, shallow groundwater plumes generally follow short flowpaths to nearby discharge points. Bedrock plumes follow more complex pathways and are only loosely constrained at ETTP. Due to their relatively low attenuation rates, the primary contaminants of concern (COCs) at ETTP – VOCs – are readily transported in groundwater at ETTP.

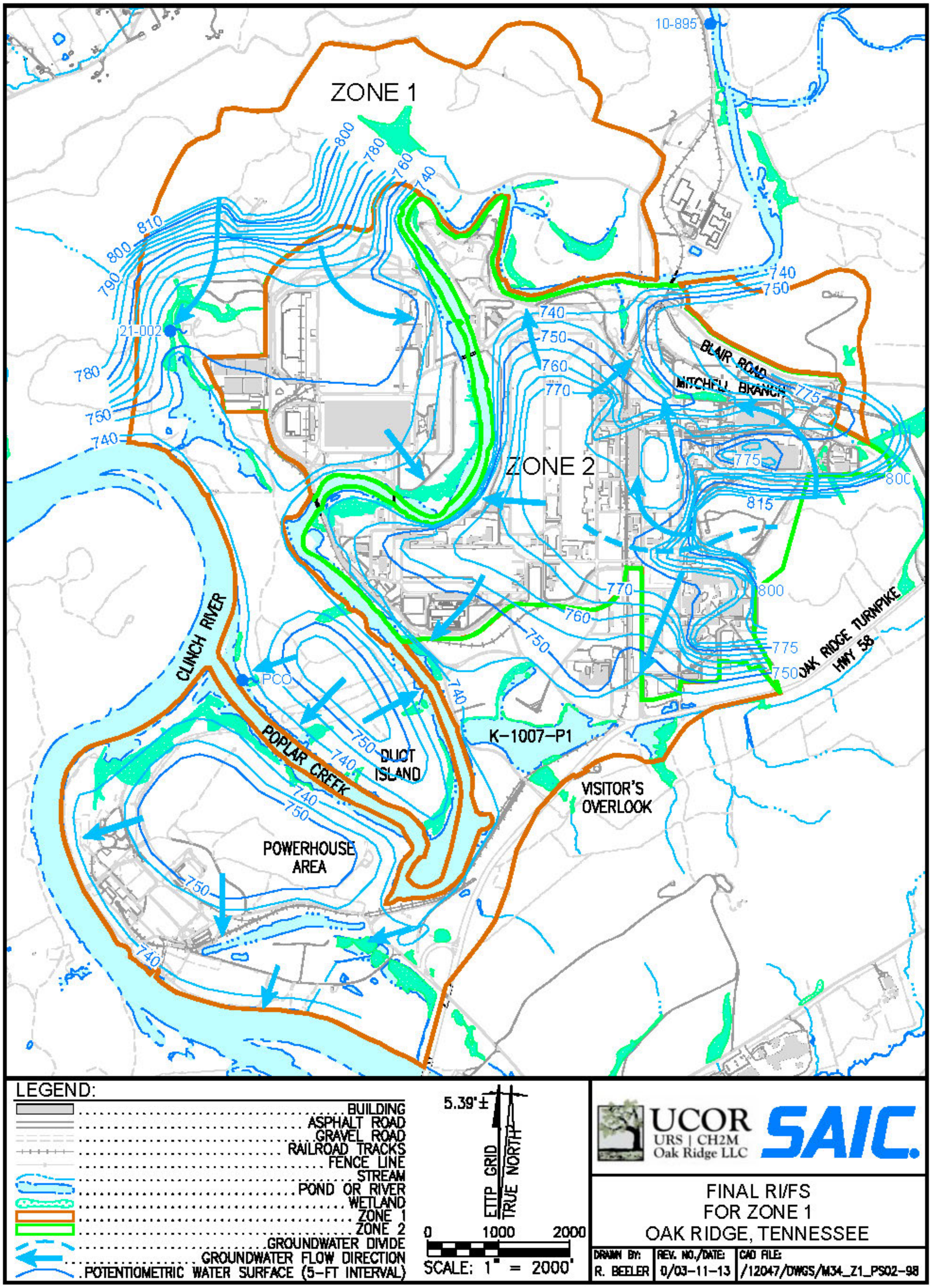
Risk

The interim Record of Decision (ROD) for Zone 1 and the ROD for soil, buried waste, and subsurface structures in Zone 2 (see Fig. E.2 for Zone 1 and 2 boundaries) anticipates the following future land use for the ETTP,:

Zone 1: Consists of 1400 acres outside the fenced main plant area – unrestricted industrial, with land use controls (LUCs) to prevent disturbance of soils below 10 ft in depth;

Zone 2: Consists of 800 acres comprising the main plant area – restricted industrial.

However, the northern section of Zone 1 has been designated as part of the Black Oak Ridge Conservation Easement (BORCE). The BORCE is utilized for recreational purposes: hiking, bicycling, and select controlled deer hunts. The end use identified in the Zone 1 Interim ROD is unrestricted industrial (i.e., recreational use was not designated). The U.S. Department of Energy (DOE) has



Source: DOE 2007

Fig. E.5. Potentiometric map for the ETTP site (February 1998 water level data).

acknowledged that the end use difference exists between the BORCE use and that which is in the Zone 1 Interim ROD, and will change the end use of the portion of Zone 1 that is also identified as part of the BORCE from industrial to recreational in the Zone 1 Final ROD. A risk assessment has been prepared and approved in the *Addendum to the Phased Construction Completion Report (PCCR) for the Duct Island and K-901 Areas* (DOE 2009) to demonstrate protectiveness for recreational use.

The Final Zone 1 RI/FS (DOE 2013a) includes the following media-specific Remedial Action Objectives (RAOs):

- Provide for the use of the majority of Zone 1 as a future industrial site (at a minimum of 10 ft in depth) to an incremental lifetime cancer risk (ILCR) target risk range of 10^{-6} to 10^{-4} or a hazard index (HI) of 1 for incidental ingestion, direct exposure, inhalation, and dermal exposure pathways in exposure units (EUs) as previously defined; alternatively, protect a future recreational user to an ILCR target risk range of 10^{-6} to 10^{-4} or an HI of 1 for the same pathways in EUs defined for industrial use. For either receptor, prevent exposure to residual asbestos in soil.

- Protect local-level terrestrial wildlife receptor populations from contamination in surface soil as defined by lowest observed adverse effect level (LOAEL) exceedances averaged over a habitat area.

- Protect underlying groundwater and nearby surface water to risk-based levels and applicable or relevant and appropriate requirements (ARARs) from contamination in soil.

- Meet ARARs in surface water bodies.

- Protect recreational and residential receptors of surface water bodies to an ILCR target risk range of 10^{-6} to 10^{-4} or an HI of 1 from fish ingestion.

- Protect future piscivorous wildlife to LOAELs from polychlorinated biphenyl (PCB)-contaminated fish averaged over a single pond.

- Prevent exposure to contaminated groundwater in excess of the ILCR target risk range of 10^{-6} to 10^{-4} or an HI of 1 for any use.

- Restore groundwater to beneficial use and meet groundwater ARARs.

In May 2013, agreement was reached to move forward on a final Zone 1 soil decision and to defer the final Zone 1 surface water and groundwater decisions to the future.

A goal of the Zone 1 and Zone 2 interim RODs was to identify residual sources of groundwater contamination that result in exceedances of MCLs in groundwater and remove them from the environment. An approach for ensuring that residual soil contamination would not contribute to underlying groundwater MCL exceedances was established in the RODs and has been completed for Zone 1. A threat to groundwater by soils is evaluated by reviewing existing area groundwater data for MCL exceedances that occur on a regular basis. If the groundwater data are sufficient and there are no consistent MCL exceedances, then No Further Action is appropriate for soils. If the groundwater data are insufficient to discern regular MCL exceedances, or the data are sufficient and regular MCL exceedances occur, then soil concentrations are screened against the screening levels for groundwater protection as defined in the Zone 2 ROD and adapted for Zone 1. Based on the screening results, site-specific modeling may be conducted if additional evaluation is determined to be necessary. Consideration of an action is required if modeling results indicate soils may be a potential source of contamination to groundwater.

E.4 CONCEPTUAL MODEL, SOURCE AREA SCALE

E.4.1 K-901 AREA

VOCs are the primary organic contaminants in the groundwater of the K-901 Area. The compounds 1,1,1-TCA; 1,1,2-TCA; 1,1- DCE; carbon tetrachloride; PCE; and TCE have exceeded their MCL values in historical groundwater samples. The VOC 1,2-dichloroethane (DCA); benzene; toluene; total xylenes; *cis*-1,2-DCE; and *trans*-1,2-DCE have been detected in groundwater but have not exceeded their drinking water MCLs. DNAPLs are not assumed to be present in groundwater within the K-901 Area based on the recently detected concentrations of VOCs.

Technetium-99 (^{99}Tc) has been the only radionuclide to exceed its derived MCL. Other radionuclides with MCLs (e.g., ^{90}Sr and $^{234/235/238}$U) have been detected but have not approached or exceeded their respective MCLs.

ETTP-1 K-1070-A Burial Ground

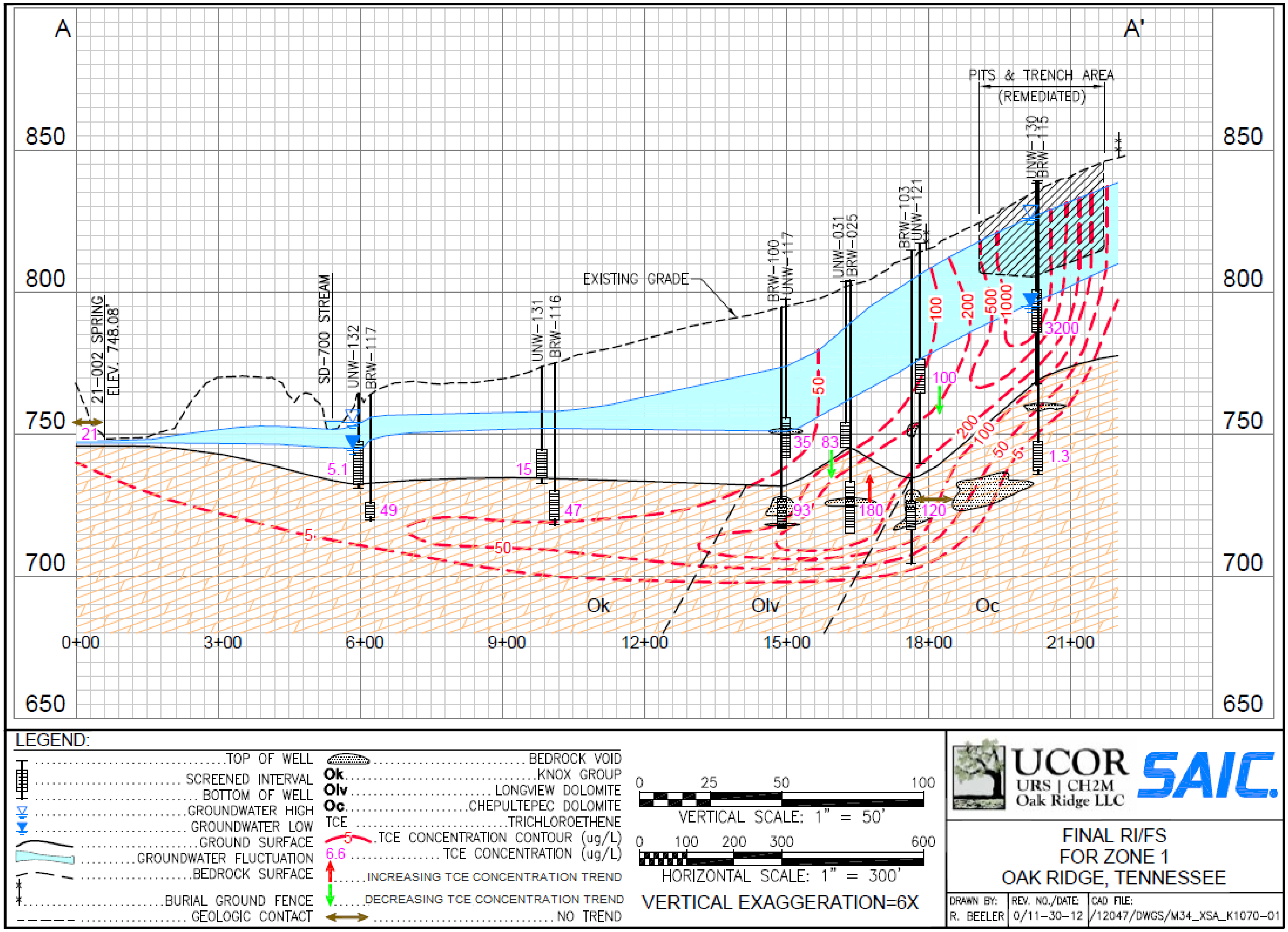
The K-1070-A Burial Ground contained wastes disposed in trenches and pits. Substantial quantities of radiologically contaminated metal and organic liquids were likely disposed in the burial ground in unlined trenches and pits starting in the late 1940s to March 1976. The burial ground wastes and associated soil were excavated between June 2002 and June 2003, after which the excavation was backfilled with clean soil and the site was restored. Approximately 16,700 yd^3 of waste and soil were excavated from depths up to approximately 25 ft bgs within the vadose zone, which extends to depths greater than 30 ft bgs at the site.

The primary groundwater contaminants present in the K-1070-A plume are VOCs. TCE is the most prevalent VOC, with 1,1,1-TCA; 1,1,2-TCA; 1,1-DCE; carbon tetrachloride; and PCE also present, although to a lesser extent. Thallium and ^{99}Tc have been detected in groundwater in a limited number of wells at concentrations that historically have exceeded their respective MCLs. However, recent data do not indicate MCL exceedances for any metals or radiological constituents.

Once in the groundwater, contaminants are transported by groundwater flow south and southwestward to discharge to the K-901-A Holding Pond (see Fig. E.6), primarily via Spring 21-002. Solution cavities and interconnected fractures and bedding planes act as conduits for the rapid transport of groundwater and serve as primary flowpaths in bedrock. Dye-tracer test results indicate travel times as rapid as 2 ft/min (2900 ft/d) between bedrock beneath the K-1070-A Burial Ground and Spring 21-002. Vertical gradients generally show downward gradients from the unconsolidated zone to bedrock, although some reversals in direction of gradient have been observed. This indicates that advective flow could transport dissolved constituents from the unconsolidated zone into bedrock.

Although dye tracing and contaminant distribution indicate a strong flow component in the downgradient direction to the south-southwest from the burial ground to the spring/K-901-A Holding Pond, the possibility of a more west-southwest flow component following geologic strike may also exist.

Concentration trends have been determined for selected wells located in the K-1070-A plume. Historical data since 1994 were compared to the most recent data to identify locations where a conceivable trend for TCE was observed. Based on an analysis of TCE concentration trends for the entire sampling range and over the last 6 years (calendar years 2005 to 2011), decreasing TCE concentration trends were indicated for the unconsolidated monitoring wells. However, bedrock monitoring well BRW-025



Source: DOE 2013a

Fig. E.6. Cross-section of K-1070-A Burial Ground Area.

experienced an increasing trend in TCE concentrations in recent years (Fig. E.7), while other bedrock wells such as BRW-103 experienced generally stable trends similar to the overall trends (Fig. E.8).

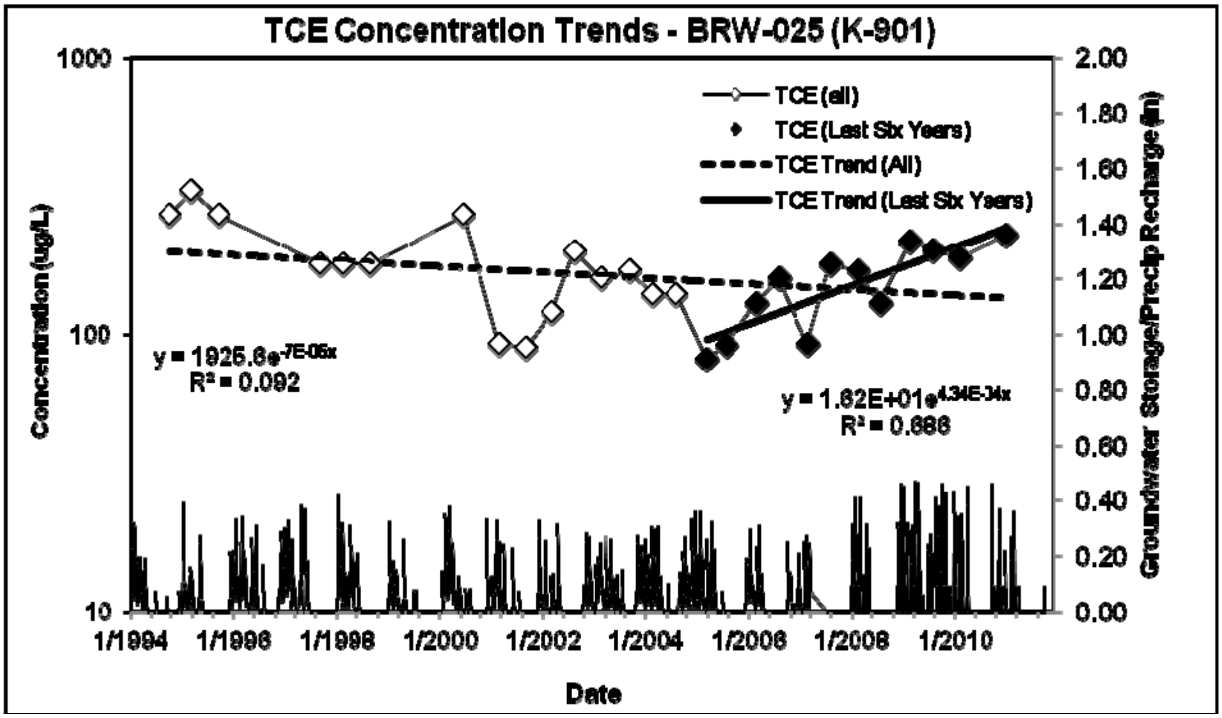
It is likely that contaminants currently present in the soil and bedrock matrix are being diffused back out into the fractures and karst conduits. Because of such high groundwater velocities, dilution is probably a significant attenuation mechanism in the bedrock pathways. Other attenuation processes, such as adsorption, degradation, etc., probably play some role as well. The presence of high concentrations of daughter compound 1,1-DCE relative to TCE suggests that some reductive dechlorination is occurring. The virtual absence of the most common daughter compounds (*cis*-1,2-DCE and VC) due to anaerobic reductive dechlorination of TCE suggests that reductive dechlorination is occurring through a less common pathway, such as mineralization.

ETTP-2 Contractor's Spoil Area (CSA)

Located in the BORCE area, the CSA was first opened in 1974 by the Tennessee Valley Authority (TVA) to obtain fill material. In 1978, the TVA borrow pit was used as a disposal area. The CSA was dedicated to the disposal of noncontaminated waste materials generated by construction activities performed by outside contractors, plant maintenance personnel, and plant operations. The CSA consists of three adjacent disposal units: (1) fly ash pile, (2) aerosol disposal area, and (3) borrow pit. The fly ash pile is approximately 1 acre in size and was used for the disposal of fly ash in an unlined, above-grade disposal area. The aerosol disposal area consists of three unlined pits 10 to 12 ft deep and 6 ft in diameter. These pits received aerosol cans that had been emptied of their contents. The borrow pit is approximately a 6-acre area and was primarily used for the disposal of construction and demolition debris in a below-grade, unlined pit. In 1982 and 1983, approximately 13,750 gal of oil were landfarmed on the roads and through the area to suppress dust. The site was capped with clay and topsoil and seeded with fescue in 1985. The closure of the area was approved by the Tennessee Department of Environment and Conservation (TDEC) in 1987. Soil sampling conducted under the Zone 1 Interim ROD indicates the soil cap ranges from 1.5 to 8 ft in thickness, but was most commonly 3 to 5 ft in thickness. No remedial actions have been implemented at this site. Results from the sampling under the Zone 1 Interim ROD found no residual sources to groundwater contamination. However, extensive source sampling was not conducted.

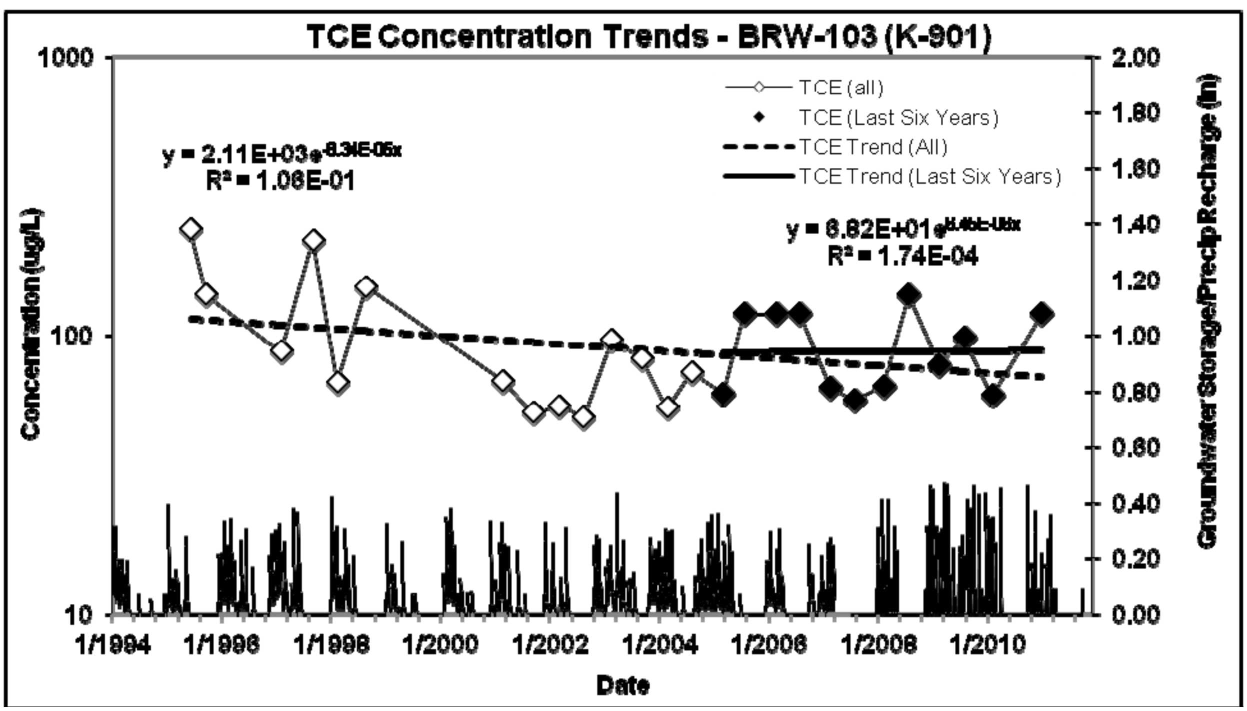
Surface water transport includes overland flow and movement via an unnamed stream along the north boundary of the CSA. Infiltration of precipitation could mobilize and transport constituents in the waste materials to groundwater. Shallow groundwater likely follows topography and discharges to the north and to the east into Poplar Creek. Groundwater flow in the bedrock is anticipated to follow solution-enlarged features such as bedding planes and fractures, both along strike and down-dip toward Poplar Creek. Samples from the U.S. Geological Survey (USGS) 10-895 Spring in the bank of Poplar Creek to the east, and located approximately 2700 ft from the disposal area, contain concentrations of TCE that are at, or slightly above, the MCL. The source of the TCE is unknown.

Regression trend analysis of the concentration plot of TCE at Spring 10-895 and a Mann-Kendall (M-K) statistical analysis showed no trend in TCE concentration for the entire sampling period, as well as over the last 6 years. The M-K analysis showed that TCE concentrations were stable at Spring 10-895 over the entire sampling range, as well as over the last 6 years based on a 90% confidence level. Concentrations of TCE at this spring show minor variations between sampling events that may be attributed to seasonal rainfall dilution of groundwater, water table rise, or groundwater gradient change. TCE concentrations are relatively low, and daughter compounds have not been detected.



Source: DOE 2013a

Fig. E.7. TCE concentration trends in bedrock monitoring well BRW-025.



Source: DOE 2013a

Fig. E.8. TCE concentration trends in bedrock monitoring well BRW-103.

Table E.3 provides a summary of the K-901 Area plume sources located over Knox Group bedrock. In addition to the information on the table, key considerations include:

- The Zone 1 dynamic verification strategy (DVS) found that soils to a depth of 10 ft bgs do not pose a threat to groundwater based on the DVS and historical soil sample results screening.

- VOCs are not detected in surface water samples collected at the K-901-A Pond weir, or in Poplar Creek.

E.4.2 DUCT ISLAND/POWERHOUSE AREA

ETTP-3 K-1085 Old Firehouse Burn Area

The K-1085 Old Firehouse Burn Area, located in the southwestern portion of ETTP (see Fig. E.2), had a pit with dimensions of approximately 20 × 25 × 15 ft. The exact location of the former pit is unknown, but it has been narrowed to a 2-acre area that was extensively regraded when State Highway 58 was rerouted in the early 1960s. The firehouse area was operational from 1944 to 1960, although waste oil was burned in the unlined pit only until 1951 when the pit was filled. Open burning of contaminated oil took place in metal pans on the concrete pads remaining from the former firehouse, fuel station, and garage buildings until 1960. Exact details of the types and quantities of waste burned at this unit are unknown. Pit burning was extinguished with water at the end of each day, and water was periodically pumped from the pit onto the surrounding ground or road, which sloped downhill from the pit.

A time-critical removal action (TC RmA) completed at the K-1085 site in 2002 (DOE 2012) included the excavation and disposal of discovered drums and some associated soil. Under the DVS process, additional remedial action was recommended for the K-1085 Area. Remedial action consisted of excavating the uppermost 8 ft of soil and stockpiling for use as backfill. With the upper 8 ft of soil removed, the lowermost VOC- and PCB-contaminated soil from the 8- to 12-ft depth, which comprised approximately 300 yd^3, was excavated for disposal. Remedial actions were completed in July 2008.

The J.A. Jones Maintenance Complex area, located near the former burn area, covered approximately 10 acres and consisted of one 385- by 50-ft building with fuel pumps, two smaller gas stations with fuel pumps, and small accessory buildings. The area was operational from 1944 to 1946. Wastes possibly include leaded gasoline, kerosene, diesel fuel, lubricating oils and grease, antifreeze, and miscellaneous solvents. Two underground storage tanks (USTs) were determined to be present in the J.A. Jones Maintenance Area and the tanks were closed in-place in 2007 in accordance with TDEC UST rules.

Groundwater occurs in both the unconsolidated overburden and bedrock, which consists of Rome Formation shales, siltstones, and sandstones. Much of the area is unpaved and/or undeveloped, so groundwater is probably locally recharged. Groundwater flow in the unconsolidated zone is expected to follow mapped hydraulic gradients and short flowpaths, and it discharges locally to the beaver dam ponds and/or the Clinch River. A shallow groundwater divide runs through the J.A. Jones Maintenance Area and directs shallow groundwater flow to the north to Poplar Creek or to the south toward the ponds and the Clinch River. Numerous seeps located to the south in the cloverleaf and to the southwest in the vicinity of the beaver dam ponds suggest these areas represent discharge zones for shallow groundwater flow from the K-1085 Area.

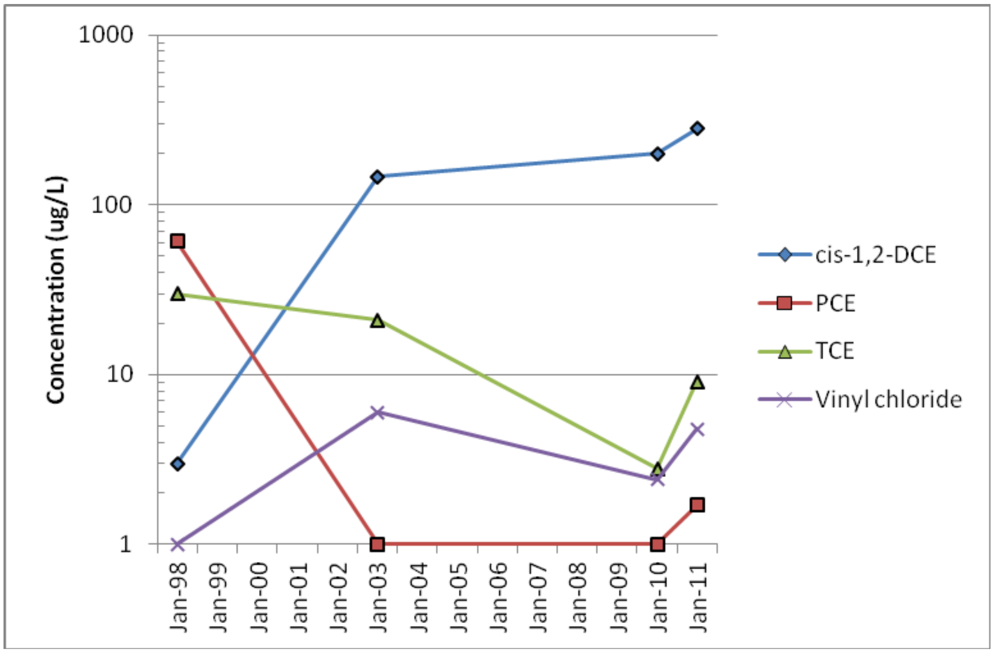
Table E.3. Conceptual model elements for K-901 Area groundwater plumes

Plume No.	Plume	Description: Downgradient length (ft)	Description: Depth (ft bgs)	Description: Maximum concentration (µg/L)	Flowpaths	Groundwater exit points	Data gaps and uncertainties
ETTP-1	K-1070-A Burial Ground	1,800	>100	TCE: 3,200 1,1-DCE: 450 CT: 190	Follows hydraulic gradient and karst pathways along-strike and down-dip in Knox	Spring 21-002 at head of K-901 Pond	Mass and distribution of residual source are uncertain Potential off-site migration along-strike is uncertain
ETTP-2	Contractor's Spoil Area	If source for spring discharge – 2,000	Unknown	TCE: 10 at spring	Likely along-strike and down-dip flow in Knox	USGS spring 10-895 on Poplar Creek	Source of TCE at spring is unknown

bgs = below ground surface.
CT = carbon tetrachloride.
DCE = dichloroethene.
ETTP = East Tennessee Technology Park.
TCE = trichloroethene.
USGS = U.S. Geological Survey.
µg/L = micrograms per liter.

Groundwater from seeps and unconsolidated zone wells indicates maximum TCE concentrations greater than 300 micrograms per liter (µg/L) and *cis*-1,2-DCE and VC greater than MCLs. The only bedrock well contained PCE and TCE greater than 20 µg/L. Figure E.9 shows VOC concentrations over time at spring 247, located immediately downgradient of the K-1085 site.

The primary evidence of biodegradation of the parent TCE is the occurrence of daughter products. The presence of high concentrations of daughter compound *cis*-1,2-DCE relative to TCE suggests that reductive dechlorination is occurring.



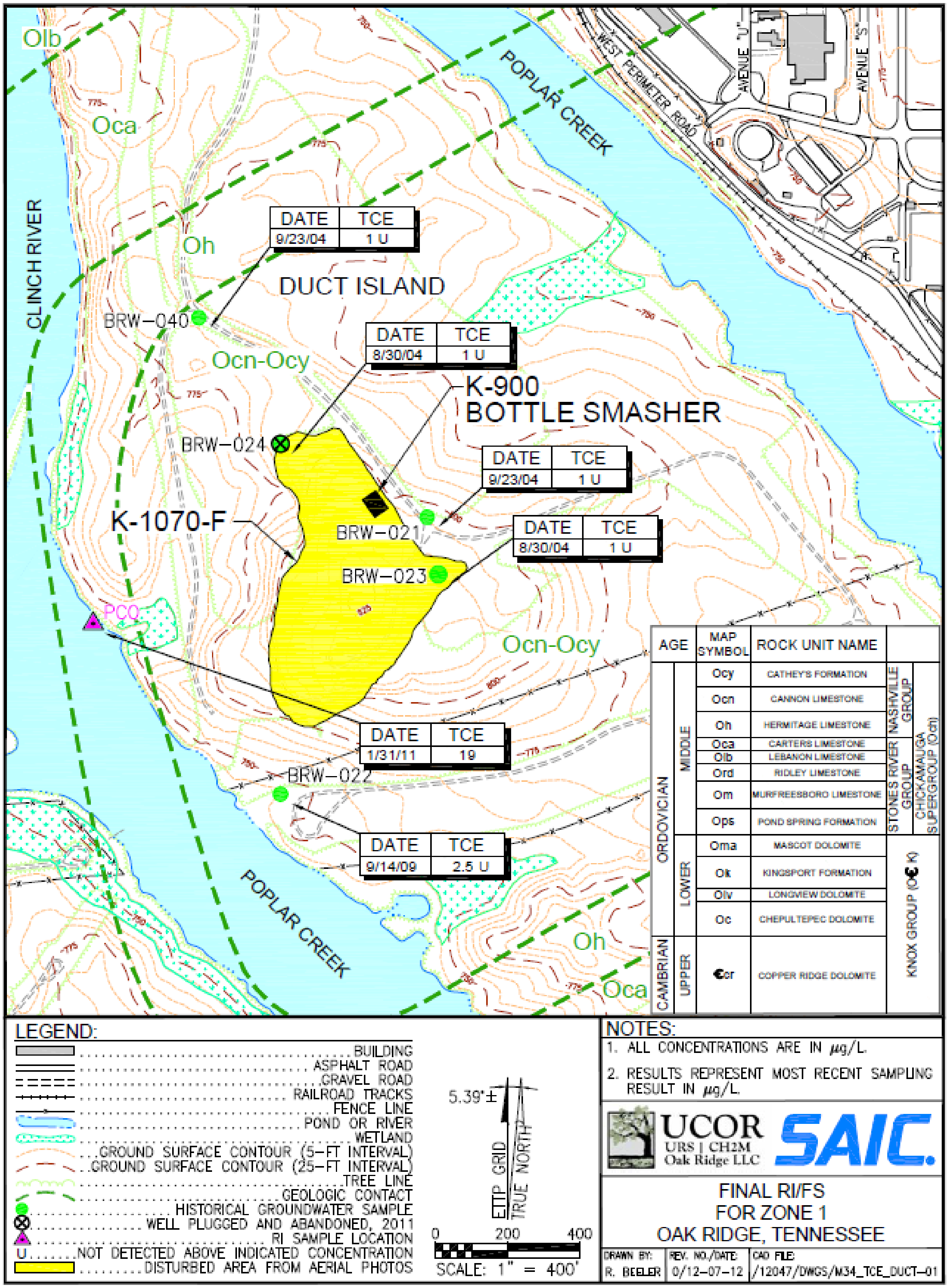
Source: DOE 2013a

Fig. E.9. VOC concentrations at Spring 247 in the K-1085 Firehouse Burn Area.

ETTP-4 K-1070-F Construction Spoil Area

The K-1070-F Construction Spoil Area is approximately 5 acres in size and is generally believed to have been in operation from 1974 to 1978. Disposed material at the K-1070-F Construction Spoil Area included soil and rock, concrete, asphalt, clean scrap, building materials, asbestos, transite, roofing materials, pallets, and cross ties. After the disposal area was closed, the K-900 Bottle Smasher, which was a Resource Conservation and Recovery Act of 1976 (RCRA) Subtitle C hazardous waste treatment unit, was located and operated within the K-1070-F Area. This metal unit was used from 1980 to 1988 for the disposal of bottles of organic chemicals and sodium/potassium metal chips in water. Bottles of organic chemicals were remotely crushed in the smasher and the contents were ignited using a heating element. The bottle smasher was closed under RCRA in 1993 and removed from the site. A soil cap, varying in thickness from 0.5 ft to greater than 10 ft, covers most of the disposal area; however, there are substantial quantities of building debris and rubble surrounding the main fill area that is not covered. No remedial actions have been implemented at the disposal area and none were determined to be needed under the Zone 1 Interim ROD.

Only sporadic detections of VOCs have been observed in the monitoring wells located at K-1070-F, historically. Spring PCO, located below the high pool level of Poplar Creek (Fig. E.10), shows TCE



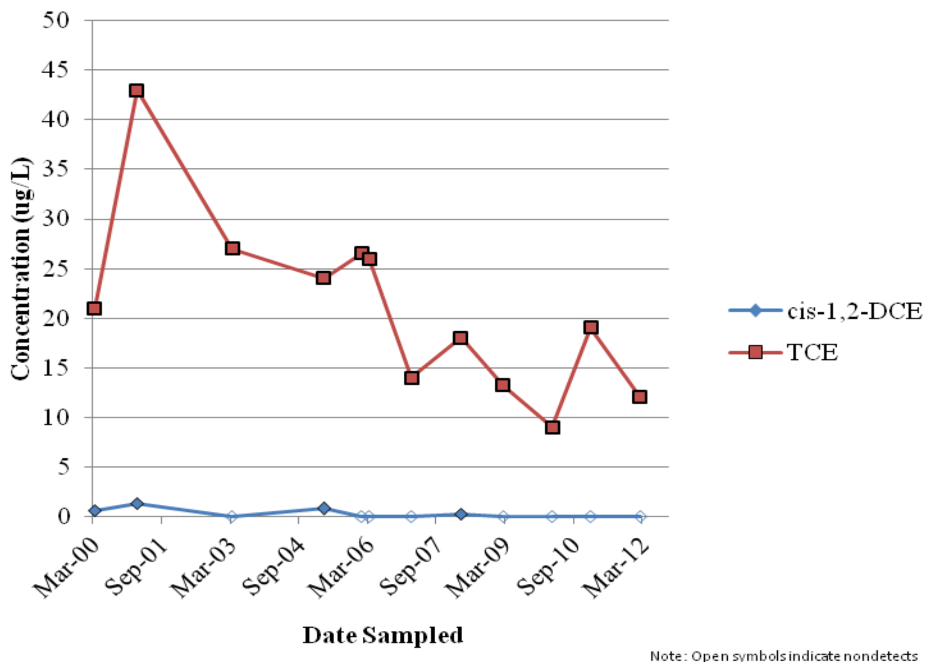
Source: DOE 2013a

Fig. E.10. TCE concentrations in the K-1070-F Construction Spoil Area.

concentrations of generally less than 20 µg/L since 2006, with a maximum TCE concentration at PCO of 43 µg/L.

Spring PCO shows minor variations in concentration (Fig. E.11) between sampling events that may be attributed to seasonal rainfall dilution of groundwater, water table rise, or groundwater gradient change. A regression analysis showed a decreasing TCE concentration trend for the entire sampling period of record, as well as a decreasing TCE concentration trend over the last 6 years. The M-K analysis showed that TCE concentrations also decreased at Spring PCO over the entire sampling period, as well as over the last 6 years based on a 90% confidence level.

Data available to demonstrate natural attenuation of VOCs are limited. TCE concentrations are relatively low and the daughter compound *cis*-1,2-DCE has only occasionally been detected at very low estimated concentrations and VC has not been detected. Therefore, it is likely that some biodegradation might be occurring, but conditions are not favorable for rapid or continuous reductive dechlorination.



Source: DOE 2013a

Fig. E.11. VOC concentration at the PCO Spring, K-1070-F Construction Spoil Area

ETTP-5 K-720 Fly Ash Pile

The K-720 Fly Ash Pile is located adjacent to a former coal pile area and between the K-720 Slough and the Clinch River at the southern edge of the Powerhouse Geographic Area (see Fig. E.2). The K-720 Fly Ash Pile was operational from 1944 to 1962. The fly ash pile contains bottom ash, slag, and coal fines from the K-701 Powerhouse coal-fired steam plant operation. During 1993, application of lime to control low pH in nearby surface water began. Placement of a soil cover over the ash pile began in 1994. Subsequent actions also included implementation of improvements to the fly ash soil cover along the northern boundary of the ash pile with a wet weather conveyance. The soil cover improvements were

completed in September 2011 and included additional soil cover over exposed fly ash and placement of riprap along a portion of the south bank of the wet weather conveyance.

The principal mechanism of contaminant transport at the K-720 Fly Ash Pile is infiltration through the unsaturated soils that causes contaminants to leach from the soil into the groundwater or by direct contact of the water table with the contaminated soil mass, thereby leaching contaminants from the soils to groundwater. Modeling conducted in support of the Zone 1 ROD (DOE 2010) indicated that seven metals (antimony, arsenic, cadmium, lead, mercury, selenium, and thallium) and one SVOC [benzo(*a*)pyrene] could be leaching to groundwater with concentrations exceeding their respective MCL or screening level. Results from transport modeling conducted to predict contaminant migration through groundwater and the expected future concentrations at the downgradient receptor location (the Clinch River) indicated that none of the metals, nor benzo(*a*)pyrene, which were predicted to be leaching to the water table would migrate to the downgradient receptor location. The contaminants were predicted to naturally attenuate in the groundwater system through chemical immobilization, advection, adsorption, and dispersion.

Elevated concentrations above MCLs or screening levels for the metals cobalt, iron, manganese, and thallium have historically (sampled between 1994 and 1998) been detected in existing monitoring wells downgradient of the fly ash pile. Thallium had been consistently detected at a concentration exceeding its MCL value of 0.002 milligrams per liter (mg/L). However, the most recent data (2009 and 2011 sampling events) [DOE 2013a] show that these metals, including thallium, are either not detectable or are at concentrations much below their respective MCL in groundwater at any of the monitoring wells. The metals arsenic, lead, and chromium have only exceeded their MCLs in recent unfiltered samples. The filtered samples for these metals did not exceed MCLs.

ETTP-6 K-770 Scrap Metal Yard

The K-770 Scrap Metal Yard site is located at the western edge of the Powerhouse Area and is adjacent to the Clinch River (see Fig. E.2). The site covered an area of approximately 21 acres and stored about 40,000 tons of metal. The facility also contained asbestos-contaminated metal, primarily pipe. The area operated during the 1940s as an oil storage area and operated from the 1960s to 2007 as a scrap yard, when the scrap was removed in 2007. Remedial action for the removal of the scrap metal at K-770 began in June 2004 and was completed in April 2007. Following removal of the scrap material from this site, remediation of contaminated soils was initiated in 2009 and completed in 2011. Sampling conducted after remediation under the Zone 1 Interim ROD illustrated no residual source of groundwater contamination.

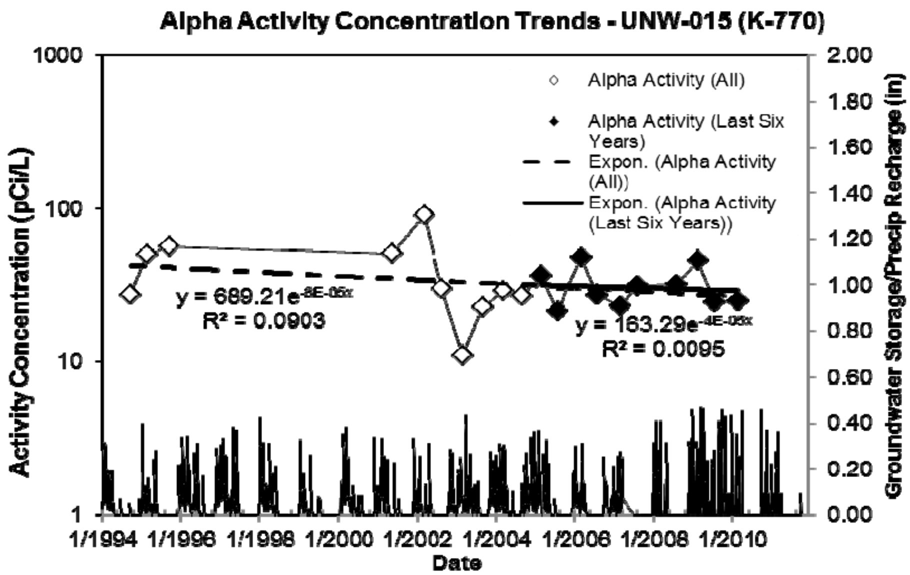
Much of the area is unpaved and/or undeveloped, so groundwater is probably locally recharged. Groundwater flow in the unconsolidated zone follows mapped hydraulic gradients and short flowpaths, and discharges locally to the Clinch River. Groundwater flow in bedrock likely follows solution-enlarged features such as bedding planes and fractures in the Chickamauga bedrock, both along strike and down-dip toward the Clinch River.

Samples from two of the monitoring wells (UNW-013 and UNW-015) located along the western boundary of the K-770 Scrap Metal Yard by the Clinch River have reported alpha and beta activity at or slightly above the MCL and guidance values. Historical leaching from scrap metal stored within the K-770 Scrap Metal Yard is the potential source of the radiological (primarily uranium) contamination in groundwater, which may be discharging directly to the Clinch River. However, isotopic results for groundwater samples from these wells have been inconclusive as to the radiological constituents causing the elevated alpha and beta activities.

Contaminant concentration trends using historical alpha and beta activities indicate that alpha activity at monitoring well UNW-015, based on both the most recent 6 years of data and the full data set since 1994, are almost stable with a very slight decreasing trend over time, and the decreasing trend is even slower over the last 6 years than for the full period of analysis (Fig. E.12). Trends for beta activity at monitoring well UNW-013 show a slight decreasing trend for beta activity with some variations since 1994, and the decreasing trend has changed to stable/no trend over the last 6 years (Fig. E.13).

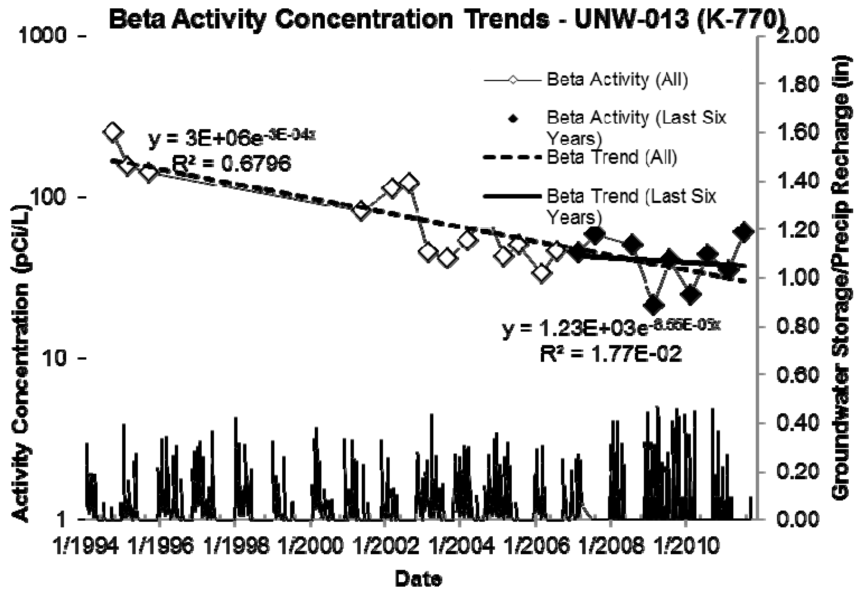
Although constituent migration can be attenuated by retardation reactions such as adsorption, surface complexation, and ion-exchange reactions with soils they contact, alpha and beta activities are expected to remain relatively constant and decrease only slightly over time

Table E.4 provides a summary of the Duct Island/Powerhouse Area plume sources located over both Chickamauga carbonates and Rome Formation clastics.



Source: DOE 2013a

Fig. E.12. Alpha activity concentration trends at UNW-015.



Source: DOE 2013a

Fig. E.13. Beta activity concentration trends at UNW-013.

E.4.3 ADMINISTRATIVE AREA

The hydrogeologic framework of this watershed is characterized by complex geology. The contaminant source areas and plumes are within the broad synclinal fold that underlies the south-central portion of the ETTP main plant area. The K-25 Fault cuts through the northern edge as it trends from southeast to northwest. The unconsolidated materials that cover portions of the area are composed primarily of residuum derived from the underlying Rome and Chickamauga bedrock units. Weathering of the Rome Formation yields saprolite consisting of progressively weathered shale or siltstone overlain by up to 15 ft of clay or silty clay. The saprolite bears the relict structures of the bedrock, such as folds and fractures, but is more weathered so that it is often more permeable than the competent bedrock. Weathering of the carbonate Chickamauga Supergroup commonly results in complete weathering to clay and silty clay. Overburden materials are generally thickest over the areas underlain by the Rome Formation and thinner over areas underlain by the Chickamauga Supergroup. Much of the area was formerly paved or covered by buildings, minimizing natural groundwater recharge; however, decontamination and decommissioning (D&D) activities in recent years have produced large grass-covered areas formerly occupied by buildings and other structures. Recharge occurs in these vacant areas and in areas of higher elevation, such as the K-1070-C/D Burial Ground.

Shallow groundwater discharges to the K-1007-P Holding Ponds, which subsequently discharge to Poplar Creek. The water table occurs at depths ranging from less than 5 ft near Poplar Creek to as much as 35 ft in the north-central part of the area. The water table occurs within overburden over much of the northern and western portion of the area, with saturated overburden ranging up to 20 ft. The water table occurs below the top of bedrock in much of the southeastern portion of the area where depth to bedrock is shallow due to site grading. Groundwater flow in the saturated overburden is expected to follow hydraulic gradients, possibly influenced by cut and fill, storm drains, and other anthropogenic features. Groundwater flow in the bedrock zone is more complex and is dominated by flow through interconnected

Table E.4. Duct Island/Powerhouse Area groundwater plumes

Plume No.	Plume	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Downgradient length (ft)	Depth (ft bgs)	Concentration (μg/L)			
ETTP-3	K-1085 Old Firehouse Burn Area	800	Uncertain	TCE: >300 *cis*-1,2-DCE: >150 PCE: >25 VC: >5	Hydraulic gradient to southwest for shallow flow and fracture flow in Rome	Beaver Ponds and Clinch River to southwest	Full extent of plume and remaining source mass is uncertain.
ETTP-4	Duct Island/K-1070-F	~800 from landfill to spring	Unknown	TCE: >10 VC: >5	Along-strike flow in Chickamauga	Poplar Creek	Source of TCE at spring is unknown.
ETTP-5	K-720	200	30	As: 42 Cr: 180 Pb: 55	Hydraulic gradient for shallow flow and along-strike in Chickamauga	Clinch River	Discharge of elevated metals to Clinch River is uncertain.
ETTP-6	K-770	150	40	Alpha: >20 pCi/L Beta: >50 pCi/L	Hydraulic gradient shallow flow and along-strike in Chickamauga	Clinch River	Vertical extent into bedrock is unknown.

As = arsenic.
bgs = below ground surface.
Cr = chromium.
ETTP = East Tennessee Technology Park.
Pb = lead.
PCE = tetrachloroethene.
pCi/L = picocuries per liter.
TCE = trichloroethene.
VC = vinyl chloride
μg/L = micrograms per liter.

fractures, bedding planes, joints, faults, and solution cavities. Bedrock lows probably influence groundwater flow at the top of bedrock.

Groundwater contamination in the Administrative Area consists predominantly of VOCs. Two separate VOC plume areas have been identified: one in the vicinity of the K-1200 complex and a second in the K-1004 laboratory area to the south. PCE is present in high concentrations; however, TCE is more widespread throughout the area. Degradation products of these parent compounds, primarily *cis*-1,2-DCE and VC, are also present. The observed VOC contamination is associated predominantly with groundwater in the bedrock zone. Based on dissolved-phase concentrations, PCE DNAPL may be present adjacent to the K-1200 complex and might originate in the K-1070-C Area. Historical records do not provide information to link a specific site to a release that could have resulted in impacts to groundwater.

ETTP-7 K-1200 Area

The K-1200 complex includes centrifuge test and support facilities in the northern part of the area (see Fig. E.2). The south bay of Bldg. K-1200 was used primarily for manufacturing, testing, and storage from 1974 to 1985. The high bay contains a pit measuring approximately 50- × 20- × 20-ft deep. The K-1210 Centrifuge Test Facility was used to test the reliability and operability of numerous centrifuge machines. This facility also served as a pilot plant for testing feed, withdrawal, and uranium hexafluoride (UF_6) transfer systems. The K-1220 Centrifuge Plant Demonstration Facility operated from 1981 to 1985 as a research facility. Potential waste characteristics include uranium, hydrocarbon oils, and fluorocarbon oils.

The source of contamination in the K-1200 Area may be associated with the K-1070-C/D Burial Ground, which is located just north of the K-1200 complex. The VOC plume likely originates from the C area of the K-1070-C/D Burial Ground; however, disposal records are limited for the C area. Detailed disposal records and soil and groundwater data suggest that the D trenches are not the source. Concentrations of VOCs found in surface soils adjacent to the K-1070-C/D Concrete Pad located north of the K-1200 Area, and the inferred groundwater flow direction from the area of the Concrete Pad, indicate this area as a likely source of the VOCs in groundwater in the K-1200 Area.

The K-25 Fault cuts through the northern edge of the K-1200 Area as it trends from southeast to northwest. The hydraulic gradient trends south and southwest from the K-1200 Area toward the K-1007-P Holding Ponds (see Fig. E.5). VOCs are the principal groundwater contaminants in the area. DNAPLs are suspected in the K-1200 source area based on the presence of PCE at concentrations of 1% to 10% of its effective solubility and stable or increasing concentration trends.

The uncertainty of bedrock flowpaths and extent of contaminant mass remaining in the matrix portion of the aquifer lead to uncertainty as to the long-term behavior of concentration trends in the K-1200 plume. Although degradation of the parent VOCs is occurring, the degree of degradation is uncertain given the general absence of VC and both increasing and decreasing trends in parent compound concentrations. Figure E.14 shows a general conceptual model for the K-1200 Area plume.

Fate and transport (F&T) analysis has indicated that PCE concentrations in the K-1200 plume are not expected to decline to below their MCL within >400 years, even if 90% of the DNAPL source mass were to be removed (DOE 2007). However, if a DNAPL source does not exist in this area, then PCE concentrations were predicted to decline to below its MCL in <400 years. Other VOCs in these plumes were predicted to decline to below their respective MCL in less than 40 years.

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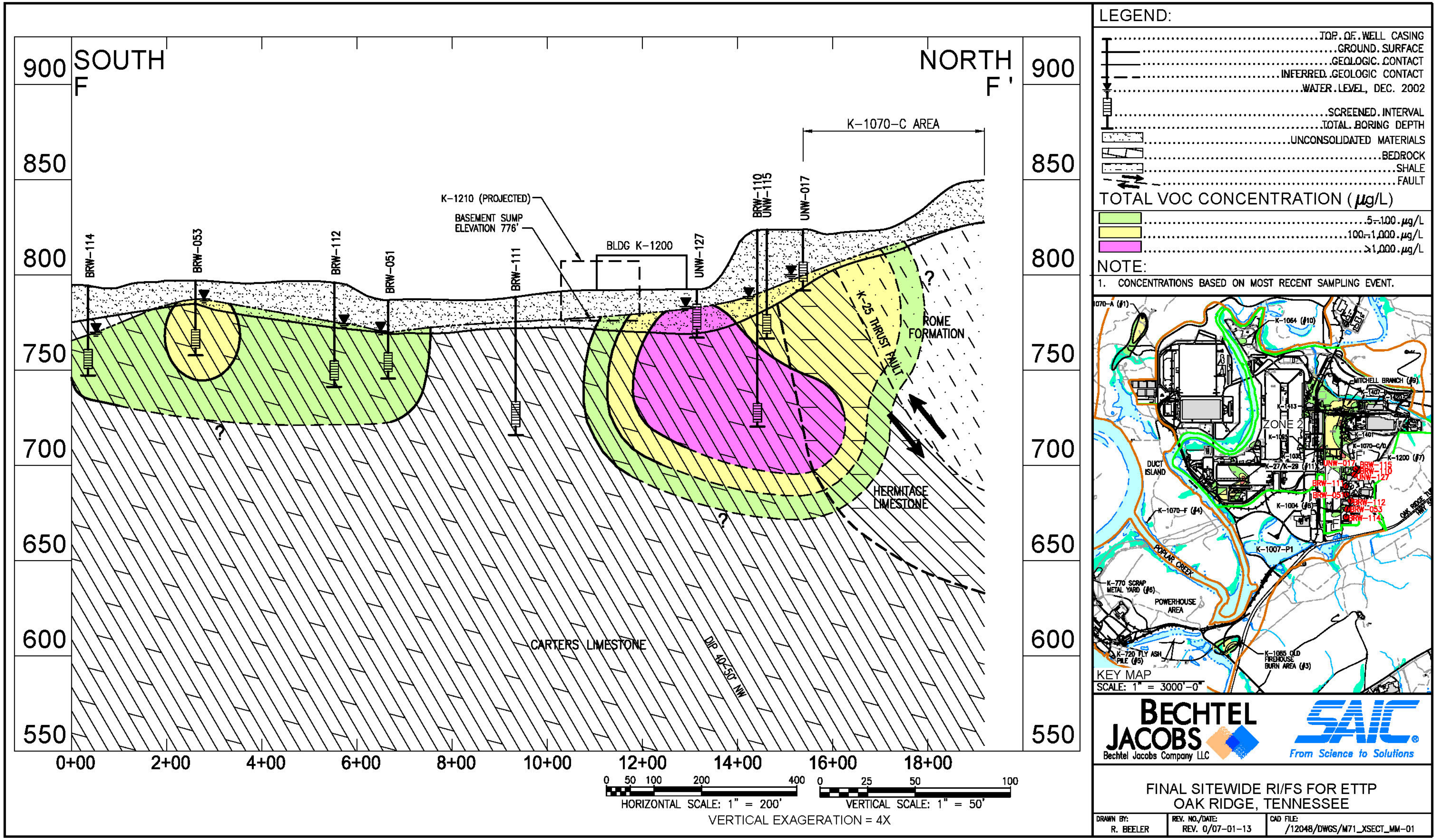

Source: DOE 2007

Fig. E.14. Conceptual site model illustrating VOC concentrations and geology for the Administrative geographic area.

Concentrations of the degradation product *cis*-1,2-DCE above the MCL of 70 μg/L occur in an area of lesser extent than PCE or TCE on the north side of the K-1200 complex in both the unconsolidated zone and bedrock (DOE 2007). The presence of *cis*-1,2-DCE indicates that degradation processes are occurring in groundwater in this area. VC is generally absent in groundwater in the K-1200 plume. In addition, TCE may be a daughter product of the PCE in portions of the K-1200 plume.

In the unconsolidated zone, the maximum detected PCE concentration in 2012 was in well UNW-127 (2600 μg/L), which demonstrates a fluctuating trend. Nearby well UNW-126 (1500 μg/L) shows an overall decreasing trend in PCE concentration over time. Both of these wells are located at the bottom of the unconsolidated zone at the interface with the bedrock. Other monitoring wells in the area also demonstrate a decreasing trend in parent concentrations; however, some monitoring wells show increasing trends for parent concentrations. Concentration trends for daughter compounds generally correspond with those of the parent compounds with both decreasing and increasing trends indicated.

ETTP-8 K-1004 Area

The K-1004 Area formerly included a wide variety of administrative and support facilities. These included a research and development (R&D) facility for the recovery of uranium for the conversion of uranium trioxide to UF6 and a variety of laboratory facilities. Laboratory waste solutions were sent to either process waste drains or waste vaults. Tanks or vaults located outside the southwest corner of one laboratory once housed a 5500-gal storage tank and a 750-gal "hot tank" for disposal of radioactive materials. Several former maintenance and support shops were also formerly located in this area.

Groundwater in bedrock contains low concentrations of VOCs, primarily TCE. The uncertainty in bedrock flowpaths precludes identification of specific historical source areas based on the distribution of VOCs in groundwater. It is possible that these VOCs in bedrock have migrated through deeper bedrock flowpaths from upgradient sources, such as the K-1200 plume (see Fig. E.14). The VOCs detected include PCE, TCE, and the degradation products *cis*-1,2-DCE and VC. The occurrence of TCE is more widespread than that of PCE. The presence of the degradation products suggests that active biodegradation is occurring in some areas.

VOCs within the K-1004 plume are transported by groundwater flow along-strike southwestward toward the K-1007-P Holding Ponds. Results of groundwater F&T modeling have concluded that although groundwater ultimately discharges to the ponds, attenuation processes will degrade the VOC contaminants before they reach the pond.

The predominant mechanisms affecting F&T of VOCs in the K-1004 plume include dispersion and matrix diffusion. Biodegradation appears to be slow and occurs to a lesser degree. These mechanisms would result in natural attenuation of contaminant concentrations and gradual reduction in contaminant mass. In general, most of the wells located in the K-1004 plume show decreasing TCE concentration trends. Concentrations of *cis*-1,2-DCE show similar trends to those of TCE. Concentrations are decreasing throughout much of the plume; however, fluctuating trends are demonstrated at some wells.

Table E.5 provides a summary of the Administrative Area plume sources located over both Chickamauga carbonates and Rome Formation clastics.

Table E.5. Administrative Area groundwater plumes

Plume No.	Plume	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Downgradient length (ft)	Depth (ft bgs)	Concentration (µg/L)			
ETTP-7	K-1200	Uncertain	>100	PCE: >2500 TCE: >700 *cis*-1,2-DCE: >1000	Uncertain; anticipated to be along-strike and down-dip in Chickamauga/Rome	Uncertain; possibly K-1007-P Ponds	Source of VOCs is uncertain. Extent in bedrock is unknown.
ETTP-8	K-1004	Uncertain	>50	TCE: >30 PCE: >20	Along-strike and down-dip in Chickamauga	K-1007-P Ponds	Source of VOCs is uncertain.

bgs = below ground surface.
DCE = dichloroethene.
ETTP = East Tennessee Technology Park.
PCE = tetrachloroethene.
TCE = trichloroethene.
VOC = volatile organic compound.
µg/L = micrograms per liter.

E.4.4 ETTP-9 MITCHELL BRANCH AREA COMMINGLED PLUMES

The Mitchell Branch geographic area encompasses several hundred acres of land that included most of the former gaseous diffusion process support facilities, such as maintenance shops and liquid waste handling and treatment facilities. The subsurface geology is dominated by complex thrust faulting and folding. The primary thrust fault, the K-25 Fault, extends through the Mitchell Branch Area from the K-1070-C/D Burial Ground in the south to the K-1407-B Holding Pond in the north. The influence of the K-25 Fault on groundwater movement is uncertain.

The shallow subsurface in the Mitchell Branch geographic area was significantly reworked during original plant construction, with large areas of cut and fill. Fill thicknesses range up to 25 ft, with as much as 30 ft excavated from adjacent areas. This fact is significant in that, locally, filled areas could serve as preferential pathways for lateral groundwater contaminant migration, and excavated areas could serve as pathways for vertical contaminant migration to groundwater in the underlying bedrock.

The primary surface water feature in the area is Mitchell Branch, which flows from east to west through the northeastern portion of ETTP. Mitchell Branch serves as the primary receiving body for both surface water and groundwater. Preconstruction survey maps, topographic maps, and historical aerial photos indicate that the channel of Mitchell Branch formerly consisted of a dendritic drainage pattern. The original course of Mitchell Branch was relocated north to the present-day channelized course to accommodate the K-1420 building and K-1407-B Holding Pond. Surface water runoff from the surrounding hillsides and storm drain discharge are both directed to the stream. Numerous storm drain systems also discharge to Mitchell Branch. Groundwater discharge to Mitchell Branch is through diffuse flow to the streambed and through seeps and springs. Both gaining and losing reaches have been identified in Mitchell Branch; however, these conditions appear to be transient due to variable antecedent conditions. Mitchell Branch discharges to Poplar Creek after passing through a weir structure near the confluence of the two streams.

The water table occurs at depths ranging from Mitchell Branch stage level to as much as 60 ft in the K-1070-C/D Burial Ground. The water table occurs within overburden over much of this area, with saturated overburden ranging up to 20 ft thick. The water table occurs below the top of bedrock in areas of higher topography or where bedrock relief is high. The water table generally reflects topography, implying radial flow from the K-1070-C/D Burial Ground and surrounding ridges toward Mitchell Branch. Maps of the potentiometric surface (Fig. E.5) indicate groundwater flow is to the northwest and north throughout the area. Groundwater flow in the saturated overburden is expected to follow mapped hydraulic gradients, possibly influenced by cut and fill, storm drains, and other anthropogenic features. Water movement could also be influenced by relict features in the unconsolidated overburden such as bedding, fractures, and other structures. The former Mitchell Branch channel could also influence water movement. The bedrock surface also appears to influence groundwater flow in the Mitchell Branch Area because portions of several plumes correspond to bedrock surface lows.

Groundwater tracer tests conducted in 2005 indicated groundwater flowpaths that agreed well with the anticipated flow directions. The results also indicated average groundwater seepage velocities between 1.3 and 12 ft/d in the Mitchell Branch Area.

Historical releases from multiple sources have produced groundwater plumes that have become commingled as they follow various flowpaths toward Mitchell Branch. Groundwater in this area is contaminated primarily with chlorinated organics and other VOCs. The chlorinated VOC plumes identified in the Mitchell Branch Area include the K-1070-C/D plume, K-1035 plume, K-1401 plume, K-1413 plume, K-1407-B plume, K-1420 plume, and the Northwest K-1070-C/D plume. The primary

VOC present in groundwater in the Mitchell Branch Area is TCE, with 1,1,1-TCA and PCE being less widespread throughout the area. Degradation products of these parent compounds (primarily *cis*-1,2-DCE; 1,1-DCE; and VC) are also present in substantial concentrations in some areas.

DNAPLs have been observed in the K-1401 Area and are suspected in other locations within the Mitchell Branch geographic area based on process knowledge, the presence of VOCs at concentrations of 1% to 10% of their effective solubility, and stable or increasing concentration trends decades after site operations have ceased. The potential presence of DNAPLs, particularly at depth, indicates a probable secondary source of continuing contamination to groundwater, as the DNAPLs slowly dissolve into the water. Concentrations of PCE at 1% to 10% of its effective solubility are present in the vicinity of Bldg. K-1035, and the K-1407-B Holding Pond, suggesting the occurrence of PCE as a potential DNAPL in the subsurface in these plume areas. TCE is also present at concentrations ranging from 1% to 10% of its effective solubility in these same areas. Additionally, 1,1,1-TCA is also present at concentrations of 1% to 10% of its effective solubility in the K-1070-C/D source area, indicating the possible occurrence of 1,1,1-TCA as a potential DNAPL in the subsurface. Dissolved concentrations of chlorinated hydrocarbons indicative of DNAPLs are present at depths of at least 100 ft in the K-1407-B Holding Pond Area despite the presence of upward vertical hydraulic gradients.

A non-TC RmA designed to capture and treat contaminated groundwater was performed in the K-1070-C/D and Mitchell Branch Areas (DOE 1998). The removal action completed in 1999 involved the installation of a groundwater collection system, transport of the collected groundwater to the Central Neutralization Facility (CNF) for treatment, and discharge of the treated groundwater under the CNF National Pollutant Discharge Elimination System (NPDES) permit. The groundwater collection system in the K-1070-C/D Area consisted of approximately 600 linear ft of interceptor trench installed to the top of bedrock. Groundwater was collected and pumped from the trench to the pre-existing SW-31 Spring sump. The groundwater was then transferred by pipeline to the CNF for treatment and discharge. The Mitchell Branch collection system consisted of approximately 1100 linear ft of interceptor trench and 29 extraction wells. A subsurface vertical barrier was installed between the interceptor trench and Mitchell Branch to prevent dewatering of the stream. In addition, a bottom liner system was installed along approximately 700 ft of Mitchell Branch, opposite the extraction wells, to prevent dewatering of this reach of the stream. Groundwater was routed from both the collection trenches and the extraction wells to a central collection sump and then transferred by pipeline to the CNF for treatment and discharge. Approval to discontinue operation of these collection systems due to poor cost-effectiveness was granted by the U.S Environmental Protection Agency (EPA) and TDEC in February 2005.

The SW-31 Spring, located downgradient of the K-1070-C/D Burial Ground G-Pit, has historically shown high levels of VOC contamination. In the mid-1970s, the swampy spring discharge area near the base of the K-1070-C/D Burial Ground was filled and a pipe inserted into the hillside to collect the natural seepage and route the flow to the storm drain. This pipe discharge became known as the SW-31 Spring. The spring was addressed by an interim ROD signed in 1992 (DOE 1992). The remedial action consisted of collection of the spring discharge and treatment at the CNF. Operation of the system began in 1996. Approval from EPA and TDEC to terminate the SW-31 action was granted in 2007 based on samples indicating that the untreated water meets all ambient water quality criteria (AWQC) and other ARARs.

K-1407-B Pond

The K-1407-B Holding Pond was an unlined impoundment located immediately south of Mitchell Branch and west of Bldg. K-1420 (Fig. E.2). Opened in 1943, it was used as a settling basin for metal hydroxide sludges that were precipitated after neutralization in the K-1407-A Neutralization Pit—CNF. These included wastes discharged to the K-1401 Acid Line, K-1413 Laboratory solutions, and K-1420 plating operations waste solutions. The discharge of wastes into the K-1407-B Holding Pond ended in 1988.

During the late 1980s, waste sludge from the pond was excavated in anticipation of its closure as a RCRA-regulated unit. Verification sampling conducted after sludge removal confirmed the presence of low-level, residual radiological contamination in the pond soils. A RCRA clean closure was granted in 1994. The pond was filled with gravel, capped with topsoil, and revegetated.

Groundwater concentrations of TCE, PCE, and 1,1,1-TCA in the range of 1% to 10% of their effective solubility in the area downgradient of the K-1407-B Holding Pond suggest it was a historical source of groundwater contamination and that DNAPLs might be present as a continuing secondary source.

The highest concentrations of TCE have been reported for samples collected from a bedrock well (BRW-108). A TCE concentration of 31,000 μg/L was reported for a sample collected in September 2012 from this well, which is screened from 62.4 to 72.4 ft bgs. TCE was also detected at concentrations in excess of 1 mg/L at two other well locations in the vicinity of the former pond. PCE and *cis*-1,2-DCE have also been detected at concentrations in excess of 1 mg/L.

High concentrations of PCE/TCE degradation products (i.e., 1,1-DCE; *cis*-1,2-DCE; and VC) correspond to the locations with high parent compound concentrations. In the downgradient direction (northwest), degradation products begin to dominate the total VOC mass.

The effective solubility of observed concentrations of PCE and TCE, increasing concentration trends for parent compounds, and process knowledge suggest that DNAPL is present in the subsurface. The distribution of VOC concentrations at depths of 100 ft bgs indicates that the DNAPL source is relatively deep, because higher concentrations of TCE and PCE occur at depth despite upward vertical hydraulic gradients. Although the K-1407-B Holding Pond appears to be the primary source of VOCs in this portion of the Mitchell Branch Area, additional upgradient sources have contributed to the overall VOC plume.

The average groundwater seepage velocity based on dye tracer studies was approximately 12 ft/d, based on the tracer velocity measured over the seepage length. A seepage velocity of approximately 1 ft/d from the bedrock into the unconsolidated zone was also indicated as was a groundwater seepage velocity of approximately 5 ft/d from the K-1407-B Pond Area westward.

K-1401 Area

The K-1401 Area includes the former K-1401 Acid Line and associated degreasing pits that were located in the K-1401 building (Fig. E.2). The K-1401 Acid Line was a buried, 10-in.-diam pipe running along the east side of Bldg. K-1401. The line has a total length of approximately 1500 ft and ranges from 4 ft to 15 ft below grade. Between 1944 and 1987, the line was used to transfer corrosive solutions from Bldg. K-1401 to the K-1407-A Neutralization Pit at the CNF. A leak was discovered in 1975, and the leaking portion of the pipeline was replaced. Subsequent leaks resulted in the entire pipeline being slip-lined with a 10-in. polyethylene sleeve in 1982. The pipeline was taken out of service in 1987 when it was found that the line continued to leak.

Degreasers within Bldg. K-1401 were used, beginning in 1944, for cleaning of various parts associated with the uranium enrichment process. TCE was the common degreaser from the 1940s through the 1960s but was replaced by TCA in the 1970s. Carbon tetrachloride was also used in the early years. Records indicate TCE usage was at a rate of about six 55-gal drums per day in the 1940s through the 1960s. TCA was used at an unknown rate during the 1970s and 1980s. The K-1401 degreaser cleaning tanks were located along the east wall of Bldg. K-1401 in an area of acid-brick-covered floors with a floor trench surrounding the area. Spent cleaning solutions were drained onto the floor and collected in an acid-brick-lined floor trench surrounding the cleaning tanks. The floor trench emptied into a small, acid-brick-lined

sump at the exterior wall. From the sump the effluent entered the exterior acid drain line through a pipe opening through the sump wall.

Acid line leak rates of 4 to 100 gallons per minute (gpm) for some line segments have been estimated from historical leak rate testing. The maximum concentrations of TCE observed in groundwater correlate to 9% of its effective solubility, which provides strong indirect evidence of DNAPL presence. The plume area with groundwater concentrations >1000 µg/L is estimated to be about 350 ft long by 100 ft wide and extends at least 100 ft bgs.

Groundwater data in the vicinity of the K-1401 Acid Line have indicated the presence of a VOC plume containing 1,1,1-TCA; PCE; TCE; and their degradation products (i.e., 1,1-DCA; 1,1-DCE; 1,2-DCE; and VC). Native dehalogenating microbes are present and may be capable of degrading site VOC contaminants based on the presence of TCE/TCA transformation products and the results of microbial studies.

A two-phase groundwater treatability study began in fiscal year (FY) 2009 to support selection of a groundwater remedy under a future CERCLA decision. The purpose of the study is to determine the feasibility of two in situ treatment technologies – thermal conductive heating and biological treatment – to restore groundwater. DNAPL was identified in the first phase in fractured bedrock extending to depths of approximately 100 ft bgs using FLUTe™ (Flexible Liner Underground Technologies, LLC) technology.[1]

Complex structural relationships dominated by fractures preclude prediction of bedrock flowpaths as determined by rock coring, borehole logging, and geophysics.

K-1070-C/D G-Pit and Concrete Pad

The K-1070-C/D Burial Ground is a 22-acre tract of land located in the southeast portion of the Mitchell Branch Area (Fig. E.2). It is composed of several areas: large trenches, small pits, earthen dike areas, a landfarm area, and a concrete pad. Operations in the area began in 1975 and closed when the last burial trench in K-1070-D was filled in 1989. K-1070-C is approximately 300 ft by 300 ft and is in the southwest portion of the area. Opened in 1975, K-1070-C was closed in 1977 as the larger K-1070-D was being opened. K-1070-D consists of three trenches, each 300 ft long, 100 ft wide, and 40 ft deep, oriented north to south, and were in use from 1977 to 1989. These trenches received both low-level radioactive and nonradioactive, nonhazardous waste materials and equipment. Ten pits (A through J) were also excavated in the K-1070-D Area in 1977 and used until 1979 for disposal of chemical and glass wastes. The pits were closed in the early 1980s. Waste disposal records indicate that organic compounds were poured into the G-Pit from 15 to 40 gal at a time, with a total of approximately 9100 gal discarded in G-Pit. Thus, G-Pit is the point of entry for TCE; PCE; 1,1,1-TCA; and other VOC liquids into the soil, and to the underlying bedrock and groundwater.

Three earthen dike storage areas, designated K-1070-D1, -D2, and -D3, covered about 0.15, 0.26, and 0.21 acres, respectively. The K-1070-D1 and -D2 Areas were located on the north side of the K-1070-C/D Burial Ground, while the K-1070-D3 Area was located on the south side. These storage areas were constructed in 1979 for the staging of various hazardous organic compounds, including waste oils, solvents, and solvent-contaminated waste oil. Operations ended in 1985. PCBs and uranium were present in some of the waste. K-1070-D2 was used for the sampling of drums. During closure, results of sampling showed no RCRA hazardous waste constituents in the soils. Closure, consisting of a non-RCRA cap and revegetation, was completed in November 1986.

[1] Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

A ROD signed in 1998 for the K-1070-C/D G-Pit and Concrete Pad (DOE 1997) specified excavation and removal of waste at the G-Pit, and placement of an interim 2-ft soil cover over the Concrete Pad until remediated. The 2-ft soil cover was placed over the Concrete Pad in April 1999 and excavation of the G-Pit contents, placement of the excavated material into interim storage, and the treatment and disposal of the excavated material began in December 1999 and was completed in January 2000. DNAPLs may be present in the K-1070-C/D G-Pit area. Samples of soil and leachate from the vicinity of G-Pit contained high concentrations of VOCs, providing evidence that G-Pit represents a source of potential DNAPL based on observed concentrations.

Groundwater within the K-1070-C/D G-Pit plume is contaminated with VOCs, primarily 1,1,1-TCA; TCE; PCE; their degradation products; and benzene. Concentrations of VOCs in groundwater in the K-1070-C/D Area generally exhibit decreasing trends at monitoring wells immediately downgradient of the G-Pit source area.

Northwest K-1070-C/D

A localized area of groundwater contamination is defined by a single well, two springs, and a French drain collection pipe, all located near the northwest corner of the K-1070-C/D Burial Ground (Fig. E.2). Concentrations of TCE; PCE; *cis*-1,2-DCE; and VC routinely exceed MCLs. Concentrations of 1,2-DCE have remained relatively steady at the well, indicating that degradation of the TCE contamination is occurring. This plume appears to commingle with the K-1401 Area plume as it moves downgradient toward Mitchell Branch.

K-1420

The former Bldg. K-1420, located in the northeast portion of the Mitchell Branch Area (Fig. E.2), was used for a variety of small-scale operations, such as converter conditioning and recovery, mercury recovery, uranium-containing oil reclamation, parts disassembly and cleaning, cascade and feed plant cleaning and decontamination, uranium recovery, and aluminum leaching from 1954 to 1993. A nickel plating facility operated during the 1960s. From the onset of operations at K-1420, degreasing of parts occurred in a degreasing booth located on the south side of the building. To prepare parts for plating, they were degreased with TCE and Freon 113.[2] Records indicate that PCE was also used as a degreaser. Several underground pipes led from one of two drains that service the building to the treatment facilities. The drain at the south end of the building served the degreasing, stripping, rinsing, and plating areas. The north drain served the mercury recovery and oil reclamation areas. Originally, effluents flowed through the process lines to either the K-1407-A Neutralization Pit at the CNF or directly to the K-1407-B Pond. Building K-1420 also had a deep basement area containing a tunnel that housed a conveyor and storage tanks for storage of nitric acid and other decontamination rinse solutions. Facility D&D occurred during 2006.

Constituents detected in groundwater in the K-1420 Area above MCLs include VOCs (i.e., *cis*-1,2-DCE; PCE; and TCE) and some metals (i.e., antimony, arsenic, barium, chromium, thallium, and uranium). However, the metals have only been detected above their MCLs sporadically. Low concentrations of 1,1-DCE and VC have been reported in the vicinity of K-1420; however, concentrations of these compounds have not exceeded their respective MCLs.

During FY 2007, hexavalent chromium was detected in surface water in Mitchell Branch at levels exceeding the AWQC (11 μg/L). The source of the discharge was determined to be Outfall SD-170 located near

[2] Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

Bldg. K-1420. In response to this condition, a TC RmA was performed to install and operate groundwater collection pumps to capture chromium-contaminated groundwater associated with the storm drain backfill and in-leakage to the SD-170 drain line (DOE 2008).

At Mitchell Branch kilometers (MIKs) 0.71 and 0.79, which are locations in Mitchell Branch immediately downstream from the Outfall 170 discharge point, hexavalent chromium was measured at levels as high as 0.78 mg/L. Recent surface water monitoring indicates that the chromium collection system has been effective in reducing the levels of chromium in Mitchell Branch to levels that are now consistently below the AWQC value of 0.011 mg/L. Although the former Bldg. K-1420 represents a possible source of the chromium contamination, a definitive source has not been determined.

Activities associated with the removal action included:

- Located the hexavalent chromium release path to the storm drain system and into Mitchell Branch.
- Installed a grout wall to impede the release of hexavalent chromium through Outfall 170 headwall seeps into Mitchell Branch.
- Installed two interception wells into the gravel bed that surrounds the Outfall 170 discharge pipes to collect the hexavalent chromium groundwater plume before it infiltrates the Outfall 170 collection system network piping.
- Began operating the two interception wells in December 2007. The collected groundwater was initially treated at the CNF. The treatment of the collected groundwater transitioned to the Chromium Water Treatment System in FY 2012.

Surface water results in Mitchell Branch show that the chromium collection system has been effective in reducing the levels of chromium from a maximum measured value of 0.78 mg/L to levels that are now consistently well below the hexavalent chromium AWQC value of 0.011 mg/L during dry and wet weather periods.

K-1035

The K-1035 Acid Pits/Drain Lines consist of two cylindrical pits, an acid pit and a neutralization pit, and associated drain lines located near the south end of Bldg. K-1035. The acid pit has a diameter of 34 in. and a depth of 31 in., while the neutralization pit has a 28-in. diameter and is 24 in. deep to the top of the stone base (total depth unknown). Both pits are below grade. Drain lines connect both pits to a single catch basin, which is part of the storm drain system. The pits received primarily acid wastes and chlorinated organics from electroplating and etching activities from the early 1960s until 1976 or 1977 and from decontamination activities until 1985. Both pits contained a limestone gravel bed, and the effluent from the neutralization pit also percolated through a limestone-filled pipe prior to entering the catch basin. The acid pit and neutralization pit both discharged to a catch basin where the liquids were diluted with storm water prior to flowing out the SD-190 storm drain system, which ultimately discharges to Mitchell Branch.

Operational records indicate that a variety of VOCs were used for cleaning purposes. Disposal records indicate that, in addition to TCE, PCE; 1,1,1-TCA; methylene chloride; and methyl ethyl ketone were sent from K-1035 to the K-1070-C/D G-Pit for disposal from March 1978 through February 1980. Soil and groundwater data indicate that releases of VOCs have occurred in this area.

Constituents detected in groundwater at concentrations above MCLs in the vicinity of Bldg. K-1035 include 1,1,1-TCA; 1,1-DCE; *cis*-1,2-DCE; PCE; TCE; and VC. Historical (i.e., 2007) groundwater concentrations of PCE and TCE with 1% to 10% of their respective effective solubilities in the immediate vicinity of the

acid pits indicate the potential presence of DNAPLs as a continuing secondary source of contamination. Concentrations of the degradation products 1,1-DCA; 1,1-DCE; and *cis*-1,2-DCE indicate that some degradation of the parent VOCs is occurring.

Once in the groundwater, VOC contamination is transported primarily northward toward Mitchell Branch. The seepage velocity indicated by dye tracer test was approximately 11 ft/d.

K-1413

Building K-1413 was operated as an R&D facility from 1952 to 1985. The building contained a pit (East Pit) used for the disposal of liquid wastes. In the late 1960s, an annex was added to Bldg. K-1413, and a second pit (North Pit) was constructed. Both pits had a capacity of 2500 gal and were filled with limestone for treating wastes by neutralization. Treated waste streams were discharged to the storm drain on either side of Bldg. K-1413, which ultimately discharge to Mitchell Branch through SD-190. In 1974 and 1975, a third pit (South Pit) was installed to treat wastes, and the East and North Pits were taken out of service. The South Pit had a capacity of 25,000 gal. All three pits were connected to a pumping station by means of a 225-ft length of 4-in.-diam plastic pipe. The pumping station was connected to the K-1401 Acid Line.

In addition to operations at Bldg. K-1413, historical records indicate that cleaning facilities downgradient and east of Bldg. K-1413 were used to clean pipe for use in the K-25 building. Hundreds of miles of piping were required for construction of the K-25 building. Piping and equipment that came into contact with the process gas had to meet rigid specifications for cleanliness. Six of these cleaning facilities existed in the vicinity of Bldg. K-1413 in 1943 and had been demolished by 1947. Records indicate that cleaning of the process pipe began with a degreasing step using TCE. Other chemicals used in the facilities may have included sodium hydroxide, hydrochloric acid, sulfuric acid, chromic acid, Freon, sodium dichromate, ammonium hydroxide, and small parts degreasing solvents (carbon tetrachloride, alcohol, acetone, etc.).

Constituents detected above MCLs in groundwater in the K-1413 plume area include *cis*-1,2-DCE; methylene chloride; TCE; and VC. Concentrations of TCE above 1.0 mg/L are present in the groundwater immediately downgradient of Bldg. K-1413. Once in the groundwater, VOC contamination is transported by groundwater flow northward.

K-1095 Paint Shop

An isolated plume of groundwater contaminated with TCE has been identified in the vicinity of the K-1095 Paint Shop located in the central portion of ETTP. The K-1095 facility began operation in 1980 as a paint shop and a storage area for paint and associated solvents and thinners. The building housed a sign shop, preparation room, spray area, drying room, and two spray booths equipped with water wash systems. Two containment pits covered by grating and located inside the building were used to collect waste paint and water generated from operations within the building. Wastes were poured into 55-gal drums placed on the grating over the westernmost containment pit. When full, these drums were placed on a storage pad at the northwest corner of the building to await disposal.

One drive-point piezometer exists in the vicinity of the K-1095 Paint Shop and has shown TCE concentrations consistently above the MCL. The concentration of TCE from the initial sample collected in 1998 was 2700 μg/L; however, concentrations were 480 and 420 μg/L in the 2012 wet and dry season samples, respectively. In addition to TCE, *cis*-1,2-DCE has been detected at low concentrations (2 to 10 μg/L). The actual source and extent of this plume are not known.

Table E.6 provides a summary of the Mitchell Branch Area plume sources located over Chickamauga carbonates and Rome Formation clastics.

Table E.6. Mitchell Branch Area groundwater plumes

Plume No.	Plume	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Downgradient length (ft)	**Depth (ft bgs)**	**Concentration (µg/L)**			
ETTP-9	Mitchell Branch Commingled Plume	>1200 (width > 1000)	>100	TCE: >200,000 *cis*-1,2-DCE: >35,000 1,1-DCA: >3000 1,1-DCE: >3000 VC: >1500 PCE: >500 1,1,1-TCA: >100 Chromium: >700	Uncertain; along-strike and down-dip in Rome; hydraulic gradient for shallow flow; preferential pathways via buried channels and utility lines	Mitchell Branch/ Poplar Creek	Vertical extent of plumes is uncertain. Residual mass uncertain Presence of DNAPL at source areas other than K-1401 Unknown chromium source

bgs = below ground surface.
DCA = dichloroethane.
DCE = dichloroethene.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
PCE = tetrachloroethene.
TCA = tetrachloroethane.
VC = vinyl chloride.
µg/L = micrograms per liter.

E.4.5 K-31/K-33 AREA

Topographic elevations in the area range from a high of approximately 860 ft amsl in the north along the toe of Blackoak Ridge to approximately 740 ft amsl at Poplar Creek. Minimal relief characterizes most of the areas occupied by industrial facilities. Runoff occurs as overland sheet flow directly to Poplar Creek during storm events, as there are no established surface streams draining the area. Numerous storm drains also discharge to Poplar Creek. Surface runoff and storm drains discharge to the K-901-A Holding Pond in the westernmost portion of the K-31/K-33 Area and to Poplar Creek in the eastern portion. The K-31/K-33 Area is a highly industrialized area of ETTP; prior to D&D of the K-33 building and the west wing of the K-25 building, much of the area was paved or covered by buildings, minimizing natural groundwater recharge and resulting in a low groundwater flux. Bedrock is mantled by overburden ranging up to 57 ft thick. Overburden materials are generally thickest in the northern part of the area, near the toe of Blackoak Ridge, and thinner near the banks of Poplar Creek. The unconsolidated zone in the K-1064 peninsula is very thin, generally less than 5 ft. Bedrock formations of the Chickamauga Supergroup are present in the vicinity of the K-31 building and the southern half of the former K-33 building footprint, whereas bedrock of the upper Knox Group is present in the northern half of the former K-33 building footprint and the northern portion of the K-1064 Peninsula.

Saturated overburden ranges from 2 ft thick near the surface water bodies to as much as 35 ft thick in the interior areas. Groundwater flow in the saturated overburden is expected to follow mapped hydraulic gradients, which generally mimic the topography, but locally can be influenced by cut and fill sections, storm drains, and other anthropogenic features. Unconsolidated zone flowpaths are short and terminate at Poplar Creek. Bedrock zone groundwater flow is likely to be primarily through secondary features, such as faults, joints, bedding surfaces, and karst conduits.

Groundwater contamination is dispersed and typically not present in well-defined plumes. Historical contaminant sources appear to be associated with the K-31 and K-33 buildings and former facilities in the K-1064 Area. Although historically chromium, associated with leaks in the RCW lines, has exceeded its MCL in some wells, recent data indicate that results for filtered samples do not exceed the MCL. An investigation was conducted in FY 2006 to determine if the chromium in groundwater in this area was hexavalent chromium. The results indicated that the chromium was essentially all the less toxic trivalent species. Both field-filtered and unfiltered samples have been collected. Chromium concentrations in the field-filtered groundwater samples are consistently below the MCL.

ETTP-10 K-1064 Peninsula

The K-1064 peninsula was developed in 1957 as a storage area for containerized oils and liquids, to provide burning of select liquids, and for storage and staging for building and maintenance materials. Radioactively contaminated materials were stored on an interim basis before final disposal, as were uncontaminated materials. Other operations included the incineration of organic liquid wastes, storage of drummed liquid wastes, truck washing, cylinder venting, drum deheading, and drum cleaning. There is evidence of organic, metal, and radiological contamination throughout the peninsula from past and present activities.

All groundwater monitoring wells on the K-1064 peninsula are bedrock wells. TCE has been consistently detected in two wells since 1994, but concentrations have been declining, and recent data indicate that only one of two samples at one well slightly exceeded the MCL with a concentration of 5.4 µg/L.

Arsenic has also been detected above its MCL of 0.01 mg/L in these wells. Groundwater samples collected in 2012 ranged from 0.014 to 0.025 mg/L.

Table E.7 provides a summary of the K-31/K-33 Area K-1064 Peninsula plume source located over both Chickamauga and Knox carbonates.

E.4.6 ETTP-11 K-27/K-29 AREA

The K-27/K-29 Area lies in the main process area of ETTP and is bounded by Poplar Creek to the north, west, and southwest and the K-25 process building to the east. The hydrogeologic framework of this subwatershed is characterized by complex geology, large-scale cut and fill, transient interactions with Watts Bar influenced Poplar Creek, and a high degree of anthropogenic influences such as building sumps, French drains, leaking storm drains and subsurface utilities, RCW pipes, and extensive paved areas. The K-27/K-29 peninsula is a highly industrialized portion of ETTP and contains numerous facilities that may be sources for groundwater contamination observed in this area.

The overburden in the area ranges in thickness from 15 to 50 ft. Historical aerial photos showed a fill area extending from Bldg. K-27 south beneath the K-731 Switchhouse to Poplar Creek. The bedrock underlying the area consists of the Chickamauga Supergroup. Bedrock is encountered at depths of up to 50 ft, with bedrock outcropping in and along the banks of Poplar Creek. A potentiometric divide transects the northern portion of the K-27/K-29 peninsula from east to west.

The K-27/K-29 Area is located on the neck of the peninsula formed by a meander in Poplar Creek. As such, the groundwater gradient in the area is toward Poplar Creek on the north and the southwest. Groundwater flow and the extent of dissolved contaminants in the unconsolidated zone follow mapped hydraulic gradients, which are obviously impacted by anthropogenic features. Bedrock flowpaths are likely to be along geologic strike and down dip through fractures, solution conduits, and along bedding planes.

Two areas of groundwater plumes have been identified in the K-27/K-29 Area based on the potentiometric maps. The South K-27/K-29 plume extends from the K-27 building southwestward to Poplar Creek. The North K-27/K-29 plume extends from the K-27 building northward to Poplar Creek and includes the isolated bedrock plume located northeast of the K-27 building. VOCs are the primary contaminant in these plumes. The VOCs are assumed to be entirely in dissolved phase for the majority of the plume; however, a potential DNAPL source has been suspected in the K-27 Area due to persistent and slightly increasing to stable concentrations of TCE at well UNW-088 (~600 µg/L). The source of TCE is uncertain.

TCE daughter compounds are virtually nonexistent in the K-27/K-29 Area. Decreasing concentration trends of TCE are observed in most of the plume. F&T analysis has indicated that TCE concentrations in the South K-27/K-29 plume are not expected to decline to below the MCL in less than 400 years, even if 90% of the potential DNAPL source mass were to be removed. However, if a DNAPL source does not exist in this area, then TCE was predicted to decline to below its MCL in approximately 200 years. In the North K-27 plume, TCE would decline to below its MCL in a little over 100 years through natural attenuation.

The source of VOC contamination in the solitary well located north of the K-27 building is not suspected to be from the K-27/K-29 Area operations. VOC concentrations in this area show very slowly declining concentrations.

Table E.8 provides a summary of the K-27/K-29 Area plume sources located over Chickamauga carbonates.

Table E.7. K-31/K-33 Area groundwater plumes

Plume No.	Plume	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Downgradient length (ft)	Depth (ft bgs)	Concentration (µg/L)			
ETTP-10	K-1064	200	40	TCE: ~5	Along-strike in Chickamauga/ Knox	Poplar Creek	Source of TCE is uncertain.

bgs = below ground surface.
ETTP = East Tennessee Technology Park.
TCE = trichloroethene.
µg/L = micrograms per liter.

Table E.8. K-27/29 Area groundwater plumes

Plume No.	Plume	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft)	Depth (ft bgs)	Concentration (μg/L)			
ETTP-11	K-27/K-29	~1000	>100	TCE: >600 *cis*-1,2-DCE: >40	Hydraulic gradient for shallow flow, along-strike and down-dip in Chickamauga	Poplar Creek	Source of VOCs is uncertain. Vertical and horizontal extent of plumes is uncertain.

bgs = below ground surface.
DCE = dichloroethene.
ETTP = East Tennessee Technology Park.
TCE = trichloroethene.
VOC = volatile organic compound.
μg/L = micrograms per liter.

E.4.7 SUMMARY OF KEY DATA GAPS

The following discussion provides the important data gaps with respect to the primary groundwater plumes at ETTP. Table E.9 provides a summary of these data gaps. Plumes ETTP-5 and ETTP-10 are not included below as these two plumes either do not have significant data gaps, or it does not appear that there is a long-term concern associated with the plume.

Table E.9. Summary of key data gaps for ETTP groundwater plumes

Plume No.	Description	Data gaps and uncertainties
ETTP-1	K-1070-A Burial Ground	Mass and distribution of residual source are uncertain Potential off-site migration along-strike is uncertain
ETTP-2	Contractor's Spoil Area	Source of TCE at downgradient spring is unknown
ETTP-3	K-1085 Old Firehouse Burn Area	Full extent of plume and remaining source mass is uncertain
ETTP-4	Duct Island/K-1070-F	Source of TCE at spring PCO is unknown
ETTP-6	K-770 Scrap Metal Yard	Vertical extent into bedrock is unknown
ETTP-7	K-1200	Source of VOCs is uncertain Remaining mass of source material is unknown
ETTP-9	Mitchell Branch Commingled Plumes	Unknown vertical extent of plumes Residual mass uncertain Presence of DNAPL at source areas other than K-1401 Unknown chromium source
ETTP-11	K-27/K-29 Area	Source of VOCs is uncertain Vertical and horizontal extent of VOC plumes is uncertain

DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
TCE = trichloroethene.
VOC = volatile organic compound.

ETTP-1 K-1070-A Burial Ground

The nature and extent of the continuing source of VOCs to the Knox bedrock is uncertain. The stable to increasing trends in VOC concentrations in bedrock wells indicate a secondary source exists; however, the distribution in the subsurface of this secondary source is unknown. Thus, the remaining mass of the residual source is unknown. In addition, the potential for along-strike migration off-site is uncertain.

ETTP-2 Contractor's Spoil Area

The source of the TCE present at spring 10-895 is unknown; thus, the flowpath from the source to the spring is also unknown. Groundwater data for the CSA are too limited to determine if this former landfill, located upgradient of the spring, is the source. No monitoring wells have been installed at the CSA; however, available seep and surface water sample data do not indicate the presence of VOCs.

ETTP-3 K-1085 Old Firehouse Burn Area

The vertical and horizontal extent of VOCs in the dissolved plume and the remaining mass of the residual source are uncertain. Although discharge of shallow groundwater to the Beaver Dam Ponds is indicated by the presence of TCE in surface water collected from the ponds, the lateral extent of the plume has not been fully constrained. The vertical extent has only been investigated through the installation of a single bedrock well near the source area. Although this well contained only low concentrations of TCE (23 μg/L) and PCE (29 μg/L), the high degree of deformation in bedrock at this site precludes identification of definitive flowpaths. Thus, it cannot be stated with certainty that higher concentrations are not present in bedrock.

ETTP-4 Duct Island/K-1070-F

The source of the TCE present at the PCO spring is unknown. Groundwater data from the existing wells at the upgradient K-1070-F Construction Spoil Area have only exhibited the sporadic presence of low concentrations of VOCs. TCE has only been detected once each at three different wells at concentrations ranging from 2 to 16 μg/L. The transport of VOCs from the K-27 plume, located to the east of K-1070-F, beneath Poplar Creek to the PCO spring cannot be entirely discounted based on available data.

ETTP-6 K-770

The vertical extent of the elevated radioactivity in these two wells has not been investigated. The possibility exists that bedrock flowpaths beneath the Clinch River could exist.

ETTP-7 K-1200

The source of the high concentrations of VOCs in the K-1200 Area may be in the area of the K-1070-C/D Concrete Pad; however, there remains some uncertainty with the location. Likewise, the mass of residual source is unknown. Bedrock contamination is present upgradient of K-1200, indicating possible bedrock flowpaths to the K-1200 Area. However, bedrock flowpaths would be impossible to fully delineate in this area of severe structural deformation and faulting.

ETTP-8 K-1004

The source and vertical extent of the low concentrations of VOCs found in bedrock wells in the Administrative/K-1004 Area is uncertain. Given the downgradient position of these wells from the K-1200 Area, it is possible that this plume represents a downgradient extension of the K-1200 plume.

ETTP-9 Mitchell Branch

The full extent of the VOC hot spots (i.e., greater than 1000 μg/L molar concentrations of ethanes and ethenes) and possible DNAPL sources in bedrock within the K-1070-C/D, K-1035, K-1401, K-1413, and K-1407-B source areas is not fully defined. Although further refinement of the extent of these hot spots was obtained during the sitewide RI, data gaps remain for both the horizontal and vertical extent. The extent of contaminant mass remaining in the matrix portion of the aquifer is also uncertain at these sites. Detailed delineation of source area extents is extremely difficult because of the complex geology and physical behavior of dense VOC liquids in heterogeneous overburden material and fractured and karstic bedrock. Although discharge of VOCs to Mitchell Branch is occurring (TCE: 10 to 30 μg/L at the K-1700 weir), flowpaths in the deeper bedrock are unknown.

ETTP-11 K-27/K-29

The source of the VOCs detected in the K-27/K-29 plumes is unknown. Results of storm drain dye tracer tests conducted as part of the sitewide RI suggest that the source might lie on the north side of the building and may be the same source contributing to groundwater contamination in the K-27/K-29 North plume. Detectable concentrations of TCE have historically been present in the discharge from an unknown pipe that appears to originate beneath Bldg. K-27 and feeds into the SD-430 system on the south side of the building. The extent of the K-27/K-29 South plume is also uncertain and could also be greatly influenced by the storm drain system; sumps in and around Bldg. K-731, which are known to collect groundwater containing VOCs; and the filled sinkhole south of the K-27 building. Well UNW-038, which is located adjacent to Poplar Creek, has shown little fluctuation in TCE concentration (~100 μg/L) since monitoring began in 1989; thus, a residual source of uncertain mass remains in the K-27 Area.

E.5 REFERENCES

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APPENDIX F
BETHEL VALLEY SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

ACRONYMS

ARRA	American Recovery and Reinvestment Act of 2009
bgs	below ground surface
BV	Bethel Valley
BVGWES	Bethel Valley Groundwater Engineering Study
Ci	curie
COC	contaminant of concern
CY	calendar year
DCE	dichloroethene
DHC	*Dehalococcoides* sp.
DOE	U.S. Department of Energy
EOS	Edible Oil Microemulsions
FS	feasibility study
FY	fiscal year
FYR	Five-Year Review
HRC	Hydrogen Release Compound
LLLW	liquid low-level waste
MCL	maximum contaminant level
MV	Melton Valley
μg/L	micrograms per liter
ng/L	nanograms per liter
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCE	tetrachloroethene
PDSA	pre-design study area
pCi/L	picocuries per liter
PWTC	Process Waste Treatment Complex
PWTP	Process Waste Treatment Plant
RAO	remedial action objective
RAWP	Remedial Action Work Plan
RDR	Remedial Design Report
RER	remediation effectiveness report
RI	remedial investigation
ROD	Record of Decision
SWSA	Solid Waste Storage Area
TCE	trichloroethene
TRU	transuranic
TS	treatability study
VC	vinyl chloride
VOC	volatile organic compound
WAG	Waste Area Grouping
WOC	White Oak Creek

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F.1. INTRODUCTION

This Appendix provides a summary of the conceptual model for the Bethel Valley (BV) Watershed, located in the southwestern portion of the Oak Ridge Reservation (ORR), based on the available data and the understanding of the hydrogeologic framework at the time of data collection. The following sections provide a chronology of events associated with the BV Watershed, the primary groundwater contaminant sources identified in the watershed, the geology and hydrology of the watershed, and summaries of the source area conceptual models, including discussions of key data gaps in the individual source area conceptual models. Much of the background information provided herein is from the BV Remedial Investigation/Feasibility Study (RI/FS) [DOE 1999a] and the BV Engineering Study Report for Groundwater Actions (DOE 2005). Updated contaminant concentrations and concentration trends have been obtained from the Treatability Study (TS) for the BV 7000 Area Groundwater Plume (DOE 2012a) and recent ORR Remediation Effectiveness Reports (RERs) [DOE 2012b; DOE 2013]. The sources for the illustrations presented in this Appendix are indicated on the individual figures.

F.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH THE BV WATERSHED

Table F.1 provides a chronology of historical operations and relevant events related to groundwater contaminant plumes for the BV Watershed.

Table F.1. Chronology of events associated with the BV Watershed

Event	Date
X-10 – currently referred to as Oak Ridge National Laboratory (ORNL) – is built as part of the Manhattan Project in World War II. The Bethel Valley (BV) watershed received operational wastes from the X-10 Complex and other DOE facilities as shown on Fig. F.1.	1943
Liquid low-level waste (LLLW) system is installed, including a complex system of underground lines and tanks.	1940s
First surface impoundment is constructed to receive LLLW streams for settling prior to discharge to White Oak Creek; three additional impoundments are developed and used from 1944 to 1996.	1943
Shallow land burial of solid low-level radioactive waste occurs in BV SWSA 1, SWSA 2, and SWSA 3 prior to moving disposal operations to Melton Valley.	1943 – 1951
SWSA 1 receives solid waste from Bldg. 3019 (Pilot Processing Plant), Bldg. 706-A (Chemistry Division), and Bldg. 3001 (Graphite Reactor).	1943 – 1944
SWSA 2 receives solid waste; waste is later excavated and moved to SWSA 3.	1944 – 1946
SWSA 3 receives solid wastes from ORNL and other sites (Mound and Argonne).	1946 – 1951
ORNL performs early environmental sampling of sediments, groundwater, and surface water.	1981 – mid-1990s
Series of environmental sampling efforts get underway in BV in response to ORR NPL listing, including Waste Area Grouping 2 (ORNL surface water) and Waste Area Grouping 1 (BV groundwater). These data sets provide the first understanding of the conceptual contaminant release model in BV and identify key source areas.	1991 – 1995
The SIOU ROD is signed, identifying excavation as the selected alternative.	1997
The ROD for Interim Action: Sludge Removal from the Gunite and Associated Tanks is signed.	1997

Table F.1. Chronology of events associated with the BV Watershed (cont.)

Event	Date
Based on initial characterization work, several removal actions are undertaken in BV, including key Corehole 8 collection system and removal and grouting of LLLW tanks. (Additional information on the chronology of the Corehole 8 Plume actions is provided in Table F.8.)	1999 – 2003
The BV RI/FS is issued. The RI/FS accounts for all 72 tanks located in BV; tanks not yet grouted are identified for sludge/liquid removal and grouting	1999
Action under the Gunite and Associated Tanks ROD is completed.	2001
The ROD for Interim Actions in BV is signed.	2002
The BV groundwater engineering study is performed to better delineate soil source area and groundwater plumes.	2005
Several BV ROD projects receive ARRA funding including SWSAs 1 and 3.	2009 – 2011
The *Remedial Design Report/Remedial Action Work Plan for Soils, Sediments and Dynamic Characterization Strategy for Bethel Valley, Oak Ridge, Tennessee* (DOE 2009) includes process to address leaching to groundwater	December 2009
SWSAs 1 and 3 are capped. The Phased Construction Completion Report is approved in May 2012.	2010 – 2012
A groundwater treatability study for the 7000 Area VOC plume to test in situ microbial treatment indicates that anaerobic reductive dechlorination can be successfully implemented to treat trichloroethene in groundwater.	2010 – 2012
The Corehole 8 groundwater extraction system is upgraded	2010 – 2012
Tank W-1A and surrounding soil are removed.	2011 – 2012

ARRA = American Recovery and Reinvestment Act.
DOE = U. S. Department of Energy.
FFA = Federal Facility Agreement.
NPL = National Priorities List.
ORR = Oak Ridge Reservation.
RI/FS = remedial investigation/feasibility study.
ROD = Record of Decision.
SIOU = Surface Impoundments Operable Unit.
SWSA = Solid Waste Storage Area.
VOC = volatile organic compound.

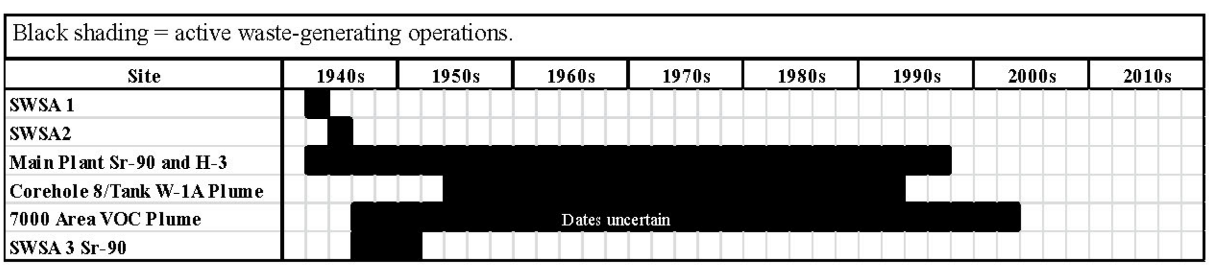

Fig. F.1. Schedule of historical waste operations in Bethel Valley.

F.1.2 PRIMARY CONTAMINANT SOURCES IN BV

Figures F.2 through F.4 show the Oak Ridge National Laboratory [ORNL] (X-10)–BV. Figure F.2 shows the location of the ORNL main plant area in relation to the geology and the three surface water watersheds (from east to west, Bearden Creek, White Oak Creek [WOC], and Raccoon Creek) and the four "administrative areas" identified in the RI. Figure F.3 shows a more detailed view of the administrative source areas in the RI, and Fig. F.4 shows the current agreements on future long-term land use in BV. For the groundwater strategy approach, four groundwater contaminant plumes have been identified (see Table F.2 and Figs. F.5 and F.6):

- BV-1 – The main plant area contains widespread, shallow ^{90}Sr, ^{3}H (tritium), and mercury contamination. This source area is divided into four quadrants and the 4000 Area.
- BV-2 – The Corehole 8 Plume is associated with ^{90}Sr, $^{233/234}$U, and ^{137}Cs contamination.
- BV-3 – The 7000 Area volatile organic compound (VOC) plume is associated with trichloroethene (TCE) contamination.
- BV-4 – Solid Waste Storage Area (SWSA) 3 contains a ^{90}Sr plume.

The primary groundwater contaminants of concern (COCs) that define plumes in BV are:

- Strontium-90;
- Uranium (alpha; beta as U decay products);
- Tritium (^{3}H);
- Various radioisotopes unique to the reactor operations within ORNL (^{137}Cs, ^{214}Am, ^{233}U, plus transuranic [TRU] isotopes);
- VOCs (tetrachloroethene [PCE], TCE, dichloroethene [DCE], and vinyl chloride [VC]); and
- Mercury.

The information contained within this conceptual model summary document relies upon several primary documents including the BV RI/FS (DOE 1999a; DOE 1999b), Bethel Valley Groundwater Engineering Study (BVGWES) [DOE 2005], Remedial Design Report/Remedial Action Work Plan (RDR/RAWP) for the BV/Corehole 8 Extraction System (DOE 2010a), TS for the BV 7000 Area Groundwater Plume (DOE 2012a), and 2012 and 2013 RERs (DOE 2012b and DOE 2013, respectively).

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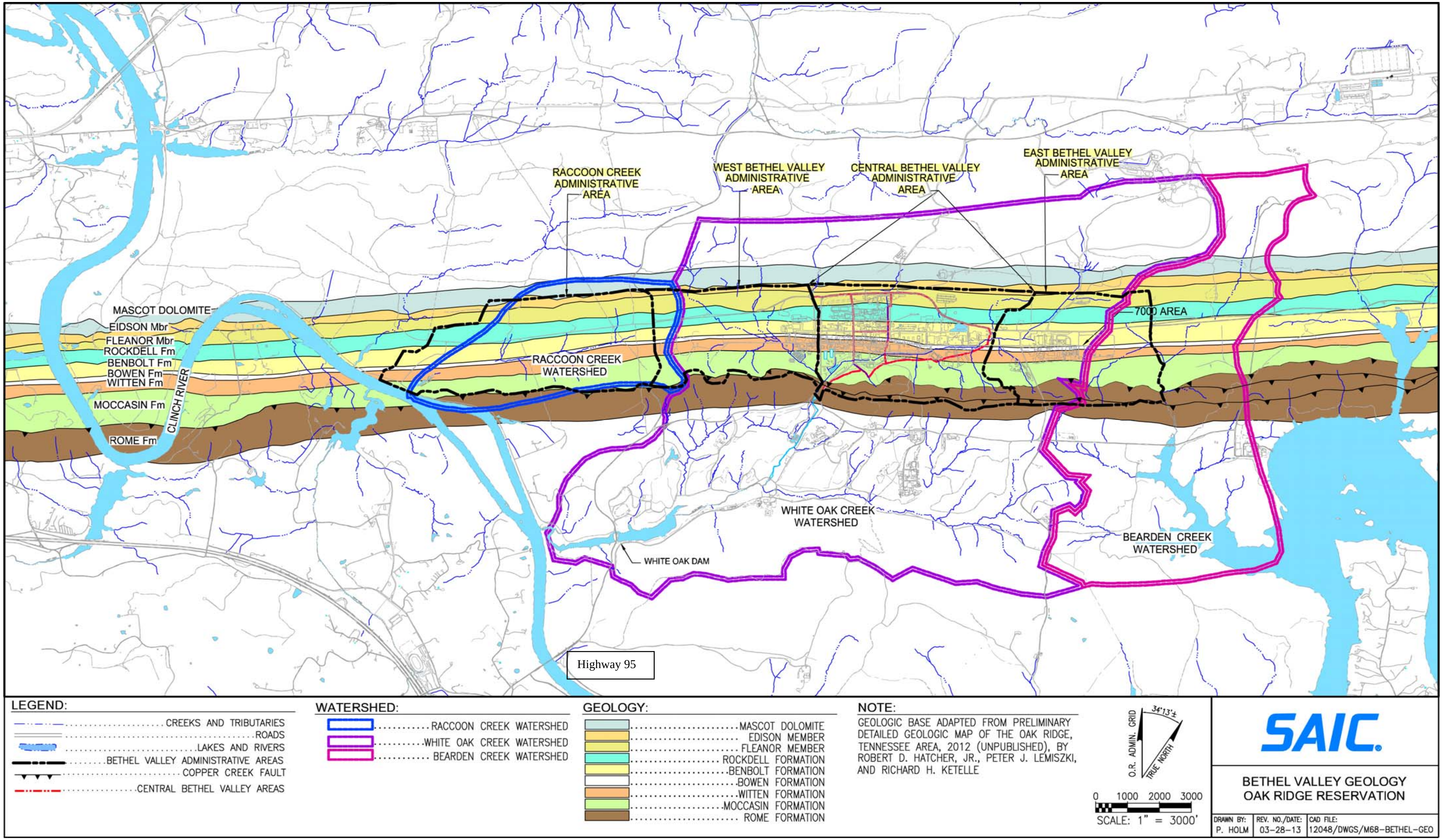
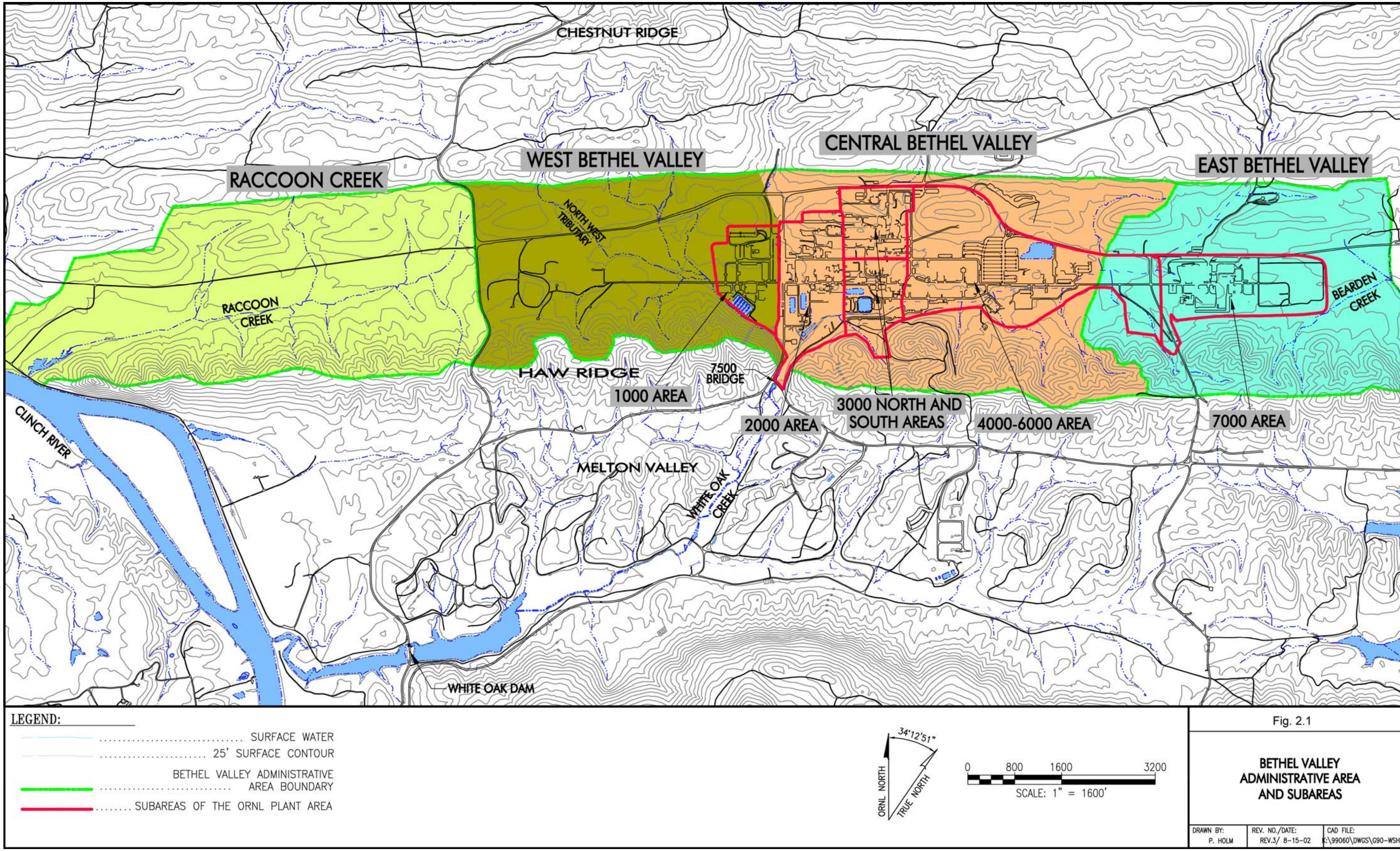


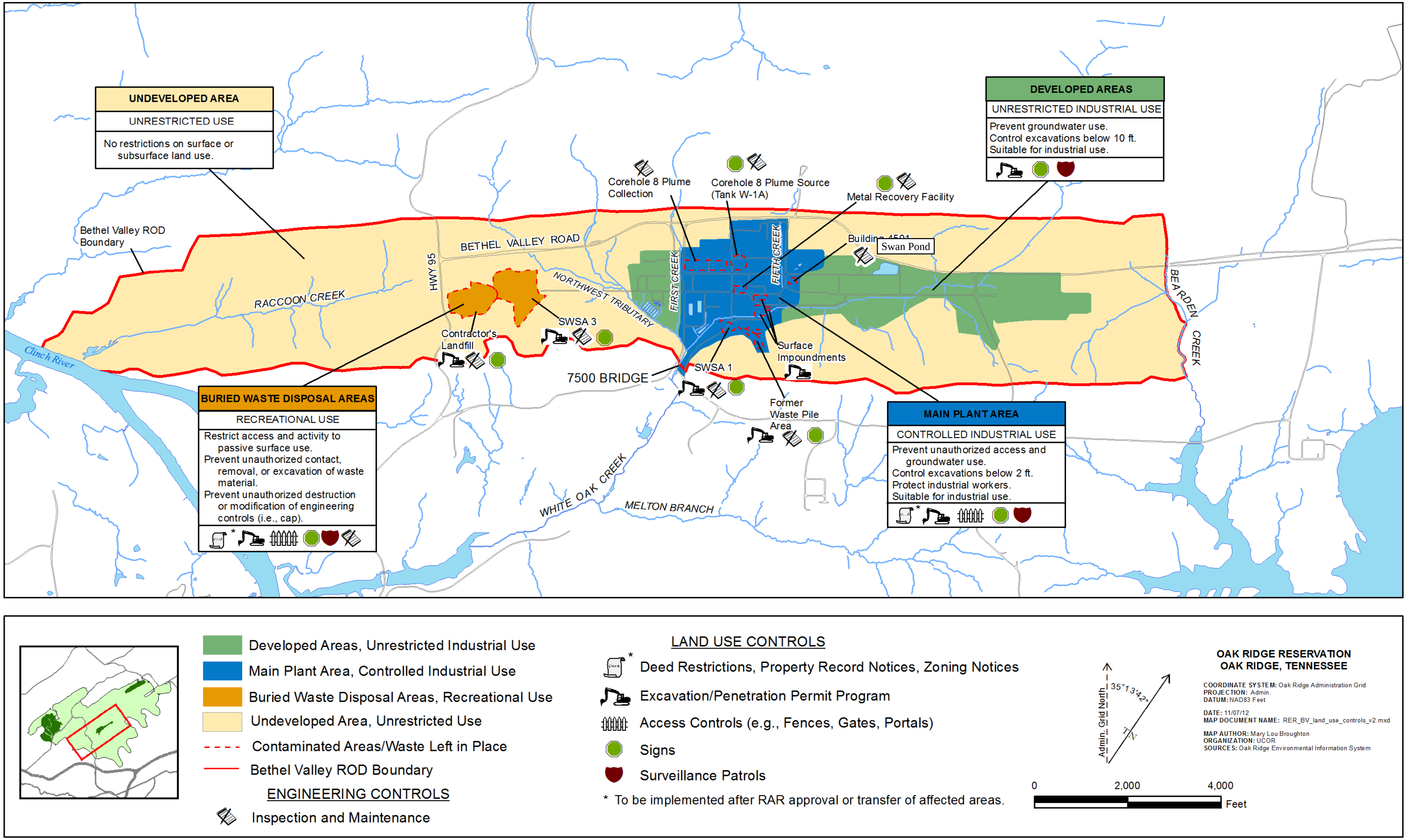
Source: adapted from DOE 2010b

Fig. F.2. Bethel Valley–Oak Ridge National Laboratory plant area, surface water watersheds, and subsurface geology.



Source: DOE 2005

Fig. F.3. Waste Management/Administrative Areas in Bethel Valley.



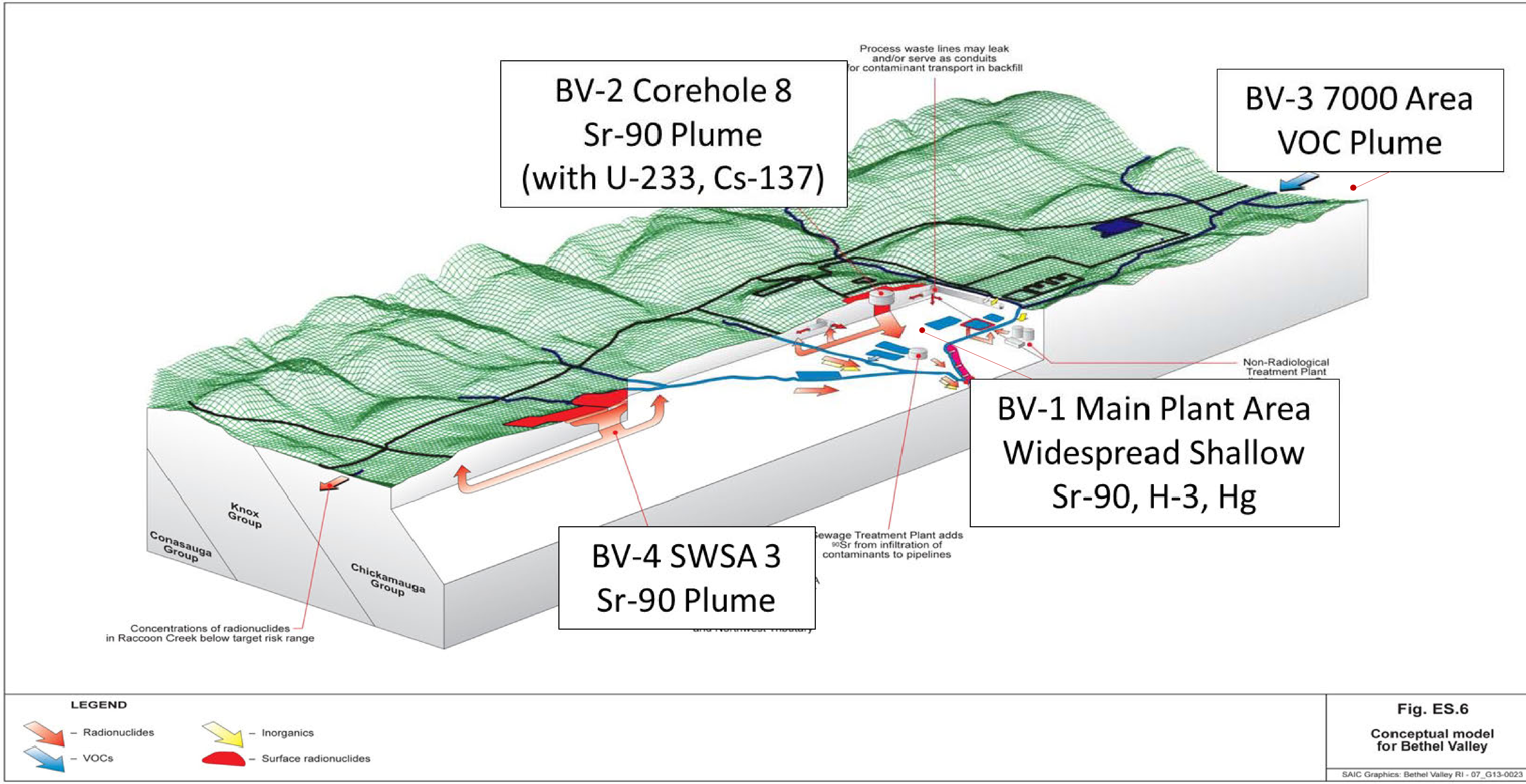
Source: DOE 2013

Fig. F.4. ROD-designated land use, interim controls, and contaminant source areas in Bethel Valley.

Table F.2. Groundwater plumes in Bethel Valley

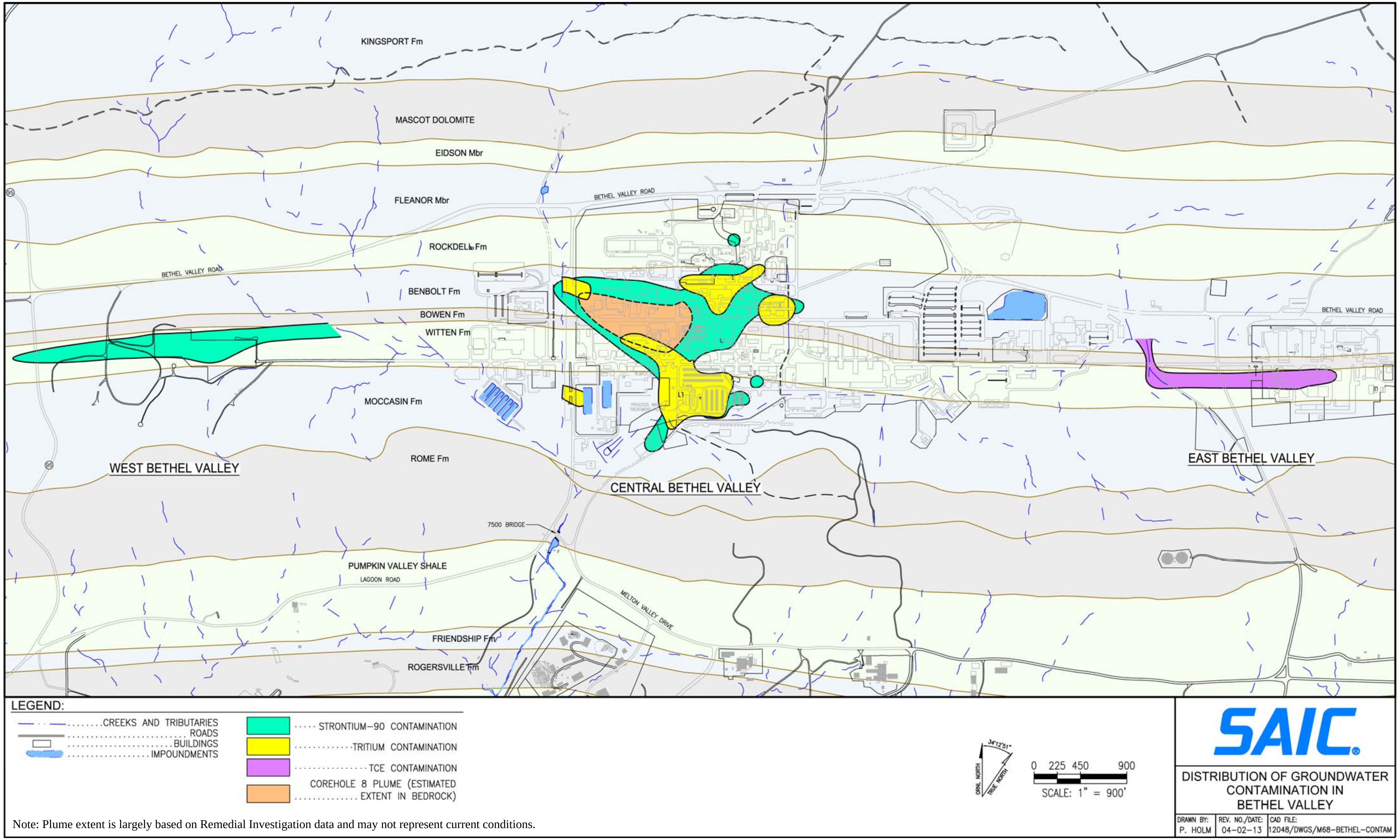
Source area	Plume No.	Description
Main plant area widespread, shallow ^{90}Sr, ^{3}H, and Mercury	BV-1a	Quadrant 1 – North Tank Farm; LLLW lines around Bldg. 3019
	BV-1b	Quadrant 2 – Pipeline leaks and spills from former radioisotope production and distribution facilities
	BV-1c	Quadrant 3 – Mercury-contaminated soil (Bldgs. 3592, 3503, and 4501) and mercury in Fifth Creek sediments
	BV-1d	Quadrant 4 – South Tank Farm/Bldgs. 3517, 3515, and surface impoundments
	BV-1e	4000 Area Hg sources
Corehole 8 Plume ^{90}Sr, $^{233/234}U$, and ^{137}Cs	BV-2	Strontium-90, uranium, and ^{137}Cs in shallow/deep Benbolt limestones and siltstones
7000 Area VOC Plume	BV-3	VOCs, primarily TCE and daughters, in Witten shaley siltstones and limestones; relatively minor VOCs in shallow/deep Benbolt limestones and siltstones
SWSA 3 ^{90}Sr Plume	BV-4	Strontium-90 in Witten shaley siltstones and limestones migrating both east (to Northwest Tributary) and west (Raccoon Creek)

BV = Bethel Valley.
LLLW = liquid low-level (radioactive) waste.
SWSA = Solid Waste Storage Area.
TCE = trichloroethene.
VOC = volatile organic compound.



Source: adapted from DOE 1999a

Fig. F.5. Conceptual model and plume identification for Bethel Valley.



Source: adapted from DOE 1999a

Fig. F.6. Distribution of groundwater contamination in Bethel Valley from the BV Remedial Investigation.

F.1.3 GEOLOGY AND HYDROLOGY

BV, located between Chestnut Ridge to the northwest and Haw Ridge to the southeast, contains rocks of the middle Ordovician Knox and Chickamauga groups. The general outcrop pattern of bedrock formations is provided on Figs. F.7 and F.8. The local geologic structure is characterized by a series of thrust faults that formed during the Appalachian Orogeny, 300 million years ago. BV is located on the White Oak Mountain thrust sheet about 2 miles southeast of the White Oak Mountain fault (which is located just to the north of the Y-12 National Security Complex/Bear Creek Valley). The next regional thrust to the southeast of the White Oak Mountain Fault is the Copper Creek Fault that crops out on the slope of Haw Ridge, which forms the southern margin of the BV watershed (Fig. F.7).

Most of BV is underlain by bedrock of the Ordovician Chickamauga Group. Seven recognized formations within the Chickamauga form a relatively uniform geologic structure with an average bedrock strike of about N55°E and bedding dip of about 30 to 35° to the southeast. The bedrock structure, both large-scale in terms of general orientation and small-scale in terms of fracture location, density, and orientation, is important because it strongly influences the occurrence and movement of groundwater. Prominent fracture sets observed in rock core from BV are bedding plane partings and joints. Bedding plane partings are the most abundant fracture features because most of the formations in the Chickamauga Group are composed of thin-bedded (0.5- to 4-in.) limestone/shale interbeds. The more limestone-rich geologic units, such as the Rockdell and Witten Formations, contain thicker limestone beds that tend to fracture in the strike-set and dip-set orientations. These limestone-rich formations are subject to chemical weathering and dissolution, resulting in the development of karst features, including cavities and conduits.

The unconformity and associated paleokarst probably enhance the permeability of the uppermost Knox Group, whereas the lower permeability formations in the overlying Chickamauga tend to confine the groundwater in the Knox Group. The net effect of these factors is: (1) the presence of springs and seeps along the toe of Chestnut Ridge, where groundwater from the Knox Group rises to spill across the lower Chickamauga Group bedrock in spring-fed streams; and (2) the presence of springs in the lower Chickamauga Group that are fed by the Knox Aquifer and local discharges. Most of the perennial streams in BV are fed by springs that originate from the Knox Group on Chestnut Ridge or as springs in the lower half of the Chickamauga Group in the northwestern portion of the valley. This relationship is observed along the entire length of Chestnut Ridge and BV on the ORR and is also observed in the relationship between Blackoak Ridge and East Fork Poplar Creek Valley in the city of Oak Ridge (see Fig. F.9 for the groundwater potentiometric surface).

The relationship between groundwater beneath Haw Ridge and BV differs from Chestnut Ridge because the northwest slope of Haw Ridge is underlain by the scarp slope of the Moccasin Formation and the overlying Rome Formation in the Copper Creek thrust belt. Bedding plane and fracture pattern controls on groundwater flow tend to cause groundwater in the Rome Formation to flow down-dip and along-strike beneath Haw Ridge to discharge at springs, in-stream valleys, and water gaps. Some streams cut into the scarp slope of the ridge and carry the spring discharges northwestward to WOC, the Northwest Tributary, or Raccoon Creek

The conceptual model of groundwater flow for the BV system includes shallow groundwater flow through fractured bedrock to streams and deeper groundwater flow confined in bedrock fractures, fault-rock of the Copper Creek Fault, or sandy strata of the Rome Formation.

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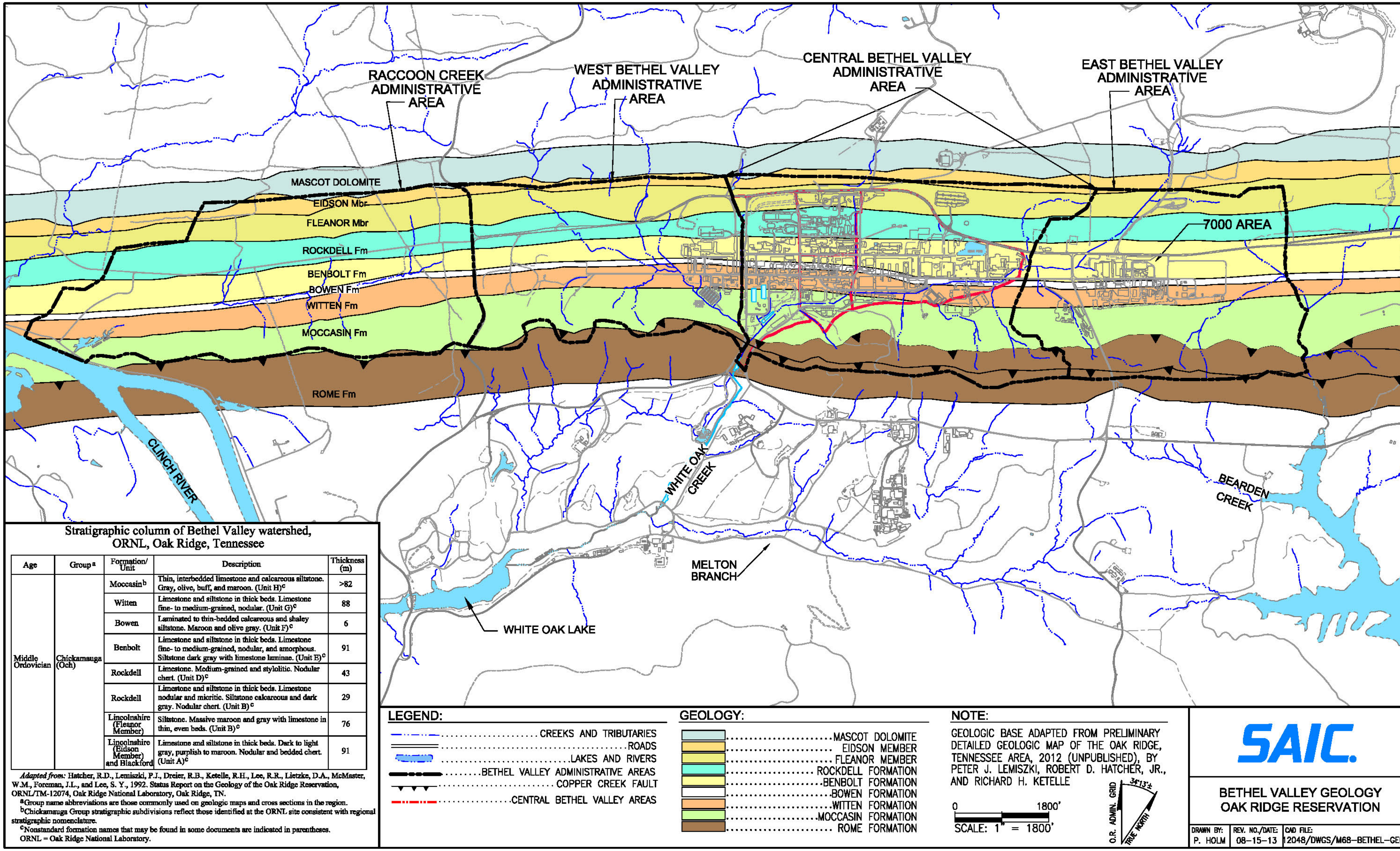


Stratigraphic column of Bethel Valley watershed, ORNL, Oak Ridge, Tennessee

Age	Group[a]	Formation/ Unit	Description	Thickness (m)
Middle Ordovician	Chickamauga (Och)	Moccasin[b]	Thin, interbedded limestone and calcareous siltstone. Gray, olive, buff, and maroon. (Unit H)[c]	>82
		Witten	Limestone and siltstone in thick beds. Limestone fine- to medium-grained, nodular. (Unit G)[c]	88
		Bowen	Laminated to thin-bedded calcareous and shaley siltstone. Maroon and olive gray. (Unit F)[c]	6
		Benbolt	Limestone and siltstone in thick beds. Limestone fine- to medium-grained, nodular, and amorphous. Siltstone dark gray with limestone laminae. (Unit E)[c]	91
		Rockdell	Limestone. Medium-grained and stylolitic. Nodular chert. (Unit D)[c]	43
		Rockdell	Limestone and siltstone in thick beds. Limestone nodular and micritic. Siltstone calcareous and dark gray. Nodular chert. (Unit B)[c]	29
		Lincolnshire (Fleanor Member)	Siltstone. Massive maroon and gray with limestone in thin, even beds. (Unit B)[c]	76
		Lincolnshire (Eidson Member) and Blackford	Limestone and siltstone in thick beds. Dark to light gray, purplish to maroon. Nodular and bedded chert. (Unit A)[c]	91

Adapted from: Hatcher, R.D., Lemiszki, P.J., Dreier, R.B., Ketelle, R.H., Lee, R.R., Lietzke, D.A., McMaster, W.M., Foreman, J.L., and Lee, S. Y., 1992. Status Report on the Geology of the Oak Ridge Reservation, ORNL/TM-12074, Oak Ridge National Laboratory, Oak Ridge, TN.

[a] Group name abbreviations are those commonly used on geologic maps and cross sections in the region.

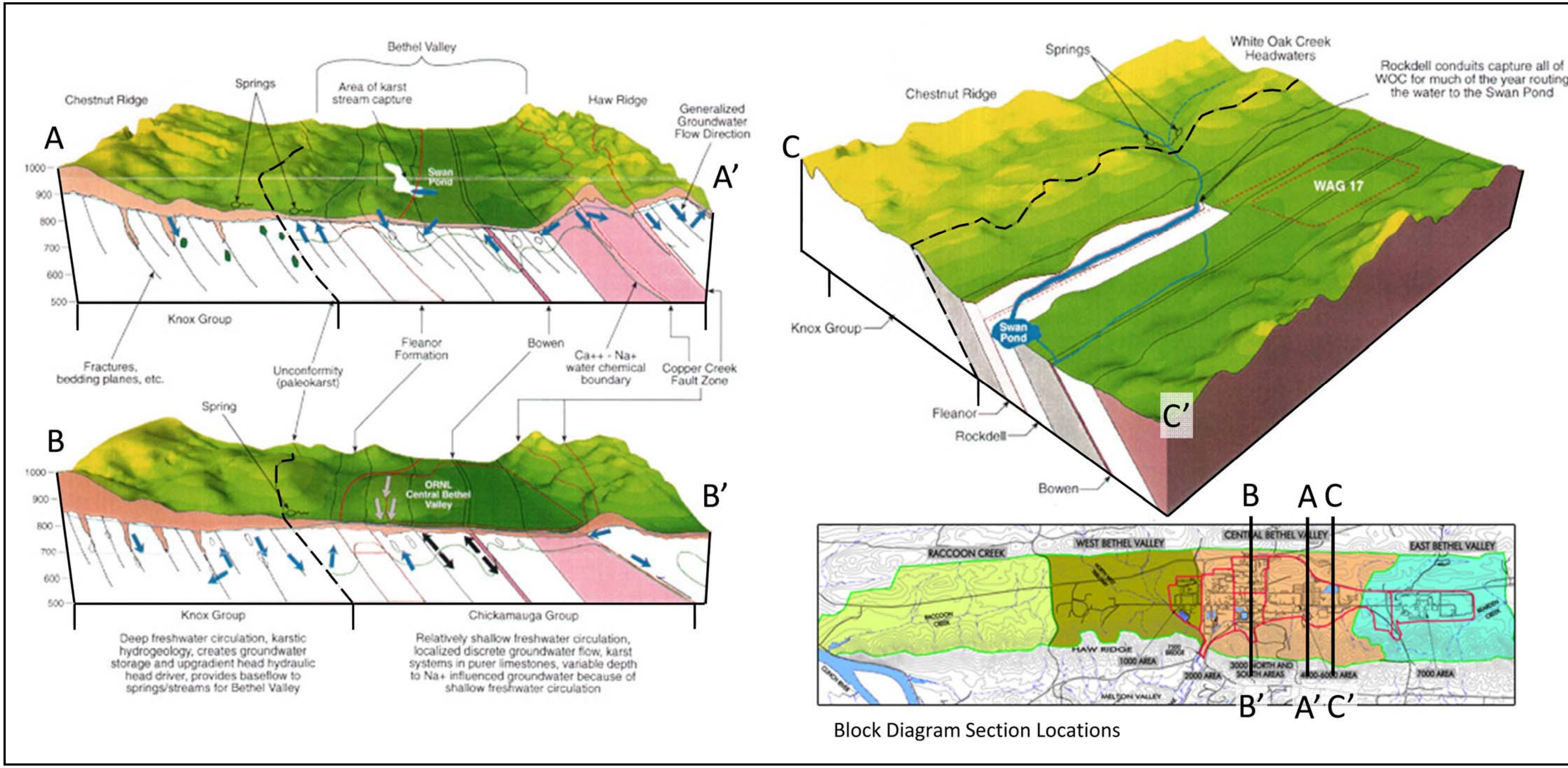
[b] Chickamauga Group stratigraphic subdivisions reflect those identified at the ORNL site consistent with regional stratigraphic nomenclature.

[c] Nonstandard formation names that may be found in some documents are indicated in parentheses.

ORNL = Oak Ridge National Laboratory.

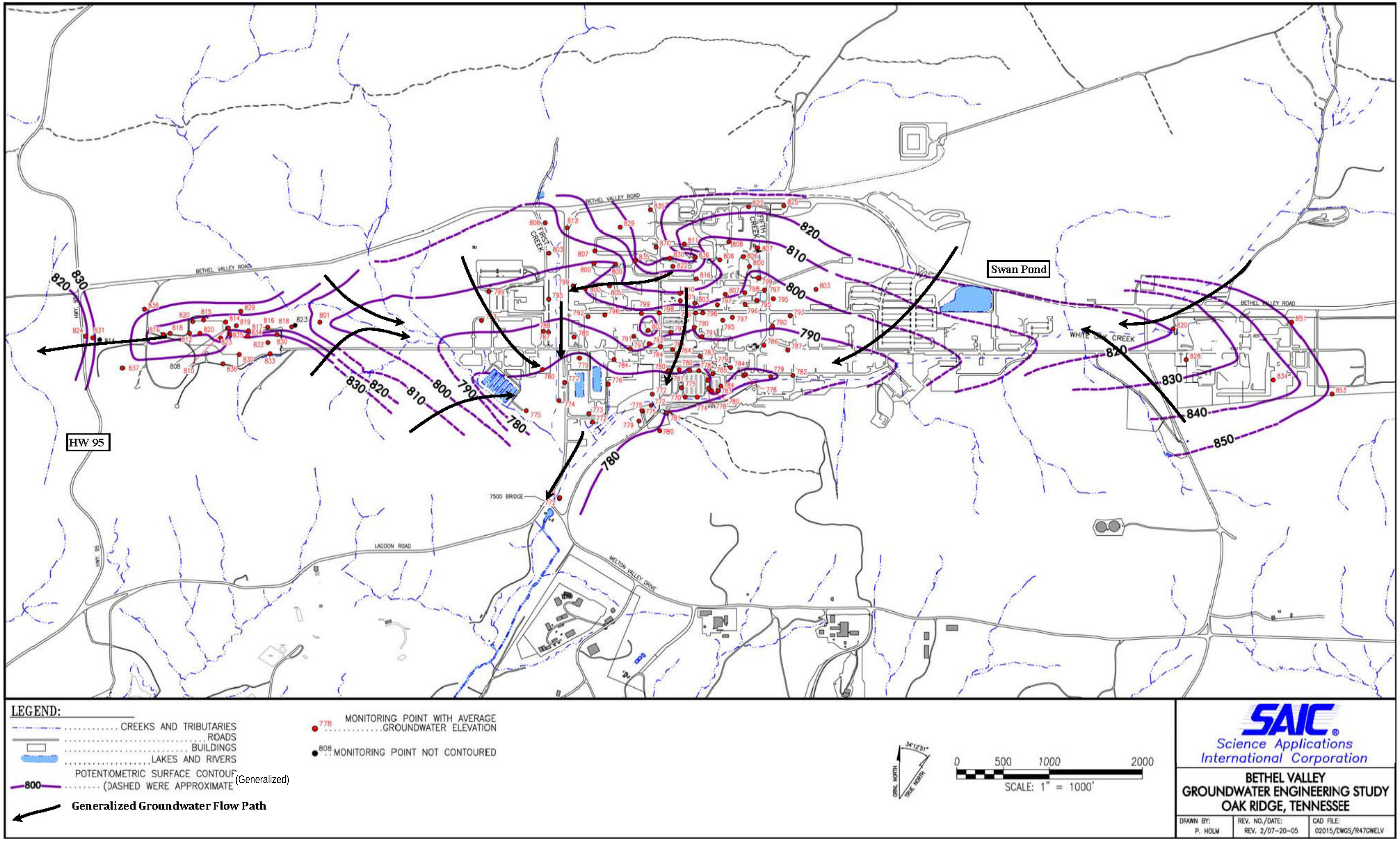
Source: adapted from Hatcher. 2013

Fig. F.7. Geology of Bethel Valley.



Source: DOE 1999a

Fig. F.8. Block diagram showing head relationships of Bethel Valley and adjacent ridges.



Source: DOE 2005

Fig. F.9. Generalized water table contour map of the Bethel Valley Watershed.

Shallow groundwater discharges quickly to surface water, with major plant area groundwater contaminant signatures showing up in First Creek, Fifth Creek, and WOC (Fig. F.10). In the western portion of the valley in the SWSA 3 area, ^{90}Sr contaminants infiltrate groundwater and follow fracture and conduit pathways in both an eastward direction (eventually to 7500 Bridge) and westerly exit pathway to Raccoon Creek. This divergence of pathways is associated with a groundwater divide close to Highway 95 as shown on Fig. F.9.

The rocks underlying BV are composed of interbedded limestone, calcareous shales, and siltstone of the Chickamauga Group, which is often solutionally weathered, forming enlarged voids (karstic) that may form conduits for preferential groundwater flow and contaminant transport. Clay/silt-rich shales may help to attenuate flow within the weathered limestone units. Preferential weathering of the limestone units results in groundwater flow along the east–west orientation (strike) of the bedrock.

Risk

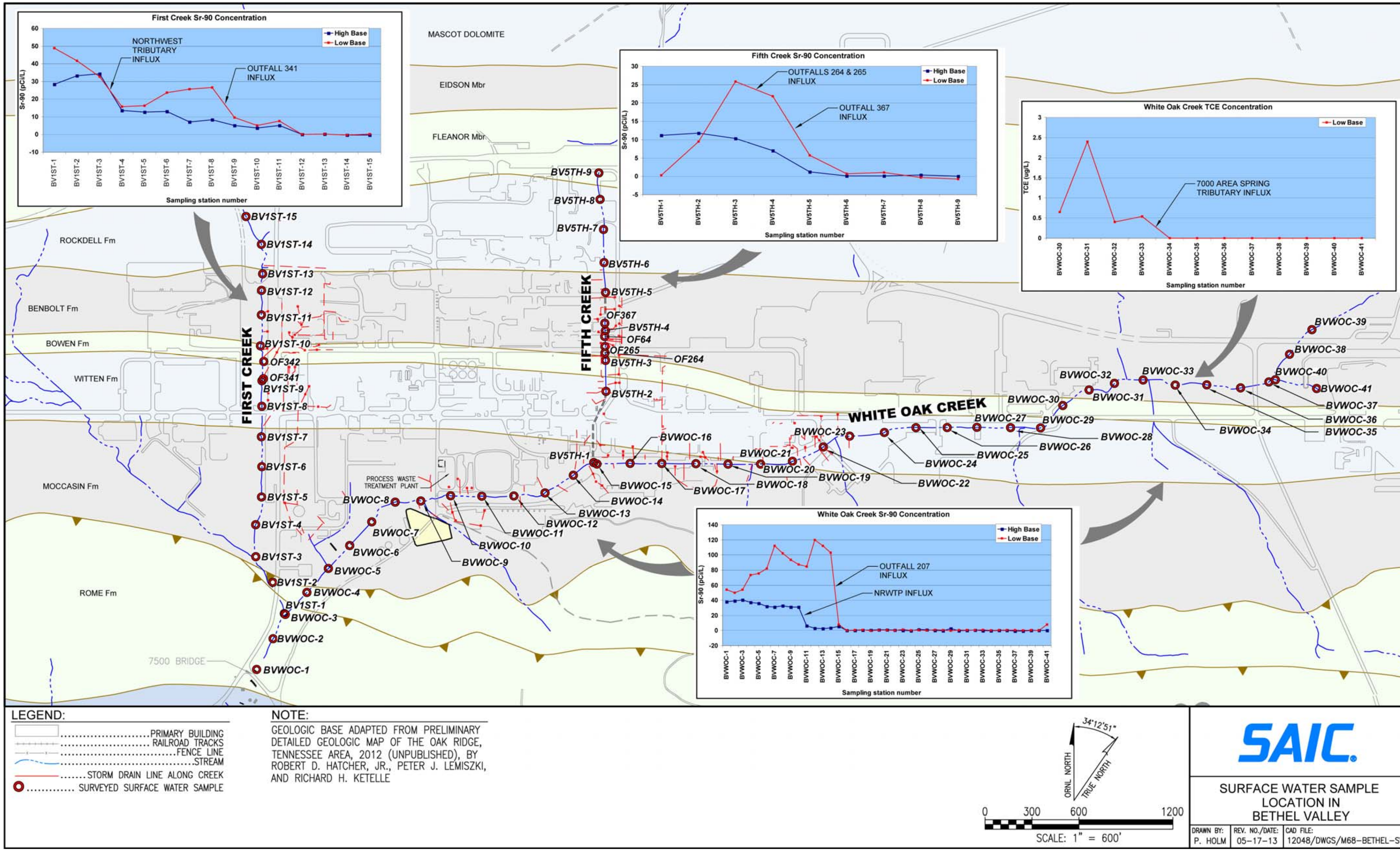
Groundwater risks presented in the RI for a hypothetical residential scenario are as high as 3.3×10^{-2} primarily because of ^{90}Sr. Industrial worker risk from the RI for surface water in First Creek exceeded 1.0×10^{-4} because of ^{90}Sr (however, this was calculated before remedial actions for the Corehole 8 Plume; see Fig. F.12 for recent surface water evaluation). Ecological risk for the Central BV 2000 Area indicates potential adverse effects on aquatic organisms in WOC and First Creek from exposures to surface water and sediment.

The *Record of Decision for Interim Actions in Bethel Valley* (DOE 2002) stipulated remedial action objectives (RAOs) for BV based on future end use, including controlled industrial use (the main ORNL plant area); unrestricted industrial use (the other currently developed areas); a recreational use area (buried waste disposal areas); and unrestricted use areas (including West BV/Raccoon Creek and portions of the Bearden Creek drainage to the east); and protection of surface water, protection of groundwater, and protection of ecological receptors (Table F.3). RAOs in Table F.3 are supported by ongoing monitoring and are discussed in detail in subsequent sections.

Table F.3. Remedial action objectives for Bethel Valley[a]

Issue	Protection goals
Future end use	Protect human health for: (1) controlled industrial use in ORNL's main plant area, (2) unrestricted industrial use in the remainder of the ORNL developed areas, (3) recreational use of SWSA 3 and the Contractor's Landfill, and (4) unrestricted use in the undeveloped areas, all to a risk level of 1×10^{-4}.
Protection of surface water bodies	Achieve AWQC for designated stream uses in all waters of the state. Achieve at least 45% risk reduction at the 7500 Bridge. Maintain surface water and achieve sediment recreational risk-based limits to a goal of 1×10^{-4}.
Groundwater protection	Minimize further impacts to groundwater. Prevent groundwater from causing surface water exceedances in all waters of the state.
Protection of ecological receptors	Maintain protection for area populations of terrestrial organisms; protect reach-level populations of aquatic organisms.

[a] *Record of Decision for Interim Actions at Bethel Valley* (DOE 2002).
AWQC = ambient water quality criteria.
ORNL = Oak Ridge National Laboratory.
SWSA = solid waste storage area.



Source: adapted from DOE 2005

Fig. F.10. Bethel Valley Groundwater Engineering Study surface water sampling stations and graphs of ^{90}Sr and TCE contamination in BV surface water.

Figure F.11 shows the groundwater and surface water monitoring network in BV, including exit point locations for each of the surface water watersheds (DOE 2013).

The first exit point monitoring location is the 7500 Bridge, which is the Bethel Valley Watershed integration point and the point at which surface water exits BV and enters Melton Valley (MV). The 45% risk reduction objective at the 7500 Bridge is tied to the MV Watershed Record of Decision (ROD) [DOE 2000] goal of protecting an off-site resident user of surface water at the confluence of WOC with the Clinch River.

Figure F.12 and Table F.4 show changes in contaminant mass flux at the 7500 Bridge over time. Although the average ^{90}Sr activity at the 7500 Bridge increased slightly during fiscal year (FY) 2010, the mass flux of ^{90}Sr discharged remained stable at 0.33 curies (Ci) due to the lower rainfall in 2010. During FY 2010, ungauged ^{90}Sr sources contributed about 5% of the total in comparison to the approximate 40% that originated from Corehole 8 Plume discharges to First Creek.

The second exit point location is Raccoon Creek Weir. Table F.5 shows an update of ^{90}Sr concentrations and mass flux at Raccoon Creek. There is no ROD goal specified for this location. The Raccoon Creek Weir will be a significant monitoring point for the upcoming RERs and the 2016 Five-Year Review (FYR) since it tracks releases from SWSA 3, which has recently completed American Recovery and Reinvestment Act of 2009 (ARRA)-funded remediation. Based on the available groundwater analytical data, ^{90}Sr, which is the principal groundwater contaminant at SWSA 3, shows decreasing to stable or no trend activity behavior where it is detected in groundwater at levels greater than the drinking water maximum contaminant level (MCL). Wells 4645, 4646, and 4647 that were installed to monitor groundwater in the Raccoon Creek headwater (see Fig. F.11) did not contain contaminants above drinking water criteria. Strontium-90 is consistently detected in the shallowest of those wells at levels less than the MCL of 8 pCi/L.

A third location for monitoring exit point releases is Bearden Creek, downstream of the 7000 Area in East BV (Fig. F.11). Of 23 results obtained since the mid-1990s, 12 results contained detectable concentrations of tritium, likely coming from the former tritium handling facility at Bldg. 7025. Wells nearby to Bldg. 7025 include Wells 1198 and 1199. Well 1198 is a shallow well, screened from about 28 to 43 ft below ground surface (bgs) and Well 1199 is a deeper well screened from about 53 to 73 ft bgs. Tritium concentrations in these wells have decreased steadily since the inception of monitoring in 1991 when peak tritium activities of about 8000 picocuries per liter (pCi/L) were measured in Well 1199 and about 15,000 pCi/L in Well 1198. During FY 2012, tritium was detected in Well 1198 in January at 384 pCi/L but was not detected in September. In Well 1199, tritium activity was measured at 1179 pCi/L in January and 1330 pCi/L in September. VOCs have occasionally been detected in Well 1199.

Section F.2 provides further discussion of data gaps and uncertainties in BV.

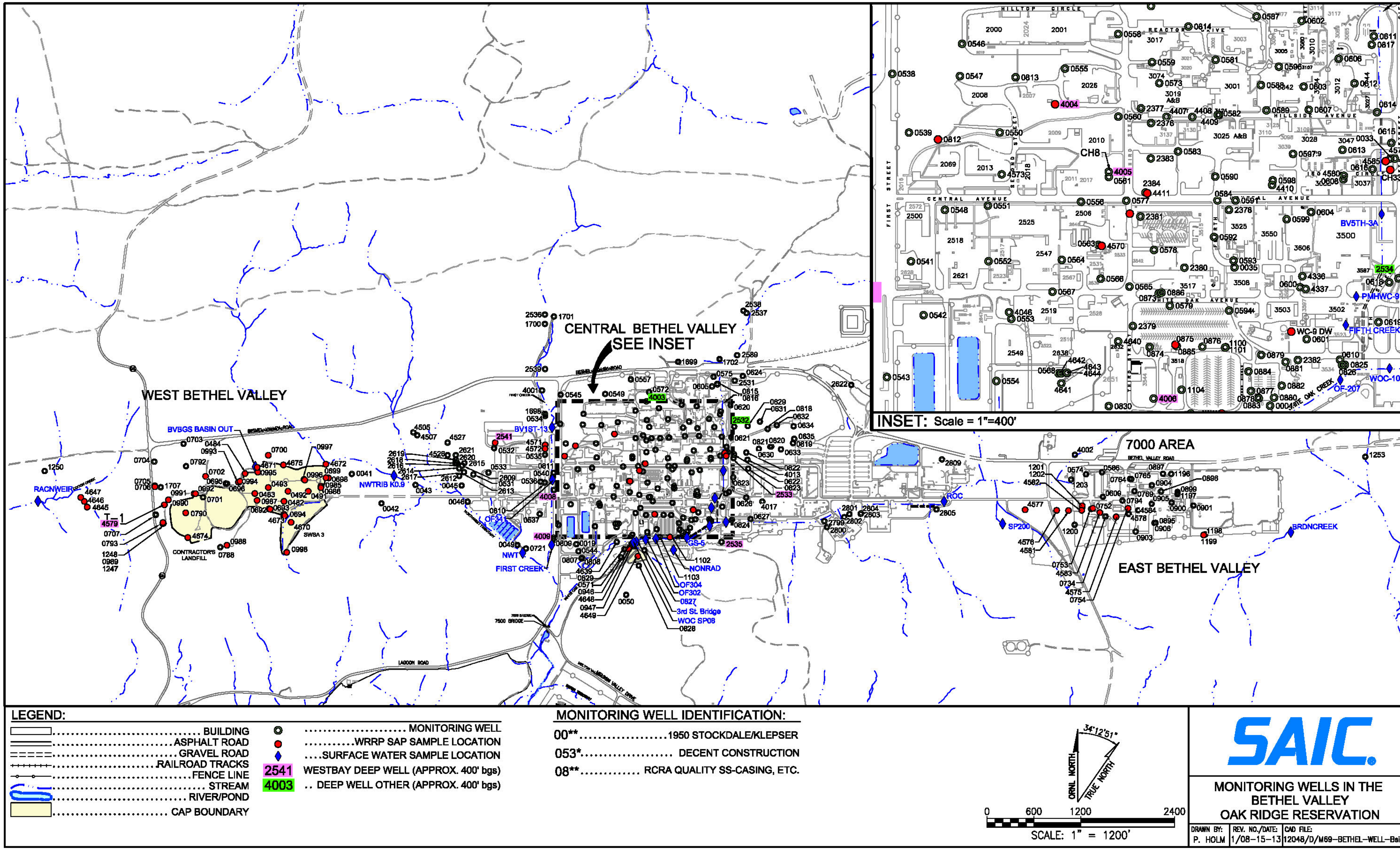
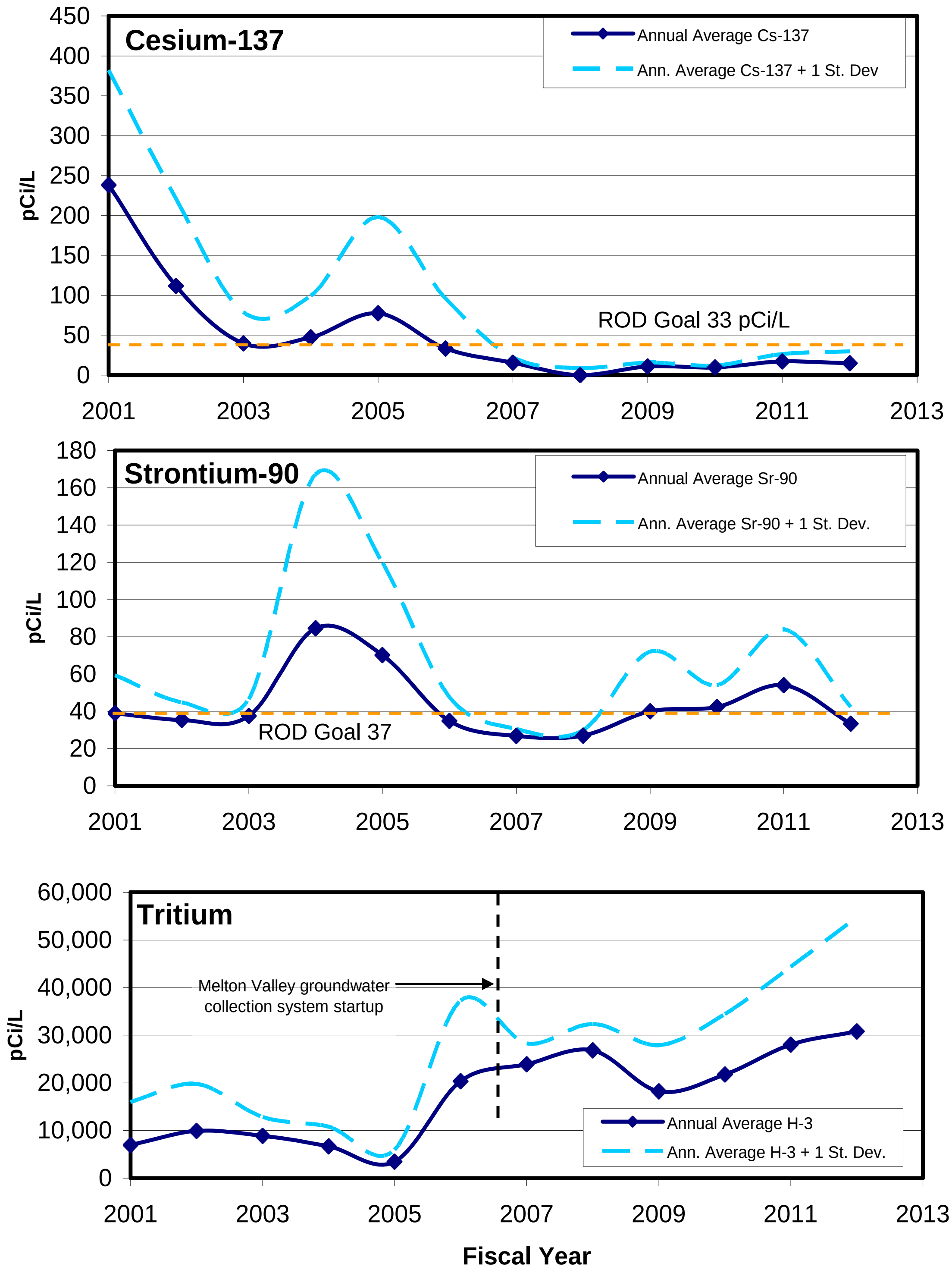


Fig. F.11. Groundwater and surface water monitoring network in Bethel Valley.



Source: DOE 2013

Fig. F.12. Annual average activities of ^{137}Cs, ^{90}Sr, and tritium (^{3}H) at the 7500 Bridge.

Table F.4. Changes in contaminant flux at the 7500 Bridge
1993 to 2010 (*Baseline Monitoring 1993 – 2006)*

Year	^{3}H Flux (Ci)	% Change[a]	^{90}Sr Flux (Ci)	% Change[a]	^{137}Cs Flux (Ci)	% Change[a]
CY 1993	58	--	0.61	--	0.99	--
CY 1994	81	40%	0.75	23%	0.66	-33%
CY 1995	70	-14%	0.45	-40%	NA	NA
FY 1996	NA	NA	NA	NA	NA	NA
FY 1997	NA	NA	NA	NA	NA	NA
FY 1998	48	-31%	0.22	-51%	NA	NA
FY 1999	31	-35%	0.19	-14%	0.34	-48%
FY 2000	81	161%	0.15	-21%	0.98	188%
FY 2001	27	-67%	0.22	47%	1.4	43%
FY 2002	61	126%	0.25	14%	0.74	-47%
FY 2003	96	57%	0.41	64%	0.43	-42%
FY 2004	60	-38%	0.64	56%	0.37	-14%
FY 2005	27	-55%	0.69	8%	0.82	122%
FY 2006	88	226%	0.20	-71%	0.15	-82%
FY 2007	122	39%	0.14	-30%	0.08	-47%
FY 2008	141	16%	0.15	7%	0.006	-93%
FY 2009	133	-6%	0.33	120%	0.083	1283%
Five-year review assessment[b]						
FY 2010	142	426%	0.33	-52%	0.089	-89%

Source: DOE 2012b.
[a] Percent change from previous year.
[b] Percent change from previous Five-Year Review (2010 vs. 2005).
Ci = curie.
CY = calendar year.
FY = fiscal year.
NA = not applicable.

Table F.5. Strontium-90 data from Raccoon Creek Weir

Year	Detection frequency and maximum value [No. detects/ No. samples] (Maximum pCi/L)	Flow volume for months with detected ^{90}Sr (L)	Average detected ^{90}Sr (pCi/L)	^{90}Sr flux (Ci)
FY 1999 Total	8 / 12 55.9	84,336,484	20.9[a]	3.7E-04
FY 2001 (11 months)	7 / 11 8.15	6,6011,324	5.2[a]	3.10E-04
FY 2002	7 / 12 25.1	3,0153,673	13.2[a]	9.35E-04
FY 2003 (11 months)	10 / 12 17.9	241,405,801	6.4[a]	9.8E-04
FY 2004	12 / 12 26.9	254,130,320	9.6[a]	1.68E-03
FY 2005	12 / 12 64.8	--[b]	16.8[a]	--
FY 2006	12 / 12 77.2	--[b]	29.3[a]	--
FY 2007 (Feb. – Sept.)	6 / 8 32.4	86,992,200[c]	12.7[a]	1.1E-03
FY 2008	12 / 12 59.6	117,209,419	15.5[a]	6.4E-04
FY 2009	8 / 12 35.6	150,003,288	10.7[a]	6.2E-04
FY 2010	5 / 12 18.4	20,509,344	11.5[a]	1.9E-04
FY 2011	11 / 12 18.3	277,034,731	5.2	6.4E-04
FY 2012	8 / 12 9.05	146,306,405	4.0	4.3E-04

Source: DOE 2013.

[a] Activity value represents average activity for all monthly flow composite samples with detected ^{90}Sr.

[b] The fiscal year (FY) 2005 and 2006 flow and flux data are not reported as the data have been deemed unusable due to problems associated with the weir.

[c] Station was returned to full operation at the end of January 2007. Reported flows and fluxes are calculated for the months when flow was present after station maintenance.

Ci = curie.
FY = fiscal year.
L = liter.
NA= not applicable.
pCi/L = picocuries per liter.

F.2. CONCEPTUAL MODEL, SOURCE AREA SCALE

F.2.1 BV-1 MAIN PLANT AREA WIDESPREAD SHALLOW ^{90}SR, ^{3}H, AND MERCURY

The BV main plant source area consists of the old portion of X-10 within the Central BV area (see Figs. F.3 and F.4). For the BVGWES (DOE 2005), the central portion of BV (2000 and 3000 Areas) was described as four separate quadrants (1 through 4). Figure F.13 presents the four study quadrants in the central plant area as delineated by the BVGWES. Within these quadrants there are some distinct plume signatures, like the Corehole 8 Plume and the Corehole 33 Plume; however, much of the ^{90}Sr and ^{3}H contamination is from former tank and pipe leaks and spills and has become comingled over time.

- Central/East BV contains more than 17,000 linear meters (56,000 linear ft) of inactive pipelines constructed of various materials (vitrified clay, steel, etc.) with diameters of up to 15 cm (6 in.). Most (90%) of these pipelines were used to transfer waste from the research facilities (liquid low-level waste [LLLW] pipelines) to the tanks, impoundments, and/or treatment facilities. The remainder (process waste pipelines) transported lightly contaminated wastewater.

- Pipelines and their trenches and backfill represent a potential flow pathway for contaminated groundwater. Associated with the underground pipelines are a number of pump pits, valve boxes, manholes, manways, vaults, dry wells, and other subsurface structures used to house, control, or monitor utilities. Groundwater collected by these features either discharges directly to surface water (as with storm drains and some sumps) or is collected and routed to ORNL water treatment facilities.

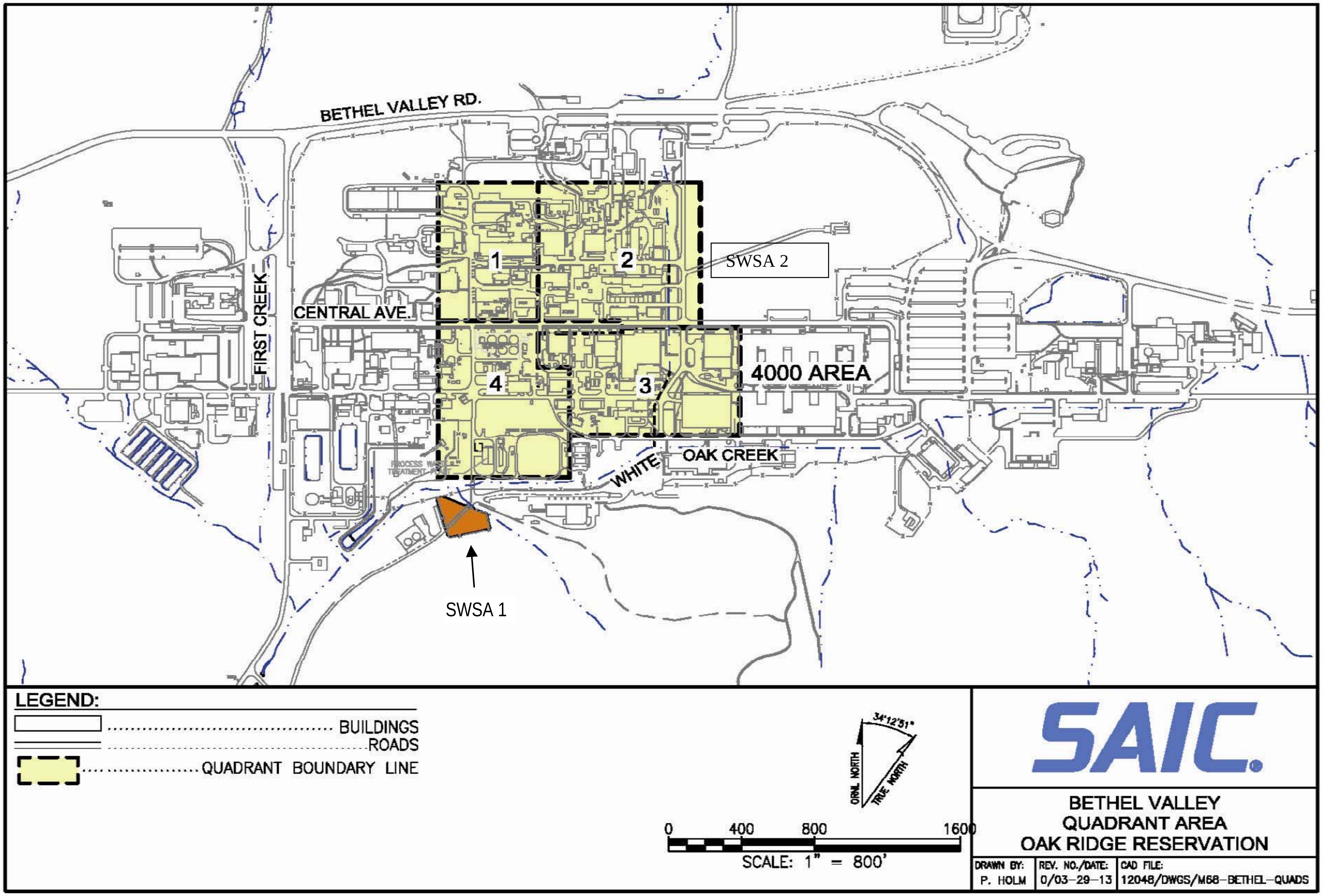
- The main plant source area of the BV watershed is drained by WOC with First Creek (Quadrants 1 and 4) and Fifth Creek (Quadrants 2 and 3) as major tributaries. WOC continues out of BV and into MV, before entering White Oak Lake prior to discharging over White Oak Dam to the White Oak Creek Embayment and then into the Clinch River. The 7500 Bridge is established as the monitoring point, or point of integration, for contaminants leaving BV via WOC.

- The BVGWES installed numerous Geoprobe® samples throughout the central valley in an attempt to identify sources of direct industrial risk and groundwater contaminant sources.

Figures F.14 and F.15 present both north–south and east–west cross-sections in the 2000 Area and 3000 Area of the central plant area that are dominated by the Corehole 8 Plume. Shallow ^{90}Sr-contaminated groundwater exists over much of the soils/formations in the 3000 Area, including the reach from Bldg. 3019 south through the North and South Tank Farms to WOC.

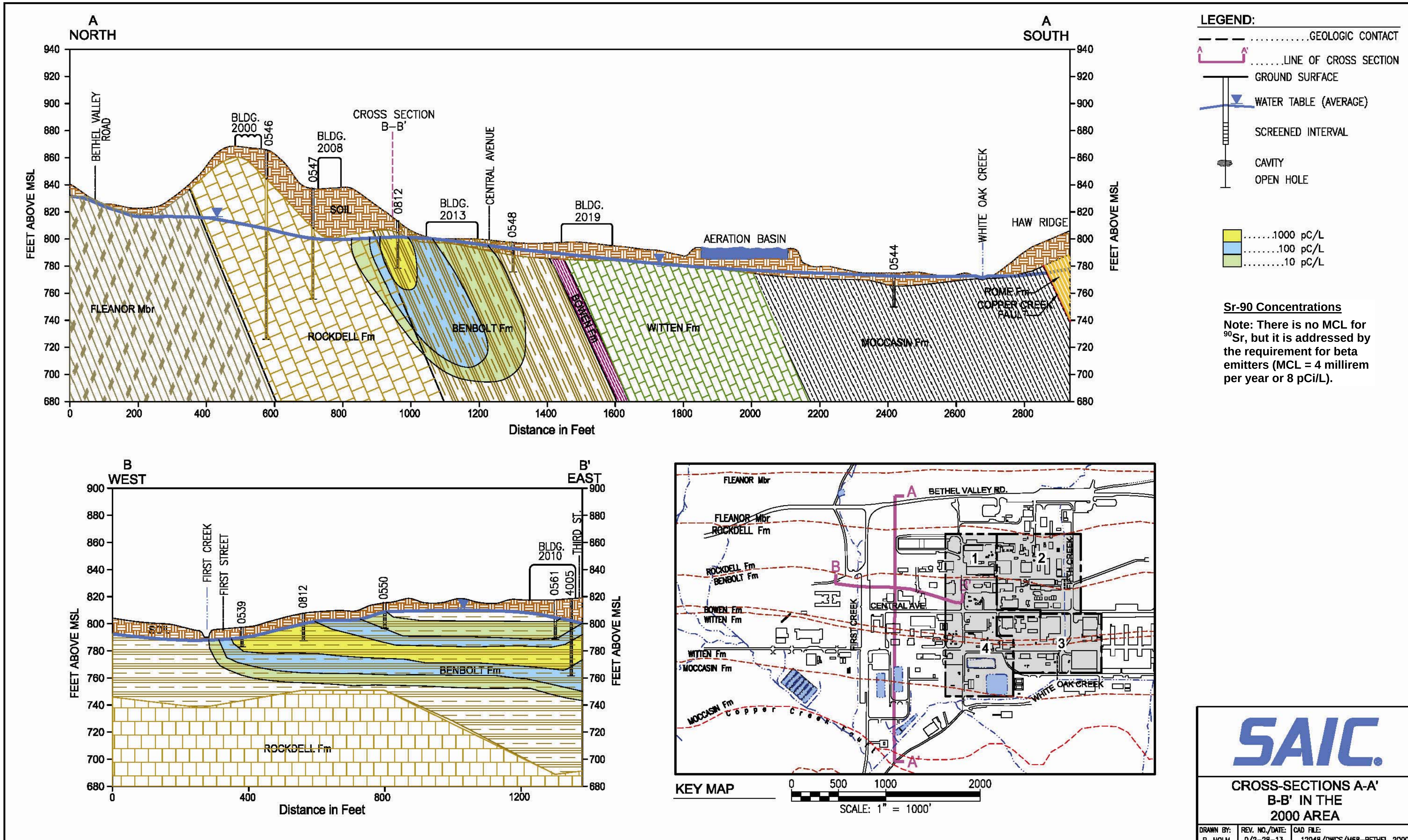
BV-1a Quadrant 1

As shown on Fig. F.15, Quadrant 1 includes the primary radiochemical processing facility (Bldg. 3019) and waste management facilities (the North Tank Farm). As described below, geologic and hydrogeologic conditions of Bldg. 3019 on the hill differ greatly from those in the Tank Farm. The primary contaminant release mechanisms throughout Quadrant 1 are LLLW and process waste transfer pipeline leaks. The primary groundwater plume in Quadrant 1 is the Corehole 8 Plume source discussed under plume BV-3 (the major plume identified in Fig. F.14). However, there are additional known and suspect sources of groundwater contamination. Areas of concern include the “Hot Bank” Area (vicinity of Bldg. 3019), Isotopes Area, and North Tank Farm. Specific known areas of soil contamination that could



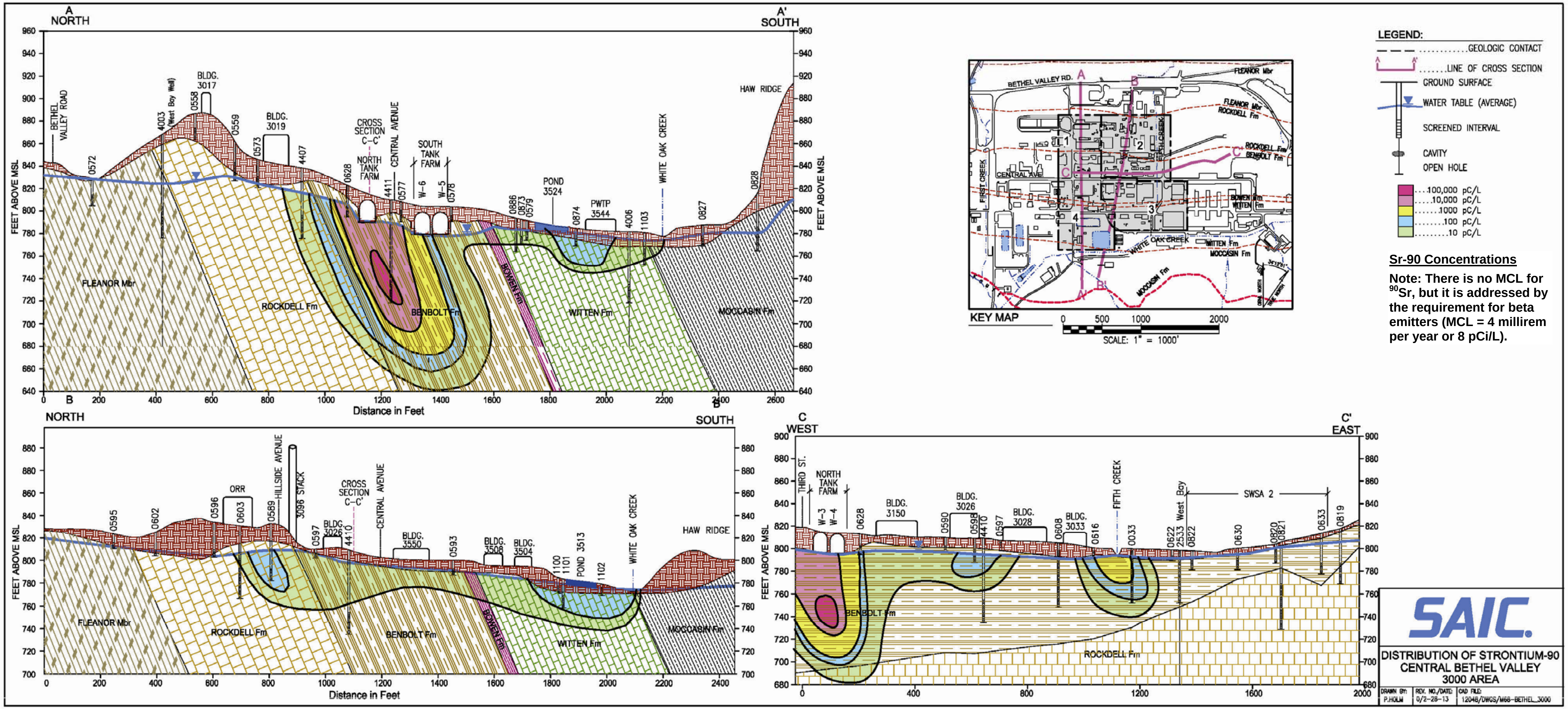
Source: DOE 2005

Fig. F.13. Location of study quadrants in the BVGWES.



Source: DOE 1999a

Fig. F.14. Stratigraphic cross-sections of Main Plant, 2000 Area showing distribution of ^{90}Sr.



Source: DOE 1999a

Fig. F.15. Stratigraphic cross-sections of Main Plant, 3000 Area showing distribution of ^{90}Sr.

contribute to groundwater contamination include the pipeline chase north of (former) Tank W-1A and in the pipelines and soils surrounding Bldg. 3019.

BV-1b Quadrant 2

Quadrant 2 encompasses the bulk of the former radioisotope production and distribution facilities at ORNL. There is an extensive, documented history of releases in addition to any number of anecdotal accounts of releases from spills and pipeline leaks.

Geologic and hydrologic conditions in Quadrant 2 are the same as those in Quadrant 1, with the exception that shallow groundwater flow is primarily to First Creek in Quadrant 1 and to Fifth Creek in Quadrant 2. From roughly Hillside Avenue north, bedrock consists of the Rockdell Formation with its thick, clayey residual soil; karst features; and deep water table surface. The Benbolt formation underlies the area south of Hillside Avenue where the water table surface roughly coincides with the soil/bedrock interface, which becomes shallower approaching Fifth Creek.

The major contamination in Quadrant 2 is a ^{90}Sr plume referred to as the Corehole 33 Plume (Table F.6 and Fig. F.15, left-middle portion of cross-section C-C'). The source of the Corehole 33 Plume is likely an unknown area(s) in the Isotopes Area. Contaminant concentrations in the Corehole 33 Plume appear to be in decline. The BVGWES study did not identify any specific soil source areas associated with this contamination, but as indicated by the cross-section, these sources may be under buildings, which were not accessed during the BVGWES.

Table F.6. Summary results for indicator radiochemical parameters in Corehole 33 Plume monitoring wells

	High-base conditions			Low-base conditions		
Well number	Gross alpha (pCi/L)	Gross beta (pCi/L)	^{90}Sr (pCi/L)	Gross alpha (pCi/L)	Gross beta (pCi/L)	^{90}Sr (pCi/L)
4574	Not detected	34.6	7.75	Not detected	11.7	17.4
4585	389	22,000	4,480	85.3	12,200	6,160
4580	Not detected	56.3	1.6	1.61	42.6	Not detected
622	Not detected	38.5	6.62	Not detected	19.4	5.4

Source: DOE 2005.
pCi/L = picocuries per liter.

BV-1c Quadrant 3

Quadrant 3 contains research and support facilities and underground storage tank facilities. Activities in many of the facilities varied over the years as ORNL's mission evolved. Large volumes of mercury were used in several of the research facilities, and reports of mercury spills, some of them large, are well documented.

Bedrock consists of the lower portion of the Benbolt, the Bowen, and the Witten Formations. The Bowen is a thin, maroon, calcareous siltstone, which forms a subdued topographic high throughout the valley, while the Witten is a variably clean limestone with carbonate-rich silt lenses and stringers throughout. While not well demonstrated, the Bowen is suspected of acting as a barrier to shallow and possibly deep groundwater flow, while minor cavities in the Witten add a dimension of karst flow. In all cases, shallow groundwater flow directions are altered locally by underground pipelines and building sumps.

- The BVGWES did not identify containment sources to groundwater in Quadrant 3; however, as indicated in Fig. F.15, there is elevated contamination along cross-section B-B' in Quadrant 3 downgradient of Bldg. 3504.

- Mercury-contaminated soil from undisturbed areas around Bldg. 4501 (pre-design study area [PDSA] 5) was not found at concentrations approaching the trigger level or that could account for the mercury-contaminated groundwater being removed by sump pumps from the basement of Bldg. 4501 (where mercury lithium isotope process pilot operations occurred). Releases from Bldg. 4501 are a known source of mercury discharge to Fifth Creek.

- This quadrant includes the area surrounding the WC-10 Tank Farm. A sump pump (currently shut down) within the tank farm excavation historically contained extraordinarily high levels of ^{90}Sr and ^{137}Cs contamination. In contrast, results from Geoprobe® installations from just outside of the excavation indicate that contamination does not extend beyond the tank farm excavation. The bulk, if not essentially all, of the water removed from the tank excavation during operation of the sump pump was believed to be derived from Fifth Creek, and the contamination is believed to be coming from the tanks or an unknown source from outside of the tank farm.

- Investigations in 1990 to 1991 indicated ^{90}Sr and ^{137}Cs in soils in the WC-9 Tank Farm area. The tank farm excavation has a sump pump in the northeast corner that runs continuously to suppress the water table around the tanks.

BV-1d Quadrant 4

Quadrant 4 contains the bulk of the LLLW and process waste management areas, including underground tanks, former surface impoundments, the Process Waste Treatment Plant (PWTP) [Bldg. 3544], the LLLW evaporator, and the pipelines that serve them. Several buildings formerly used in radioactive materials processing are also in Quadrant 4.

Bedrock and hydrologic conditions in Quadrant 4 are the same as those in Quadrant 3. An extensive array of underground pipelines is believed to alter shallow groundwater movement to an unknown, but possibly large, extent.

Contaminant release mechanisms are almost exclusively from leaks in the underground waste transfer and storage system. Many of the tanks have dry wells or sump pumps that discharge to the PWTP. Closure of the surface impoundments and grouting of the Gunite tanks in the South Tank Farm were major strides in reducing risk in the quadrant.

Review of Fig. F.15 suggests the following:

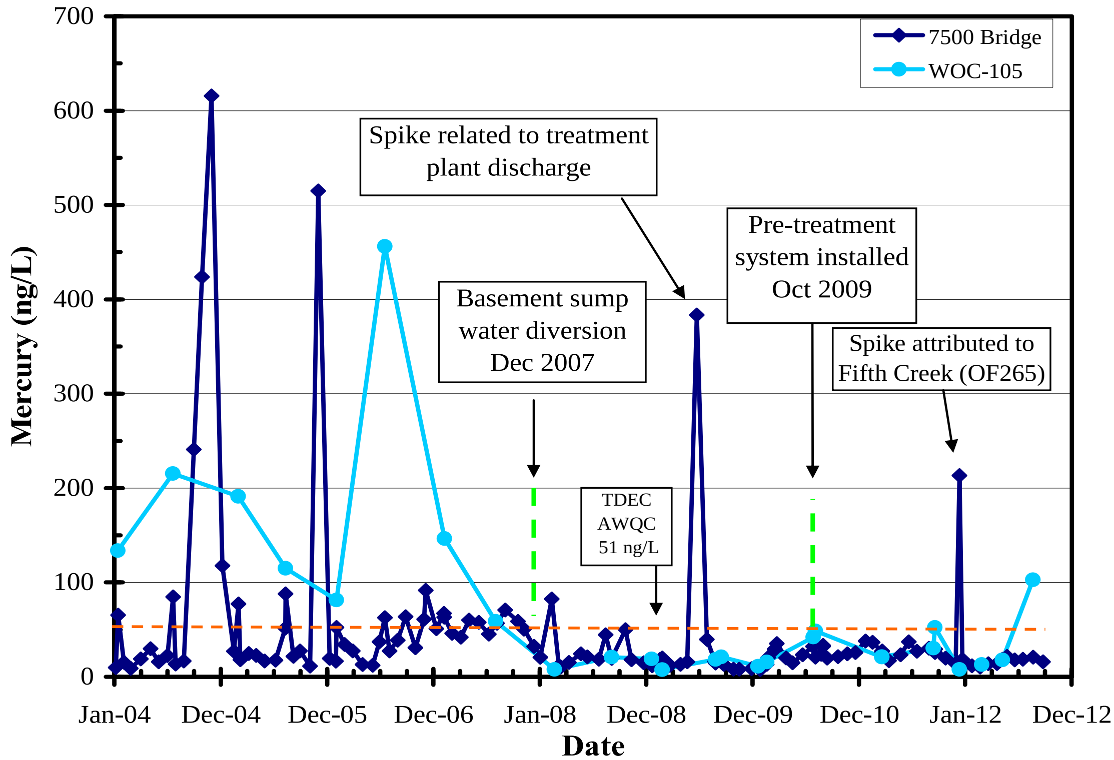
- Based on cross-section B-B', there is contamination in the groundwater starting at Central Avenue and extending the southern-most extent of BV (WOC).

- There is elevated radioactivity under the former surface impoundments and the PWTP. There are few data to evaluate the current status (post-surface impoundment remediation) of this situation.

BV-1e 4000 Area

The Central BV 4000 Area includes several ORNL research areas and the site of SWSA 2 (Fig. F.13) that was excavated and moved to SWSA 3 in the 1940s. The research areas in Central BV 4000 include contaminated hot cells and several areas of mercury contamination. An unknown source or sources of

mercury from the western side of Fifth Street contribute to the discharge from Outfall 265. Figure F.16 shows the mercury concentration history for the WOC-105 and 7500 Bridge locations.



Source: DOE 2013

Fig. F.16. Mercury concentration history at the 7500 Bridge and White Oak Creek-105 monitoring locations.

Figure F.17 presents a conceptual model for the Central BV 4000 Area. Mercury-contaminated groundwater from four building sumps [3592, 3503, 4508 (not shown on Fig. F.17), and 4501] and mercury in Fifth Creek sediments is targeted for treatment. Activities related to mercury remediation include:

- In December 2007, mercury-contaminated basement sump water at Bldg. 4501 was rerouted to the Process Water Treatment Complex (PWTC).

- In October 2009, the Bldg. 4501 sump system was completed with the installation of an ion exchange system to remove mercury. In 2011, sampling showed that more than 40% of the mercury in Fifth Creek originated from the Outfall 265 (located west of Bldg. 4501) source area. The Outfall 265 source is suspected to have caused the high mercury concentration measured in December 2012, and an elevated mercury level (213 nanograms per liter [ng/L]) was measured at the 7500 Bridge sampling location on the same date.

The groundwater and surface water COCs in the 4000 Area are listed in the RI and include:

- Groundwater: ^{90}Sr, ^{3}H, mercury, ^{228}Ra, and Sb (antimony).

Table F.7 summarizes the characteristics and major uncertainties related to the groundwater plumes in the main plant area.

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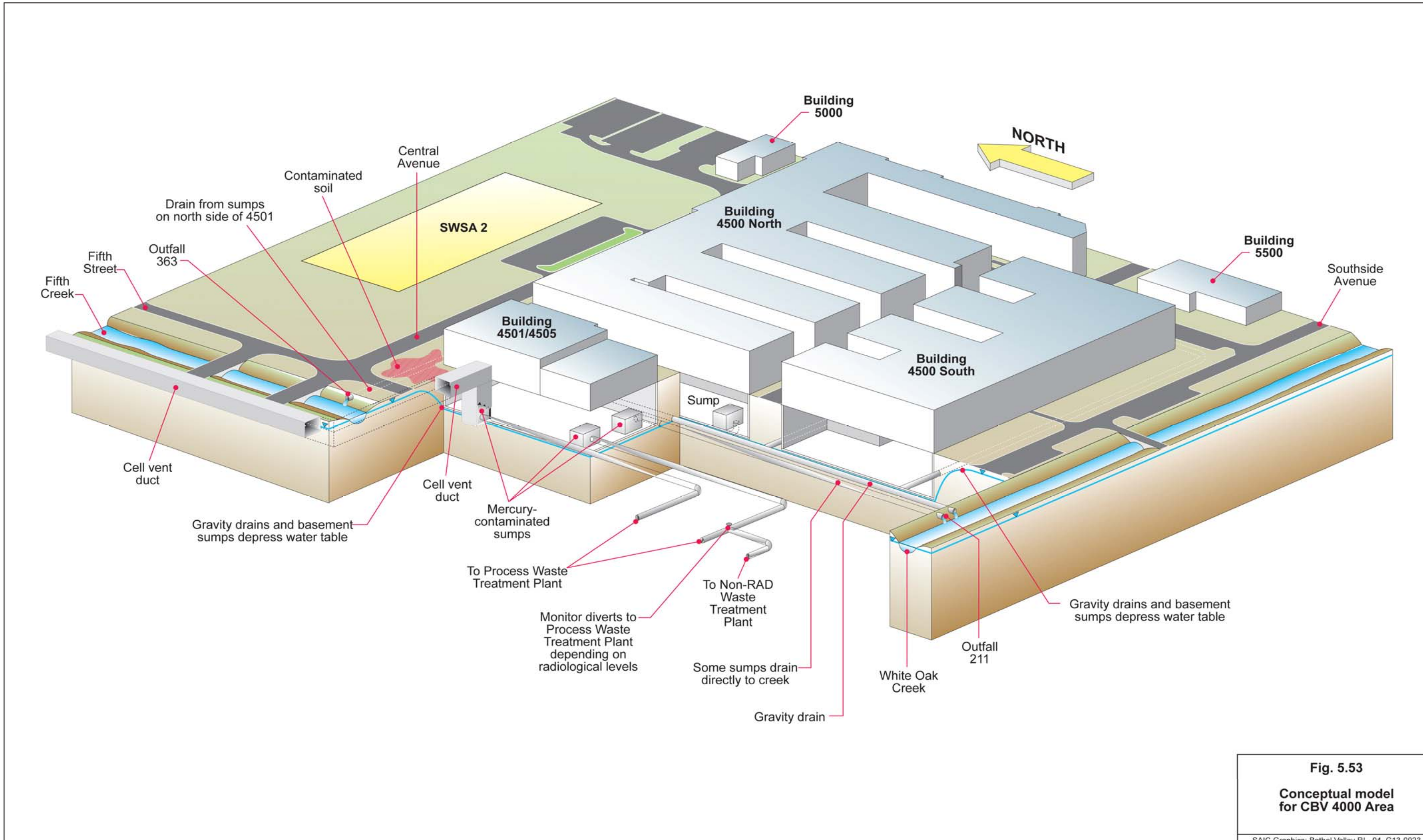

Source: DOE 1999a

Fig. F.17. Conceptual model of Main Plant, 4000 Area.

Table F.7. Main plant source area groundwater plumes

Plume No.	Name	Description: Length[a] (ft down valley)	Description: Depth[a] (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
BV-1 (a–e)	Shallow/deep contamination ^{90}Sr in Benbolt, shallow ^{3}H and mercury contamination in Bowen, Witten, and Moccasin Fm.	Variable; up to 2,500 × 2,000 for ^{90}Sr; 1,200 × 500 for ^{3}H; and localized for Hg	200	Sr-90: 10 – 100,000 pCi/L; H-3: >100,000 Mercury: uncertain	Along-strike flow in formations; ^{3}H and mercury primarily on east side of the main plant area	White Oak Creek at 7500 Bridge	• Investigations have not been able to delineate contamination around and under active facilities to determine if groundwater plumes have active and continuing sources around infrastructure, piping, appurtenances, etc., or if one-time spills or former operations were responsible • Depth of some contamination is unknown • Full list of COCs is uncertain • Distribution of mercury contamination is poorly defined; also not listed as a primary COC in the BV RI • Nature and extent of contamination from Bldg. 3019 and other source areas on the Rockdell Formation outcrop belt in 2000 and 3000 Areas is not well understood

[a] Values are approximate based on RI plume maps.
BV = Bethel Valley.
COC = contaminant of concern.
pCi/L = picocuries per liter.
RI = remedial investigation.

F.2.2 BV-2 COREHOLE 8 PLUME

The Corehole 8 Plume (Fig. F.18a), with the exception of the Hydrofracture deep groundwater plume, is the most highly concentrated radioactive groundwater plume on the ORR. In June 1991, rock core drilling at Corehole 8 revealed radiologically contaminated groundwater in the uppermost portion of the bedrock of the Benbolt Formation. In 1994, Waste Area Grouping 1 (WAG 1) characterization work identified that contaminated groundwater seeping into the ORNL storm drain system was being discharged into First Creek at storm drain Outfall 342 via three catch basins in the western part of ORNL (Table F.8). The source was identified as contaminated soil surrounding and waste within Tank W-1A. Uncertainty regarding the extent of the plume exists, and alternate interpretations show different configurations with respect to migration of contaminant depth and interformational migration (Fig. F.18b).

Although the Corehole 8 Plume typically is referred to as a ^{90}Sr plume, this plume has a much broader contaminant profile (Table F.9). These FY 2010 data show high levels of alpha (^{233}U and ^{241}Am), beta (primarily ^{90}Sr), and ^{137}Cs (gamma) activity in the groundwater immediately surrounding Tank W-1A. Cs-137 concentrations from filtered groundwater away from the source area in Well 4411 are typically undetected.

The Corehole 8 Plume has been addressed through a series of removal action remedies, remedy updates, and additional characterization (Table F.8).

The original removal action was to intercept and remove ^{90}Sr-contaminated groundwater before it entered First Creek from the storm drains associated with Outfalls 341 and 342. Additional actions included the capture of the plume at the Corehole 8 sump and pumping from Well 4411. In 2010, an upgrade of the total system was completed to increase the total plume volume extraction and transfer capacity by adding more pumping locations and a larger diameter transfer pipe. The existing plume extraction facilities were refurbished for continued service (as needed) and to make these facilities compatible with new equipment.

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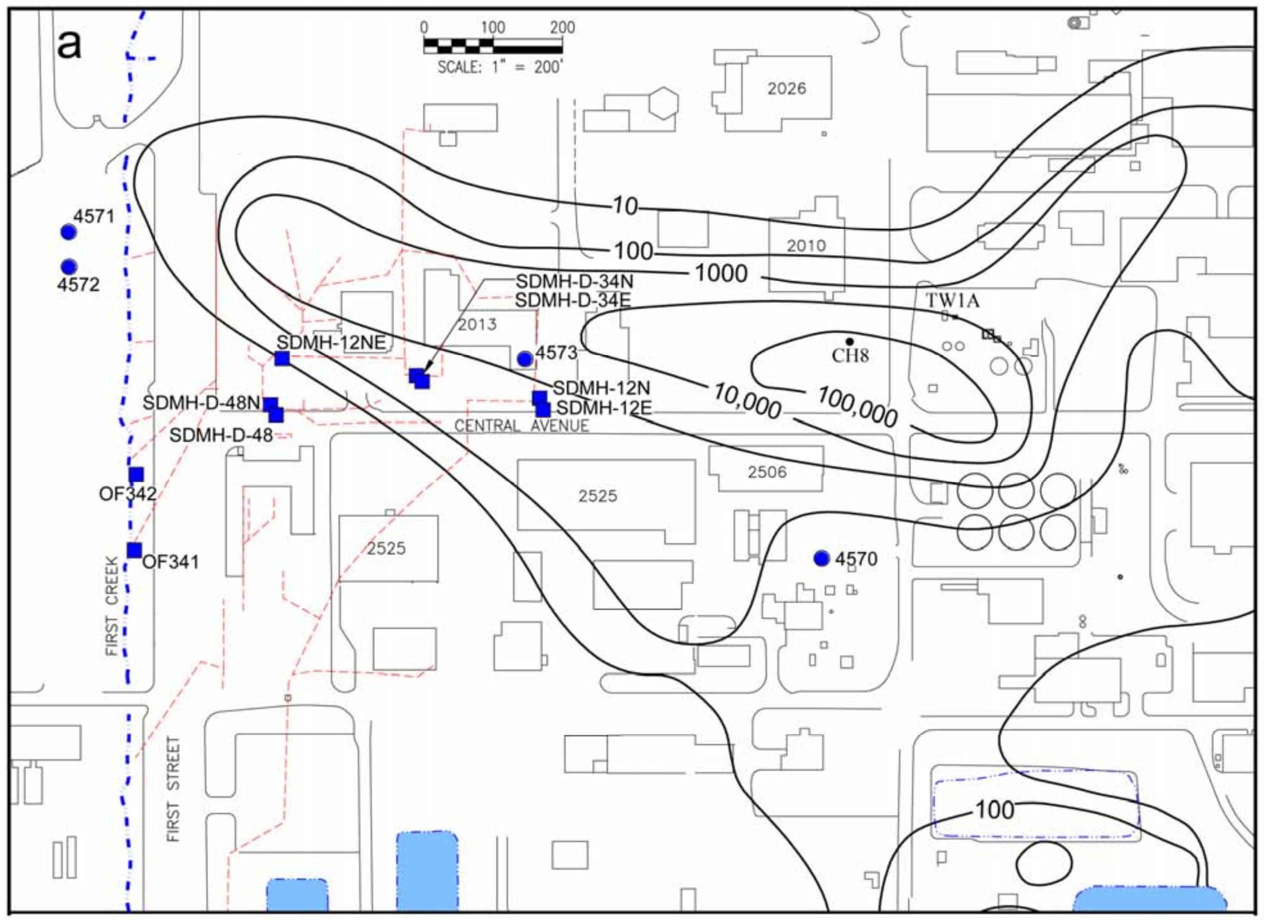


Source: DOE 2005

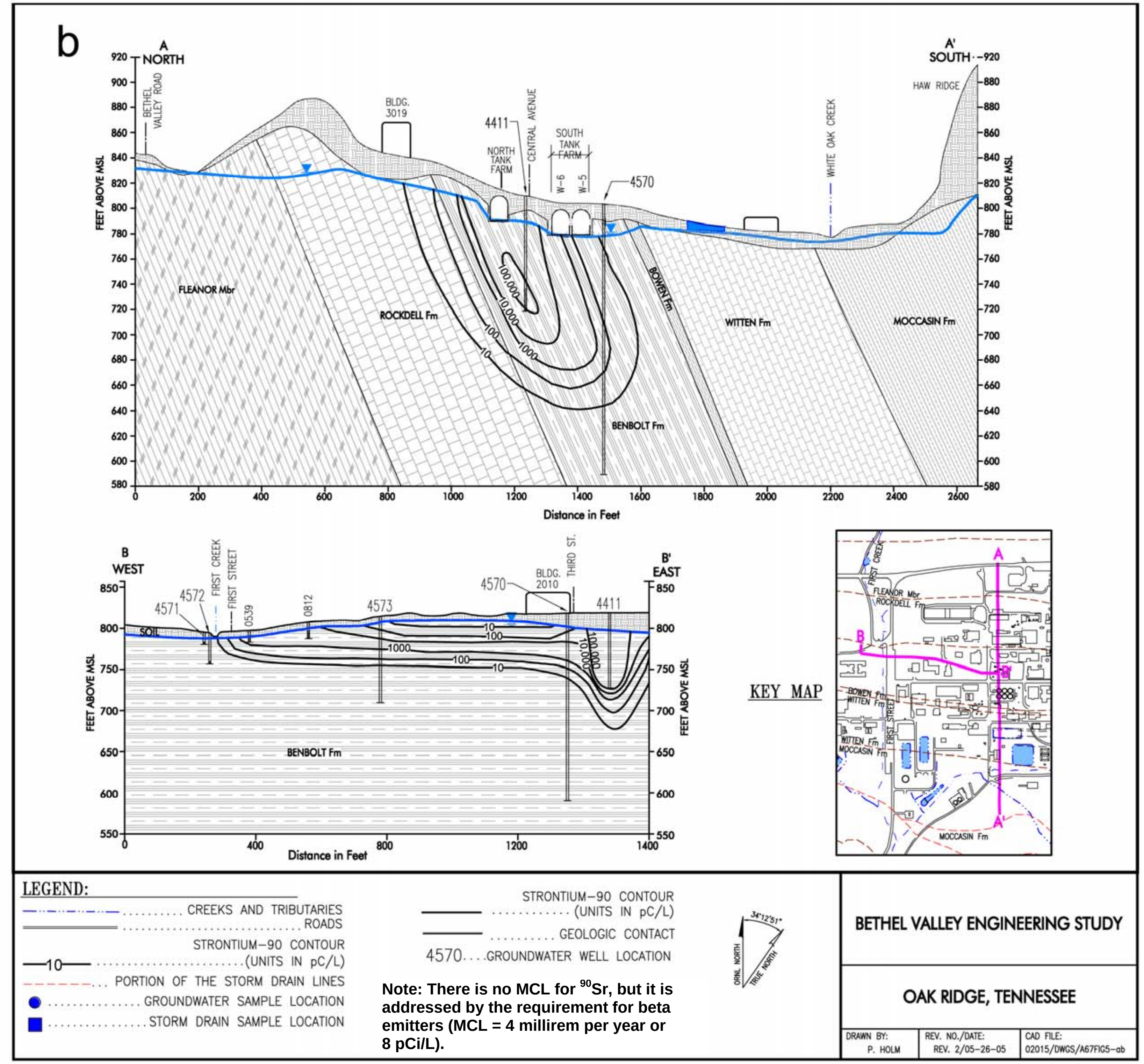
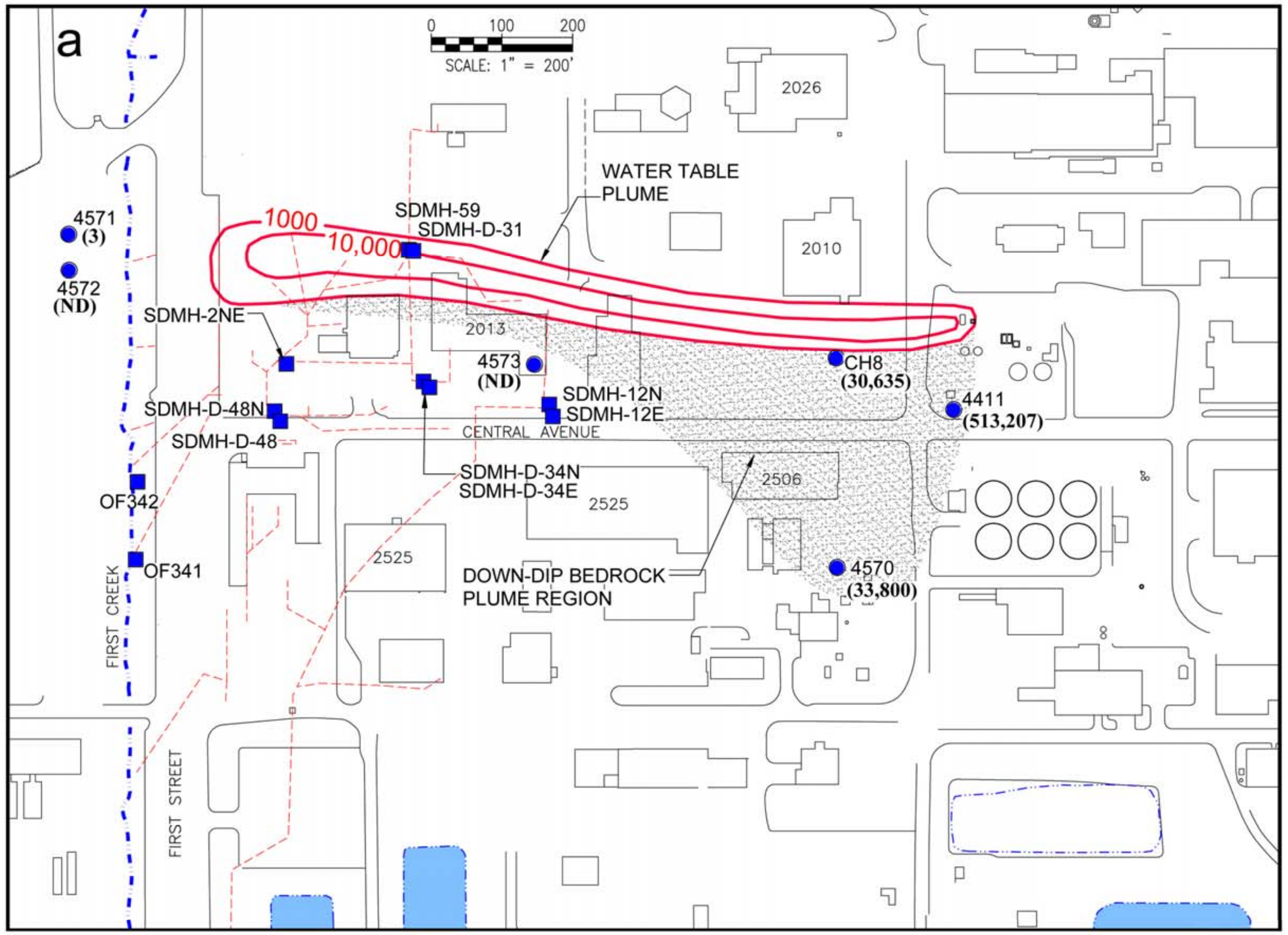


Fig. F.18a. Stratigraphic cross-sections and plume map of Corehole 8 Plume showing distribution of ^{90}Sr.



Source: DOE 2005

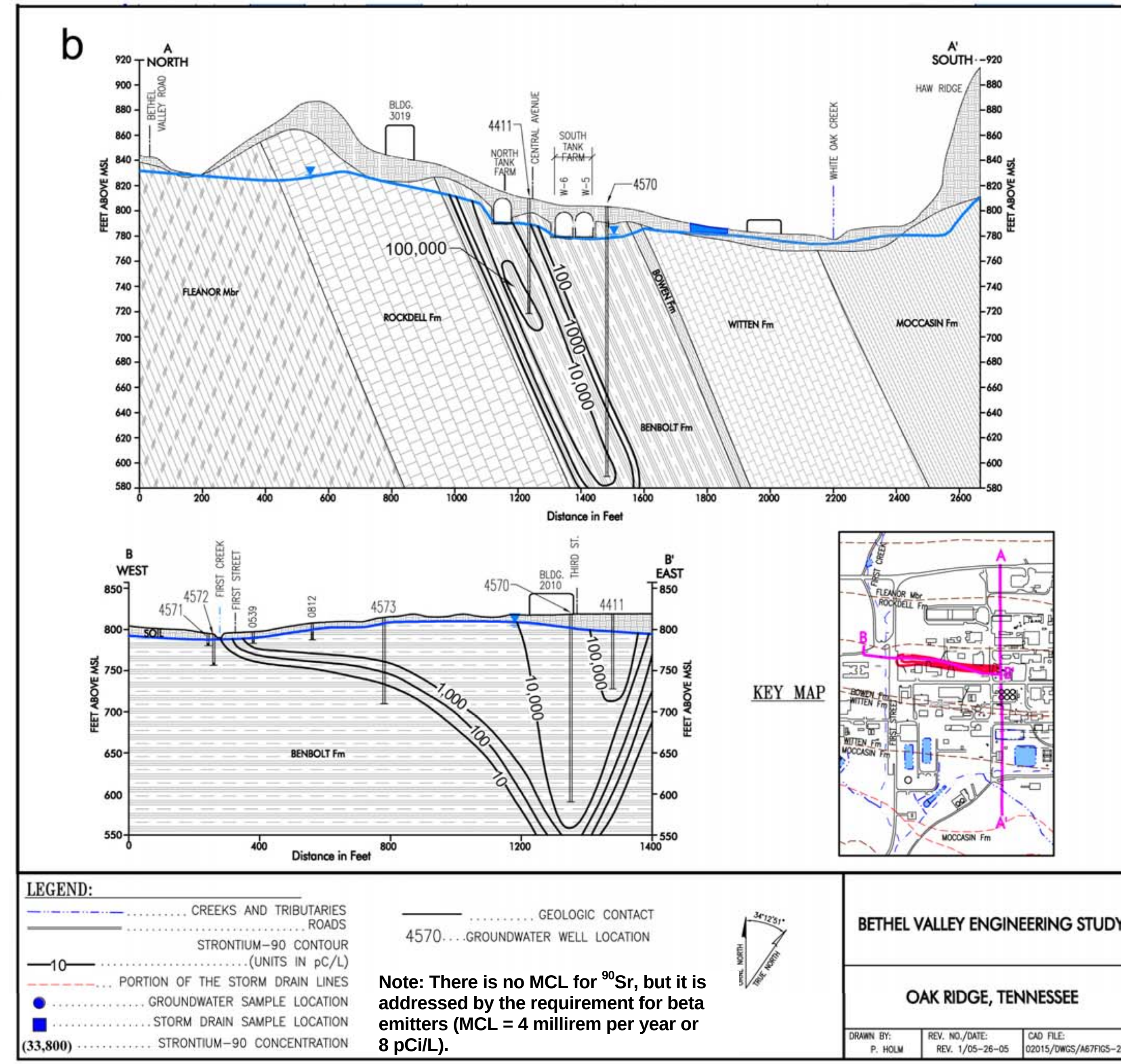


Fig. F.18b (alternate). Stratigraphic cross-sections and plume map of Corehole 8 Plume showing distribution of ^{90}Sr.

Table F.8. Chronology of events associated with the Corehole 8 Plume in BV

High levels of radioactivity detected in Corehole 8 well.	1991
CERCLA investigation finds that contaminated groundwater seeping into the ORNL storm drain system was being discharged into First Creek at storm drain Outfall 342.	1994
First Corehole 8 Plume AM approved; installation of a groundwater collection and transmission system.	November 1994
Startup of the plume collection system.	March 1995
Monitoring of surface water in First Creek identified elevated levels of ^{233}U, an isotope associated with the reactor waste placed in Tank W-1A in the North Tank Farm.	October 1997
Two unlined storm drain manholes were identified as the contaminant entry point.	December 1997
Addendum to the AM authorizes the installation of an additional groundwater interceptor trench that connects to one of the Corehole 8 Plume collection sumps.	March 1998
Second addendum to the AM authorizes additional groundwater extraction out of well 4411 and treatment at the PWTP.	September 1999
Well 4411 extraction rate adjusted when PWTP filter cake shows strontium concentrations > Envirocare WAC.	1999
Separate removal action at Tank W-1A removes three-quarters of highly contaminated soil around the tank before high radiation levels halt completion of work.	2001
BV ROD includes a requirement to perform the BVGWES, including further delineation of the Corehole 8 Plume.	2002
BVGWES and RERs indicate that contaminant fluxes entering First Creek drop markedly, indicating the soil excavation and collection systems are successfully reducing contaminant releases to surface water.	2003 – 2005
BVGWES finds the plume is present at greater depths than previously understood. The study recommends three options for addressing the plume.	2005
Additional characterization is performed at highly contaminated soils around Tank W-1A.	2005
Problems begin to occur with sump collection system due to age of the system; ^{90}Sr fluxes at 7500 Bridge begin to rise to pre-action level.	2009
DOE provides ARRA funding to the completion of the Tank W-1A source removal.	2009
The Tank W-1A project identifies additional contaminant mass in the subsurface soil located north of Tank W-1A, along the lines that fed the tank, suggesting additional source to the Corehole 8 Plume.	2009 – 2010
Mechanical issues related with the pump on well 4411 shut down the pumping system.	2010
DOE develops the *Remedial Design Report/Remedial Action Work Plan for the BV (Corehole 8) Extraction System* as an action under the BV ROD.	2010
Installation of BV ROD plume extraction wells begins.	2010
BV ROD plume extraction wells are completed.	2012

AM = Action Memorandum.
ARRA = American Recovery and Reinvestment Act of 2009.
BV = Bethel Valley.
BVGWES = BV Groundwater Engineering Study.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U. S. Department of Energy.
ORNL = Oak Ridge National Laboratory.
PWTP = Process Waste Treatment Plant.
RER = Remediation Effectiveness Report.
ROD = Record of Decision.
WAC = Waste Acceptance Criteria.

Table F.9. Results from FY 2010 for groundwater from temporary piezometers in the Tank W-1A source area

Contaminant	Result	Units	Validation qualifier	Rad error
Alpha activity	566,000 pCi/L	pCi/L	=	10,400
Beta activity	3,180,000 pCi/L	pCi/L	=	16,500
Cesium-137	3,520,000 pCi/L	pCi/L	=	107,000

pCi/L = picocuries per gram.

Data collection after the system upgrade shows that it did achieve the performance goal for reduction of ^{90}Sr discharge to First Creek as discussed below. During FY 2012, the system was non-operational from October through mid-March when the refurbished collection system was placed in operation. Table F.10 shows data prior to any actions at Corehole 8 (1994) versus data collected during FY 2012. The refurbished system was online in March 2012.

Table F.10. First Creek ^{90}Sr fluxes pre-action and in FY 2012

	Calendar year 1994 (pre-action)				Fiscal year 2012		
Month	^{90}Sr (pCi/L)	Flow volume (liters)	^{90}Sr flux (Ci)	Month	^{90}Sr (pCi/L)	Flow volume (liters)	^{90}Sr flux (Ci)
January 1994	124.4	102,893,891	0.0128	October 2011	170	31,492,642	0.0054
February 1994	95.6	126,569,038	0.0121	November 2011	96.9	173,757,586	0.0168
March 1994	89.2	228,699,552	0.0204	December 2011	66.1	137,833,214	0.0091
April 1994	105.4	166,982,922	0.0176	January 2012	59.9	142,099,934	0.0085
May 1994	236.5	41,437,632	0.0098	February 2012	70.2	128,810,491	0.0090
June 1994	297.3	32,963,337	0.0098	March 2012[a]	31.1	119,321,052	0.0037
July 1994	324.4	25,585,697	0.0083	April 2012	9.32	66,207,478	0.0006
August 1994	378.4	30,919,662	0.0117	May 2012	17.5	52,275,253	0.0009
September 1994	364.9	26,586,673	0.0097	June 2012	9.52	23,343,618	0.0002
October 1994	133.6	24,700,599	0.0033	July 2012	15.4	27,903,244	0.0004
November 1994	260.9	37,178,996	0.0097	August 2012	28	26,226,108	0.0007
December 1994	179.8	66,740,823	0.012	September 2012	104	35,383,209	0.0037
Total		911,258,822	0.137	Total		964,653,830	0.0592

Source: DOE 2013.
[a] Refurbished collection system comes back online.
Ci = curie.
FY = fiscal year.
pCi/L = picocuries per liter.

Table F.11 shows the history of ^{90}Sr fluxes and flux reduction factors in First Creek from calendar year (CY) 1993 through FY 2012.

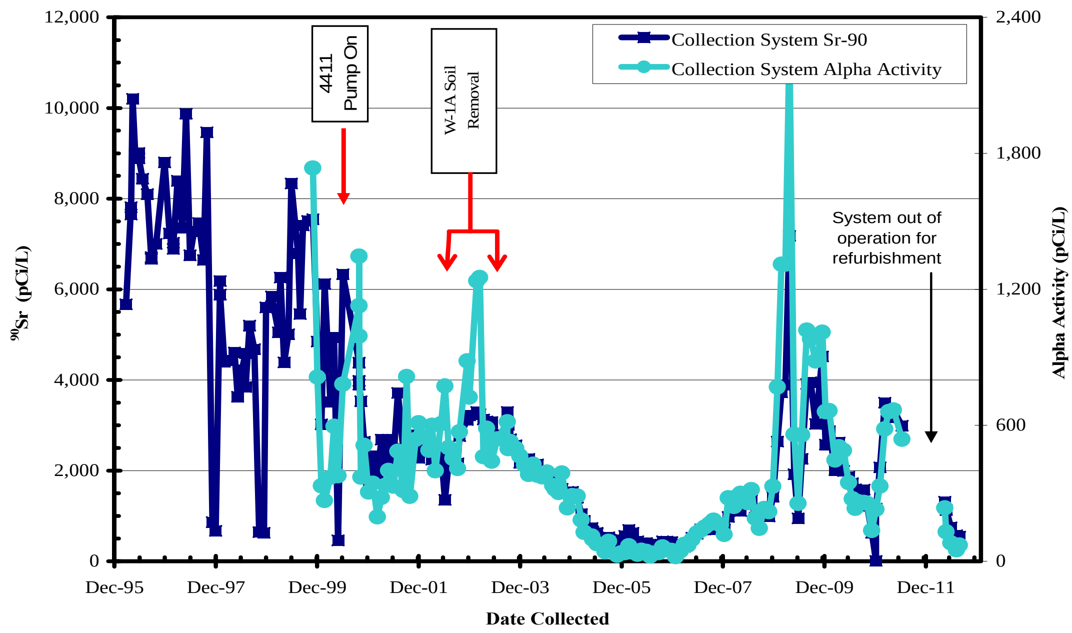
Table F.11. Strontium-90 flux changes at First Creek Weir, 1993–2012

Year	Strontium-90 flux (Curies)	Percent reduction from CY 1994[a]
CY 1993	0.13	
CY 1994	0.137	
CY 1995	0.067	51.1
FY 1996	NA	NA
FY 1997	0.036[b]	73.7
FY 1998	0.044[c]	67.9
FY 1999	0.044[c]	67.9
FY 2000	0.026	81.0
FY 2001	0.035	74.8
FY 2002	0.034	75.0
FY 2003	0.016	88.0
FY 2004	0.016	88.5
FY 2005	0.019	86.2
FY 2006	0.011	92.0
FY 2007	0.014	89.2
FY 2008	0.022	84.0
FY 2009	**0.119**	12.9
FY 2010	**0.131**	5.0
FY 2011	**0.116**	8.5
FY 2012	0.059	43.1

Source: DOE 2013.
[a] Remedy effectiveness (20 to 50% reduction from 1994 flux).
[b] Represents 10 months of data.
[c] Represents 11 months of data.
Bold table entries indicate years when the remedy has not achieved the performance goal.
CY = calendar year.
FY = fiscal year.
NA = not applicable.

Well 4411 is a plume extraction well that intersects the plume at a depth of approximately 90 ft bgs in a location approximately 120 ft south of the former Tank W-1A location, where leakage from a broken LLLW pipeline created the plume source. Samples from Well 4411 are taken at the wellhead and represent contaminant concentrations in extracted groundwater that is being pumped to the PWTC for treatment. Corehole 8 is a 50-ft-deep well in which a Westbay® multizone sampling system was installed to allow sampling of discrete intervals in the well. Zone 2 is the second zone from the bottom of the well, and its sampling interval spans the depth of 41.2 to 43.2 ft bgs. During well installation and initial sampling, this zone was found to produce the highest activities of contaminants in the well, and for that reason, it has become the focal point for ongoing monitoring at that location. Data show that during FY 2011 at Corehole 8, ^{90}Sr and $^{233/234}$U activities remained high. Well 4411 was non-operational during FY 2011 because of pump failure and was returned to service in March 2012.

Figure F.19 shows the Corehole 8 groundwater collection sump ^{90}Sr and alpha activity data from system startup in 1995 through FY 2012. Notations on the figure show approximate dates when extraction of contaminated groundwater via Well 4411 started, as well as the approximate dates during which contaminated soil was excavated from the North Tank Farm. The data demonstrate that both actions had visible benefits in reducing contaminant activities in the plume collection system that is located in the western end of the plume.



Source: DOE 2013

Fig. F.19. Strontium and alpha activity results over time in the Corehole 8 Plume collection system.

Table F.12 provides a summary for the groundwater plume in the Corehole 8 source area. Both the BVGWES and 2010 Northern Characterization (DOE 2011) identify ^{90}Sr as a primary COC that poses a threat to groundwater from leaching. Other radionuclides that were identified in high concentrations by the removal action and 2010 Northern Characterization include uranium isotopes, ^{137}Cs, plutonium isotopes, ^{241}Am, and ^{244}Cm. Soils close to Tank W-1A have already been excavated and removed from the site. During the Tank W-1A excavation, the Northern Characterization work was performed north of the tank in the direction of Bldg. 3019. Laboratory and data analysis showed a definitive area of contamination directly north of the former tank along a pipe chase that failed the criteria for protection of groundwater. No action has been taken on that area.

The Corehole 8 groundwater and surface water COCs from the BVGWES and 2010 Northern Characterization include:

- Groundwater: Sr-90, $^{233/234}$U, ^{137}Cs, and other alpha emitters including TRU isotopes.
- Surface Water: Sr-90 and $^{233/234}$U.

Table F.12. Corehole 8 source area plume groundwater plumes

Plume No.	Name	Description			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
BV-2	Corehole 8 Plume	1,500 ft east–west and 100 to 200 ft north–south	>500	Shallow: Up to 410,000 pCi/L ^{90}Sr; 5,000 to 10,000 pCi/L alpha Deep: 10 to 50,000 pCi/L ^{90}Sr	Direct release into the Benbolt near Tank W-1A footprint; down-dip and along- strike flow in the Benbolt to First Creek	First Creek	• Extent of plume migration down-dip (~35° to vertical) and into formations adjacent to the Benbolt uncertain (various versions of the BVGWES show migration into Rockdell Formation underlying limestone formation located north of Tank W-1A) • Currently, no evidence suggesting that plume direction is toward Fifth Creek to the east • Unknown mid- to long-term effect of upgrades to Corehole 8 Plume capture system • Long-term availability of treatment capability

BV = Bethel Valley.
BVGWES = Bethel Valley Groundwater Engineering Study (DOE 2005).
pCi/L = picocuries per liter.

The 2011 FYR identified the following issue for this area:

- Corehole 8 Plume collection system operation and maintenance issues are preventing it from currently meeting the Removal Action Report performance goals.

Since the 2011 FYR, the refurbished Corehole 8 Extraction System has been upgraded and refurbished and is fully operational (DOE 2013).

F.2.3 BV-3 7000 AREA VOC PLUME

The 7000 Area (plume BV-3) of ORNL contains a VOC plume (TCE, and its degradation products) that extends into the bedrock aquifer to depths >100 ft.

The plume is westward-migrating, narrow, elongated, and strata-bound in the sense that it appears to migrate via a discrete set of fractures within a thin limestone bed within the Witten Formation (see Figs. F.6 and F.20).

In the 7000 Area, the lower half of the Witten formation contains two relatively distinct, pure limestone members referred to as the "Little Lime" and the "Big Lime" (which is not correlative with the Mississippian-age Big Lime that is a prominent petroleum-producing formation beneath the Cumberland Plateau and Mountains). The core portion of the plume occurs in the "Little Lime."

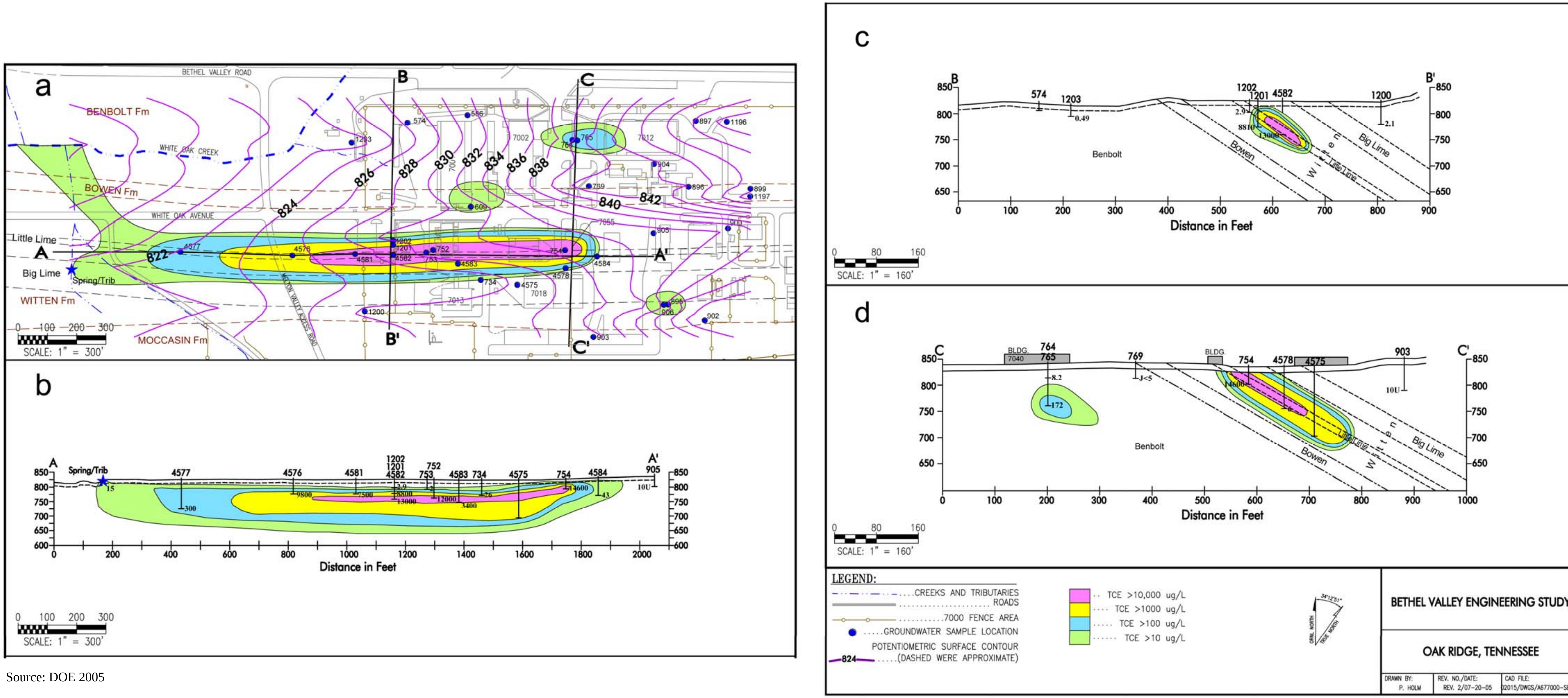
The source area is at, or near, a former small building (Bldg. 7055) that had a sump in its concrete slab that was graded to exit at the western edge of the slab. Building 7055 and its slab were demolished in the summer of 2004. Data suggest that substantial amounts of degreaser from an unknown activity likely seeped both through the building's concrete slab and/or sump and directly onto the ground outside of the building and/or through the outside plumbing network.

The 7000 Area VOC plume discharges to a tributary spring, which discharges to WOC.

The BV ROD for Interim Action for the 7000 Area TCE plume calls for an in situ bioremediation approach to contaminant reduction.

A TS work plan for the 7000 Services Area groundwater plume (DOE 2010b) was designed to test the feasibility of bioremediation technologies to remove VOCs from groundwater in the area. FY 2010 activities included: groundwater sampling to determine the presence of naturally dechlorinating microbes; groundwater analysis to determine the degradation capacity of the indigenous microbes; and dye injection into several wells to determine the groundwater transport characteristics, including the injection of bioaugmentation materials into the aquifer (Edible Oil Microemulsions [EOS] and Hydrogen Release Compound [HRC®]). Monitoring of the effect of the biostimulants took place over several quarters in 2011. The results indicated that the TS showed bioremediation of the 7000 Area VOC plume is a viable remedial option (DOE 2012a).

June 2012 correspondence from the Tennessee Department of Environment and Conservation expressed a recommendation that the U.S. Department of Energy (DOE) continue the groundwater remediation activities in the 7000 Area in accordance with the plans outlined in the *Treatability Study Work Plan for the 7000 Area in Bethel Valley* (DOE 2010b).



Source: DOE 2005

Fig. F.20. Stratigraphic cross-sections and plume map of 7000 Area VOC Plume (BVGWES).

More recently the general conclusions enumerated from the ongoing monitoring include the following (DOE 2013):

- After 2 years of TCE biodegradation from the single injection, VOC concentrations within and downgradient of the treatment zone remain significantly lower than during pre-injection concentrations (see pre- and post-treatment contaminant concentration levels on Fig. F.21).
- TCE concentrations have begun to level out in several wells (e.g., 0752 and 1201).
- The TCE daughter products, *cis*-1,2-DCE and VC, continue a slight decreasing trend (e.g., 0752, 1201, and 4576).
- *Dehalococcoides* sp. (DHC) populations are beginning to decrease near the injection point (e.g., Well 0752) but remain high in the downgradient wells suggesting VOC reductions may continue to occur.
- The estimated reduction of TCE mass from December 2010 to January 2012 (in the portion of the plume that was monitored) was approximately 217 kilograms.
- Since the plume occurs in a karst limestone unit, there is rapid migration of recharging groundwater through the upgradient and shallower portions of the plume during and after rainfall events. In the absence of additional injections, these influxes of fresh, oxygenated groundwater likely will return the natural chemical conditions to the treatability test area with an expected re-invasion of TCE contamination from the upgradient plume area into the pilot treatment zone.

Table F.13 provides a summary of the 7000 Area VOC plume.

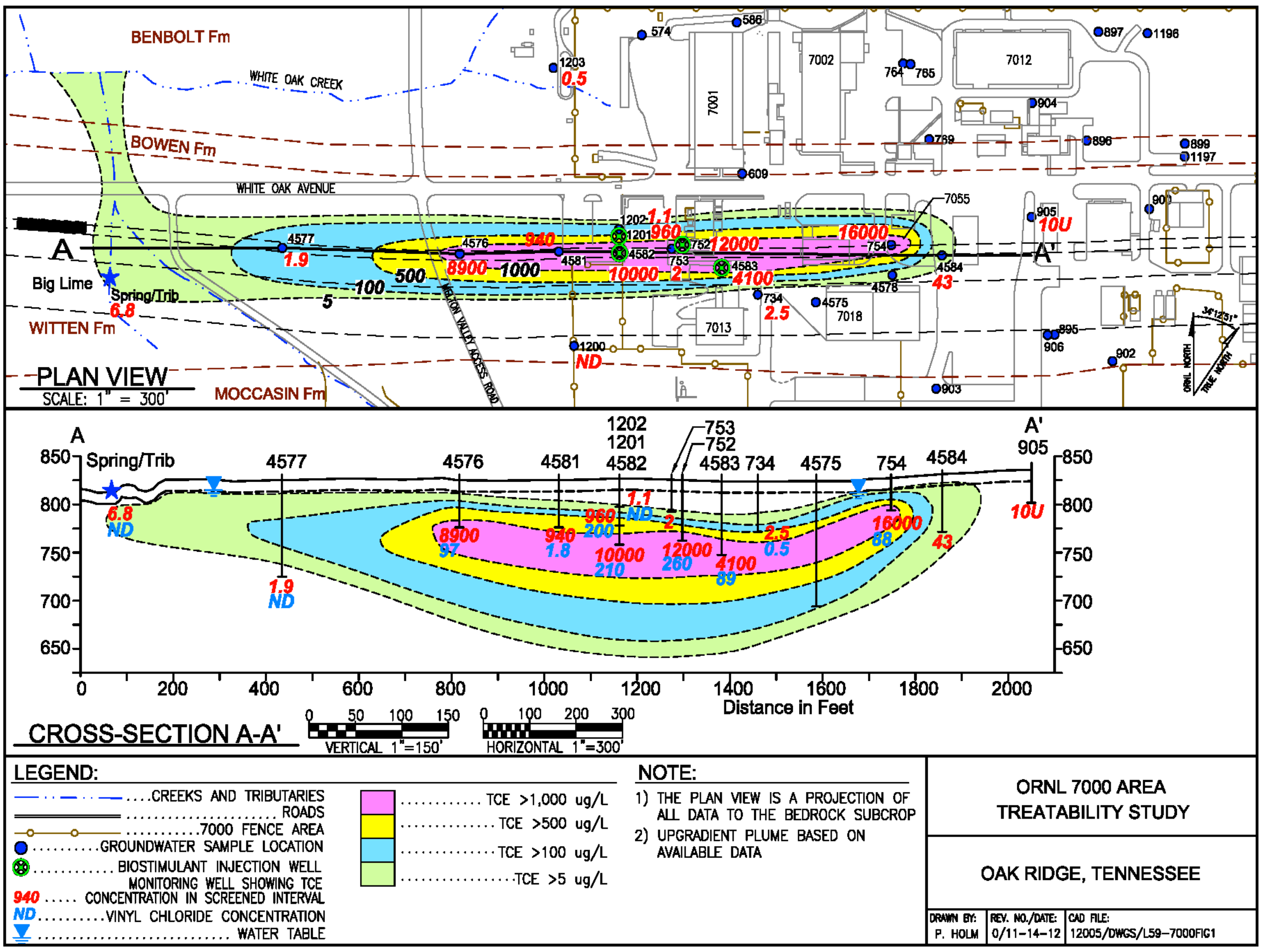
F.2.4 BV-4 SWSA 3 SOURCE AREA

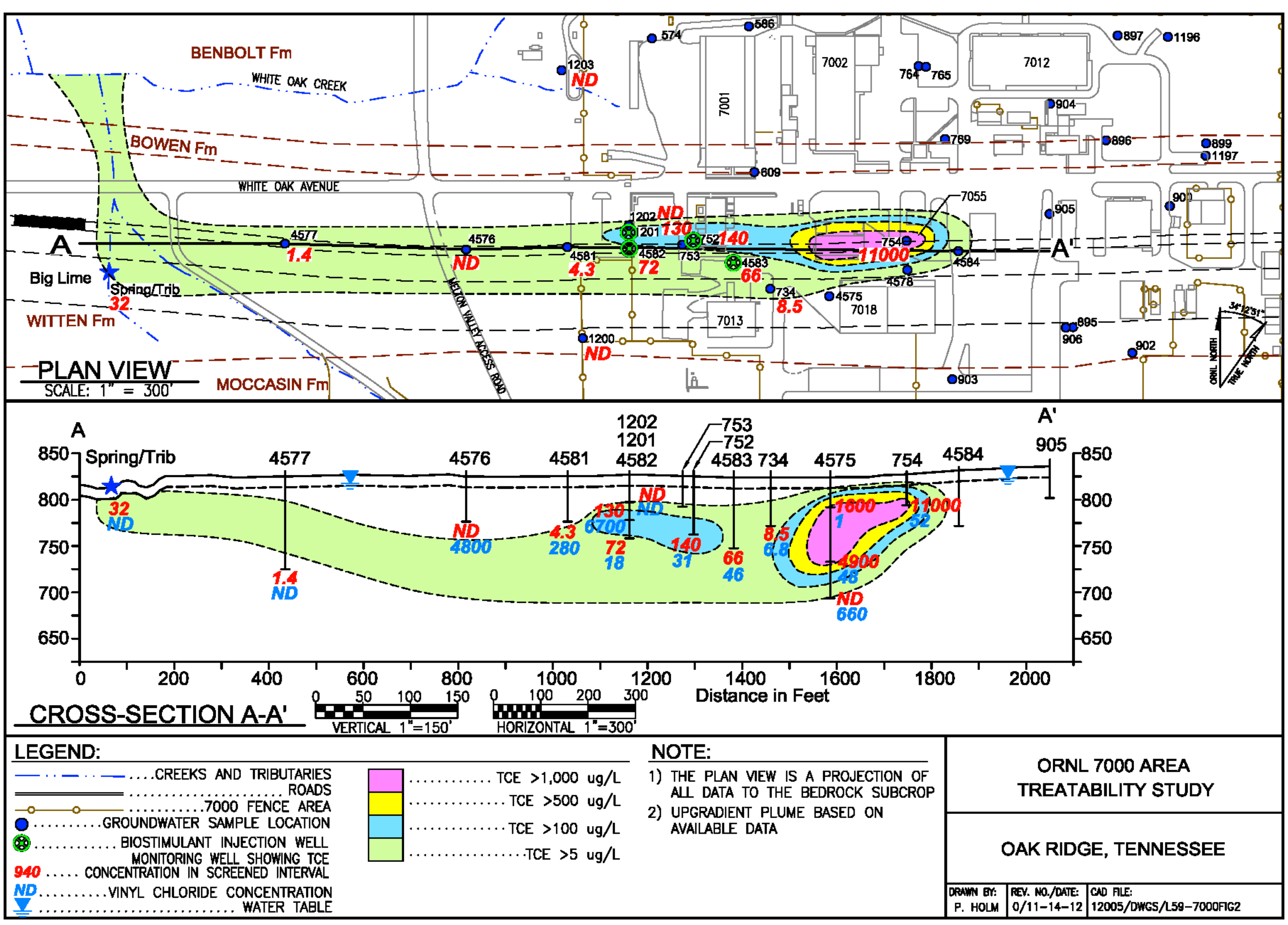
Waste disposal is the only activity known to have occurred in the West BV Area. The SWSA 3 burial ground covers an area of 7 acres and is located approximately 0.6 miles west of the ORNL main plant complex areas.

An estimated 600,000 to 750,000 ft^3 of radioactive waste with approximately 44,000 to 56,000 Ci of radioactivity was buried in SWSA 3. SWSA 3 disposal operations occurred from 1946 to 1951 and wastes were typically buried with several feet of soil cover. Some actinide-contaminated wastes were buried in SWSA 3.

SWSA 3 is underlain by the Witten Formation. When weathered the Witten Formation develops clay-rich residual soils. Bedrock to the north of the disposal units is the Bowen formation, which is a thin (~30-ft-thick) siliceous shale with a thin limestone zone in its mid-section, and the Benbolt formation which is another mixed argillaceous and pure limestone formation. Because of its siliceous nature, the Bowen formation is somewhat less susceptible to chemical weathering and thus may act as an aquitard between the overlying and underlying limestone-rich bedrock formations.

Site investigations at SWSA 3 conducted in the late 1970s and early 1980s documented the existence of karst and conduit conditions at SWSA 3 as evidenced by cavities encountered in bedrock boreholes and rapid movement of groundwater. Three groundwater tracing activities were conducted at SWSA 3 and groundwater seepage velocities in karst pathways were documented to range from about 120 ft/day to over 43,000 ft/day. The tracer tests documented shallow groundwater movement at rapid velocities





Source: DOE 2012

Fig. F.21. 7000 Area pre-treatment (top) and one year post-biostimulation (bottom) VOC plume plans and sections.

Table F.13. 7000 Area VOC groundwater plume plumes

Plume No.	Name	Description[a]: Length (ft down valley)	Description[a]: Depth (ft bgs)	Description[a]: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
BV-3	7000 Area VOC plume shallow/deep (DNAPL) VOCs in limestones and siltstones of Witten Formation	1800 east–west 200 north–south. Outlier plumes less than 100 × 200	>150	10 to 15,000 µg/L	Along-strike shallow to deep flow in Witten; three minor outlier plumes in Benbolt, Bowen, and Witten Formations; and density-driven vertical flow	Tributary spring and White Oak Creek	• Bottom and west end of Plume somewhat poorly defined • Existence and mass/distribution of DNAPL are unknown, possibly bringing into question the effectiveness of bioremediation • Degradation of all daughter products down to ethane is uncertain

bgs = below ground surface.
BV = Bethel Valley.
DNAPL = dense non-aqueous phase liquid.
VOC = volatile organic compound.
µg/L = micrograms per liter.

emerging at springs and seeps in the headwaters of both the Northwest Tributary and Raccoon Creek. A tracer injected in Well 0493 in the western/central portion of SWSA 3 was observed in both streams with a migration velocity of about 240 ft/day to the east into the Northwest Tributary and a velocity of about 131 ft/day to the west into the Raccoon Creek headwater. Tracer migration both east and west from the injection point suggests the existence of the shallow groundwater divide in the vicinity of the injection point location.

The distribution of SWSA 3 contaminants defines a long (>3000 ft) and narrow (approximately 250 ft) area that suggests flow through a discrete bedrock pathway. This pathway is likely to be associated with the "Little Lime" member of the Witten Formation, which may provide a conductive pathway for both the tracer and the observed ^{90}Sr discharges that occur coincidentally. Figure F.22 presents a cross-section showing stratigraphic units and ^{90}Sr contaminant distribution at SWSA 3 and the Contractor's Landfill.

The BV RI indicates that ^{90}Sr is the principal COC; however, several constituents other than ^{90}Sr have been detected in groundwater in the West BV area. Most occur in wells in and near SWSA 3, and only a few maximum contaminant level exceedances have been observed (^{3}H at a single well; TCE, VC, and methylene chloride at four wells; and antimony and cadmium in one or two wells).

In April 2010, DOE received regulatory approval for the *Remedial Design Report/Remedial Action Work Plan for the Bethel Valley Burial Grounds at the Oak Ridge National Laboratory* (DOE 2010c), which presents the design for hydrologic isolation of buried waste at SWSA 1 in Central BV and SWSA 3 and adjacent contaminated areas in West BV. Soil covers to the Former Waste Pile Area and Nonradioactive Wastewater Treatment Plant Debris Pile soil covers were completed in 2010. Three new monitoring wells (4645, 4646, and 4647) were installed west of Highway 95, along Raccoon Creek, to monitor the SWSA 3 western Exit Pathway. Groundwater analytical results from FY 2012 indicate that these wells did not contain contaminants above drinking water MCLs.

Recently (August 2011) the BV Burial Grounds Remediation Project was completed which, as described above, included the capping of SWSA 3. Two areas of soil contamination and the former Closed Scrap Metal Area were also covered by the SWSA 3 cap. A gravel road that crosses the capped area was rebuilt on top of the cap. Both caps are constructed of several layers of impermeable cap material placed to prevent migration of contaminants. Further hydrologic isolation was undertaken by inclusion of two upgradient French drains and surface water ditches that will divert shallow groundwater and rain water away from the SWSA 3 closure area. Historical time series showing ^{90}Sr activity for the Northwest Tributary and Raccoon Creek are presented on Fig. F.23, including sampling that post-dates completion of the SWSA 3 cap (Table F.14).

Table F.5 shows an update of ^{90}Sr concentrations and mass flux at the Raccoon Creek weir. There is no ROD goal specified for this location; however, Raccoon Creek Weir will be a significant monitoring point for the upcoming RERs and the 2016 FYR since it tracks releases from SWSA 3, which recently completed ARRA-funded remediation.

Table F.15 provides a summary of the SWSA 3 source area.

The groundwater and surface water COCs in the SWSA 3 source area are listed in the RI and include:

- Groundwater: Sr-90 (also includes As [arsenic] and Sb [antimony]).
- Surface Water: Sr-90.

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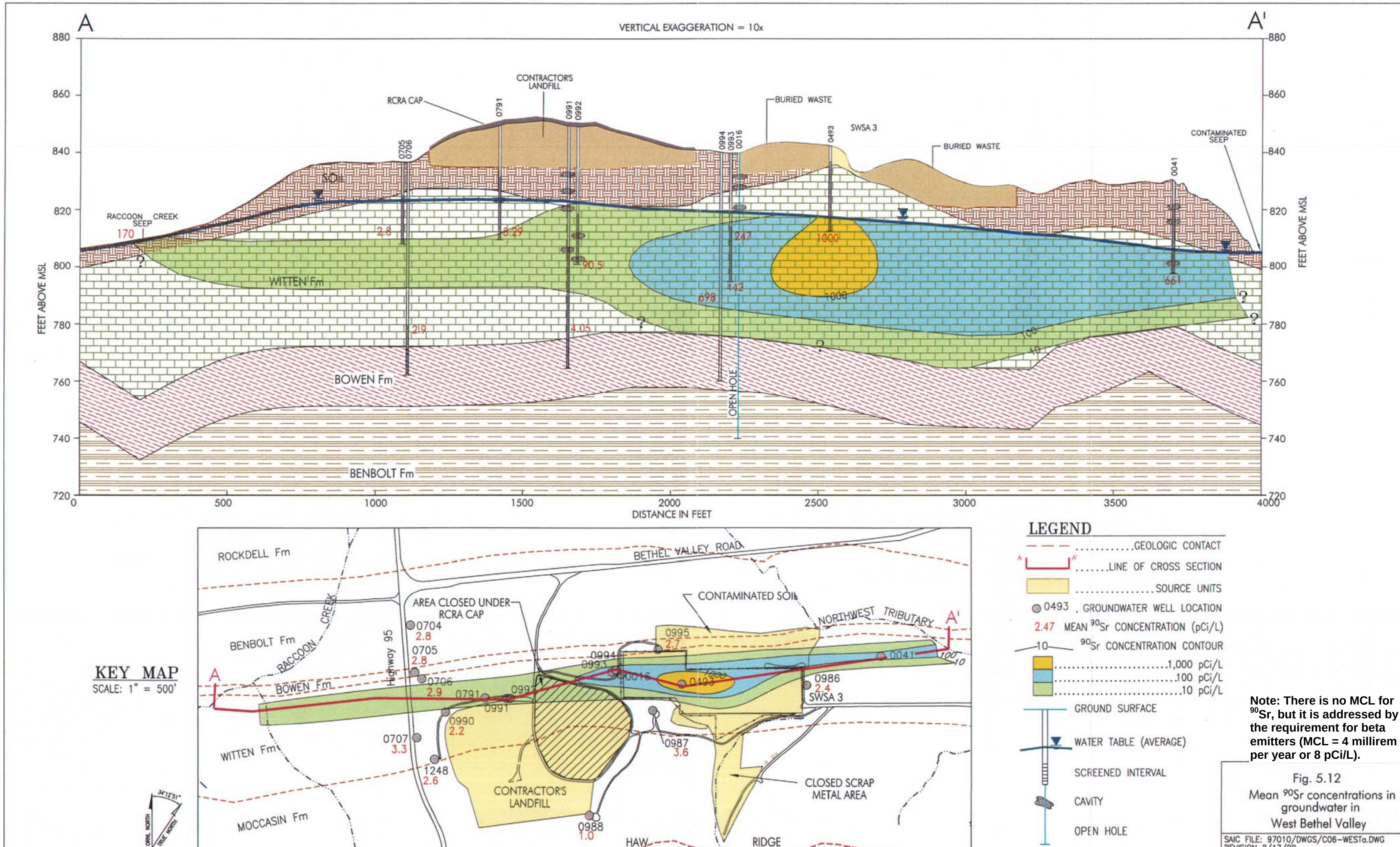
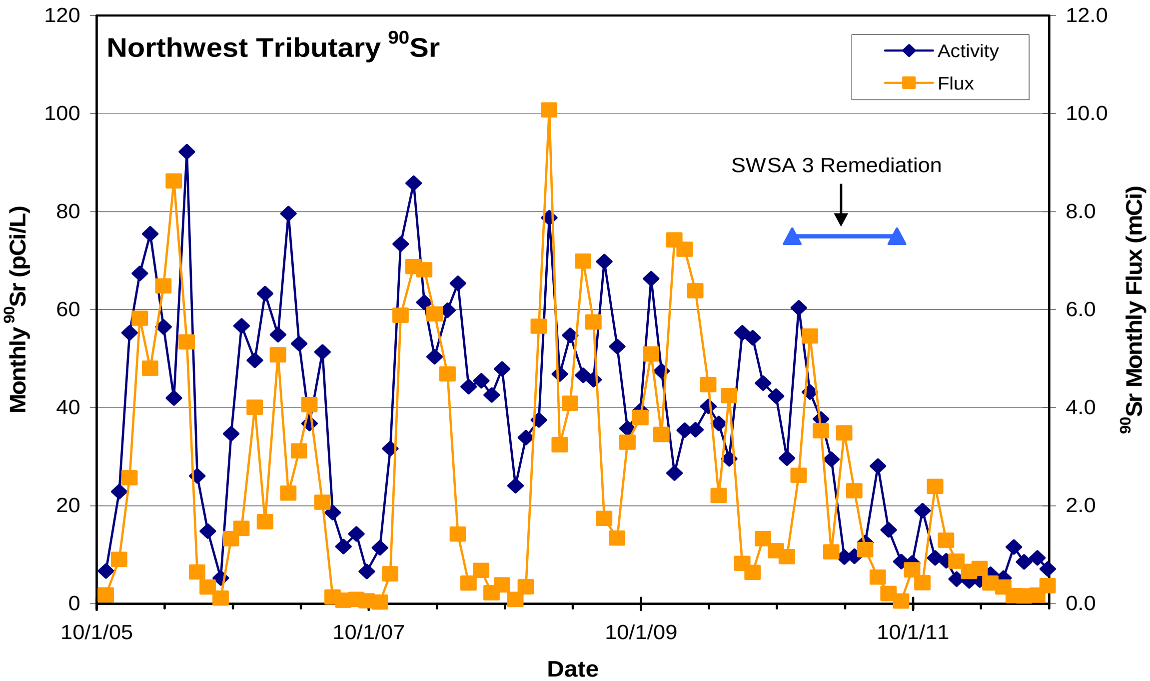
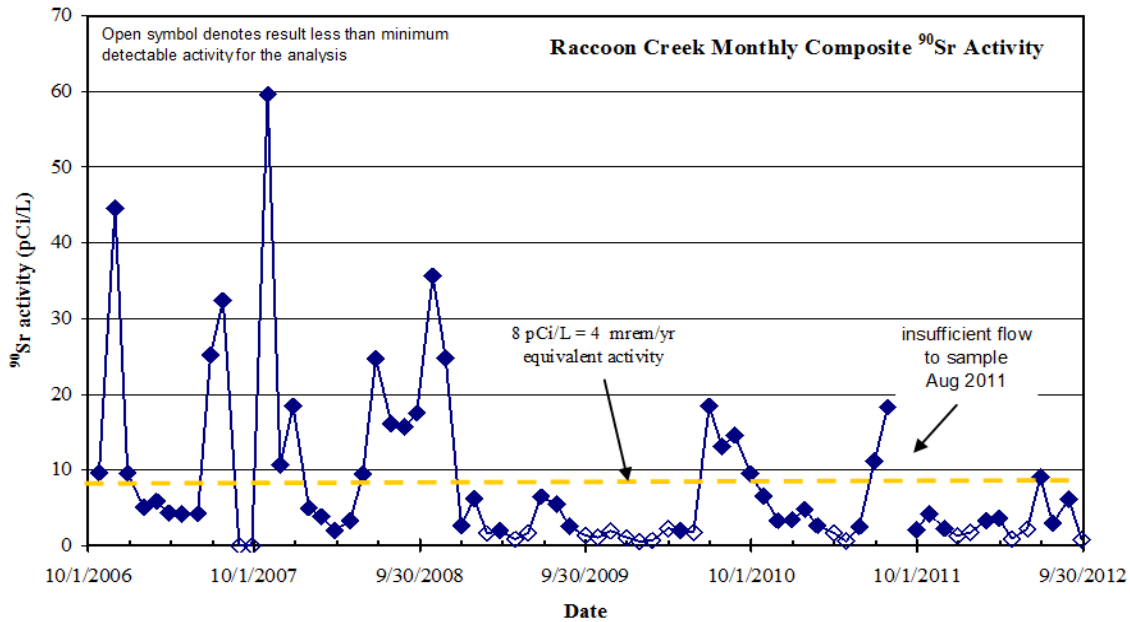


Source: DOE 1999a

Fig. F.22. Stratigraphic cross-section of SWSA 3 and Contractors' Landfill showing distribution of ^{90}Sr





Source: DOE 2013

Fig. F.23. Sr-90 concentration time series for the Northwest Tributary and Raccoon Creek.

Table F.14. Summary of FY 2012 SWSA 3 groundwater maximum contaminant level exceedances and related contaminant trends

Well	Anal. type	Analyte	All data			MCL	Units	Pre-remediation FY 2009 to 2011		Post-remediation FY 2012		Mann-Kendall trend analysis	Notes
			No. of analyses	No. of detects	Results > MCL			No. of detects	Average	No. of detects	Average		
0992	RAD	Beta activity[a]	11	11	8	50	pCi/L	10	142	1	58.5	Decreasing	
0992	RAD	Strontium-90	11	11	11	8	pCi/L	10	66.9	1	25.3	Decreasing	
0993	RAD	Strontium-90	11	11	11	8	pCi/L	10	167	1	25.1	Decreasing	
0994	RAD	Beta activity	16	16	15	50	pCi/L	15	1330	1	375	Decreasing	
0994	RAD	Strontium-90	14	14	14	8	pCi/L	13	655	1	186	Decreasing	
0997	RAD	Strontium-90	12	12	12	8	pCi/L	11	40.1	1	9.85	Decreasing	
4579-01	Anion	Fluoride	14	14	13	4	mg/L	13	9.1	1	10	Stable	
4579-01	VOA	Benzene	10	10	10	5	μg/L	7	9.49	3	9.03	Stable	
4579-01	RAD	Beta activity	19	10	3	50	pCi/L	9	60.7	1	58.7	No trend	Sus. outlier, pre-remediation
4579-01	RAD	Beta activity	20	8	3	50	pCi/L	6	34.3	2	12.68	No trend	Sus. outlier, pre-remediation
4579-02	VOA	Benzene	10	9	5	5	μg/L	6	5.53	3	6.37	Stable	
4579-02	RAD	Strontium-90	20	8	2	8	pCi/L	6	14.75	2	16.52	No trend	Poss. outlier FY 2012
4579-02	RAD	Strontium-90	20	8	2	8	pCi/L	6	14.75	1	3.33	Stable < MCL	Censored, excl. outlier
4579-03	RAD	Strontium-90	20	19	7	8	pCi/L	16	8.71	3	8.1	Stable	

Source: DOE 2013.

[a] The value of 50 pCi/L is used to trigger analyses to determine beta-emitting radionuclides present in public water supplies.

Notes: Average concentration calculated using detected results.

Mann-Kendall analyses based on all results. Non-detects were assigned the detection limit (minimum detectable activity [MDA]).

FY = fiscal year.

MCL = Safe Drinking Water Act of 1974 maximum contaminant level

mg/L = milligrams per liter.

μg/L = micrograms per liter.

pCi/L = picocuries per liter.

RAD = radionuclide.

VOA = volatile organic analyte.

Table F.15. SWSA 3 Source Area groundwater plumes

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
BV-4	SWSA 3 source area, ^{90}Sr plume shallow in limestones of Witten Formation	3,000 east–west 250 north–south.	<100	10 to 1,000 pCi/L	Along-strike shallow flow in Witten Formation	East to Northwest Tributary (NWT) drainage and West to Raccoon Creek drainage	• Bottom and both east and west ends of Plume are somewhat poorly defined

BV = Bethel Valley.
pCi/L = picocuries per liter.
SWSA = Solid Waste Storage Area.

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APPENDIX G
MELTON VALLEY SITE CONCEPTUAL MODEL

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CONTENTS

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TABLES

FIGURES

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ACRONYMS

3-D	three-dimensional
bgs	below ground surface
BV	Bethel Valley
Ci	curie
COC	contaminant/chemical of concern
CT	carbon tetrachloride
D&D	decontamination and decommissioning
DCA	dichloroethane
DCE	dichloroethene
DOE	U.S. Department of Energy
FFA	Federal Facility Agreement
FS	feasibility study
FYR	Five-Year Review
HF-1	Hydrofracture Experiment Site 1
HF-2	Hydrofracture Experiment Site 2
HF-3	Old Hydrofracture Facility
HF-4	New Hydrofracture Facility
HFIR	High Flux Isotope Reactor
HRE	Homogenous Reactor Experiment
HRT	Homogenous Reactor Test
ILLW	intermediate-level liquid waste
LLW	low-level waste
LLLW	liquid low-level waste
LUC	land use control
μg/L	micrograms per liter
MV	Melton Valley
NHF	New Hydrofracture Facility
OHF	Old Hydrofracture Facility
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
P&A	plugging and abandonment
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PVC	polyvinyl chloride
PWSB	Process Waste Sludge Basin
PWTC	Process Waste Treatment Complex
PWTP	Process Waste Treatment Plant
RAO	remedial action objective
RER	remediation effectiveness report
RH-TRU	remote-handled transuranic
RI	remedial investigation
ROD	Record of Decision
S&M	surveillance and maintenance
SOF	sum of fractions
SWSA	Solid Waste Storage Area
TCE	trichloroethene
TRU	transuranic

TVA	Tennessee Valley Authority
VC	vinyl chloride
VOC	volatile organic compound
WAG	Waste Area Grouping
WOC	White Oak Creek
WOD	White Oak Dam

G.1 INTRODUCTION

This Appendix provides a summary of the conceptual model for the Melton Valley (MV) Watershed, located in the southwestern portion of the Oak Ridge Reservation (ORR), based on the available data and the understanding of the hydrogeologic framework at the time of data collection. The following sections provide a chronology of events associated with the MV Watershed, the primary groundwater contaminant sources identified in the watershed, the geology and hydrology of the watershed, and summaries of the source area conceptual models, including discussions of key data gaps in the individual source area conceptual models. Much of the background information provided herein is from the MV Remedial Investigation (RI) report (DOE 1997a). Updated contaminant concentrations and concentration trends have been obtained from the recent ORR Remediation Effectiveness Reports (RERs) [DOE 2012a; DOE 2012b; DOE 2013]. The sources for the illustrations presented in this Appendix are indicated on the individual figures.

G.1.1 CHRONOLOGY OF EVENTS ASSOCIATED WITH THE MELTON VALLEY WATERSHED

Table G.1 provides a chronology of historical operations and relevant events related to groundwater contaminant plumes for the MV Watershed. Figure G.1 illustrates the period of waste operations at the key source areas.

Table G.1. Chronology of events associated with the MV Watershed

Event	Date
The MV SWSAs serve as the U.S. Atomic Energy Commission's Southern Regional Burial Grounds for wastes from over 50 facilities. About one million cubic feet of solid waste from various off-site installations were buried in SWSAs 4 and 5.	1955 – 1981
General historical narratives (and timeline as shown on Fig. G.1) of the primary MV waste unit types and their operational history are provided as follows:	
The SWSA 6/WAG 6 RCRA Facility Investigation (RFI) is initiated; interim corrective measures caps are built; and the decision is made to integrate RCRA and CERCLA at WAG 6.	1991
The WAG 6 RFI and WAG 5 RI are completed; no RODs are developed due to a shift to watershed-scale priorities.	1993 – 1995
Seven CERCLA removal actions, including the key WAG 4 trench stabilization study and the WAG 5 Seep C and Seep D collection and treatment units, are identified within the MV Watershed.	1992 – 1999
DOE adopts the watershed approach to CERCLA decision-making; the MV Watershed -scale RI efforts begin. The RI for the White Oak Creek watershed is approved.	1997
The Melton Valley ROD for interim source actions is signed by the FFA parties. The ROD focuses on principal waste source areas and deferred the surrounding environmental media to a final ROD for Melton Valley. The original duration for completion is 14 years.	September 2000
Disposal of waste at the Interim Waste Management Facility (IWMF) in SWSA 6 is terminated.	2002
DOE begins the accelerated closure of MV; the new closure date is set for September 2006.	2002
The MV Monitoring Plan (D1) is issued (required by the ROD).	2002
The MV Picket Wells are installed; completion of six deep, multiport monitoring wells is accomplished.	2004

Table G.1. Chronology of events associated with the MV Watershed (cont.)

Event	Date
PCCRs relevant to groundwater plumes are completed for Hydrofracture Well Plugging and Abandonment; Hydrologic Isolation at SWSA 5, SWSA 4, and IHP; Trenches 5 and 7 and HRE Fuel Wells In Situ Grouting; Hydrologic Isolation at SWSA 6; Hydrologic Isolation at Seepage Pits and Trenches.	2006
The RAR is signed for MV ROD completion.	2007
Off-site wells are installed across the Clinch River from MV.	2010

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DOE = U.S. Department of Energy.
FFA = Federal Facility Agreement.
IHP = Intermediate Holding Pond.
HRE = Homogenous Reactor Experiment.
MV = Melton Valley.
PCCR = Post Construction Completion Report.
RAR = Remedial Action Report.
RCRA = Resource Conservation and Recovery Act of 1976.
RFI = RCRA Facility Investigation.
RI = remedial investigation.
ROD = Record of Decision.
SWSA = Solid Waste Storage Area.
WAG = Waste Area Grouping.

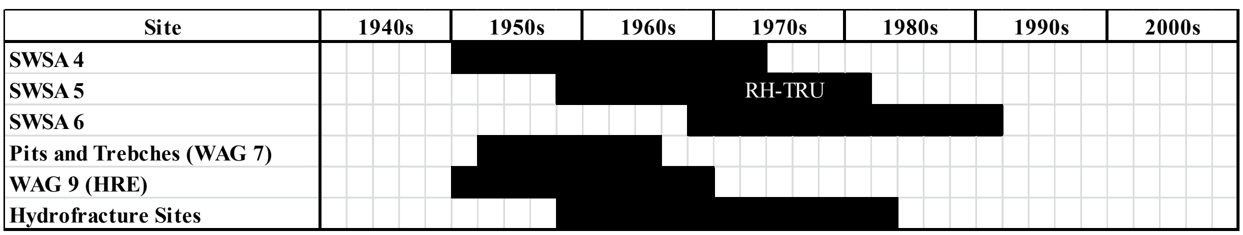


Fig. G.1. Approximate schedule of historical waste operations in Melton Valley.

The information contained within this conceptual model summary document relies upon several primary documents including the MV RI/Feasibility Study [FS] (DOE 1997a; DOE 1997b); Engineering Study for Excavation of Selected Buried TRU Waste from Solid Waste Storage Area (SWSA) 5 in MV (BJC 2001); Land Use Control (LUC) Implementation Plan for the MV Watershed (DOE 2002); Remedial Design Work Plan for Interim Actions for the MV Watershed (DOE 2000); *Status Report: A Hydrologic Framework for the Oak Ridge Reservation* (Solomon et al. 1992); RI on Waste Area Grouping (WAG) 5 (DOE 1995a; DOE 1995b), RERs (DOE 2012a; DOE 2012b; DOE 2013); and the 2011 Reservation-wide Five-Year Review [FYR] (DOE 2012c).

G.1.2 PRIMARY CONTAMINANT SOURCES IN THE MELTON VALLEY WATERSHED

The MV Watershed, which encompasses 1062 acres, was the location of various types of waste disposal operations, including buried waste, landfills, tanks, impoundments, seepage pits and trenches, and deep hydrofracture wells. The following describes conditions prior to remediation under the MV Interim Record of Decision (ROD):

- **Buried waste.** The principal waste burial sites at Oak Ridge National Laboratory (ORNL) are SWSAs 4 (operation dates 1951 to 1973), 5 (operation dates 1959 to 1981), and 6 (operation dates 1969 to 2002). Early burial procedures involved the use of unlined trenches and auger holes covered

by either soil from the trench excavation or by a combination of concrete caps and soil. In 1970, transuranic (TRU) waste was segregated and stored in a retrievable manner in SWSA 5 North. Burial of low-level waste (LLW) in unlined trenches and auger holes ceased in 1986 when ORNL began placing solid LLW in concrete-lined silos below grade in SWSA 6. Since 1988, this waste has been placed in concrete boxes and placed on aboveground concrete storage pads, which were covered with a multilayered cap before final closure (Energy Systems 1992).

- **Landfills.** Bulky solid waste (e.g., construction debris and used equipment), which was not considered LLW, was disposed on-site in landfills.

- **Tanks.** During the early years of ORNL operation, liquid low-level waste (LLLW) produced by ORNL was concentrated and stored in underground storage tanks primarily in Bethel Valley (BV). There were 9 inactive tanks [5 at the Old Hydrofracture Facility (OHF), 1 at the New Hydrofracture Facility (NHF), 2 at the Homogeneous Reactor Experiment (HRE), and 1 at the Molten Salt Reactor Experiment] and 16 tanks that are currently in service in MV as defined in Appendix F of the Federal Facility Agreement (DOE 1992). These tanks are constructed of stainless steel with only a few constructed of carbon steel (tanks T-1, T-2, and T-9) with rubber liners (tanks T-3 and T-4). Over the years, tank systems were abandoned as their integrity was breached, or as programs were terminated. Some of these tanks were abandoned in place with liquid waste and sludge left in them. Some of these tanks also have no existing cathodic protection or secondary containment.

- **Impoundments.** Impoundments were constructed in MV to store wastewater and provide additional settling and storage capacity for diversion of LLLW to avoid an off-site release due to a failure in the system. Impoundments in the MV Watershed include High Flux Isotope Reactor (HFIR) Ponds, the OHF Pond, the Process Waste Sludge Basin (PWSB), and the Emergency Waste Basin. These impoundments were constructed in the natural clays with no liner with the exception of the PWSB that has a polyvinyl chloride (PVC) liner.

- **Seepage Pits and Trenches.** In the early 1950s, chemically treated LLLW began to be disposed in large seepage pits and trenches excavated into relatively low-permeability residuum of the Conasauga Group in MV. As intended, the LLLW seeped into the surrounding soil that was primarily clay. This clay soil acted as a sorption agent for some radionuclides contained within the waste. Seven seepage pits and trenches were used from 1951 to 1966, when the hydrofracture method of liquid waste disposal became fully operational.

- **Hydrofracture Wells.** Four hydrofracture well injection sites (two experimental and two previously operational) were used to pump LLLW grout slurry into fractures in the underground bedrock formation (Pumpkin Valley Shale) at depths greater than 600 ft below ground surface (bgs). Fracturing of the shale bedrock was produced by pumping water into a slot cut in the injection well casing. The grout slurry was pumped into the formation and allowed to harden. Using this technique, the radionuclides were retained in the grout and were thought not to be subject to groundwater transport, although the possibility of excess liquid (filtrate) from incomplete grout set has long been known. Use of the hydrofracture process for waste disposal was terminated in 1984. In 1986, a well in the vicinity of the grout sheet showed the presence of radionuclides at the approximate depth of the grout sheets.

- **Buried Pipelines.** The LLLW system is complex, requiring buried pipelines to transport the aqueous radioactive waste solution from the generator facilities to storage tanks, and historically for disposal in seepage pits/trenches or hydrofracture injection. These buried pipelines were constructed of various materials, including steel, black iron, and stainless steel. These pipelines were triple rinsed and abandoned after they were no longer needed. However, poor configuration control exists on these

pipelines because of the lack of as-built drawings. Consequently, it is unknown what and where residual waste may remain in them. Soil around some known leak sites was excavated during the MV Closure Project.

- **Contaminated Soil and Sediment.** Radiological contamination of surface soil occurs in many areas of the MV Watershed. Causes of surface soil contamination include: material spills on the ground surface, contaminated biological material including leaves and animal droppings, pipeline leaks that caused surface contamination, surface breakouts of contaminated seepage during operation of the Seepage Pits and Trenches, surface breakouts of contaminated seepage and groundwater originating as leachate in primary contaminant source areas such as waste burial trenches, and contaminated sediment deposited in the floodplains of White Oak Creek (WOC) and tributaries.

Secondary groundwater contamination is present in the valley. As indicated in green in Fig. G.2, secondary shallow groundwater sources exist downgradient of trenches – primarily near trenches that are perennially inundated with groundwater.

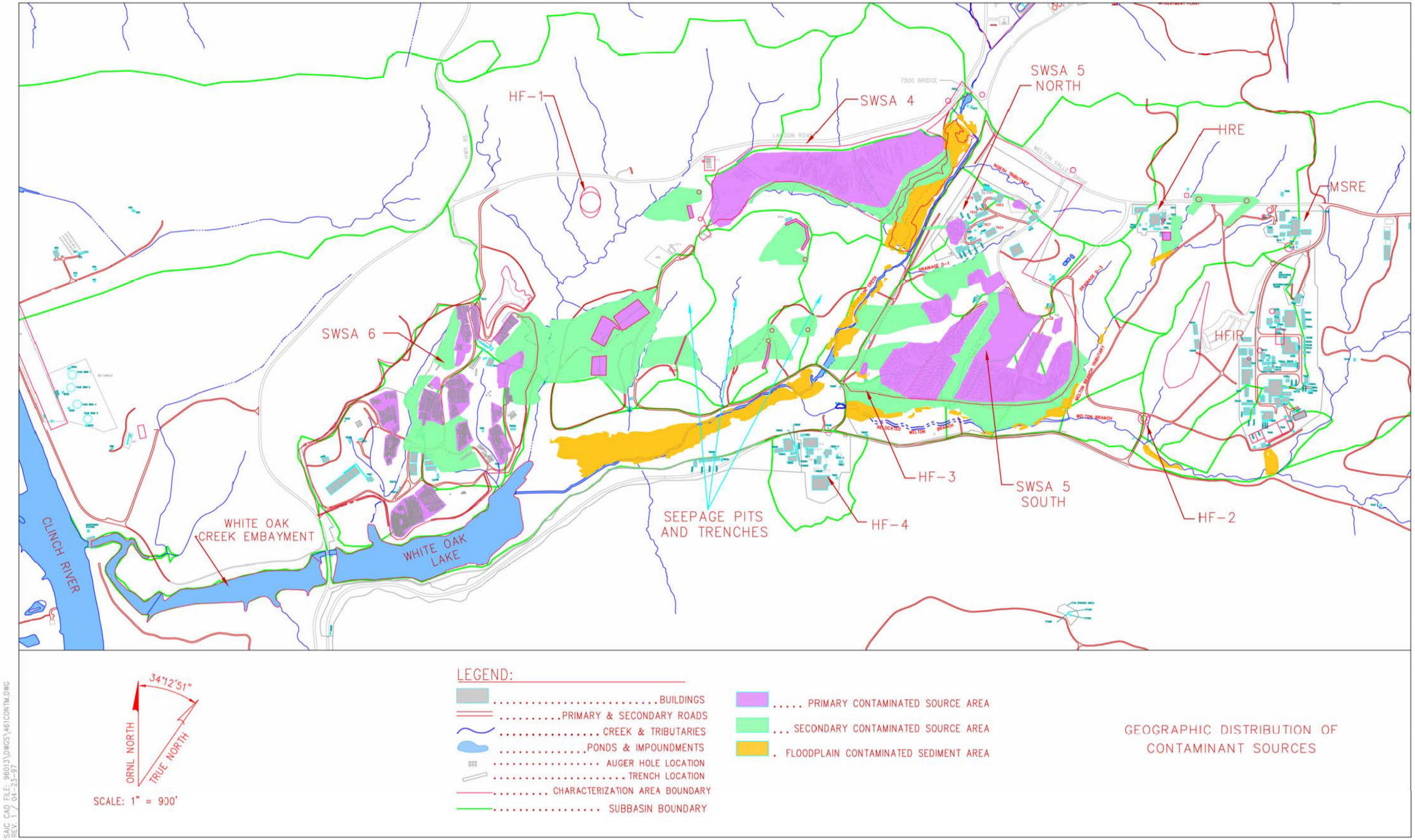
The only known source in the deep subsurface zone is the cement-grouted radioactive waste that was injected to depths of 900 to 1100 ft bgs at two operational hydrofracture sites. The geologic formation selected for deep emplacement of waste was the low-permeability Pumpkin Valley Shale, a thin-bedded, maroon, silty shale approximately 300 ft thick. The hydrofracture injection process used discrete slots cut through the casing wall to isolate the depth at which grout slurry was emplaced in each well. The injected slurry spread along induced fractures for several hundred feet from the injection wells, forming multiple, thin grout sheets. Between 1959 (start of experimental injections) and 1984 (end of operational injections), 10.1 million gal of radioactive waste and grout (approximately 1.4 million Ci) were disposed.

A secondary, deep source referred to as "grout filtrate" is a liquid containing dissolved-phase contaminants that separated from the grout mass during solidification.

The focus of the MV Interim ROD was on: (1) principal threat wastes; (2) contaminant source and release areas; (3) contaminated structures; and (4) contaminated media, primarily soils associated with these wastes, sources, and release areas. The ROD specifically excluded secondary media, including sediment, groundwater, and floodplain soils exhibiting dose levels less than 2500 μR/h; these secondary media will be addressed by the final ROD for the watershed.

The MV source actions (completed between August 2001 and September 2006) entailed the construction of engineered cover systems and groundwater diversion/collection systems that require ongoing surveillance and maintenance (S&M) programs. The MV remedial actions left hazardous substances in-place (e.g., buried wastes beneath hydraulic isolation caps) that could pose a future potential risk if exhumed. In addition, institutional controls were selected as the remedial response action for certain units within the valley.

For purposes of U.S. Department of Energy (DOE) ORR groundwater strategy discussions, the multiple sources and groundwater contaminant signatures have been consolidated into three main groundwater plumes (Table G.2), one of which has several components. Remedial action objectives (RAOs) that form the basis for interim remedial actions are based on the future end uses depicted on Fig. G.4.



Source: DOE 1997a

Fig. G.2. Location of major contaminant source areas in the Melton Valley Watershed.

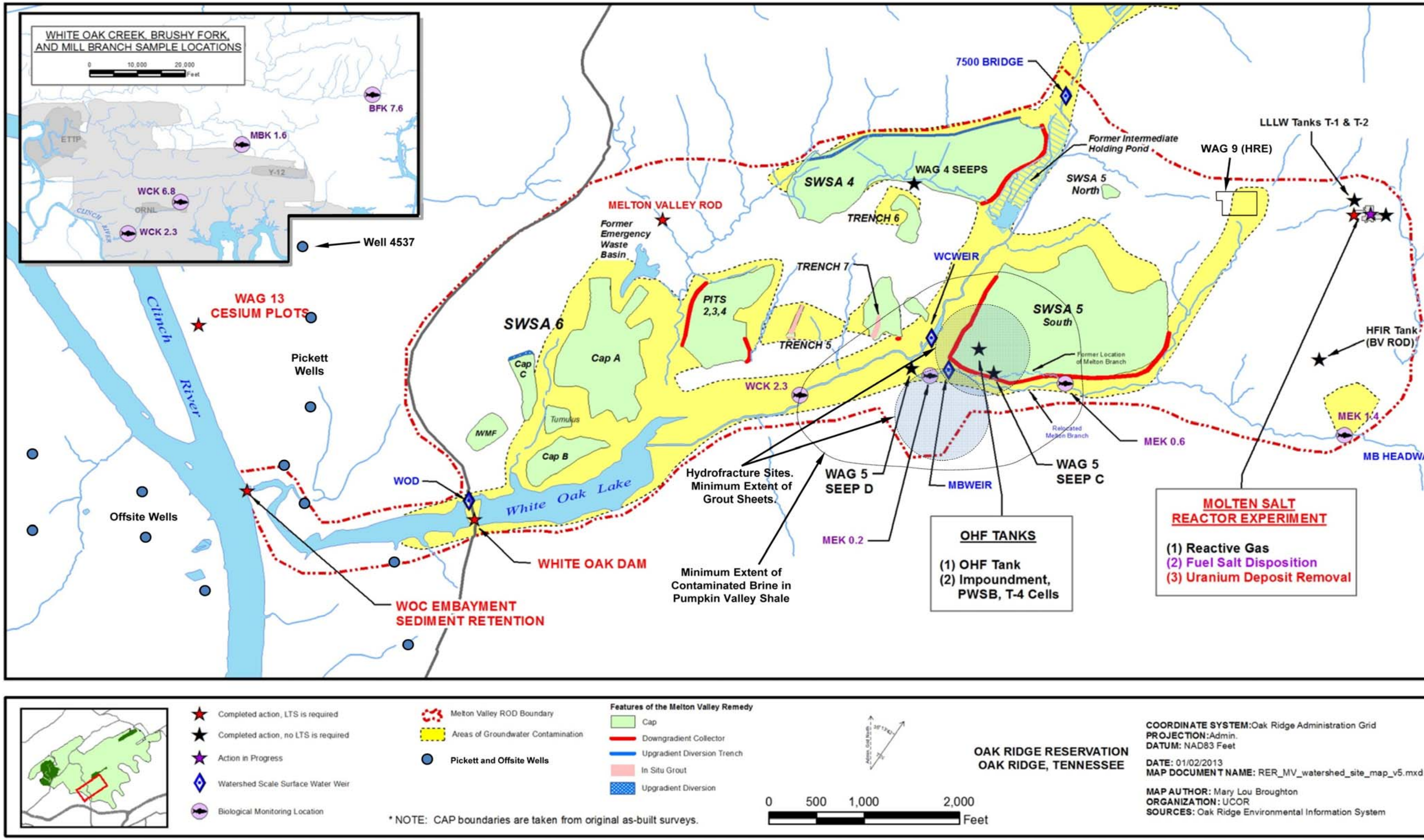
Table G.2. Groundwater contaminant plumes in the MV Watershed

Plume description	Plume No.	Source/contaminant signature
Shallow Groundwater Contamination emanating from buried waste operations overlying the Conasauga Group formations	MV-1	Contamination in shallow groundwater flow zone that quickly surfaces to nearby streams in the WOC watershed
Shallow Groundwater Contamination at SWSA 4	MV-1a	SWSA 4 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs surfacing to the WOC floodplain.
Shallow Groundwater Contamination at SWSA 5	MV-1b	SWSA 5 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, and ^{60}Co surfacing to WOC; VOCs in shallow groundwater downgradient of specific burial trenches but not at WOD.
Shallow Groundwater Contamination at SWSA 6	MV-1c	SWSA 6 shallow groundwater contamination including tritium, ^{90}Sr, ^{137}Cs, and ^{60}Co surfacing to WOC; VOCs in shallow groundwater downgradient of specific burial trenches but not at WOD.
Shallow Groundwater Contamination in the Pits and Trenches Area (also referred to as WAG 7)	MV-1d	WAG 7 shallow groundwater contamination including tritium and ^{90}Sr, surfacing to WOC.
Shallow Groundwater Contamination at WAG 9 (HRE)	MV-1e	WAG 9 ^{90}Sr and tritium contaminants from transfer pipeline leaks at HRE [7500 building area].
Hydrofracture Sites	MV-2	Deep injection of grout used as a carrier for intermediate-level liquid radioactive wastes with ^{90}Sr and tritium contaminants being the potentially mobile constituents.
Exit Pathway/Picket Wells contamination from undetermined sources	MV-3	Western migration(?) of contaminants from SWSAs or hydrofracture to MV picket wells?

HRE = Homogeneous Reactor Experiment.
MV = Melton Valley.
SWSA = Solid Waste Storage Area.
VOC = volatile organic compound.
WAG = Waste Area Grouping.
WOC = White Oak Creek.
WOD = White Oak Dam.

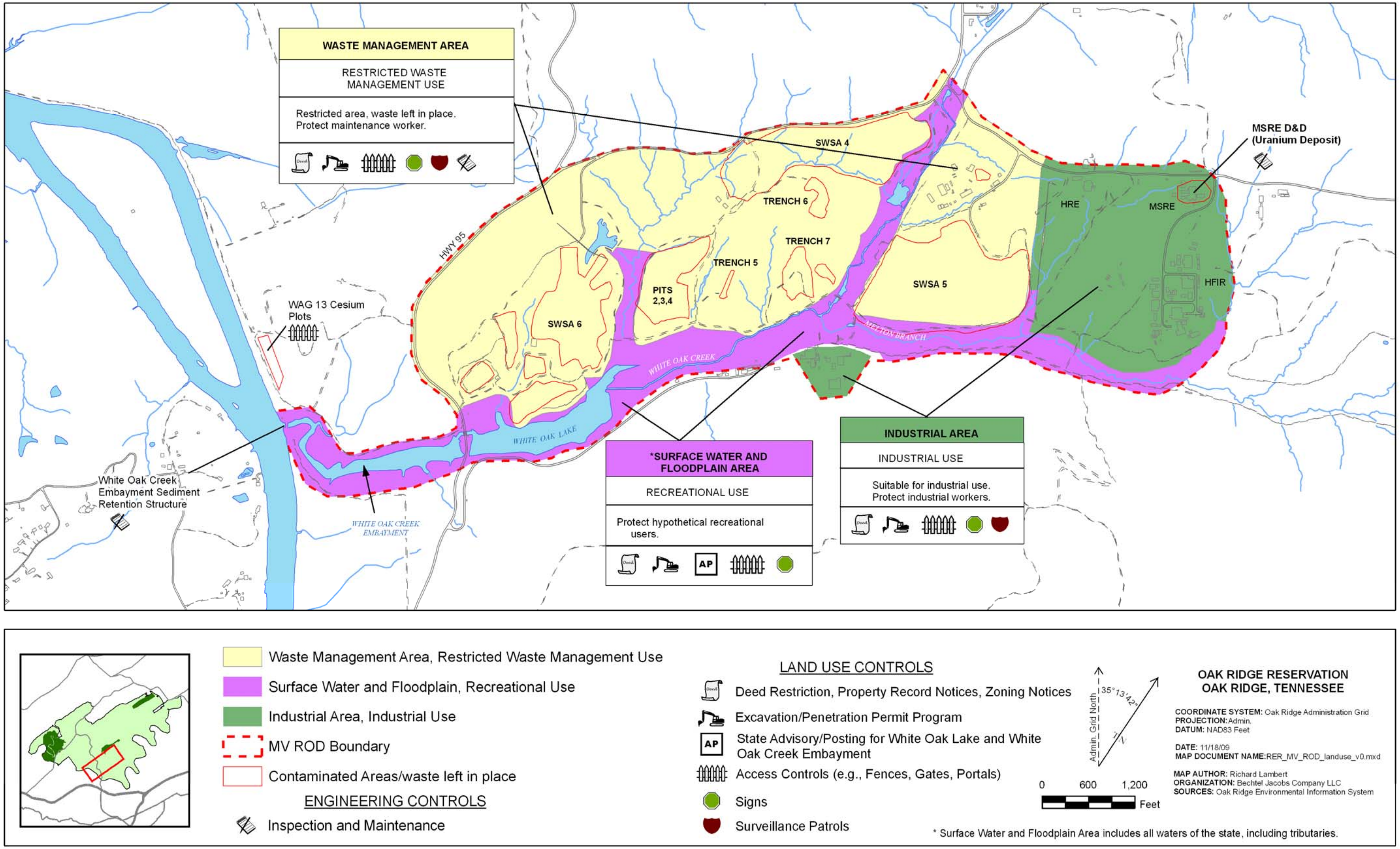
G.1.3 GEOLOGY AND HYDROLOGY

Most of the waste units in MV overlie the Maryville Limestone and the Nolichucky Shale geologic formations, which are low-permeability formations within the Conasauga Group (Fig. G.5). A geologic block model showing the configuration of various formations is presented on Fig. G.6. The vantage point of this figure is from the west, looking up-valley toward the east. Note that most of the rock types that underlie MV are siliciclastic aquitards, whereas the Knox aquifer (Knox Group and the Maynardville Limestone) stores and transmits relatively large volumes of water, including flow in solution conduits. The typical groundwater table in MV is presented on Fig. G.7.



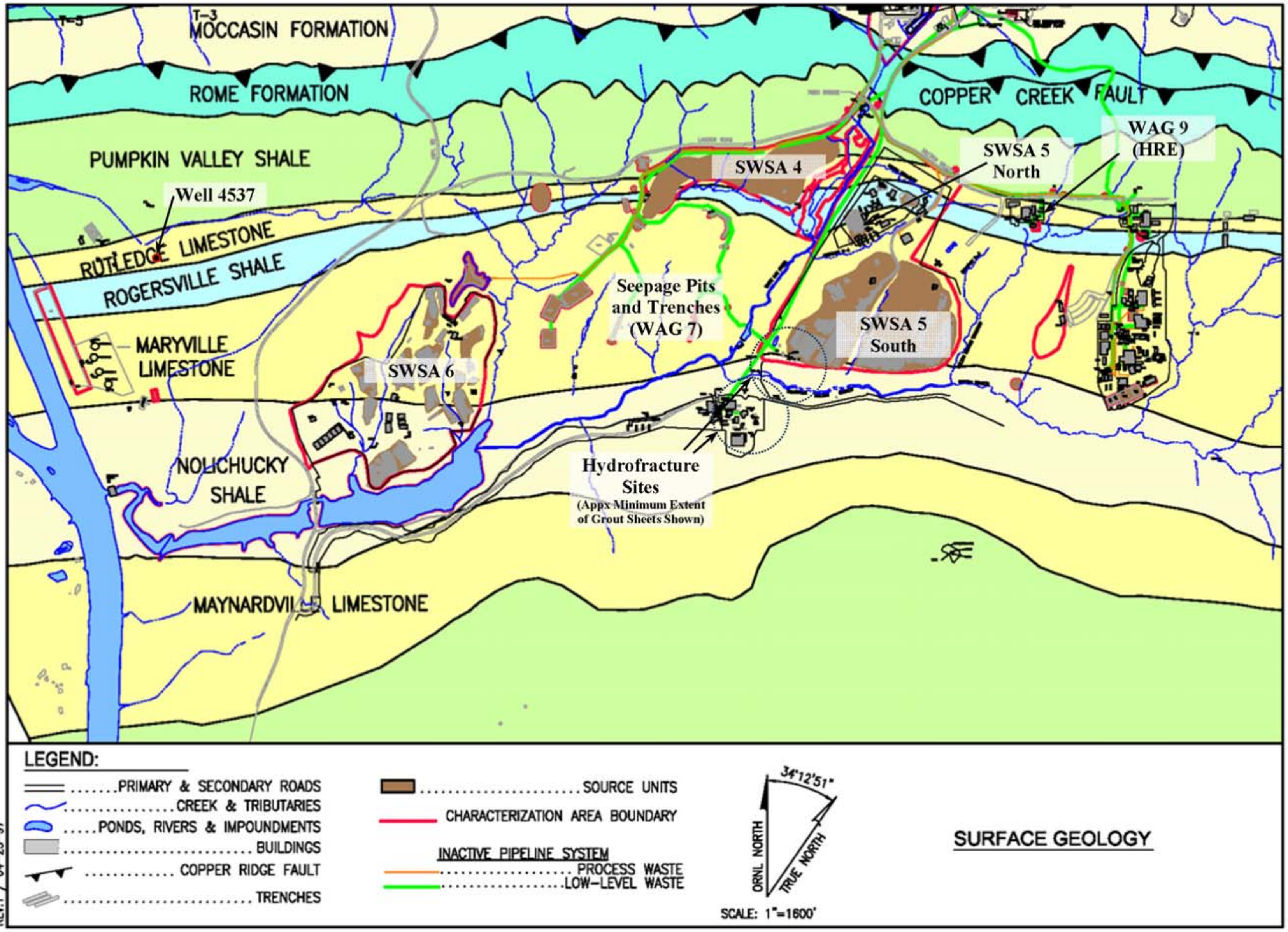
Source: DOE 2013

Fig. G.3. Location of current contaminant source areas, waste unit closure configuration and identified groundwater plumes.



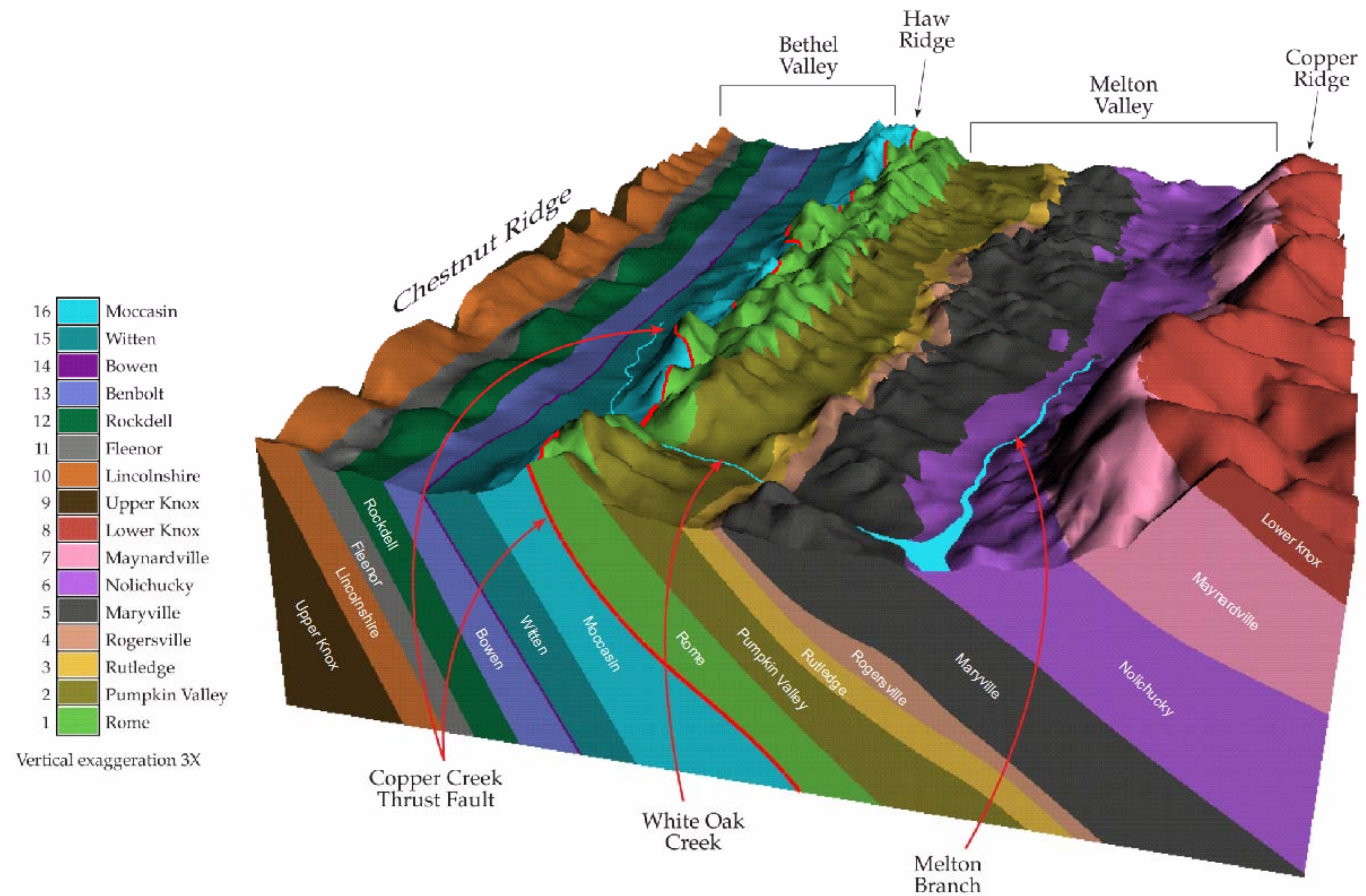
Source: DOE 2013

Fig. G.4. Melton Valley ROD-designated future end use and interim land use controls.



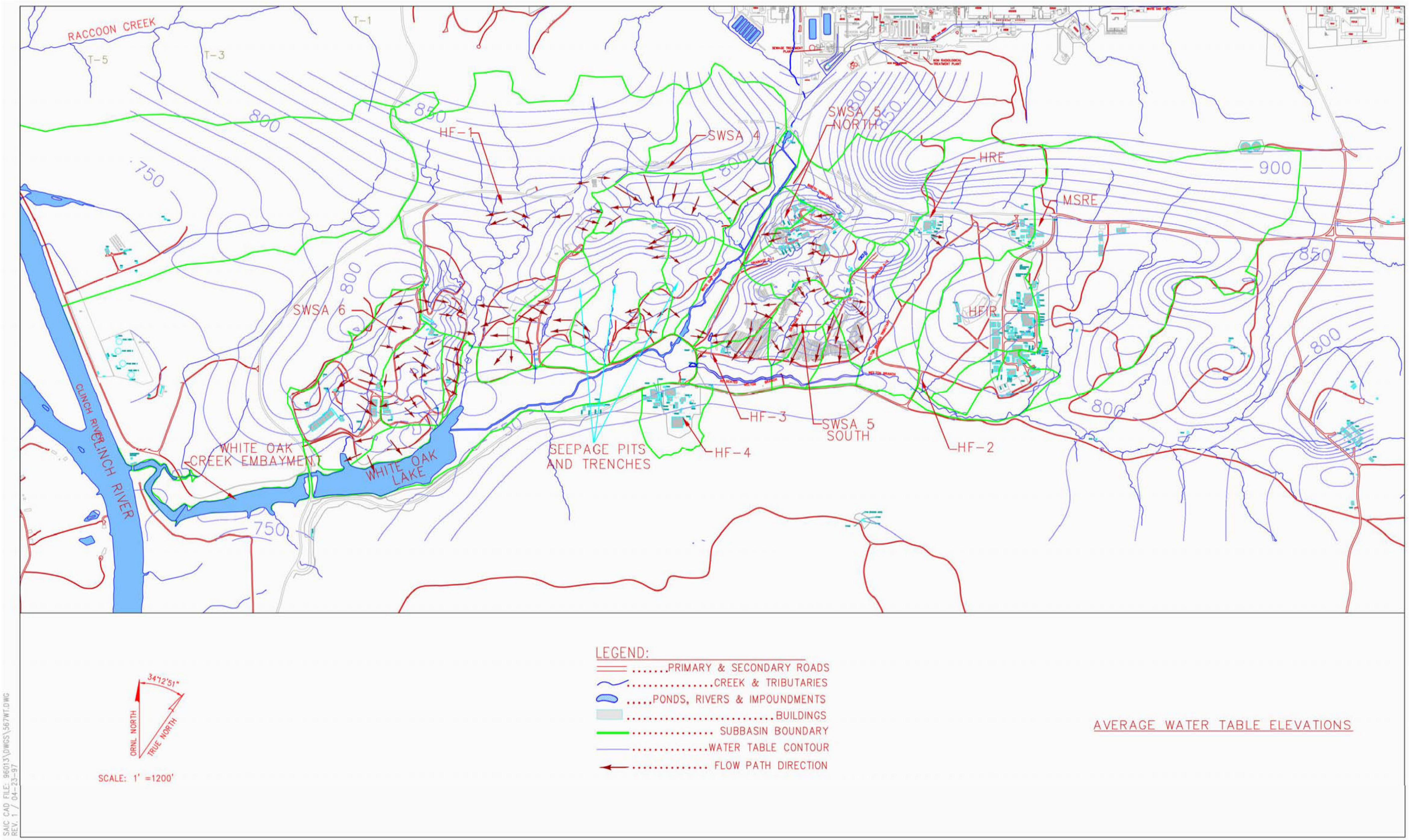
Source: adapted from DOE 1997a

Fig. G.5. Surficial geology of the Melton Valley Watershed.



Source: DOE 1997a

Fig. G.6. 3-D Block diagram of geology in Melton and Bethel Valleys (view up-valley to the east).



Source: DOE 1997a

Fig. G.7. Average water table elevation in the Melton Valley Watershed

Shallow groundwater and surface water are tightly coupled, resulting in a large fraction of infiltrated rainwater (>95%) that moves to and through the shallow groundwater/surface water system and across White Oak Dam (WOD).

- Greater than 95%[1] of that rainfall migrated to shallow groundwater and resurfaced to surface water prior to leaving the ORR. All surface water in MV drains to WOC and out to the Clinch River.

- There is a small percentage of water (<5%) that may intersect groundwater fractures and move along strike through the deeper groundwater system.

Shallow Groundwater

Because shallow groundwater release to surface water is the primary component of the MV contaminant release model, environmental monitoring in the MV Watershed has focused on surface water, with emphasis on WOD and on the major surface water sites within the watershed. Figure G.8 presents the location of the surface water monitoring locations within MV. During fiscal year (FY) 2012, rainfall was approximately 15% greater than the long-term average of 54 in. The total fluxes of ^{137}Cs, ^{90}Sr, and tritium measured at WOD were comparable to the FY 2007 through FY 2011 values (Fig. G.9) [DOE 2013]. Containment mass flux measurements in surface water show approximately a 45% reduction since the completion of the interim remedies.

Deep Groundwater

A conceptual model for the hydrofracture subsurface was developed for the MV RI:

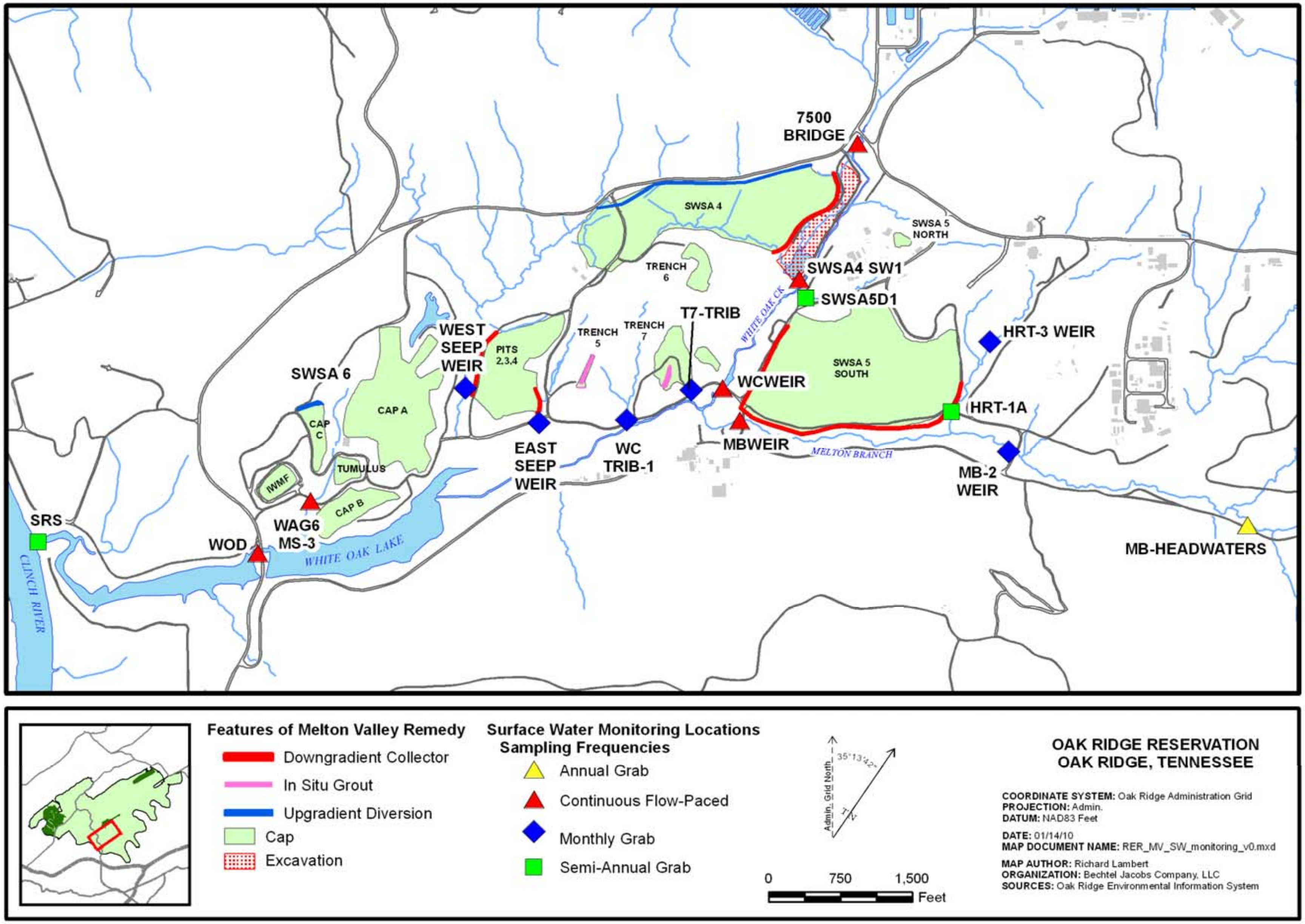
- Pressures at depth beneath the hydrofracture injection zone are influenced by groundwater recharge in the Rome Formation and in the fault rock of the Copper Creek Fault, suggesting that the grout filtrate could migrate upward (Fig. G.5).

- Vertical migration could have occurred in the well boreholes (prior to well plugging and abandonment [P&A]) because of well deterioration and voids between the casing and the boreholes.

Regional Hydrology Monitoring Discussion

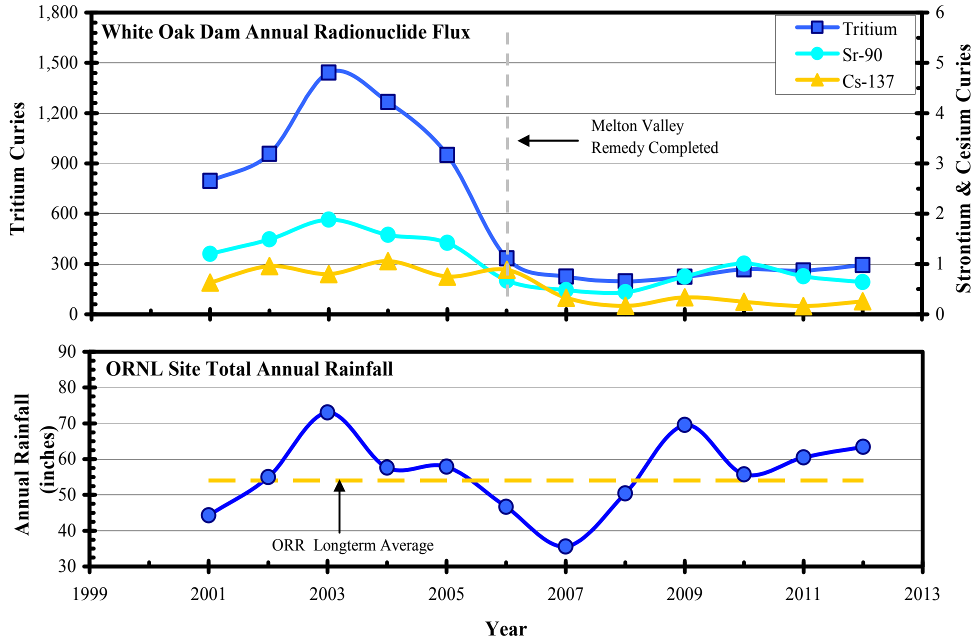
In 2004, a line of sentinel wells was constructed to monitor both intermediate and deep subsurface between the burial grounds and the Clinch River (Fig. G.10, cross-section A). In 2010, wells were constructed across the Clinch River to monitor the potential that groundwater withdrawals across the Clinch could draw contaminated groundwater under the river. Initial sampling was conducted at all new sampling points and from additional nearby residential wells in FY 2010 and FY 2011. Based on the discussions with the regulators, a new MV exit pathway monitoring strategy for both the MV sentinel wells and the off-site wells across the Clinch River was developed. The revised monitoring strategy is documented in the *Water Resources Restoration Program Sampling and Analysis Plan for the Melton Valley Watershed, Oak Ridge Reservation, Oak Ridge, Tennessee* (DOE 2012d). Summary observations from sampling reported in the 2013 RER (DOE 2013) and further discussion of the hydrologic characteristics of select off-site wells are provided in Sect. G.2.3.

[1] Section 5.1.4.1 of the FYR (DOE 2012c) indicates that "*Greater than 97% of that rainfall migrated to shallow groundwater and resurfaced to surface water prior to leaving the ORR*." Solomon et al. (1992) indicate that "*as much as 95% of this water [infiltration] is quickly discharged through a zone at and near the surface via short, transiently saturated flow paths to adjacent surface drainageways*."



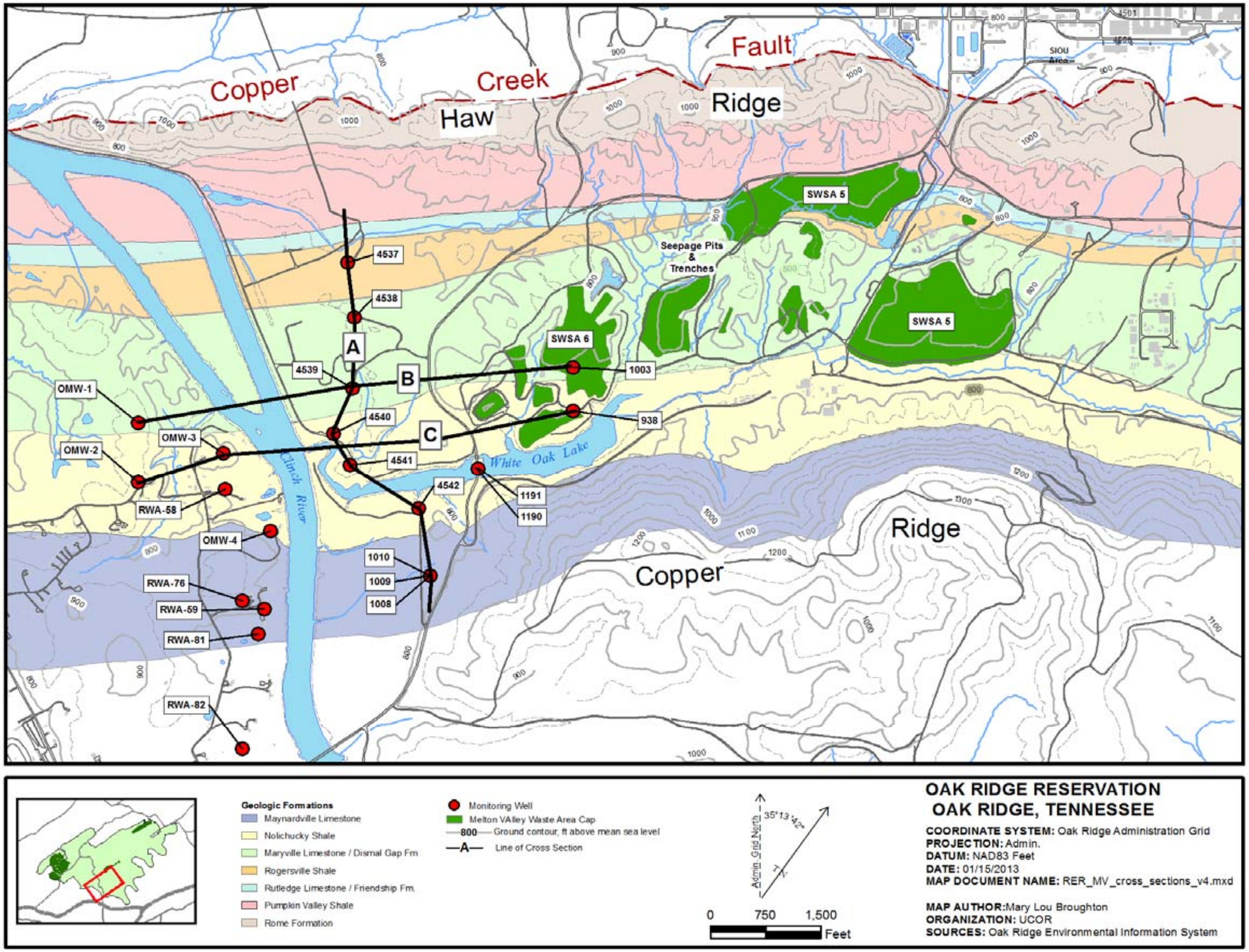
Source: DOE 2013

Fig. G.8. Melton Valley surface water monitoring locations.



Source: DOE 2013

Fig. G.9. Annual radionuclide fluxes at White Oak Dam and annual rainfall at the ORNL.



Source: DOE 2013

Fig. G.10. Locations of Melton Valley exit pathway wells and off-site monitoring wells.

G.1.4 SUMMARY OF GROUNDWATER CHEMICALS OF CONCERN AND RISK

The primary groundwater chemicals of concern (COCs) in MV are tritium, ^{90}Sr, and volatile organic compounds (VOCs):

- Tritium and ^{90}Sr were placed in most of the shallow burial areas of SWSAs 4, 5, and 6.

- VOCs are present in various locations throughout the valley, primarily in SWSA 5 and SWSA 6. VOCs are seen in these areas in shallow groundwater downgradient of specific burial trenches and/or auger holes, but are not detected at WOD.

- Cesium-137 is present primarily in soils of the WOC floodplain and is not typically found dissolved in groundwater.

- Alpha emitters, primarily uranium and TRU elements, are present in some locations of the valley but are not observed routinely in surface water and shallow groundwater.

As reported in the 2011 FYR, the excess lifetime cancer risk sum of fractions (SOF) for shallow groundwater/surface water pathways is greater than 1 (SOF = 2), indicating the overall risk goal of protecting residential exposure at WOD has not yet been met. The carcinogens include arsenic, and the radionuclides. The time frame for meeting the ROD goal is 10 years (approximately 2016).

For deep groundwater, the MV RI Report (DOE 1997a; DOE 1997b) indicates the following: "No groundwater data are associated with the area (Hydrofracture Sites), so deep groundwater COCs were not identified." One of the requirements of the ROD was the construction of wells to fill this data gap. Exit pathway groundwater monitoring includes monitoring of wells 1190 and 1191, located on WOD; monitoring of six deep groundwater wells installed in 2004 between the Clinch River and the western edge of SWSA 6. Off-site groundwater monitoring is conducted at new wells installed beginning in FY 2010 at two clusters containing five wells each, and at two residential wells that have been modified to provide multiple monitoring zones. These off-site wells are located southwest of the Clinch River (see Fig. G.10).

G.1.5 SUMMARY OF INTERIM ROD ACTIONS

The MV Closure Project, which ended in 2006, included the following remedial actions that have had a significant impact on contaminant releases in the valley:

- Construction of 145 acres of multi-layer caps covering SWSA 4, SWSA 5 South, SWSA 6, the upper four trenches in SWSA 5 North, and portions of the Seepage Pits and Trenches area.

- Installation of 3065 ft of upgradient diversion trenches at the Trench 7 Leak Site, SWSA 4, and SWSA 6, and a 2235-ft-long, low-permeability groundwater cut-off wall at SWSA 5.

- Installation of 5395 ft of downgradient interceptor trenches at SWSA 4, SWSA 5 South, and the Seepage Pits, and 14,596 ft of transfer lines to convey the water collected by the interceptor trenches to BV treatment facilities.

- Remediation of five surface impoundments in MV, including four impoundments at the HFIR Complex and the HRE Pond.

- Removal of 204 casks of TRU waste from the 22 TRU trenches in SWSA 5 North.
- Remediation of nearly 40,000 ft of inactive LLLW and process waste pipelines in MV.
- In situ grouting of Seepage Trenches 5 and 7 and the HRE fuel wells.
- Removal of contaminated floodplain soil from the Intermediate Holding Pond adjacent to WOC and SWSA 4.
- Decontamination and decommissioning (D&D) of 31 facilities, including the NHF, HRE Ancillary Facilities, MV liquid waste pumping stations, and other structures across the valley.
- Removal of tank contents and grouting of LLLW tanks T1 and T2; grouting of the HFIR LLLW tank.
- P&A of 1086 unneeded shallow wells, as well as the 4 hydrofracture injection wells and 107 wells used for monitoring of the hydrofracture program.
- Remediation of contaminated soil at six sites associated with releases of contamination from the LLLW pipeline system or hydrofracture injection experiments.
- Remediation of 25 localized hot spots identified through final verification surveys or as a consequence of pipeline remediation or small facilities D&D activities.
- Remediation of the Engineering Test Facility and EPICOR II Lysimeters.
- Completion of final verification surveys and sampling on 587 acres (the uncapped portion of MV).
- Development and implementation of plans for monitoring, S&M, and LUCs.

G.2 CONCEPTUAL MODEL, SOURCE AREA SCALE

G.2.1 MV-1 SHALLOW GROUNDWATER SOURCE AREAS

G.2.1.1 MV-1a SWSA 4

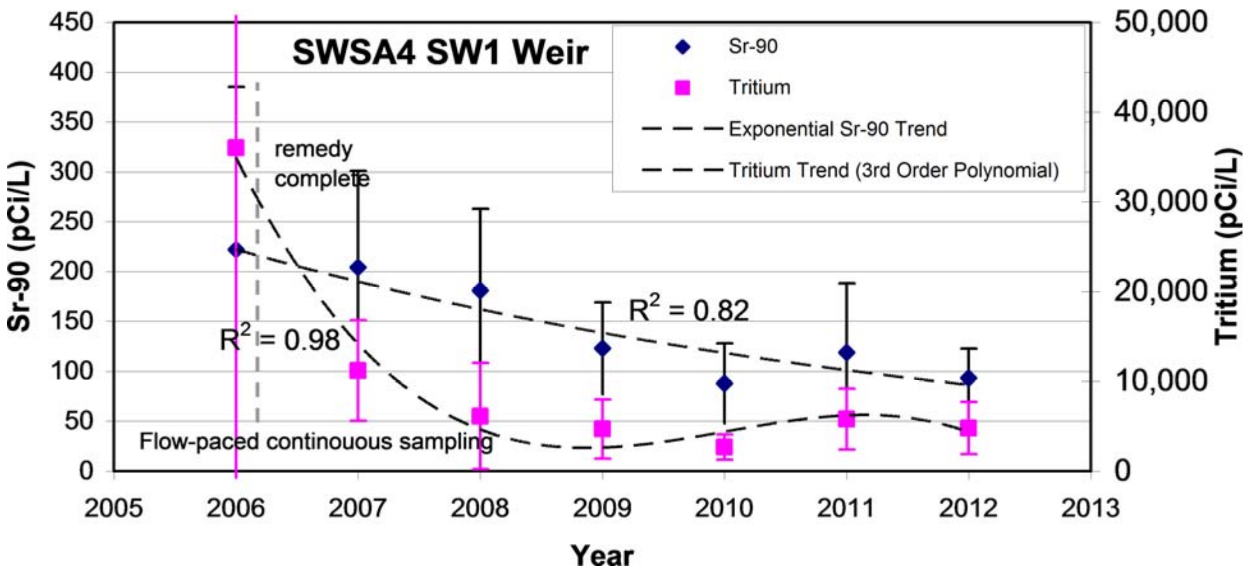
The first of the principal waste burial sites at ORNL, SWSA 4, is described below:

- SWSA 4 includes 23 acres of unlined trenches and auger holes. The total volume of waste buried at SWSA 4 between 1951 and 1959 is estimated at 57,000 m^3, with a total radioactivity of 110,800 Ci. From 1959 to 1973, SWSA 4 received only non-radioactive waste.
- Decay of radionuclides in these primary source areas will result in radionuclide inventories of less than 10% of the disposed activities by the year 2050 and less than 1% of the disposed activities by the year 2200. The relatively rapid, initial decrease in radionuclide inventories in this source area is due primarily to decay of short-lived beta emitters (e.g., ^{106}Ru, ^{60}Co, and trivalent rare earths). The bulk of the remaining inventory consists of ^{137}Cs and ^{90}Sr with half-lives of 30.2 and 28.5 years, respectively. Long-lived TRU and uranium isotopes account for less than 25 Ci in the West Seep subbasin and less than 10 Ci in the SWSA 4 Main subbasin.

- Much of the waste at SWSA 4 was located in or very near the water table. Most of SWSA 4 waste lies in the Upper Pumpkin Valley Shale and Rutledge Limestone outcrop belts (Fig. G.5).

- The selected remedy for SWSA 4 was hydraulic isolation via construction of an engineered low-permeability cap. Groundwater emanating from capped waste areas is collected by downgradient interceptor trenches along the eastern edge of SWSA 4 and is routed to an equalization tank located at SWSA 4 before being transferred to the Process Waste Treatment Complex (PWTC) for processing in BV. This downgradient Trench (1164 ft long) was installed to the top of bedrock (11 to 14 ft bgs). A separate upgradient trench located on the north side of SWSA 4 (2459 ft long) captures and diverts water from flowing under the cap. Water from this diversion trench is not sent to the PWTC treatment facility.

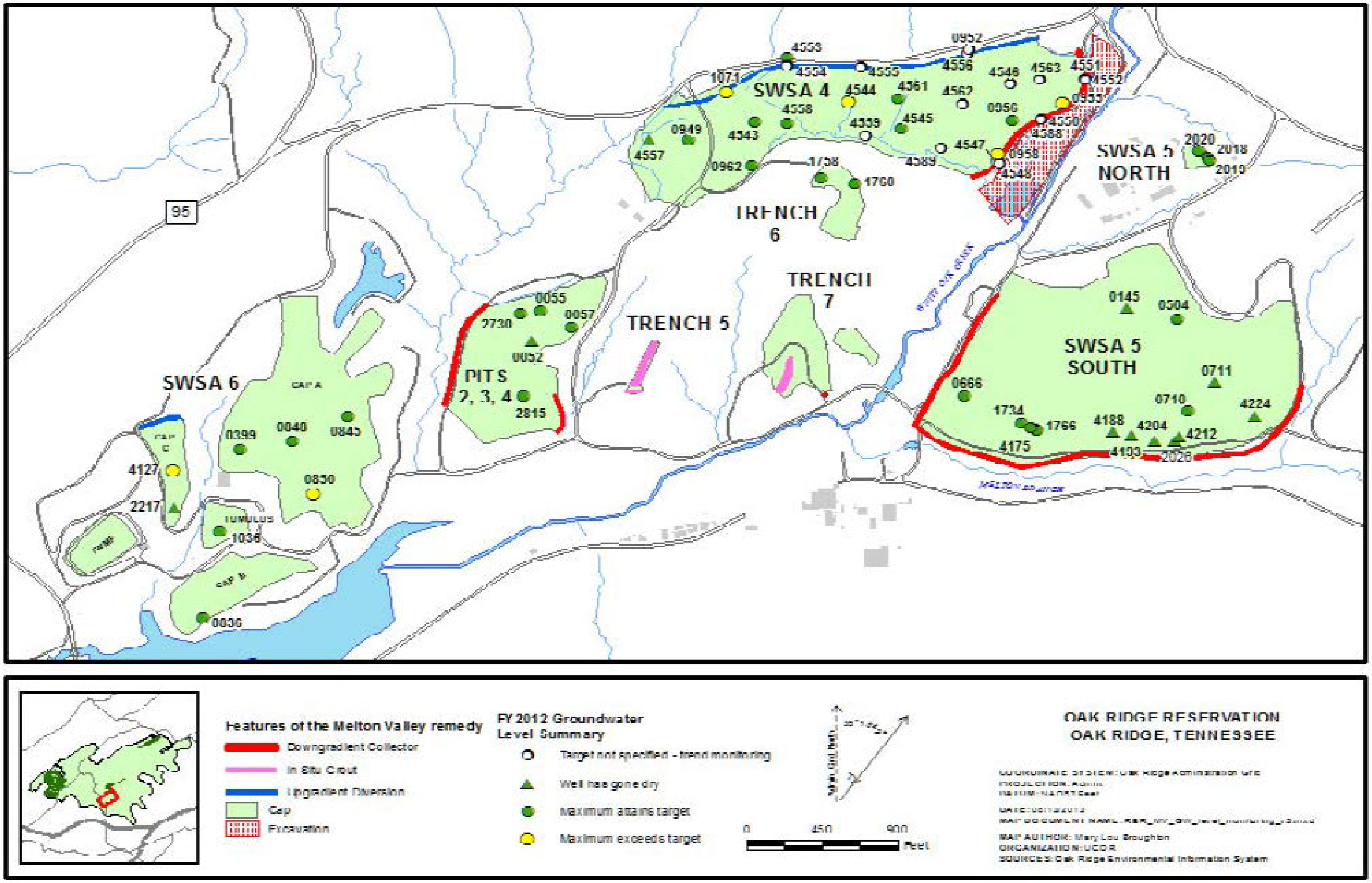
- Continuous flow-paced sampling at SWSA 4 SW1 (for location see Fig. G.8) shows tritium and ^{90}Sr trends since the MV action was completed (Fig. G.11). Tritium and ^{90}Sr activities decreased at the SWSA 4 SW1 location during FY 2012 following a slight increase observed in FY 2011 (DOE 2013).



Source: DOE 2013

Fig. G.11. Tributary surface water average annual radionuclide activities at SWSA 4 SW1 weir.

Fifty-three wells lie within the MV hydrologic isolation areas and are used to evaluate groundwater fluctuations beneath caps (Fig. G.12). During FY 2012, over 85% of the 53 wells met their target groundwater elevations while 7 wells did not (similarly 6 wells did not meet target water levels in FY 2011). Eight of the 13 wells located within SWSA 4 with water level targets attained the specified target in FY 2012. Wells within SWSA 4 that did not meet the water level target are shown as yellow circles on Fig. G.12 and include wells 1071, 4544, 4547, and 0955. One well was dry (4557). Some of the 53 wells (4127, 0938, 0850, and 1071) did not attain the design target elevations because of well construction characteristics, location very near edges of caps, location with respect to pre-remediation topography, or location near a downgradient trench. Wells that did not meet their target elevations during FY 2012 have attained essentially stable hydrologic response patterns and the same wells have been identified for several years.



Source: DOE 2013

Fig. G.12. Summary of groundwater-level monitoring results for FY 2012.

Some shallow wells inside the hydrologically isolated areas have gone dry as a result of area capping and water level decline. Some shallow wells inside hydrologically isolated areas exhibit continuing water level declines as gradual drainage of groundwater toward collector trenches or adjacent surface water bodies occurs.

The groundwater and surface water COCs in the area are listed in the MV RI (DOE 1997; *Table 3.13 subbasins SWSA 4 Main, SWSA 4 East*) and include:

- Groundwater: ^{241}Am, ^{14}C, ^{137}Cs, ^{90}Sr, ^{3}H, ^{234}U; As, Ni, Sb, 1,1-dichloroethene (DCE), *cis*-1,2-DCE, Ni, trichloroethene (TCE), and vinyl chloride (VC).

- Surface Water: Cd, Ni, Pb, Se, As, and Tl.

Table G.3 provides a summary for the groundwater plume in the SWSA 4 source area.

Table G.3. SWSA 4 groundwater plume

Plume No.	Name	Description[a]: Length (ft down valley)	Description[a]: Depth (ft bgs)	Description[a]: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
MV-1a	Shallow contamination at SWSA 4 (^{3}H, ^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Rutledge Limestone and Pumpkin Valley Shale)	Variable; SWSA 4 cap has approximate dimensions of 3000 by 750 ft; speculative along- strike travel to picket wells in excess of 5000 ft	30 to 40 ft	Sr-90 in surface water at SWSA 4 SW1 weir is about 100 pCi/L and tritium is about 5000 pCi/L	Primarily follows soil/ bedrock interface to seeps along streams; speculative along-strike flow toward picket wells	WOC via SWSA 4 SW1; SWSA 4 downgradient trench; MV Picket (well 4537)	• It is uncertain if there is along-strike flow and transport to the west in more transmissive portions of Rutledge Limestone • Failure in attainment of water level targets in some monitoring wells brings into question isolation on all waste

[a] Values are approximate based on Remedial Investigation plume maps.
MV = Melton Valley.
pCi/L = picocuries per liter.
SWSA = Solid Waste Storage Area.
VOC = volatile organic compound.
WOC = White Oak Creek.

G.2.1.2 MV-1b SWSA 5

The second principal waste burial site at ORNL, SWSA 5, is described below:

- SWSA 5 South contains over 220 unlined waste trenches and nearly 1000 unlined auger holes. Waste disposal activities occurred between 1959 and 1973, involving a variety of solid and liquid radioactive wastes from ORNL facilities. In addition, waste was received from other agencies prior to 1963 when ORNL was designated the Southeast Regional Burial Ground by the Atomic Energy Commission. Records indicate a total of approximately 85,000 m^3 of wastes containing 210,810 Ci of radioactivity were placed in the disposal facility.

- The SWSA 5 North area in MV contained 22 earthen trenches in which remote-handled transuranic (RH-TRU) wastes were retrievably stored. The 22-trench area includes trenches 1 through 7, 9, 10, 12, 13, 15, and 18 through 27, where wastes were emplaced between 1972 and 1981. Wastes consisted of 204 large concrete casks, 18 steel and/or wooden boxes, and 12 steel drums. In addition, approximately 15 m^3 of miscellaneous loose waste was placed in the 22-trench area. Most of the containers came from ORNL's Radiochemical Engineering Development Center.

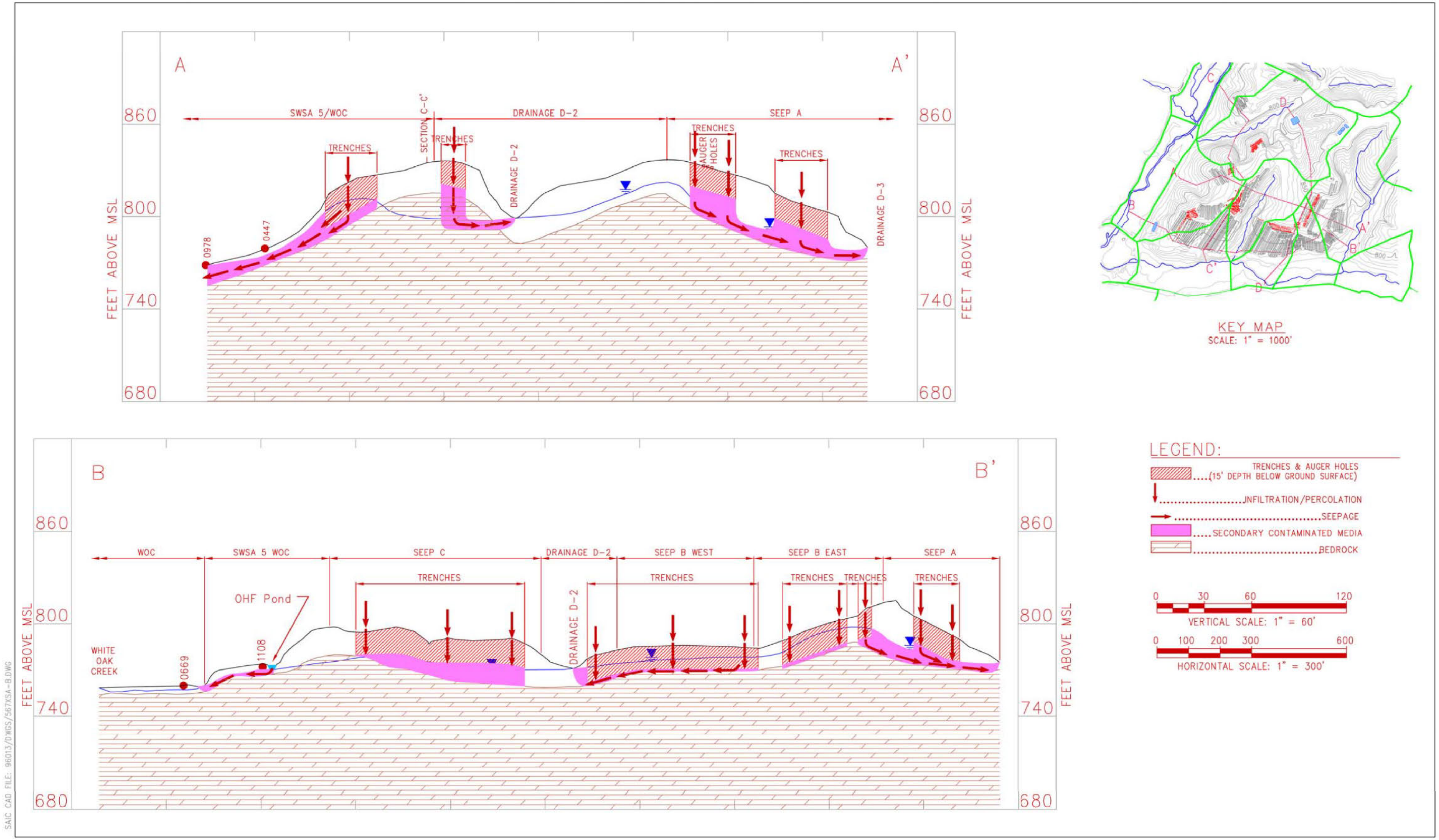
- Primary contaminants include ^{90}Sr, ^{137}Cs, ^{60}Co, and tritium, with lesser quantities of uranium-thorium isotopes and TRU contaminants. Most of the buried waste in SWSA 5 lies in the Maryville limestone outcrop belt with lesser amounts in the Nolichucky Shale (Fig. G.5).

- The TRU Trenches Waste Retrieval Project was conducted as planned with the exception that the pyrophoric wastes buried in Trench 13 were stabilized in-place in lieu of removal.

Pre-MV action cross-sections (DOE 1997a) showing the configuration of trenches, surface topography, bedrock surface, schematic infiltration/contaminant flow directions, and primary/secondary contaminated media are provided on Figs. G.13 and G.14. Capping during the MV action eliminated infiltration/percolation as a driving force, but the basic geometry of the waste cells and environment remained the same.

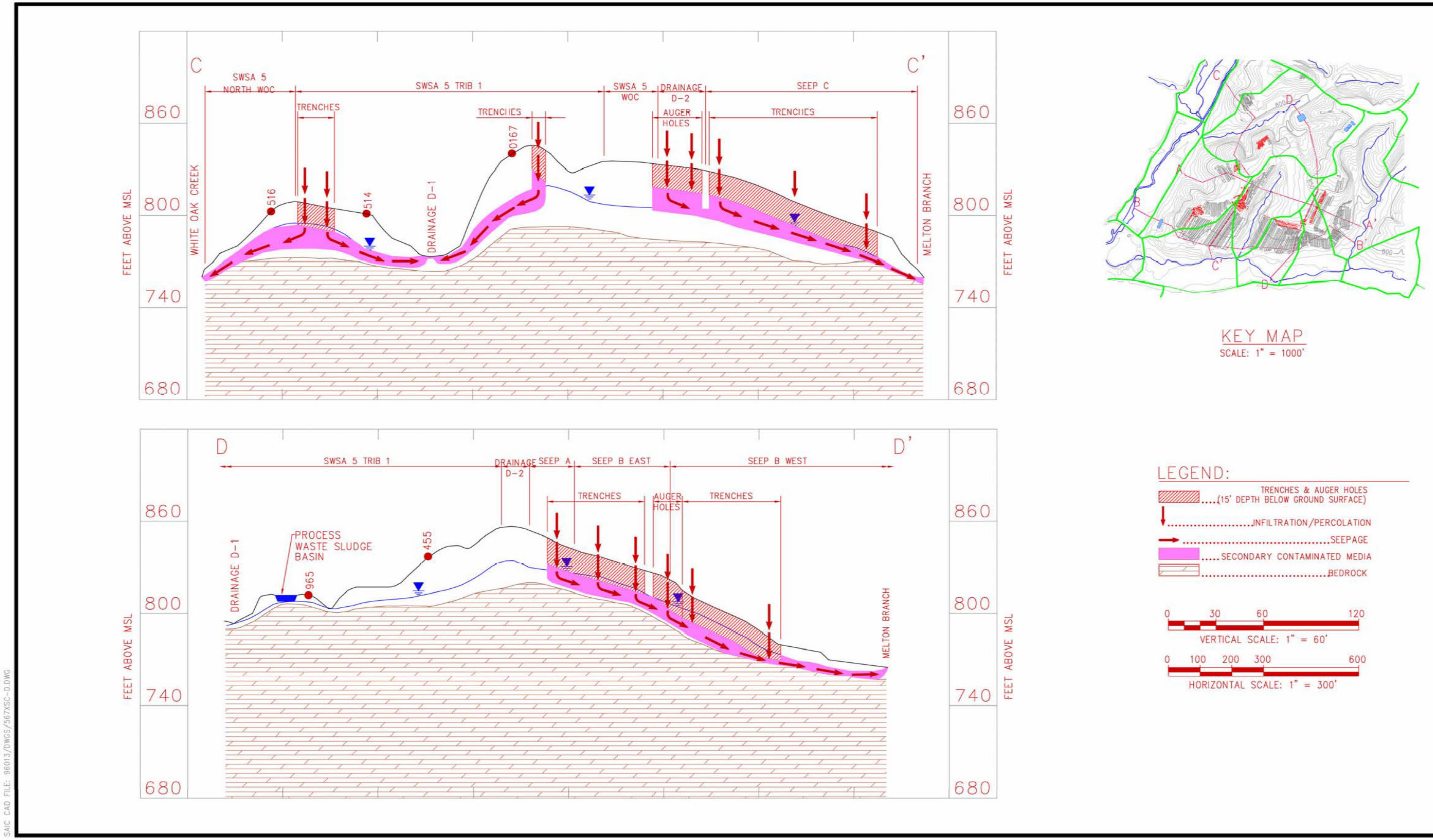
The 2011 FYR indicates that wells used to monitor hydrologic isolation in SWSA 5 South met target water levels at all monitoring locations in SWSA 5 South (in FY 2010). In SWSA 5 North the target water levels were met at two monitoring locations in FY 2010; target levels were not met at one monitoring location, 2018. More recently, the 2013 RER (DOE 2013) shows that all targets were met for FY 2012 (Fig. G.12).

The selected remedy for SWSA 5 was hydrologic isolation via construction of an engineered low-permeability cap. Groundwater emanating from capped waste areas is collected by downgradient interceptor trenches at SWSA 5 and is routed to an equalization tank located at SWSA 4 before being transferred to the PWTC for processing in BV. The interceptor trench at SWSA 5 South is located along the eastern and western sides and extends for 3513 ft. The trench consists of a bentonite slurry cut-off wall and associated sumps that are used to shunt captured water to the equalization tank.



Source: DOE 1997a

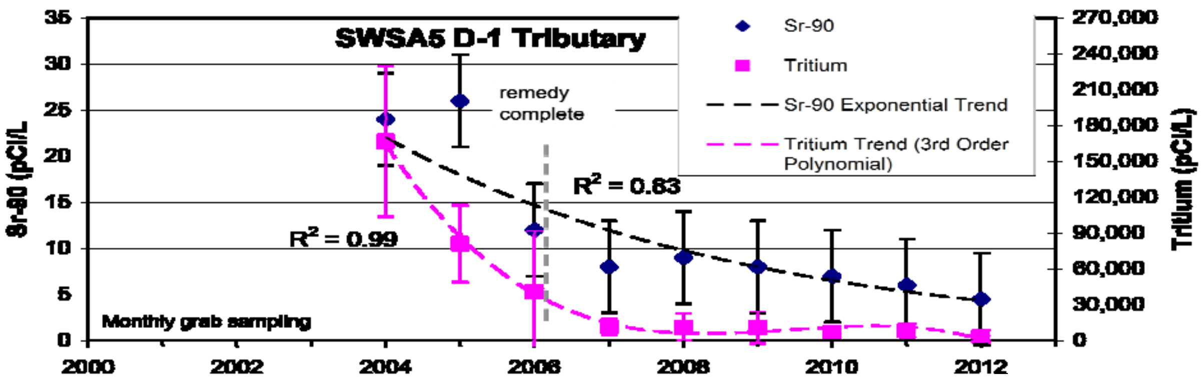
Fig. G.13. West-East cross-sections through SWSA 5 South.



Source: DOE 1997a

Fig. G.14. North-South cross-sections through SWSA 5 North and South.

Continuous flow-paced sampling at SWSA 5 D-1 weir (for location, see Fig. G.8) shows tritium and ^{90}Sr trends since the MV action was completed (Fig. G.15). Tritium and ^{90}Sr activities decreased at the SWSA 5 D-1 location during FY 2012.



Source: DOE 2013

Fig. G.15. Tributary surface water average annual radionuclide activities at SWSA 5 D-1 weir.

The groundwater and surface water COCs in the area are listed in the MV RI (DOE 1997a; *Table 3.13 subbasins SWSA 5 Trib 1, MV Drive, SWSA 5 N WOC, SWSA 5 WOC, Seep A, Seep B West, Seep B East, Drainage D-2, Seep C*) and include:

- Groundwater: ^{241}Am, ^{14}C, ^{137}Cs, ^{90}Sr, ^{3}H, ^{228}Ra, ^{60}Co, ^{234}U, ^{232}Th, ^{244}Cm; benzene, carbon tetrachloride (CT), 1,1-DCE, tetrachloroethene (PCE), TCE, VC, and Tl.
- Surface Water: As, Sb, Tl, Cu, CT, 1,1-DCE, and PCE.

Table G.4 provides a summary for the groundwater plume in the SWSA 5 source area.

Table G.4. SWSA 5 groundwater plume

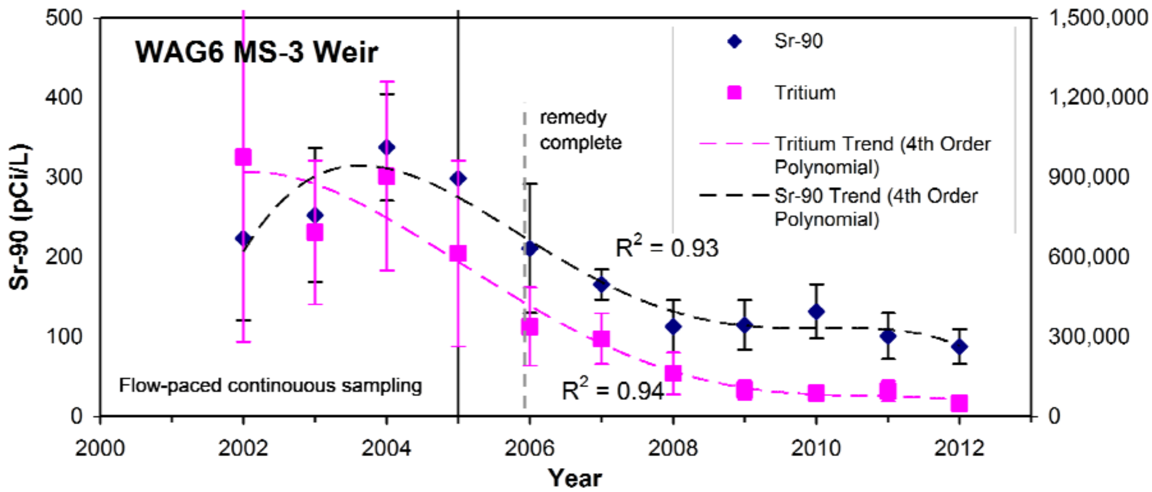
Plume No.	Name	Description[a] Length (ft down valley)	Depth (ft bgs)	Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
MV-1b	Shallow contamination at SWSA 5 (^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Maryville Limestone and subsidiary amounts in Nolichucky Shale)	Variable; SWSA 5 cap has approximate dimensions of 2500 by 1250 ft.	<= 30 to 40 ft	Sr-90 in surface water at SWSA 5 D-1 weir is about 5 pCi/L and tritium is about 5000 pCi/L.	Primarily follows soil/ bedrock interface to seeps along streams.	Nearby streams, including WOC, SWSA 5 D-1, D-2, and Melton Branch	• Unknown if there is along-strike transport toward the west in more transmissive portions of Maryville Limestone.

[a] Values are approximate based on Remedial Investigation plume maps.
MV = Melton Valley.
pCi/L = picocuries per gram.
SWSA = Solid Waste Storage Area.
VOC = volatile organic compound.
WOC = White Oak Creek.

G.2.1.3 MV-1c SWSA 6

Most of the buried waste in SWSA 6 lies in the Maryville limestone outcrop belt with lesser amounts in the Nolichucky Shale (Fig. G.5). The selected remedy for SWSA 6 was hydraulic isolation via construction of an engineered low-permeability cap.

Continuous flow-paced sampling at the WAG 6 MS-3 weir (for location see Fig. G.8) shows tritium and ^{90}Sr trends since the MV action was completed (Fig. G.16). Both tritium and ^{90}Sr activities continued to decrease at the WAG 6 MS-3 weir location during FY 2012.



Source: DOE 2013

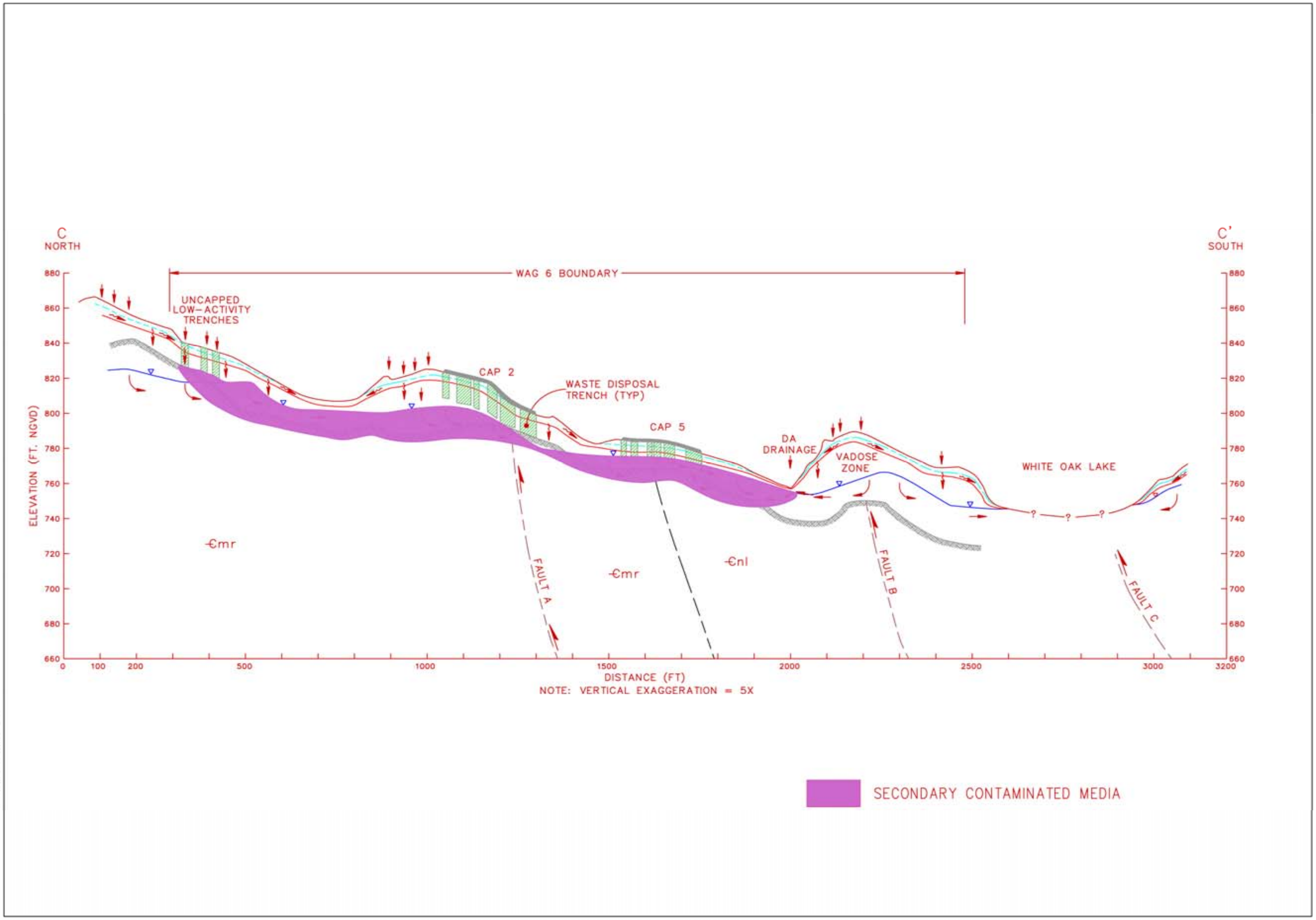
Fig. G.16. Tributary surface water average annual radionuclide activities at WAG6 MS-3 weir.

A pre-MV ROD action cross-section from the MV RI (DOE 1997a) showing the configuration of trenches, surface topography, bedrock surface, schematic infiltration/contaminant flow directions, and primary/secondary contaminated media is presented on Fig. G.17. Capping during the MV action eliminated infiltration/percolation as a driving force, but the basic geometry of the waste cells and environment remained the same. Wells used to monitor hydrologic isolation in SWSA 6 met target levels in FY 2010 at six monitoring locations; target levels were not met at three monitoring locations (wells 4127, 0850, and 0938). During both FY 2011 and FY 2012, wells 4127 and 0850 did not meet the monitoring level target (Fig. G.12). Bedrock wells are observed to respond to head changes from areas outside hydrologic isolation structures, which can cause target groundwater level exceedances.

The groundwater and surface water COCs in the area are listed in the MV RI (DOE 1997a; *Table 3.13 subbasins W6MS1,W6MS3, SWSA 6 South, SWSA 6 East*) and include:

- Groundwater: ^{3}H, ^{244}Cm, ^{90}Sr; Tl, TCE, VC, CT, and 1,2-dichloroethane (DCA).
- Surface Water: As, Hg, 1,1-DCE, Hg, Cd, Cr, Cu, and Pb.

Table G.5 provides a summary for the groundwater plume in the SWSA 6 source area.



Source: DOE 1997a

Fig. G.17. North-South cross-section through SWSA 6.

Table G.5. SWSA 6 groundwater plume

		Description[a]					
Plume No.	**Name**	**Length (ft down valley)**	**Depth (ft bgs)**	**Concentration**	**Flowpaths**	**Groundwater exit points**	**Data gaps and uncertainties**
MV-1c	Shallow contamination at SWSA 6 (^{90}Sr, ^{3}H, and VOCs in Maryville Limestone and Nolichucky Shale)	Variable; 1500 by 1000 ft for Cap A and smaller dimensions for other ancillary caps (typically 300 by 1000 ft or smaller)	<=30 ft	Sr-90 in surface water at WAG 6 MS-3 weir is about <30 pCi/L and tritium is about 270,000 pCi/L	Primarily follows soil/ bedrock interface to seeps along streams; speculative along-strike flow toward picket wells	WAG 6 MS-1, WAG 6 MS-3, and WOL; along-strike flow in intermediate groundwater to the west	• Groundwater level targets mostly met in FY 2010 (three wells exceeded target), but some uncertainty remains as to completeness of hydraulic isolation; FY 2012 (Fig. G.12) shows that two wells did not meet the target (wells 4127 and 0850) • Is there along-strike flow moving west in the Maryville or Nolichucky

[a] Values are approximate based on Remedial Investigation plume maps.
bgs = below ground surface.
FY = fiscal year.
MV = Melton Valley.
pCi/L = picocuries per liter.
SWSA = Solid Waste Storage Area.
VOC = volatile organic compound.
WAG = Waste Area Grouping.
WOL = White Oak Lake.

G.2.1.4 MV-1d Pits and Trenches

Another principal waste burial site at ORNL, the Pits and Trenches Area, is described below:

- Pits 2, 3, and 4 were used for disposal of LLLW between 1952 and 1962. Disposal of sludges from the Process Waste Treatment Plant (PWTP) continued (in Pit 4 only) until 1966. Trenches 5, 6, and 7 were constructed in 1960, 1961, and 1962, respectively, and used for the disposal of LLLW between 1960 and 1966. During the operational history of the three seepage pits, together they received approximately 21 million gallons of liquid waste containing 43,243 Ci of ^{90}Sr; 183,783 Ci of ^{137}Cs; 229,729 Ci of ^{106}Ru; and more than 67,567 Ci of trivalent rare earths. Trenches 5, 6, and 7 received nearly 76 million liters of waste containing several hundred thousand curies of activity from ^{90}Sr, ^{137}Cs, and ^{60}Co.

- Groundwater emanating from capped waste areas is collected by downgradient interceptor trenches southeast of Trench 7; along the eastern and western sides of Pits 2, 3, and 4; and at Seep D (Fig. G.3). The collected water is routed to an equalization tank located at SWSA 4 before being transferred to the PWTC for processing in BV. The downgradient trench along the western boundary (718 ft long) includes a bentonite slurry cut-off wall and sumps to transfer to the equalization tank.

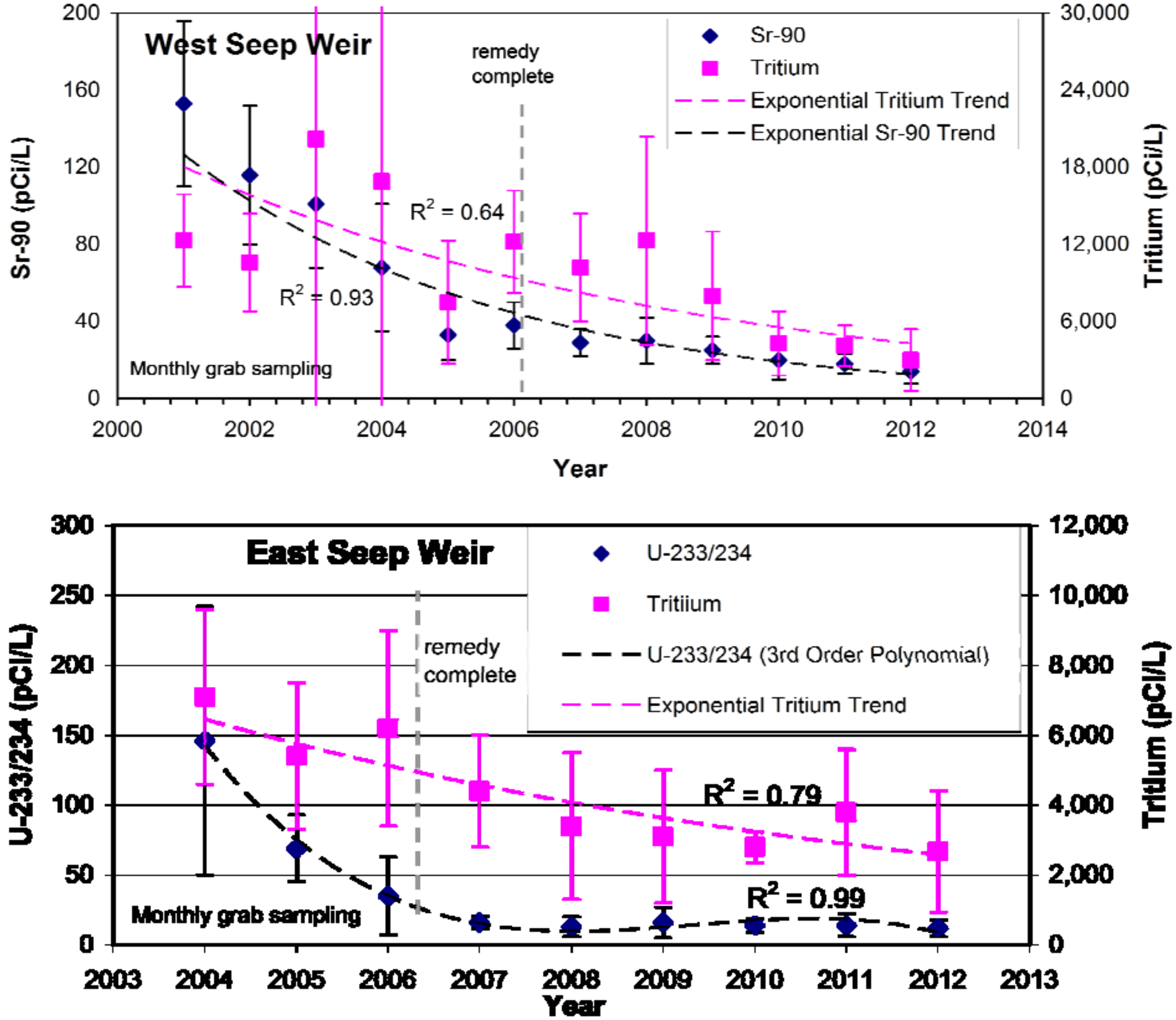
- Continuous flow-paced sampling at the pits and trench West Seep and East Seep weirs (for location, see Fig. G.8) shows tritium and ^{90}Sr trends (Fig. G.18), and activities for both radionuclides continued to decrease at the West Seep weir during FY 2012. During 2012, $^{233/234}$U and ^{90}Sr decreased at the East Seep weir following slightly elevated concentrations in 2011.

- Target water levels were met in FY 2010 at all locations in the Pits and Trenches, including Pits 2, 3, and 4 and Trench 6. This is also the case in FY 2012 where all water levels met their target (Fig. G.12). Trenches 5 and 7 were grouted in lieu of vitrification and target water levels are not applicable.

The groundwater and surface water COCs in the area are listed in the MV RI (DOE 1997a; *Table 3.13 subbasins WAG 7 WOC, Intermediate Pond, WOC, WC TRIB-1, ^{60}Co Seep, Pit 4 South, and Trench 5 South*) and include:

- Groundwater: ^{90}Sr, ^{3}H, ^{60}Co, and ^{137}Cs.
- Surface Water: Tl, As, polychlorinated biphenyls (PCBs), Sb, Tl, Cr, Hg, Se, and Cd.

Table G.6 provides a summary for the groundwater plume in the Pits and Trenches source area.



Source: DOE 2013

Fig. G.18. Tributary surface water average annual radionuclide activities at Pits and Trenches West Seep and East Seep weirs.

Table G.6. Pits and trenches groundwater plume

Plume No.	Name	Description[a] Length (ft down valley)	Depth (ft bgs)	Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
MV-1d	Shallow Groundwater Contamination in the Pits and Trenches Area, also referred to as WAG 7 (^{90}Sr, ^{3}H, ^{60}Co, and ^{137}Cs in Maryville)	Variable; Pits 2, 3, and 4 cap is about 1000 by 800 ft; trench 5 cap is about 500 by 800 ft; trench 7 cap is about 600 by 700 ft; and trench 6 cap is about 500 by 700 ft	<= 40 ft[b]	Sr-90 in surface water at West Seep Weir is about 15 pCi/L and tritium is at 3000 pCi/L; values for the East Seep Weir are about 2700 pCi/L for tritium and at 15 pCi/L for $^{233/234}$U	Primarily follows soil/bedrock interface to seeps along streams	WOC via West Seep, East Seep, and WC-Trib	• Does flow from the Pits and Trenches Area migrate under the West Seep tributary

[a] Values are approximate based on Remedial Investigation plume maps.
[b] Estimated based on Oak Ridge National Laboratory Liquid Waste Disposal Report for Trench 7 (Spalding 1991).
MV = Melton Valley.
pCi/L = picocuries per liter.
WAG = Waste Area Grouping.
WOC = White Oak Creek.

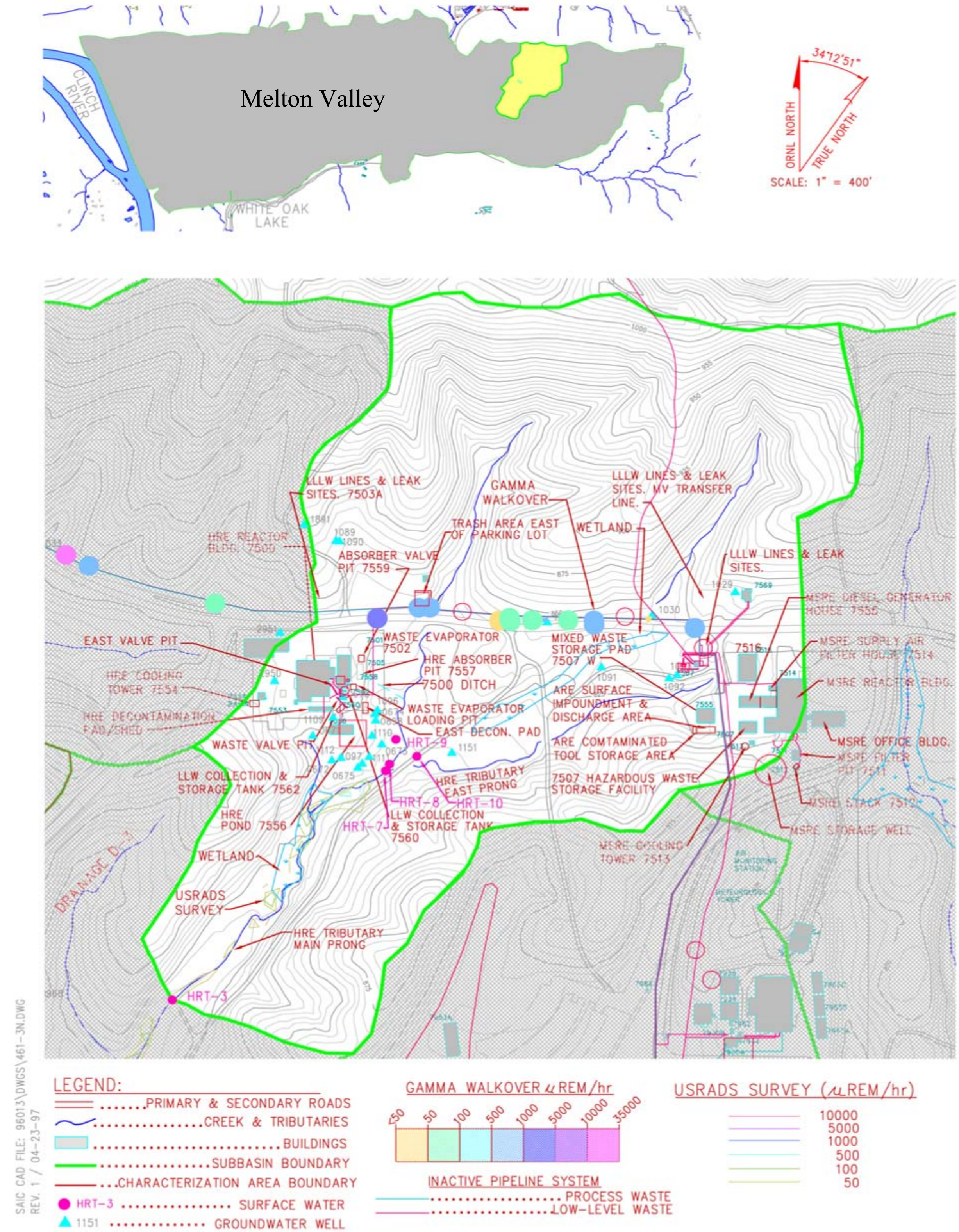
G.2.1.5 MV-1e WAG 9

The most important source of radionuclide release to surface water in WAG 9 was the HRE Pond, which was excavated as part of the ROD actions:

- The HRE Pond and associated soils were remediated and verification completed as part of the MV action in December 2005 (see Fig. G.19 for location). Several smaller surficial contamination sites (Fig. G.19) have been identified over the years; each was re-evaluated and addressed as part of the Final Status Survey.

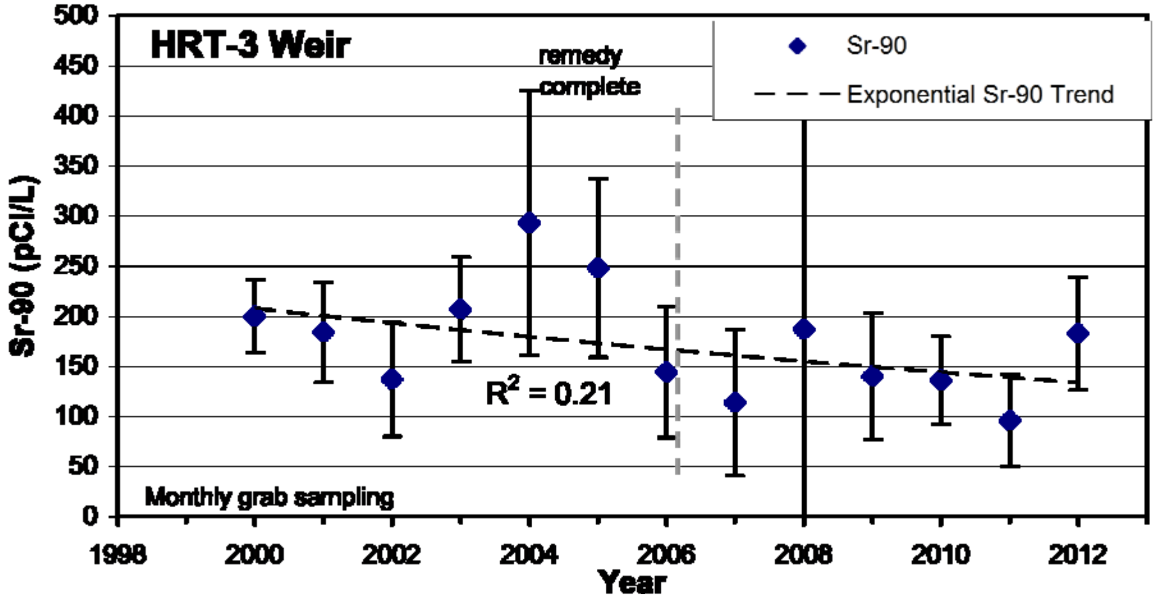
- Surface water sampling locations for the WAG 2 RI (Hicks 1996) in the vicinity of the HRE Tributary indicated that much of the elevated ^{90}Sr found in the tributary enters the stream between HRT-8 and HRT-9, downgradient of the HRE Impoundment (Fig. G.19). However, other samples indicate that ^{90}Sr is entering the north prong of the HRE Tributary upstream of HRT-9. Other potential contamination sources in WAG 9 include soil and stream sediment contamination resulting from leaks, spills, and intentional discharges of liquid waste associated with Bldg. 7500, the waste evaporator, the east and west decontamination pads, Tanks 7560 and 7562, the WAG 9 intermediate-level liquid waste (ILLW) transfer pipeline, and the MV ILLW transfer pipeline. Some uncertainty exists regarding undocumented events that may have resulted in contaminant discharges to soil/groundwater and the north prong of the HRE Tributary.

Continuous flow-paced sampling at HRT-3 weir downstream of WAG 9 (for location, see Fig. G.8) shows ^{90}Sr trends since the MV action was completed (Fig. G.20). Strontium-90 activities increased slightly in FY 2012 after exhibiting a decreasing trend from 2008 to 2011. The relatively weak trend fit to the ^{90}Sr data at the HRT-3 weir location reflects the presence of contamination in the HRE Tributary headwaters area near the former LLLW T-1 and T-2 tanks area. Monitoring continues to show elevated ^{90}Sr levels upstream of the former HRE Ponds site. Table G.7 provides a summary for the groundwater plume in the WAG 9 source area.



Source: DOE 1997a

Fig. G.19. WAG 9 (HRE) subbasin, source areas, and monitoring locations.



Source: DOE 2013

Fig. G.20. Tributary surface water average annual radionuclide activities at HRT-3 weir.

Table G.7. WAG 9 groundwater plume

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
MV-1e	Shallow Groundwater Contamination at WAG 9 (^{90}Sr and ^{3}H in Rutledge Limestone)	Variable; up to 300 by 400 ft	10 to 20 ft	Sr-90: <10 to 10,000 pCi/L in groundwater; typically 150 to 200 pCi/L in downgradient surface water.	Primarily follows soil/ bedrock interface to seeps along streams.	WOC via HRT tributary	• Uncertainty exists regarding undocumented events that may have resulted in contaminant discharges to soil/groundwater and the north prong of the HRE Tributary.

[a] Values are approximate based on Remedial Investigation plume maps.
bgs = below ground surface.
HRE = Homogenous Reactor Experiment.
HRT = Homogenous Reactor Test.
MV = Melton Valley.
pCi/L = picocuries per liter.
WAG = Waste Area Grouping.
WOC = White Oak Creek.

G.2.2 MV-2 HYROFRACTURE

Liquid radioactive wastes generated at ORNL were disposed of through underground injection between 1966 and 1984. The so-called hydrofracture waste disposal process involved pumping a radioactive waste/grout slurry into wells to hydraulically fractured Pumpkin Valley Shale at depths of approximately 1050 ft bgs. Radioactive waste disposal injections were performed initially at the OHF and later NHF. Prior to construction of OHF, field experiments were used to develop the injection technology (see Fig. G.2 for locations). Most of the approximately 1.5 million Ci of radioactive waste consisted of fission products such as ^{137}Cs and ^{90}Sr. Approximately 2000 Ci of long-lived radionuclides in TRU waste sludges were disposed of during the NHF (i.e., HF-4) grout injection process.

During injection the slurry spread along induced fractures (primarily bedding plane fractures) for several hundred feet from the injection wells, forming multiple, thin grout sheets (e.g., often less than 1/8 in. thick). The hydrofracture waste disposal process resulted in emplacement of approximately 50,000 yd^3 (10.1 million gal) of radioactive waste/grout in the 43 grout injections performed between 1959 and 1984. Four different sites at ORNL were used in the experimental/developmental and full-scale application of hydrofracture operations:

- Hydrofracture Experiment Site 1 (HF-1, also known as the 4-acre site);
- Hydrofracture Experiment Site 2 (HF-2);
- Old Hydrofracture Facility (OHF or HF-3); and
- New Hydrofracture Facility (NHF or HF-4).

Dozens of wells ranging in depth from approximately 120 to 1050 ft bgs were installed at these injection sites to monitor the performance of the hydrofracture process. These wells provided potential pathways for contaminated fluids to migrate from the injection zones to shallower groundwater zones and the surface environment both during and after hydrofracture operations.

- The ROD RAO for the Hydrofracture Well P&A project was to plug the injection and monitoring wells in a manner consistent with the technical intent of Tennessee Department of Environment and Conservation underground injection control well P&A standards. The scope of the project consisted of the P&A of 111 wells and the cleanout of 9 monitoring wells for future monitoring use.

- The basic approach for plugging and abandoning the 111 monitoring and injection wells was to fill the open hole, casing, and potential flow area outside the casing (well annulus) with cement grout from the bottom up. Wells generally underwent P&A or cleanout from least contaminated and difficult, to most contaminated and difficult, to minimize the risk of cross-contamination.

- The closure of the NHF included plugging the well and cutting of the actual injection well. The injection wellhead was cut approximately 4 ft below grade using a guillotine saw attachment following excavation of the cell floor.

There is considerable uncertainty related to the potential for migration of contaminants away from the initial injection areas:

- Waste injection pressure was the driving mechanism for possible migration of aqueous contaminants during the initial stages of injection. The induced pressure regime would, for a time, dominate the ambient head distribution and alter the normal flow system. Contaminated grout would be expected to remain within the induced fracture(s) or within boreholes or wells penetrated by grout during the injection process.

- Open and effective joints and fractures provide the most efficient natural flow path within the clastic and carbonate geologic formations underlying the hydrofracture facilities. Healed joints and fractures, while basically impermeable under undisturbed subsurface conditions, provide planes of weakness within the clastic section. When disturbed (such as by hydrofracturing) these planes of weakness could be opened to increase the effective fracture porosity/permeability, thereby increasing flow within the deep system.

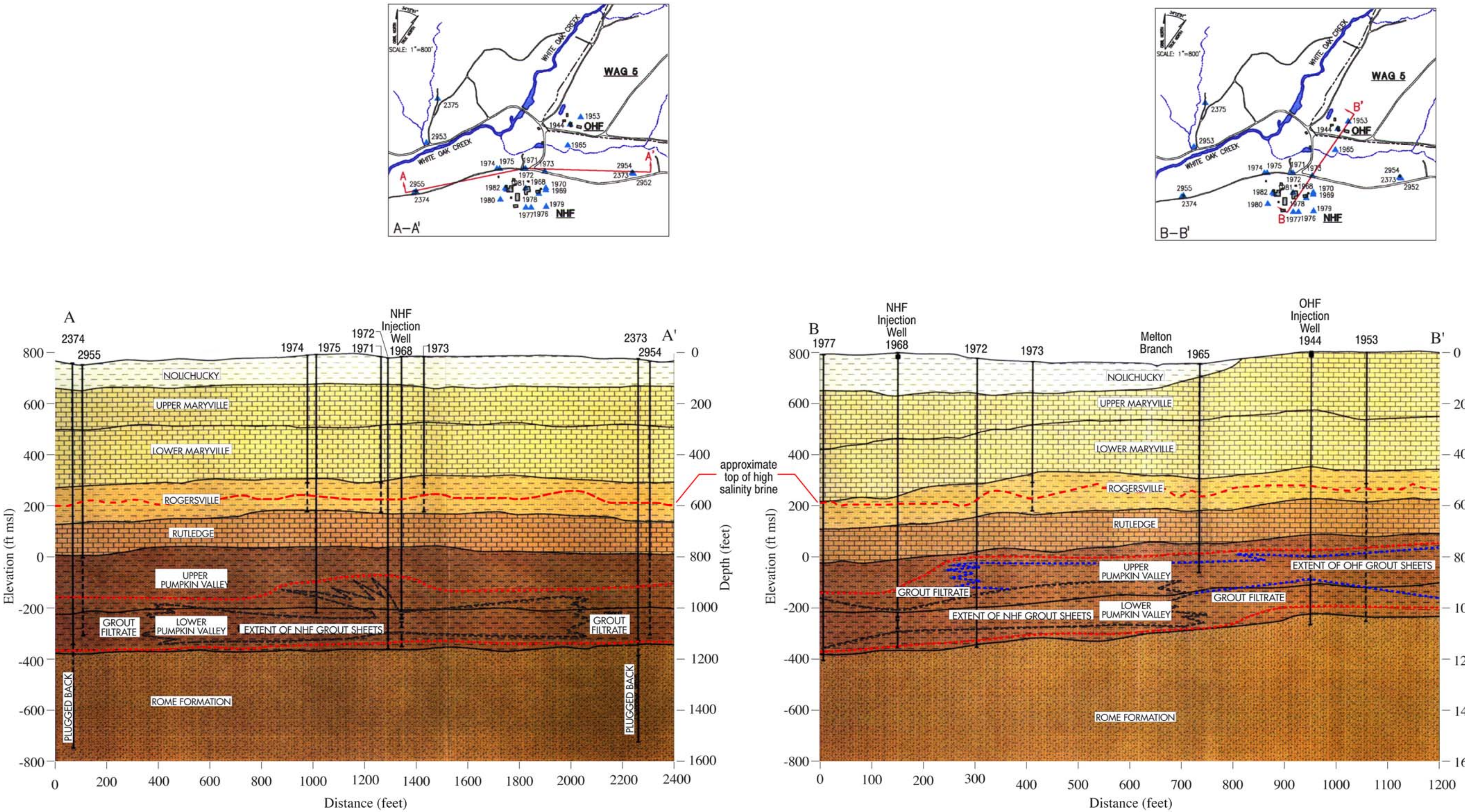
- As the leading edge of an artificially induced fracture develops and moves out from the point source (e.g., slot cut in casing) into the formation, a network of leading-edge microfractures is also created in association with the major fracture. The induced microfracture system(s) would increase the total effective fracture porosity/permeability of the rock section.

- The contaminated liquids could, under induced pressure, migrate along those planes of weakness (bedding planes and/or open fractures/joints) into beds overlying or underlying the injection horizon (Pumpkin Valley Shale). After dissipation of the induced pressure, the regional hydrogeologic flow regime would again dominate. The flow regime near NHF, however, was altered by the opening of fresh pathways (induced fractures, microfractures, and boreholes) and emplacement of grout.

- Data obtained and analyzed as part of the hydrofracture well evaluation task (DOE 1996) showed the approximate extents of the injected grout masses and the liquid containing dissolved-phase contaminants that separated from the grout after injection (referred to as grout filtrate). Figure G.21 shows sectional views of the subsurface distribution of grout and filtrate in the vicinity of the OHF and NHF sites. Figure G.22 presents a three-dimensional (3-D) block diagram of the Hydrofracture waste injection zone showing its relationship to other MV waste units, the associated geology, and calculated risk.

- Characterization data obtained have revealed the presence of artesian pressure in portions of the bedrock beneath the hydrofracture injection zone (DOE 1995c). A conceptual model of the deep hydrogeology of MV has been developed using the combined information from area geology (structural and stratigraphic), geochemistry of groundwater, and hydraulic head data. This conceptual model suggests that pressures at depths beneath the hydrofracture injection zone are influenced by groundwater recharge in the Rome Formation and in the fault rock of the Copper Creek Fault. A concern that arises from this conceptual model is the possibility that the grout filtrate (dissolved-phase contamination) may slowly migrate through the deep bedrock fracture system to mix with the shallower fresh groundwater system or to mix with groundwater or surface water beyond DOE’s controlled area boundary. Strontium-90 seeps, SW2-6, and SW2-7 were found in the floodplain area between WOC and Melton Branch, where inorganic water chemistry data suggest that the seeps may have a deeper groundwater component than typical seeps in the MV Watershed (Hicks 1996); however, this does not necessarily imply a relationship to the hydrofracture injections.

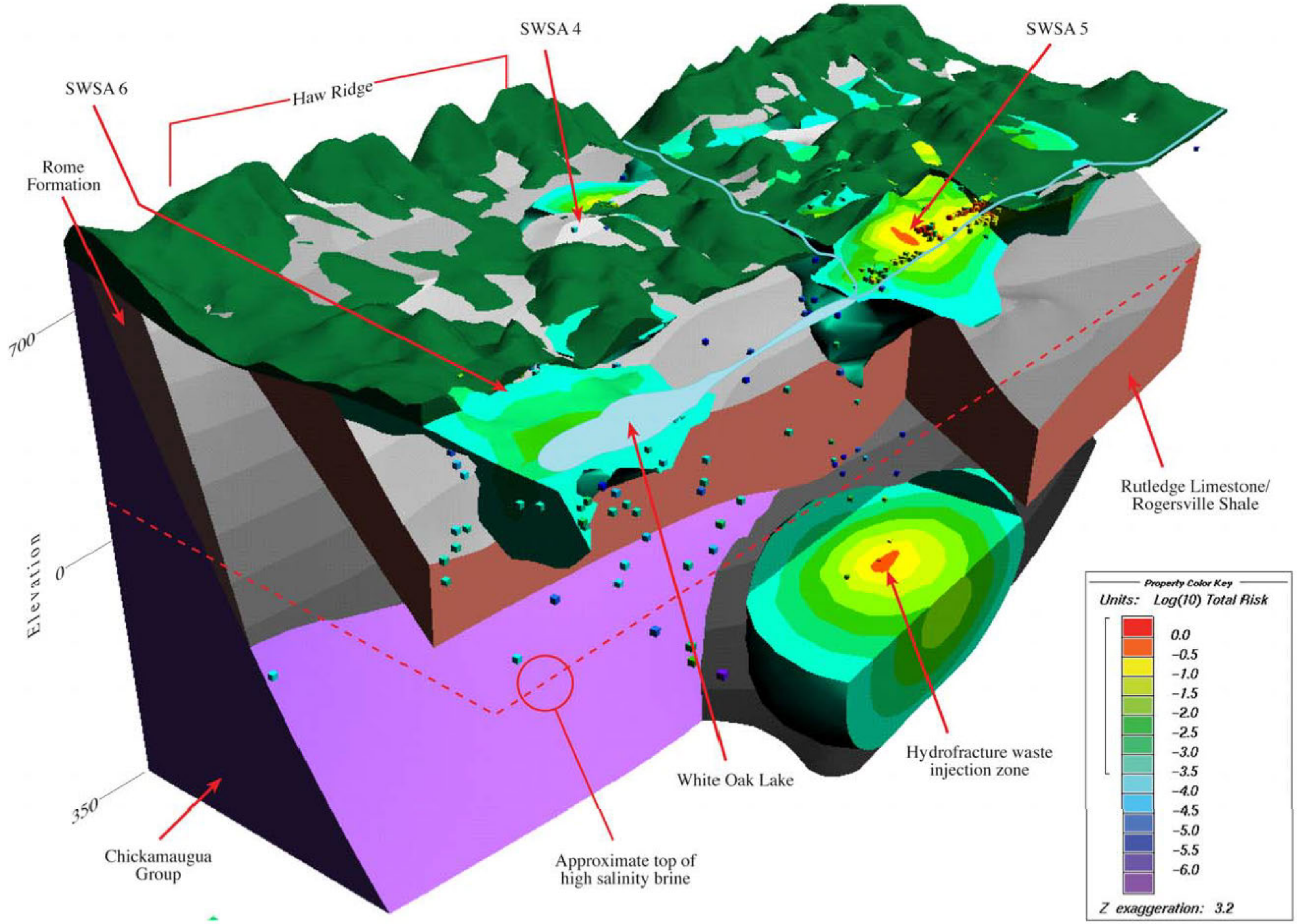
- Contaminants could also move vertically in well bores through annular or intrawell flow. Results from the hydrofracture well evaluation project (DOE 1996) identified numerous anomalies and poor casing integrity in many of the wells. Many wells were interpreted to have poor construction grout bonding (voids and channeling) between the casing and the borehole wall. Considering the combined factors of local hydrogeology, effects of hydrofracture injections on the local rock mass and on well bores, and deterioration of wells, it appears that the well bores (particularly those that penetrate the grout injection zone) represent the most probable pathway for unattenuated migration of contaminants out of the hydrofracture system. During migration through geologic pathways, contaminants are subjected to the natural attenuation mechanisms of ion exchange and geochemical interactions with the rock mass, while during seepage within a faulty or badly deteriorated well, much less attenuation would occur.



Source: DOE 1997a

G13-0032_WOC_A7B cross sections

Fig. G.21. Vertical and horizontal extent of hydrofracture grout.



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G13-0032_WOC - silicon 6

Fig. G.22. Hydrofracture waste injection zone showing relationship to other MV waste units, geology and associated risk.

Based on the above summary, an uncertainty exists with respect to the potential for hydrofracture waste disposal contamination to migrate beyond the watershed boundary in the non-potable deep groundwater system and upward through deep wells into the shallow groundwater system. However, wells associated with Hydrofracture have either been plugged and abandoned or retrofitted to isolate particular zones.

Table G.8 provides a summary for the groundwater plume in the Hydrofracture source area.

G.2.3 MV-3 EXIT PATHWAY/PICKET WELLS

Exit pathway groundwater monitoring includes wells1190 and 1191 that are located on WOD (Fig. G.10), monitoring of six deep groundwater wells (Picket Wells) between the Clinch River and the western edge of SWSA 6 (4537, 4538, 4539, 4540, 4541, and 4542), and monitoring of off-site wells located southwest of the Clinch River (OMW-1, OMW-2, OMW-3, OMW-4, and other residential wells). Three wells (1008, 1009, and 1010) in a previously constructed well cluster near the southern end of the line of Picket Wells are also shown on Fig. G.10.

The system of Picket Wells were installed in the western portion of MV in 2004 (Fig. G.10 [cross-section line A]). The completion of these six, deep multiport monitoring wells allows for tracking of potential intermediate and deep down-strike contaminant migration toward the Clinch River from waste units further to the east. The Picket Wells were drilled to bottom elevations of about 250 feet above mean sea level. Based on borehole test results, a total of 37 sampling zones were created by installation of Westbay® multizone sampling systems in the Picket Wells.

Summary observations from groundwater sampling (DOE 2013) indicate the following for the Picket Wells:

- A number of radionuclides and VOCs have been detected periodically at low levels in different monitoring zones on the MV Picket.

- Intermittent detections of metals and VOCs have been observed in off-site wells across (on the west side of) the Clinch. Two detections of ^{90}Sr and one of ^{99}Tc have been observed.

- Natural head gradients indicate groundwater movement toward the Clinch River from both east and west of the river. Alteration of the natural gradients caused by pumping can induce flow through interconnected fractures. This type of gradient alteration has the potential to induce contaminant movement from areas beneath the river to off-site wells. Additional discussion of the hydraulic head relationships in the deep wells in the vicinity of the Clinch River is presented in Appendix J.

Well 4537 is part of the system of Picket Wells. This well represents the most northern of these sentinel wells (Fig. G.10). There are five Westbay® sampling ports within well 4537, including 85, 127, 395, 425, and 450 ft bgs. Analytical information specific to well 4537 is presented on Fig. G.23, which shows 8 years of trend information for gross alpha, beta, TCE, PCE and fluoride. Both alpha and beta in the deepest port within this Westbay® (450 ft bgs) appears to have an increasing trend post-2008 time frame. Strontium-90 has been detected frequently in Picket Well 4537 and has exceeded the 8 pCi/L screening level on two occasions. VOC concentrations of TCE and PCE are generally at the detection limit, which has changed from 5 micrograms per liter (μg/L) to lower numbers (~0.25 to 0.3 μg/L) more recently. Therefore, the variation shown on the TCE and PCE graphs is an artifact of the lab reporting. Table G.9 presents a wider range of analytical parameters, including those associated with water quality. Note that -01 in the well name indicates the deepest sampling port and progresses with higher numbers up the well. Bold values are shown for exceedances of a standard.

The location of picket well 4537 and the potential uptrend in alpha and beta contamination at depth is somewhat surprising from the standpoint of its location within the MV Watershed. This entire row of wells is in a reach of the valley, which has not been formally utilized for either process or waste management activities, and is outside of the primary and secondary contamination source areas (see Figs. G.2 through G.4). Well 4537 was drilled into the Rutledge Limestone (Fig. G.5), which may locally consist of a somewhat more transmissive, limey section with less of a siliciclastic (shaley) component.

In FY 2010, off-site groundwater monitoring was initiated west of the Clinch River across from the MV waste management areas. This action was taken in response to detection of potential site-related contaminants in some of the Picket Well monitoring zones and because of concern that groundwater withdrawals on the western side of the Clinch River could potentially pull groundwater affected by DOE's waste disposal activities beneath the river.

The off-site groundwater monitoring project has included installation of two well clusters (OMW-1 and OMW-2) containing five wells each on a ridge crest west of the river, modification of two existing residential water wells (OMW-3 and OMW-4) near the river to create three sampling intervals within each borehole, and sampling of five existing residential wells in the vicinity. Locations of the off-site monitoring wells are shown on Fig. G.10. In addition to providing water quality data for off-site groundwater, these wells allow measurement of groundwater levels to determine the flow directions on the west side of the river in comparison to those on the DOE side of the river and allow groundwater sampling from discrete elevation ranges that match elevations where contamination has been detected in multizone wells on the DOE side of the river.

Samples have been collected in the off-site monitoring wells since July 2010 through FY 2012. The most common beta-emitting radionuclide in groundwater at ORNL is ^{90}Sr, which has been detected in Picket Well 4537. Early in the off-site well sampling history, two very low ^{90}Sr detections occurred in off-site wells OMW-1 and OMW-3; however, these results have not been repeated in subsequent samples from these wells. Figure G.24 provides a visual graphic of the intermittent and sporadic nature of the gross alpha and beta results seen in the off-site wells since the inception of the monitoring program.

Table G.8. Hydrofracture groundwater plume

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
MV-2	Hydrofracture Area: Deep contamination of fission products (including ^{137}Cs and ^{90}Sr) in Pumpkin Valley Shale.	Variable; up to 3500 by 2000 ft for minimum extent of contaminated brine.	~600 to 1100 ft	High levels of fission products in injected grout and separated grout filtrate.	Unknown/ speculative deep to shallow circulation or strike-west migration; speculative pressure driven up-dip.	WOD along Highway 95 was selected as the overall ROD point of compliance for meeting unrestricted use for surface water. This location is considered the integration point (IP) for MV.	• Uncertainty as to vertical (along borehole traces) or horizontal travel of separated grout filtrate. • Uncertainty as to vertical or horizontal extent of dissolved-phase contamination. • Leaching of constituents from grout into natural formation fluids containing high dissolved solids.

[a] Values are approximate based on Remedial Investigation plume maps.
MV = Melton Valley.
ROD = Record of Decision.
WOD = White Oak Dam.

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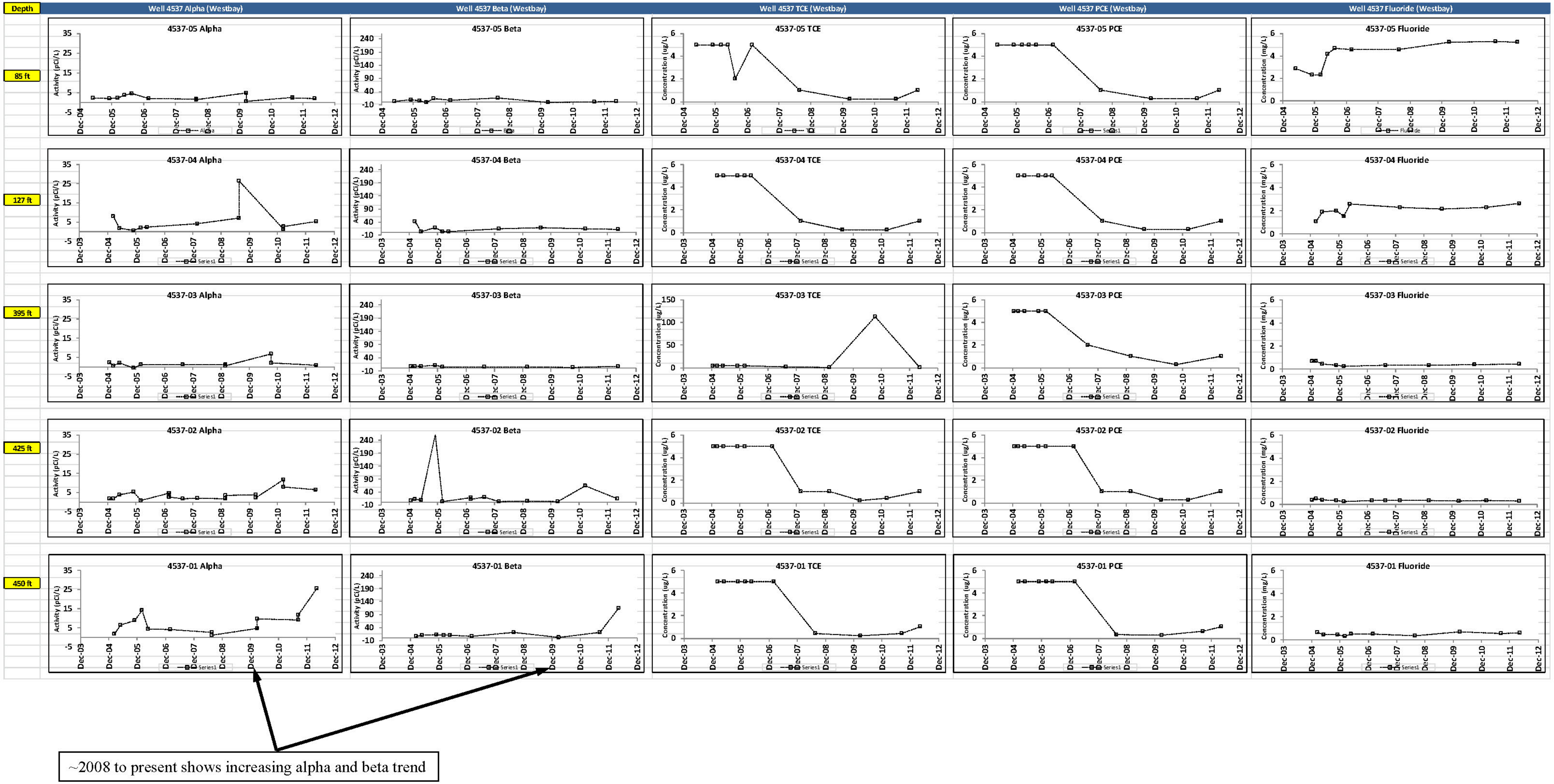


Fig. G.23. Sentinel well 4537 trends for alpha, beta, TCE, PCE and fluoride.

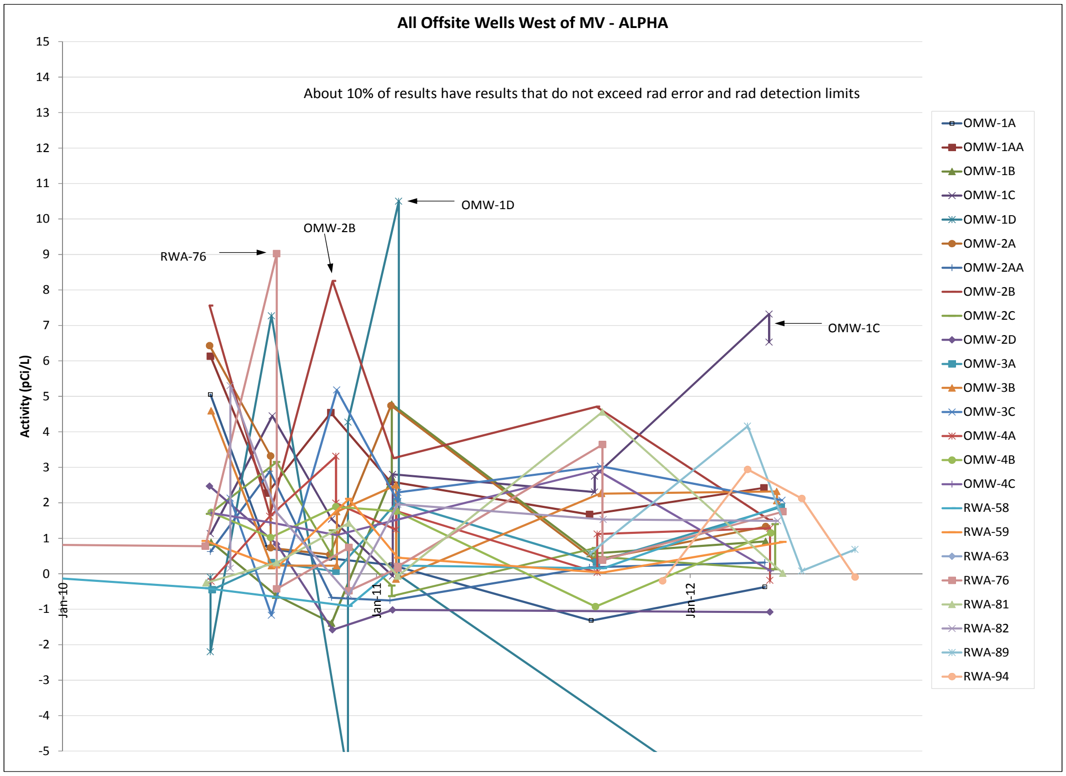
Table G.9. Summary of FY 2010 groundwater analyses from MV exit pathway wells

Sample zone	Spec. cond. (μS/cm)	TDS[b] (500 mg/L)	pH (6.5 - 8.5[a])	Redox (mV)	Turbidity (NTU)	Alpha activity (15[b] pCi/L)	Beta activity[c] (pCi/L)	^{90}Sr (8[c] pCi/L)	Al (0.2[a] mg/L)	Ba (2[b] mg/L)	Fe (0.3[a] mg/L)	Pb (15[d] μg/L)	Mn (50[a] μg/L)	Cl (250[a] mg/L)	F (2[a], 4[b] mg/L)	SO_4 (250[a] mg/L)
4537-01	1,324	**1260**	7.16	-44	2	9.76	<4.79	<2.84	0.12	0.028	**1.26**	<2.5	**124**	18.8	0.684	**648**
4537-02	840	**784**	6.85	-32	3	<3.76	<2.64	<4.4	<0.075	0.0246	<0.66	<2.5	38.8 J	5.25	0.312	**365**
4537-03	1,177	**583**	7.06	55	2	<3.93	<3.78	<0.554	<0.015	0.0338	**0.418**	<0.5	25.7	3.44	0.423	**252**
4537-05	1,315	**1070**	8	-157	10	<3.47	<2.96	<4.5	<0.075	0.0153	<0.66	<0.5	<20	14.8	**5.23**	**313**
4538-03	5,841	**4150**	6.6	-3	5	11.6	<7.87	<2.9	<0.015	0.0178	<0.033	0.575 J	32.5	**1100**	1.98	**1470**
4538-04	1,936	**1500**	7.62	-91	1	5.04	<3.41	<2.95	<0.015	0.0162	<0.033	<0.5	4.58 J	119	**4.14**	**320**
4538-05	1,917	**991**	**8.67**	47	3	2.98 J	<4.54	<0.65	<0.015	0.0296	<0.033	<0.5	3.48 J	75.3	**4.52**	152
4539-01	14,582	**14000**	6.94	-35	6	<4.75	34.5 J	<4.64	<0.015	**11.3**	0.296	<10	**207**	**1560**	1.65	0.736
4539-01	26,182	**15700**	7.98	154	21	<4.71	<4	<0.718	<0.015	**12.3**	**0.901**	<0.5	**190 J**	**8820**	1.95	<2
4539-02	1,633	**1240**	7.69	-80	9	<4.45	<3.16	<4.4	0.0285 J	0.139	<0.165	<10	2.34 J	87.6	**4.87**	4.03
4539-02	1,923	**1290**	8.5	-86	20	<4.77	<3.96	<0.61	0.0227 J	0.14	0.101	1.21 J	2.01 J	74.6	**4.85**	3.16
4539-03	1,609	**1180**	8.09	-141	6	<2.77	<3.95	<5	0.022 J	0.156	<0.165	<10	2.17 J	36.7	**5.26**	4.74
4539-04	1,447	**1040**	8.28	-101	8	<3.58	<3.27	<4.49	0.0265 J	0.152	<0.165	<10	1.75 J	41.6	**5.47**	5.24
4539-04	1,749	**1110**	**8.65**	-75	6	<5.75	4.63 J	<0.484	0.0303	0.098	0.0703 J	<0.5	1.75 J	48.9	**5.66**	4.01
4539-05	1,455	**947**	8	233	4	<4.93	<4.07	<0.891	<0.015	0.147	0.0391 J	<0.5	1.05 J	4.6	**10.1**	18.3
4539-06	1,086	**570**	8.37	-5	6	<4.67	<3.4	<0.867	0.0446	0.0958	0.0337 J	<0.5	<1	1.78	**5.23**	16.5
4539-07	430	300	8	-61	4	<3.2	<3.09	<3.98	0.0209 J	0.184	<0.165	<10	1.36 J	2.26	0.914	10.6
4539-08	398	255	7.34	212	4	<3.91	<4.26	<0.621	<0.015	0.185	0.0434 J	<0.5	2.29 J	1.64	0.896	7.51
4540-01	30,606	**18200**	7.77	33	48	**<27.1**	<26.5	<0.821	<0.075	**22.1**	**1.09**	<0.5	**145**	**9780**	<33	3.08
4540-02	2,511	**1860**	8.19	39	132	13.6	28.6 J	<0.901	<0.075	0.221	<0.165	13.1	<5	245	**4.88**	2.37
4540-03	1,244	**660**	8.82	-47	22	<4.51	<3.44	<0.857	<0.075	0.0368	<0.165	<0.5	<5	1.8	**6.05**	6.31
4541-01	3,276	**2270**	7.59	29	331	<3.39	<3.31	<6.44	0.0174 J	0.447	<0.165	<10	2.25 J	**763**	**4.22**	6.78
4541-02	5,711	**2120**	8.3	-2	6	<4.86	<4.96	<0.864	<0.015	0.305	0.033 J	<0.5	3.89 J	**713**	**3.81**	2.59
4541-03	1,889	**891**	**8.58**	129	3	<4.87	<3.5	<0.516	<0.015	0.0616	<0.033	<0.5	1.39 J	156	**4.03**	27.7
4541-04	1,616	**659**	**9.15**	-15	6	<4.64	<3.44	<0.582	0.0454	0.0317	<0.033	<0.5	1.19 J	7.35	**2.4**	35.5
4541-05	1,578	**786**	8.36	8	3	4.02	<4.98	<0.592	0.227 J	0.0414	0.0346 J	<0.5	<1	59.3	1.56	19.5
4541-06	879	**629**	**8.88**	-14.8	13	<4.91	8.04 J	<0.536	0.0798 J	0.0332	0.0393 J	<0.5	1.32 J	7.53	0.999	16.7
4541-07	369	284	6.34	27	4	<3	<4.4	<5.34	0.0923 J	0.0301	<0.165	<10	<1	4.42	0.32	7.5
4542-01	26,956	**16800**	7.16	106	39	**<28.5**	<35.6	<3.94	<0.075	**9.78**	**1.13**	<2.5	**121**	**9450**	0.89	2.28
4542-02	28,011	**15300**	7.15	30.9	6	**<24.7**	<26.8	6.77	<0.075	**7.78**	**1.15**	<2.5	**114**	**8070**	0.843	4.84
4542-03	2,127	**1750**	8.17	-47	16	<3.09	<3.4	<5.79	0.0377	0.0605	<0.165	<10	4.63 J	451	**5.64**	46.3
4542-04	1,484	**735**	8.4	53	4	<4.17	5.1 J	<0.72	0.0343	0.0517	<0.033	<0.5	1.28 J	18	**6.56**	43.6

Table G.9. Summary of FY 2010 groundwater analyses from MV exit pathway wells (cont.)

Sample zone	Spec. cond. (µS/cm)	TDS[b] (500 mg/L)	pH (6.5 - 8.5[a])	Redox (mV)	Turbidity (NTU)	Alpha activity (15[b] pCi/L)	Beta activity[c] (pCi/L)	^{90}Sr (8[c] pCi/L)	Al (0.2[a] mg/L)	Ba (2[b] mg/L)	Fe (0.3[a] mg/L)	Pb (15[d] µg/L)	Mn (50[a] µg/L)	Cl (250[a] mg/L)	F (2[a], 4[b] mg/L)	SO_4 (250[a] mg/L)
4542-05	1,386	**869**	**8.76**	-99	3	<4.81	<4.29	<0.743	0.0318	0.025	<0.033	<0.5	1.07 J	15.3	**7.23**	47.4
4542-06	1,125	**605**	**8.93**	-73	2	<4.99	<4.87	<0.771	<0.015	0.0268	<0.033	<0.5	<1	3.15	1.03	7.34
4542-07	744	**525**	**8.73**	-99	4	<2.91	<3.16	<4.81	0.032	0.0256	0.165	<10	1.06 J	1.37	0.553	11.3
4542-08	826	384	7.64	7.4	2	4.62	6.86	<0.802	<0.015	0.459	0.228	<0.5	9.03	1.84	0.195	7.74

[a] Reference concentration is a secondary drinking water standard.
[b] Reference concentration is a primary drinking water standard.
[c] The standard for "beta activity" is 8 mrem/year. This dose can be translated to a water concentration based on using water as a drinking water source for specific beta emitters but not for total beta. The translation for ^{90}Sr is 8 pCi/L
[d] This number is a Safe Drinking Water Act "action level," not an enforceable primary or secondary drinking water standard.
Bold value indicates result exceeded standard.
FY = fiscal year.
mg/L = milligram per liter.
µS/cm = microSiemen per centimeter.
MV = Melton Valley.
mV = millivolt.
NTU = nephelometric turbidity unit.
pCi/L = picocurie per liter.
TDS = total dissolved solids.
µg/L = microgram per liter.



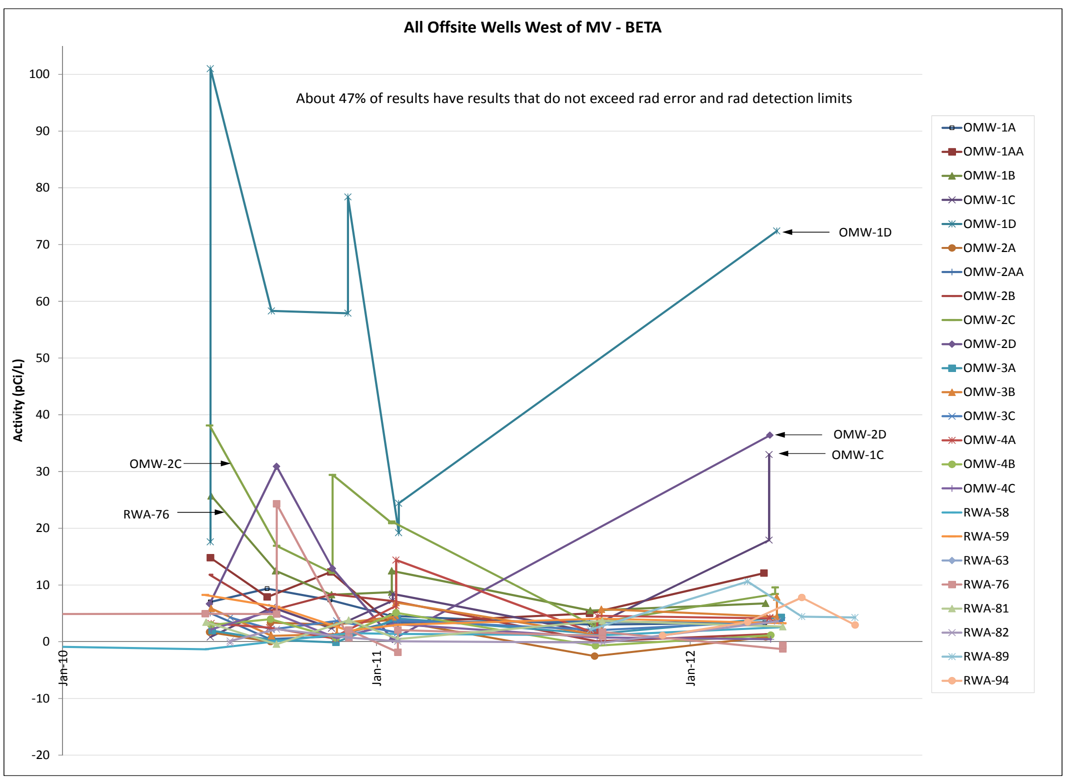


Fig. G.24. Graphical display of off-site well analytical results for gross alpha and beta.

The hydraulic head in the Rutledge Limestone and Rogersville Shale (which lie in a low-lying line of valleys and saddles between Haw Ridge and along the scarp slope of the Maryville knobs) tends to be lower than that in adjacent upland areas, but heads are not anomalously low. Low-lying areas in the Rutledge Limestone outcrop band are prone to perennial seepage at the ground surface. Significant contaminated sites that lie in this outcrop band include Seepage Pit 1, SWSA 4, and the HRE site. These sites potentially could be the contaminant source for the alpha/beta trend shown in the bottom of well 4537, but are quite some distance to the east (roughly a mile to SWSA 4 for example). Conduit flow may be involved here in some capacity and there is uncertainty as to the nature of strike-parallel contaminant migration in this reach of MV.

Although a groundwater plume has not been identified at the Exit Pathway wells, for consistency in this document the term plume is used in referring to the potential groundwater issues associated with the Exit Pathway wells, Table G.10 provides a summary of the Exit Pathway wells plume. Additional discussion of deep flow from MV, including hydrographs of water levels and cross-sections generated from the MV exit pathway/picket wells, is presented in Appendix J.

G.2.4 MAJOR DATA GAPS

Table G.11 lists relevant groundwater plumes and key data gaps for the MV Watershed.

Table G.10. Exit pathway wells groundwater plume

Plume No.	Name	Description[a]			Flowpaths	Groundwater exit points	Data gaps and uncertainties
		Length (ft down valley)	Depth (ft bgs)	Concentration			
MV-3	Exit Pathway Wells contamination from undetermined sources	Unknown; if source is SWSA 4 (speculative) then >5000 ft	200	Alpha max 25 pCi/L, beta max 116 pCi/L in Port 1 @ 450 ft bgs	Along-strike flow in formations	Clinch River; speculation of deeper flow path	• Unknown source for contamination in well 4537 – whether local or distant travel from MV waste units further to the east • Routine exceedances of fluoride in picket wells; sporadic exceedances of other non-rad metals

[a] Values are approximate based on Remedial Investigation plume maps.
bgs = below ground surface.
MV = Melton Valley.
pCi/L = picocuries per liter.
SWSA = Solid Waste Storage Area.

Table G.11. Groundwater plumes and associated key data gaps

Plume No.	Description	Data gaps and uncertainties
MV-1a	Shallow contamination at SWSA 4 (^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Rutledge Limestone and Pumpkin Valley Shale)	• It is uncertain if there if along-strike flow and transport in more transmissive portions of Rutledge Limestone. • Failure in attainment of water level targets in some monitoring wells brings into question isolation of all waste.
MV-1b	Shallow contamination at SWSA 5 (^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Maryville Limestone and subsidiary amounts in Nolichucky Shale)	• Unknown if there is along-strike transport in more transmissive portions of Maryville Limestone.
MV-1c	Shallow contamination at SWSA 6 (^{90}Sr, ^{3}H, and VOAs in Maryville Limestone and Nolichucky Shale	• Groundwater level targets mostly met in FY 2010 (three wells exceeded target), but some uncertainty remains as to completeness of hydraulic isolation. • Is there along-strike flow moving west in the Maryville or Nolichucky?
MV-1d	Shallow Groundwater Contamination in the Pits and Trenches Area (also referred to as WAG 7 (^{90}Sr, ^{3}H, ^{60}Co, and ^{137}Cs in Maryville)	• Does flow from the Pits and Trenches Area migrate under the West Seep tributary?
MV-1e	Shallow Groundwater Contamination at WAG 9 (^{90}Sr and ^{3}H in Rutledge Limestone)	• Uncertainty exists regarding undocumented events that may have resulted in contaminant discharges to soil/groundwater and the north prong of the HRE Tributary.
MV-2	Hydrofracture Area: Deep contamination of fission products (including ^{137}Cs and ^{90}Sr) in Pumpkin Valley Shale	• Uncertainty as to vertical (along borehole traces) or horizontal travel of separated grout filtrate. • Leaching of constituents from grout.
MV-3	Exit Pathway Wells contamination from undetermined sources	• Unknown source for contamination in well 4537 – whether local or distant travel from MV waste units further to the east. • Routine exceedances of fluoride in picket wells; sporadic exceedances of other non-rad metals.

FY = fiscal year.
HRE = Homogenous Reactor Experiment.
MV = Melton Valley.
SWSA = Solid Waste Storage Area.
VOA = volatile organic analyte.
VOC = volatile organic compound.
WAG = Waste Area Grouping.

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APPENDIX H
RANKING SYSTEM FOR THE OAK RIDGE RESERVATION GROUNDWATER STRATEGY

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CONTENTS

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TABLES

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ACRONYMS

AWQC	ambient water quality criteria
BCBG	Bear Creek Burial Grounds
BCV	Bear Creek Valley
BYBY	Boneyard/Burnyard
c/t	concentration/toxicity
COC	chemical of concern
CRSP	Chestnut Ridge Security Pits
CSA	Contractor's Spoil Area
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
EEVOC	East End Volatile Organic Compound
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
HCDA	Hazardous Chemical Disposal Area
HRS	Hazard Ranking System
LR	likelihood of release
MCL	maximum contaminant level
MV	Melton Valley
μg/L	micrograms per liter
NAPL	non-aqueous phase liquids
ORR	Oak Ridge Reservation
pCi	picocurie
ROD	Record of Decision
RSL	Regional Screening Level
SCF	South Campus Facility
SWSA	solid waste storage area
T	targets factor
^{99}Tc	technetium-99
TCE	trichloroethene
UEFPC	Upper East Fork Poplar Creek
UNC	United Nuclear Corporation
USGS	U.S. Geological Survey
VOC	volatile organic compound
WC	waste characteristic
Y-12 Complex	Y-12 National Security Complex

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H.1 INTRODUCTION

The U.S. Department of Energy (DOE) and its contractors have identified an approach for ranking Oak Ridge Reservation (ORR) groundwater plumes[1] as part of the overall ORR Groundwater Strategy. The goals identified for selecting an appropriate ranking approach included:

- Find a tool that would help score and categorize the groundwater plumes across the ORR to help prioritize and sequence actions over time.
- Identify a process that is robust enough to truly identify the highest risk plumes.
- Make the process simple for use in a group decision setting with limited data.
- Ensure that decision-makers can easily communicate the concepts used for ranking.

Based on these goals, it was determined that precedent ranking and scoring tools should be reviewed for use. There are several available environmental ranking tools, and most of them focus on the obvious qualities of environmental contamination that make it a problem—the toxic hazard associated with the contaminant and the possibility that a human or ecological receptor could come into contact with the hazard, now or in the future.

These qualities are accounted for in the U.S. Environmental Protection Agency's (EPA) Hazard Ranking System (HRS) [EPA 1992]; however, the HRS process does not completely align with the needs of the ORR Groundwater Strategy, particularly due to its complexity. DOE presented the concept of using a modified HRS approach to rank ORR groundwater plumes in the January 29, 2013, Groundwater Strategy Workshop initially for Bear Creek Valley (BCV) and received comments both at the Workshop and in subsequent communication from the EPA in February 2013 (see Attachment H.1). Both sets of comments were taken into consideration to develop the final ranking approach presented herein that has been applied to all watershed evaluations. All parties agreed that the ranking approach needed to remain at a high level because of: (1) either lack of or inconsistent amounts of data for the various plumes on the ORR, and (2) the higher cost of implementing a tool with large amounts of data input requirements.

The plume scoring results presented in this Appendix are ranked using an Overall ranking method that places equal emphasis on plume pathways and receptors and inherent plume hazards (plume toxicity, size, and longevity). The Overall ranking method is one of two ranking methods discussed in this groundwater strategy. The other ranking method, Pathway ranking, places greater emphasis on plume pathways and receptors than inherent plume hazards. Until uncertainties regarding exit pathways are addressed, the Pathway ranking is the more appropriate guide for the strategy focus. After exit pathway data gaps are filled, the Overall ranking can be used to prioritize ORR interior plumes (Vol. 1, Sects. 5.1.3 and 6.2). Potential groundwater projects identified by the Groundwater Strategy Team were ranked using both ranking methods (Appendix I). The identified projects include additional monitoring to fill plume data gaps and opportunities for early actions to remediate plumes. Results of the Pathway ranking guided selection of the early action project, an Off-site Groundwater Quality Assessment.

[1] The U.S. Environmental Protection Agency's definition of a plume (EPA 1997) is "*A visible or measurable discharge of a contaminant from a given point of origin…*". For this Groundwater Strategy, the listing of Oak Ridge Reservation "plumes" includes plumes from a single point source as well as other areas of groundwater contamination.

H.2 RANKING APPROACH

The HRS approach uses three key factors to score the groundwater pathway (EPA 1992, p. 34):

LR = likelihood of release.
WC = waste characteristics.
T = targets factor.

For the ORR ranking, the criteria from the HRS have been combined into two key criteria: "Hazard" (defined by waste characteristics) and "Pathway/Receptor" (that combines the likelihood for releases and the targets [receptor] of the release).

Hazard is defined by three subcriteria: "Toxicity," "Area" (a surrogate for quantity and volume), and contaminant "Longevity," all components of the HRS process. The *Pathway/Receptor* criterion is scored based on two subcriteria: the "Pathway" is a plume's ability to migrate now, or in the future, to downgradient receptors; and the "Receptor" is scored based mainly on the distance to the nearest groundwater well receptor, but also on other receptors.

Scores for all subcriteria are translated to a 1 to 10 scale, as described below, in order to keep the process simple and semi-qualitative. The exception to this is the ecological toxicity criteria, which use a 1 to 5 scale. To develop the Total Plume Score, the following equation is used:

Overall Ranking (Total Plume Score) = Weighted Total Hazard Score + Total Pathway Score

where

Weighted Total Hazard Score = (Toxicity + Area + Longevity) × 0.57*.
Total Pathway Score = Pathway + Receptor.

*The total available points for the Hazard score are 35 and the total available points for the Pathway score are 20. The Hazard score receives the weighting factor of 0.57 (20/35) to give equal weight to the Hazard and Pathway considerations. Using this weighting factor, the highest possible Total Plume Score is 40.

Information was compiled for each ORR groundwater plume as part of the site conceptual model development. The site conceptual models are presented in Appendices B through G. This information serves as the basis for the scoring exercise.

H.2.1 HAZARD CRITERION

The Hazard criterion addresses the characteristics of a groundwater plume that result in it being more or less inherently hazardous, including the toxicity of the chemicals of concern (COCs), the size of the plume (e.g., a large plume mass is presumed to be of greater concern than a small plume), and the longevity of the COCs (e.g., some chemicals degrade naturally quickly and thus will be of less concern in the future, while others do not degrade quickly). Each of the three key hazard components is discussed below.

H.2.1.1 Toxicity Subcriterion

The total available toxicity score is 15. Toxicity is scored based on two considerations: toxic or cancer effects to humans, and impacts to sensitive ecological and environmental receptors. In this scoring, human health considerations can receive a maximum score of “10” and ecological considerations can receive a maximum score of “5.” The greater consideration of human health is based on the ultimate goal of protecting drinking water users from ingesting contaminated groundwater.

Impact to human health is measured using a “concentration/toxicity” (c/t) screen, which is the ratio of the primary COC’s maximum detected concentration in the plume to the maximum contaminant level (MCL) or regional screening level (RSL) if no MCL exists. In some cases these concentrations are order-of-magnitude concentrations because of the sporadic sampling that has occurred over the past 20 years in some areas. These c/t screening results are then translated to a scale of 1 to 10, as shown in Table H.1.

Table H.1. Human health and ecological toxicity scores

	Toxicity/concentration screen result	Score
Human Health	>1,000 to 10,000	10
	>100 to 1,000	7
	>10 to 100	5
	>1 to 10	3
	<1	1
Ecological	>500 to 1,000	5
	>100 to 500	3
	>1 to 100	2
	<1	1

Ecological toxicity is evaluated by developing an ecological c/t screen using the ambient water quality criteria (AWQC) – fish and aquatic life, organisms only criteria to represent the toxicity threshold [Tennessee Water Quality Control Act T.C.A, §69-3-101, Chap. 1200-04-03-.03 (j)]. There are no ecological AWQC for radionuclides so the Canadian Water Quality Guideline for radionuclides was used (e.g., the uranium guideline is 15 micrograms per liter [µg/L]).

Ecological c/t results are normalized to a scale of 1 to 5 (Table H.1) resulting in human health scores with twice the weight as the ecological scores, since potable water use by humans is the primary target of groundwater remediation.

H.2.1.2 Plume Size Subcriterion

The total available plume size score is 10. The plume size criterion is key for understanding the secondary contaminant source in the groundwater. Typically, a large plume has the potential to act as an ongoing source of downgradient contamination for a longer period of time than a small source.

The ideal information for addressing this concern is to know the contaminant mass (in grams) or total radioactivity (in curies) of contamination in the aquifer, where:

$$\text{Mass (mg or pCi)} = \text{plume contaminant concentration (mg/L or pCi/L)} \times \text{plume volume (L)}.$$

The mass of contamination is the key input into quantitative groundwater models to predict plume migration, dilution, and attenuation over time. However, estimating the mass of contamination within a plume often requires a significant amount of data, which are not available for many the ORR groundwater plumes.

The HRS offers several other ways to describe plume size when mass cannot be used, including estimating volume and area. Based on data availability and adequacy for all the plumes across the ORR, the area of the plume based on the downgradient length of the plume × the depth of the plume was selected as the subcriteria for the ranking approach. On the ORR, along-strike flow is the predominant downgradient flow mechanism, often resulting in long, thin plumes.

Note: In a few instances plume length could not be estimated for an ORR groundwater plume and separate assumptions had to be made to address the plume size criteria. One example is groundwater plume BCV-6 Various Near-source Uranium Signatures in the Nolichucky Shale. In this case releases to groundwater quickly resurface to the creek and, therefore, the plume size is minimal: however, the contaminant mass in the burial grounds available for ongoing releases is very large and consequently the plume is given a high score for size.

The plume descriptions presented in Appendices B through G include available plume dimension information. In many cases the full extent of the plume has not been delineated, and in some cases the plume source is uncertain. In those cases conservative assumptions are made [e.g., for the East Tennessee Technology Park (ETTP)-4 Duct Island/K-1070-F plume, it is assumed that the plume length is 800 ft from the landfill to the downgradient seep, even though it has not been confirmed that the landfill is the source of the contamination in the seep].

There is a tremendous range of plume lengths and depths on the ORR [from the >2-mile (15,840-ft)-long, 300-ft-deep nitrate plume in Bear Creek Valley (BCV) to the 100- to 200-ft-long, 30-ft- deep plumes at the ETTP]. Translating these differences to a scale from 1 to 10 proved challenging (e.g., a linear scale resulted in a small number of plumes with a score a 10 and the majority of plumes with a score of 1, resulting in a potential over-emphasis of this subcriteria for certain plumes). After reviewing the range of plume sizes, the following approach was used: Plume length (ft) × plume depth (ft)/10^4, resulting in values from <1 to 475. Table H.2 shows the scale used to translate the plume size to the 1 to 10 scoring.

Table H.2. Plume size scores

Plume size	Score
>300	10
>200 to 300	7
>100 to 200	5
>1 to 100	3
<1	1

H.2.1.3 Longevity Subcriterion

Longevity scoring has a maximum score of "10" and is based on either the radioactive half-life or chemical degradation rates from the literature. Longevity is important in defining the length of time that the plume could potentially pose a threat to human health and the environment in the future. Plumes on the ORR contain contaminants with radiological and biological half-lives spanning over seven orders of magnitude. The highest scores are reserved for metals and the long-lived radionuclides (e.g., ^{238}U with a half-life of 4.47 billion years) whereas volatile organics that may degrade within 100 years receive lower scores. Because non-aqueous phase liquids (NAPLs) pose a source longevity issue that is not represented by dissolved-phase biological degradation rates, plumes that contain or may contain NAPL receive a score of 6 out of 10 regardless of the specific biodegradation rate.

Table H.3 shows an example of the entire Hazard scoring process using the BCV groundwater plumes.

H.2.2 PATHWAY/RECEPTOR CRITERION

The Pathway/Receptor subcriteria are designed to identify the likelihood that a plume could migrate to an actual off-site receptor. The approaches used to score these subcriteria are from the HRS (EPA 1992) Chap. 7, *Ground Water Pathway*.

H.2.2.1 Pathway Subcriterion

The total available pathway score is "10." Using the scoring HRS concepts, plumes located in aquifer-like formations with the potential to move off-site to a residential drinking water well receptor are given the highest scores. Plumes located in aquitard-like formations that are likely to remain on-site are given the lowest scores. Higher scores are given to plumes that have already demonstrated their ability to migrate downgradient of their sources toward off-site locations. Since each watershed has unique underlying geology, the HRS concepts had to be specifically translated for each watershed to help with a consistent application of the concepts. Table H.4 shows this translation.

H.2.2.2 Receptor Subcriterion

The total available receptor score is "10." The receptor scoring is adapted from the HRS process and gives highest scores to plumes that are at, or near, an existing groundwater well user; medium scores where groundwater could impact a fishery or sensitive environment; and the lowest scores in cases where sensitive receptors are not present and there is little likelihood of ever being present. Table H.5 shows the receptor scoring approach.

Table H.3. Example hazard scoring, Bear Creek Valley

Plume No.	Groundwater plume	Toxicity								Total toxicity ranking	Area in downgradient direction				Longevity ranking		Notes
		Plume		Human health			Ecological										
		Primary COC	Plume [c] (ppb)	MCL (ppb/ pCi)	HH [c]/t	HH ranking	AWQC (µg/L)	Eco [c]/t	Eco ranking		Length (L) (ft)	Depth (D) (ft)	L*D/ 10,000	Area ranking	Decay (years)	Longevity ranking	
Bear Creek Valley																	
BCV-1a	S-3 Shallow contamination in Nolichucky Shale and Bear Creek (Pathways 1, 2, and 3)	N, U	10,000	20	500	7	15	667	5	12	3,500	600	210	7	1.00E+09	10	
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	N	50	10	5	3	500	0	1	4	15,840	300	475.2	10	100	1	
BCV-2	Uranium in the Maynardville Limestone	U	50	20	2.5	3	15	3	2	5	7,500	200	150	5	1.00E+09	10	
BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky and Maynardville	TCE	2,000	5	400	7	300	7	2	9	9,000	200	180	5	380	6	DNAPL
BCV-4	BG-A Shallow/deep (DNAPL) VOCs in Nolichucky Shale	TCE	60,000	5	12,000	10	300	200	3	13	4,500	200	90	3	380	6	DNAPL
BCV-5	BG-C West shallow VOC in Nolichucky Shale	TCE	1,000	5	200	7	300	3	2	9	1,000	100	10	3	380	3	
BCV-6	Various near surface uranium signatures in Nolichucky Shale	U	1,000	20	50	5	15	67	2	7	NA	`		10	1.00E+09	10	

[c] = concentration.
[c]/t = concentration/toxicity screen.
AWQC = ambient water quality criteria.
BCV = Bear Creek Valley.
BG-A = Burial Ground A.
BG-C = Burial Ground C.
BYBY = Boneyard/Burnyard.
COC = chemical of concern.
D = depth.
DNAPL = dense non-aqueous phase liquid.
Eco = ecological.
HCDA = Hazardous Chemical Disposal Area.
HH = human health.
L = length.
MCL = maximum contaminant level.
N = nitrate.
NA = not available.
pCi = picocuries.
ppb = parts per billion.
TCE = trichloroethylene.
U = uranium.
VOC = volatile organic compound.

Table H.4. Pathway scores

Pathway definition	Score
Bear Creek Valley	
Is currently in the Maynardville with evidence of migration to Picket A[a]	10
Is currently in the Maynardville but not detected at Picket A	7.5
Is currently discharging to Bear Creek or North Tributaries	5
Mass remains in Nolichucky Shale or Maryville Limestone	1
UEFPC/Chestnut Ridge	
Is currently in the Maynardville with evidence of migration to Picket J[b]	10
Is currently in the Maynardville but not detected at Picket J	7.5
Is currently discharging to UEFPC or the Y-12 storm drain system	5
Mass remains in Nolichucky Shale or Maryville Limestone	1
ETTP	
Is currently in a carbonate bedrock unit (Knox or Chickamauga) with evidence of migration to, or near, Clinch River or potential drinking water well	10
Is currently in the carbonate bedrock but likely not to have migrated to the Clinch or potential drinking water well	7.5
Is currently discharging to Mitchell Branch, Poplar Creek, or ETTP Ponds	5
Mass remains in place	1
Bethel Valley	
Is currently in the Chickamauga bedrock unit with evidence of migration to, or near, Clinch River or potential drinking water well	10
Is currently in the Chickamauga bedrock unit but not likely to have migrated to the Clinch River or potential drinking water well	7.5
Is currently discharging to White Oak Creek, Raccoon Creek, or Bearden Creek	5
Mass remains in place in the Conasauga Group	1
Melton Valley	
Is currently in a higher transmissivity bedrock unit with evidence of migration to, or near, the Clinch River or potential drinking water well	10
Is currently in a higher transmissivity bedrock unit but has not migrated to the Melton Valley Picket, the Clinch River, or potential drinking water well	7.5
Is currently in a low-transmissivity formation discharging to White Oak Creek	5
Mass remains in place	1

[a] Picket A is a line of shallow and deep groundwater monitoring wells that align strike-perpendicular to flow in Bear Creek Valley. The wells are located approximately at the downgradient boundary of the waste management area in the valley and thus were identified as the boundary where the long-term goal of “unrestricted land use” was identified in the Interim Record of Decision.

[b] Picket J is a line of shallow and deep groundwater monitoring wells that align strike-perpendicular to flow in Upper East Fork Poplar Creek, a few hundred feet prior to the downgradient site boundary.

ETTP = East Tennessee Technology Park.
UEFPC = Upper East Fork Poplar Creek.
Y-12 = Y-12 National Security Complex.

Table H.5. Receptor scores

Receptor scoring general consideration	Score
Groundwater receptor wells or surface water drinking water source with actual contamination	10
Groundwater receptor wells, surface water drinking water source within 1 mile of source	9
Groundwater receptor wells, surface water drinking water source within 2 to 3 miles of source	7
Groundwater receptor wells, surface water drinking water source within 3 to 4 miles of source	5
Groundwater release to surface water considered a sensitive ecological environment	5
Groundwater release to surface water with environmental bioaccumulation potential (food chain, including fisheries)	5
Groundwater release to surface water, no sensitive receptors; potential for release but groundwater use restrictions currently in place	3
No groundwater release to receptor location	1

H.3 SCORING INFORMATION SUMMARY

Table H.6 consolidates information from the ORR groundwater conceptual models presented in Appendices B through G. This information serves as the rationale for the scoring for each groundwater plume.

H.4 RANKING RESULTS

H.4.1 OVERALL RANKING

Table H.7 presents the overall results of the ORR groundwater plume ranking, with the plumes listed in order from highest to lowest. The table shows the individual scores for each subcriterion, along with the total scores. The plumes are further grouped into “High” (with a score of >25), “Medium” (with scores of 20 to 24) and “Low” (with scores >20) categories. These groups should be viewed with caution because several plumes scored within one point of the higher or lower grouping. Several patterns emerge from the ranking results:

- With two exceptions, the high-ranked groundwater plumes on the ORR reside within a limestone aquifer formation and thus are more likely to migrate away from the original source area. All of these plumes in the limestone formation received a pathway score of either 7.5 or 10.

- The two exceptions to this are the Hydrofracture Site plume (MV-4) and the near-surface uranium signatures around the BCV Burial Grounds plume (BCV-6). These two plumes are not in limestone units but had very high Hazard scores due to the combination of their large mass source terms and almost infinite longevity.

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
BCV-1a	S-3 Shallow/deep contamination (nitrate, uranium, ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3)	3500 (Nitrate); 2500 (Uranium); 3000 (^{99}Tc)	600	Nitrate: 10 to 10,000 mg/L; Uranium: 15 to 10,000 pCi/L; ^{99}Tc: 50 to 10,000	Along-strike flow in the Nolichucky	Upper Bear Creek (BCK 12.34); NT-1, NT-2; Maynardville	• Ongoing releases from nitrate plume/secondary source in Nolichucky • Quantified estimates of total U mass that left S-3 compared to mass in current plumes • What is the extent of the U plume (bottom in Maynardville) • How much of the plume is currently being monitored • Water chemistry as related to potential actions • Few deep wells in Maynardville downgradient of S-3
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	3 miles	450	1 to 50 mg/L	Along-strike flow in the Maynardville	SS-4, SS-5 down valley (Picket W)	• Uncertain nitrate mass as secondary source in Maynardville • Nitrate degradation processes and rates; ammonia data • Bottom of Maynardville plume
BCV-2	Uranium in the Maynardville Limestone	7500	200	Shallow: Up to 2200 pCi/L; Deep: 1 to 50 pCi/L	Direct release into the Maynardville near BCK 11.54; along-strike flow in the Maynardville	NT-3, SS-4, SS-5, and SS-7 Picket A	• Shallow plume source since BY/BY action • What has happened to U in Maynardville since BY/BY action • Is the BYBY the primary source of U in Maynardville downgradient of BYBY (or S-3)
BCV-3	HCDA/Old SY200 Yard[a] shallow/deep VOCs (DNAPL) in Maynardville	7500	VOCs at approximately 200 ft depth? Unknown?	5 to 2000 µg/L	Direct release into the Maynardville near BCK 11.54	SS-4, SS-5 Maynardville - Picket B	• Is there a DNAPL source at the Hazardous Chemical Disposal Area (HCDA) and, if so, how deep • Is the conceptual model for transfer from Nolichucky to Maynardville well understood • VOC degradation rates in BCV • What is the nature of the primary HCDA source
BCV-4	BG-A North/South shallow/deep (DNAPL) VOCs in Nolichucky Shale	3000 East–West 1500 North–South	200 (DNAPL)	50 to 60,000 µg/L	Along-strike shallow flow in Nolichucky; density-driven vertical flow in Nolichucky	NT-7, NT-8 Picket A	• What do existing West Bay wells tell us about VOC (and other COC migration) and are they in the right place • Poorly defined bottom and west end of Plume #8
BCV-5	BG-C West shallow VOCs in Nolichucky Shale	1000		5 to 1000	Along-strike flow in Nolichucky	NT-8 Picket A	• Is DNAPL at Burial Ground A the source of contamination “moving” toward NT-8 • What is DNAPL mass at Burial Ground A • How far west has the VOC plume moved
BCV-6	Various near-surface uranium signatures in Nolichucky Shale	Direct discharge to NT-8; no wells to determine if plumes move along strike, but U has low solubility in neutral to high-pH groundwater	Storm flow zone	GW – ?? Surface water – ??	Immediate discharge to north tributaries	NT-7, NT-8	• Gaining/losing reaches of Bear Creek

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	7500 (nitrate) 4000 (^{99}Tc) 4000 (U, alpha) 4500 (S-2 Site VOCs)	>400	Nitrate: >10,000 mg/L ^{99}Tc: >10,000 pCi/L (gross beta) Uranium (alpha): ~1800 pCi/L VOCs (S-2 Site): ~4500 µg/L	Along-strike flow in the Nolichucky Induced flow by building dewatering sumps S-2 Site: direct leaching to along-strike karst Maynardville pathways	Storm sewer systems/ buried tributaries Basement sumps in Bldgs. 9204-4, 9201-4, and 9201-5 Discharge to UEFPC and Big Spring at Bldg. 9201-1 (nitrate)	• Central Y-12 Maynardville Limestone Exit Pathway: A limited number of wells exist in the central portion of the complex within the Maynardville Limestone, particularly in the intermediate and deep groundwater intervals. Lateral and vertical extent of contamination in the exit pathway in the western and central portions of the Y-12 Complex is not well understood. • Where is the groundwater divide between UEFPC and BCV • Do the reducing conditions in UEFPC (VOCs) result in nitrate reductions to ammonia
UEFPC-2	Western and Central Y-12 Area VOC Plume	9000	<100 (typical)	>20,000 µg/L	Along-strike flow in the Nolichucky; buried tributaries; and utilities/storm sewers	Storm sewer systems/ buried tributaries Baseflow discharge to UEFPC	• Same as Plume No. UEFPC-1 • What are/were the sources of VOCs, operations, leaks, and spills • Are there secondary DNAPL sources • Vertical and horizontal delineation of VOCs and potential DNAPL sources in the Nolichucky Shale near former production facilities in the western Y-12 area (e.g., Bldgs. 9201-5, 9201-4, and WCPA)
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	2000 (variable)	<50 (sources)	>200 pCi/L (gross alpha)	Along-strike flow in the Nolichucky; buried tributaries; and utilities/storm sewers	Storm sewer systems/ buried tributaries Basement sumps in Bldgs. 9204-4, 9201-4, and 9201-5 Discharge to UEFPC above North–South Pipe accounts for ~80% of U flux at Station 17	• Same as Plume No. UEFPC-1
UEFPC-4	Former East End Fuel Station and Garage Tanks	300	<50		Along-strike flow in the Nolichucky; utilities/storm sewers	Utility traces/storm sewers east of Portal 5; outfalls 135 and 617	• No significant data gaps identified
UEFPC-5	Uranium Sources in Maynardville Limestone	1000 (variable)	<50 (sources)	>500 pCi/L (gross alpha)	Leaching/direct contact with groundwater; along-strike karst pathways	Baseflow discharge to UEFPC	• Same as Plume No. UEFPC-1
UEFPC-6	Localized Mercury Sources to Groundwater	<1000 (variable)	<50 (sources)	Up to 1.0 mg/L	Buried tributaries; utilities/storm sewers; induced flow by building dewatering sumps; and along-strike karst pathways	Storm sewers Discharge to UEFPC Big Spring at Bldg. 9201-2	• Same as Plume No. UEFPC-1 • Is there an actual Hg plume in the shallow or deeper zones

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
UEFPC-7	East End VOC Plume	8000 (carbon tetrachloride [CT] signature)	>400	>4000 µg/L	Along-strike karst pathways; former UEFPC channel; UEFPC by-pass underdrain system	Off-ORR springs along Scarboro Creek east of Y-12 UEFPC by-pass underdrain headwall UEFPC baseflow discharge EEVOC plume capture system (GW-845)	• What is the source of the CT plume • A limited number of wells exist in the intermediate and deep groundwater intervals of the Nolichucky Shale at the ORR boundary and no wells exist in these intervals off of the ORR in Union Valley to the east. The potential for EEVOC Plume migration along strike-parallel fracture pathways is not well understood. • Is there discharge at SCR 7.18, Cattail Spring, or Picket J • Wells in UEFPC water gap should be sampled for current VOC concentrations • Existing wells in the eastern portion of the Y-12 Complex do not define the full vertical extent of VOC contamination (particularly CT) within the Maynardville Limestone and provide only partial definition of the lateral extent of the VOC plume within the eastern portion of the complex
CR-1	Chestnut Ridge Security Pits	3800 ft East–West 1300 ft North–South	270	Historical summed VOCs: 1000 µg/L Current summed VOCs: <200 µg/L	Primarily along-strike flow in the Knox Group via karst pathways; some cross-strike flow from crest of Chestnut Ridge	Springs and tributaries on flanks of Chestnut Ridge and east of CRSP along Scarboro Creek	• Lateral and vertical extent of VOC contamination and exit pathways in the Knox Group are not well understood • What is the remaining mass of VOCs in the source
CR-2	United Nuclear Corporation Site	No plume identified	NA	Historical maximum ^{90}Sr: 17.8 pCi/L Nitrate: <10 mg/L	Primarily along-strike flow in the Knox Group via karst pathways; some cross-strike flow from crest of Chestnut Ridge	Springs and tributaries on flanks of Chestnut Ridge	• No significant documented groundwater contamination; however, potential exit pathways in the Knox Group are not well understood • There is no monitoring in the southwest portion of the CR watershed
CR-3	South Campus Facility	450	<50 (sources)	Current TCE and 1,2-DCE: <5 µg/L	Shallow flow in the unconsolidated and fracture flow in shallow bedrock intervals	Scarboro Creek Embayment, Melton Hill Lake	• No significant data gaps identified
ETTP-1	K-1070-A Burial Ground	1800	>100	TCE: 3200 1,1-DCE: 450 CT: 190	Follows hydraulic gradient and karst pathways along-strike and down-dip in Knox	Spring 21-002 at head of K-901 Pond	• Mass and distribution of residual source are uncertain • There is uncertainty about the flowpath in the Knox at depth (e.g., west or east) • The depth of VOC contamination is unknown
ETTP-2	Contractor's Spoil Area	If source for spring discharge – 2000	Unknown	TCE: 10 at spring	Likely along-strike and down-dip flow in Knox	USGS spring 10-895 on Poplar Creek	• Source of TCE at spring (USGS 10-895) is unknown
ETTP-3	K-1085 Old Firehouse Burn Area	800	Uncertain	TCE: >300 *cis*-1,2-DCE: >150 PCE: >25 VC: >5	Hydraulic gradient to southwest for shallow flow and fracture flow in Rome	Beaver Ponds and Clinch River to southwest	• Full extent of plume and remaining source mass is uncertain

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
ETTP-4	Duct Island/K-1070-F	~800 from landfill to spring	Unknown	TCE: >10 VC: >5	Along-strike flow in Chickamauga	Poplar Creek	• Source of TCE at PCO spring is unknown (could be K-1070-F or K-27 or other source)
ETTP-5	K-720 Fly Ash Pile	200	30	As: 42 Cr: 180 Pb: 55	Hydraulic gradient for shallow flow and along-strike in Chickamauga	Clinch River	• Discharge of elevated metals to Clinch River is uncertain
ETTP-6	K-770 Scrap Metal Yard	150	40	Alpha: >20 pCi/L Beta: >50 pCi/L	Hydraulic gradient shallow flow and along-strike in Chickamauga	Clinch River	• Vertical extent into bedrock is unknown
ETTP-7	K-1200 Area	Uncertain	>100	PCE: >2500 TCE: >700 *cis*-1,2-DCE: >1000	Uncertain; anticipated to be along-strike and down-dip in Chickamauga/Rome	Uncertain; possibly K-1007-P Ponds	• Source of VOCs is uncertain and extent in bedrock is unknown
ETTP-8	K-1004 Area	Uncertain	>50	TCE: >30 PCE: >20	Along-strike and down-dip in Chickamauga	K-1007-P Ponds	• Source of VOCs is uncertain
ETTP-9	Mitchell Branch Commingled Plume	>1200	>100	TCE: >200,000 *cis*-1,2-DCE: >35,000 1,1-DCA: >3000 1,1-DCE: >3000 VC: >1500 PCE: >500 1,1,1-TCA: >100 Chromium: >700	Uncertain; along-strike and down-dip in Rome; hydraulic gradient for shallow flow; and preferential pathways via buried channels and utility lines	Mitchell Branch/Poplar Creek	• Vertical extent of plumes is uncertain • Source of Cr that exits to Mitchell Branch is unknown
ETTP-10	K-1064 Peninsula	200	40	TCE: ~5	Along-strike in Chickamauga/ Knox	Poplar Creek	• Source of TCE is uncertain
ETTP-11	K-27/K-29	~1000	>100	TCE: >600 *cis*-1,2-DCE: >40	Hydraulic gradient for shallow flow, along-strike and down-dip in Chickamauga	Poplar Creek	• Source of VOCs is uncertain and vertical and horizontal extent of plumes is uncertain
BV-1	Shallow/deep contamination ^{90}Sr in Benbolt, shallow ^{3}H and mercury contamination in Bowen, Witten, and Moccasin Fm.	Variable; up to 2500 × 2000 for ^{90}Sr; 1200 × 500 for ^{3}H; and localized for Hg	200	^{90}Sr: 10 to 100,000 pCi/L; H-3: ? Mercury: ?	Along-strike flow in formations; ^{3}H and mercury primarily on east side of the main plant area	White Oak Creek at 7500 Bridge	• Investigations have not been able to delineate contamination around and under active facilities to determine if groundwater plumes have active and continuing sources around infrastructure, piping, appurtenances, etc., or if one-time spills or former operations were responsible • Depth of some contamination is unknown • Full list of COCs is uncertain • Distribution of mercury contamination is poorly defined; also not listed as a primary COC in the BV RI • Nature and extent of contamination from Bldg. 3019 and other source areas on its outcrop belt in 2000 and 3000 areas not well understood • Not sure of the CH33 plume source or plume depth • What is the extent of Hg in groundwater around Bldg. 4501 • Are there historical data or monitoring wells around the old SWSA 2

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
							• The gradient is in many directions in both shallow and deep zones • There is a limited head data set with lots of inference in analysis; limited understanding of flow in BV and its impact to off-site sources • Need more deep wells and wells in same formation to test the strata-bound flow concept • Down-gradient extent of Central Plant Area plumes – is it First Creek • Need water-balance update
BV-2	Corehole 8 Plume	1500 ft East–West and 100 to 200 ft North–South	>500?	Shallow: Up to 410,000 pCi/L ^{90}Sr; 5000 to 10,000 pCi/L alpha Deep: 10 to 100,000 pCi/L ^{90}Sr?	Direct release into the Benbolt near Tank W-1A footprint; down-dip and along-strike flow in the Benbolt to First Creek	First Creek; down-gradient location in Benbolt	• Extent of plume migration down-dip (vertically) and into formations adjacent to the Benbolt is uncertain (various versions of the BVGWES show migration into Rockdell Formation underlying limestone formation located north of Tank W-1A) • There is not much data-bounding of the Corehole 8 Plume • What happens if DOE shuts down central process treatment facilities (e.g., long-term availability of treatment capability) • Assumption that plume direction is not toward the east (Fifth Creek) • Need deep well down-strike of 4570 (is the plume beyond First Creek) • Unknown mid- to long-term effect of upgrades to Corehole 8 Plume capture system • Can we currently pump and treat more water or are we limited by PWT WAC and have we optimized ^{90}Sr mass removal, location, and pumping rates
BV-3	7000 Area VOC Plume shallow/deep (DNAPL) VOCs in limestones and siltstones of Witten Formation	1800 East–West 200 North–South Outlier plumes less than 100 × 200	200	10 to 15,000 μg/L	Along-strike shallow to deep flow in Witten; three minor outlier plumes in Benbolt, Bowen, and Witten Formations; and density-driven vertical flow	Tributary spring and White Oak Creek; downgradient location in Whitten	• Bottom and west end of plume somewhat poorly defined (limited TCE data at depth) • Existence and mass/distribution of DNAPL are unknown, possibly bringing into question the effectiveness of bioremediation • Degradation of all daughter products down to ethane is uncertain • What is the best injection location
BV-4	SWSA 3 Source Area, ^{90}Sr plume shallow in limestones of Witten Formation	3000 East–West 250 North–South	<100	10 to 1000 pCi/L	Along-strike shallow flow in Witten Formation	East to Northwest Tributary; west to Raccoon Creek drainage	• Bottom and both east and west ends of Plume are somewhat poorly defined • There is ^{99}TC in off-site wells RWA-97

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Description: Depth (ft bgs)	Description: Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
MV-1a	Shallow Contamination at SWSA 4 (^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Rutledge Limestone and Pumpkin Valley Shale)	Variable; SWSA 4 Cap has approximate dimensions of 3000 × 750 ft; speculative along-strike travel to picket wells in excess of 5000 ft	30 to 40 ft	Sr-90 in surface water at SWSA 4 SW-1 weir is about 100 pCi/L and tritium about 5000 pCi/L	Follows soil/bedrock interface to seeps/streams; speculative along-strike flow toward picket wells	WOC via SWSA 4 SW-1; SWSA 4 downgradient trench; MV Picket (Well 4537)	• It is uncertain if there is along-strike flow and if transport to the west in more transmissive portions of Rutledge Limestone is occurring • Failure in attainment of water level targets in some monitoring wells brings into question isolation on all waste
MV-1b	Shallow Contamination at SWSA 5 (^{90}Sr, ^{137}Cs, ^{60}Co, and VOCs in Maryville Limestone and Subsidiary Amounts in Nolichucky Shale)	Variable; SWSA 5 Cap has approximate dimensions of 2500 × 1250 ft	<= 30 to 40 ft	Sr-90 in surface water at SWSA 5 D-1 weir is about 5 pCi/L and tritium is about 5000 pCi/L	Follows soil/bedrock interface to seeps/streams	Nearby streams, including WOC, SWSA 5 D-1, D-2, and Melton Branch	• Unknown if there is along-strike transport toward the west in more transmissive portions of Maryville Limestone
MV-1c	Shallow Contamination at SWSA 6 (^{90}Sr, ^{3}H, and VOAs in Maryville Limestone and Nolichucky Shale)	Variable; 1500 × 1000 ft for Cap A and smaller dimensions for other ancillary caps (typically 300 × 1000 ft or smaller)	<= 30 ft	Sr-90 in surface water at WAG 6 MS-3 weir is about <30 pCi/L and tritium is about 270,000 pCi/L	Follows soil/bedrock interface to seeps/streams; speculative along-strike flow toward picket wells	WAG 6 MS-1, WAG 6 MS-3, WOL; along-strike flow in intermediate groundwater to the west	• Groundwater level targets mostly met in FY 2010 (three wells exceeded target), but some uncertainty remains as to completeness of hydraulic isolation. FY 2012 (Fig. H.12) shows that two wells did not meet the target (4127, 0850). • Is there along-strike flow moving west in the Maryville of Nolichucky
MV-1d	Shallow Groundwater Contamination in the Pits and Trenches Area, also referred to as WAG 7 (^{90}Sr, ^{3}H, ^{60}Co, and ^{137}Cs in Maryville)	Variable; Pits 2, 3, and 4 cap is about 1000 × 800 ft; trench 5 cap about 500 × 800 ft; trench 7 cap about 600 × 700 ft; and trench 6 cap about 500 × 700 ft		Sr-90 in surface water at West Seep Weir is about 15 pCi/L and tritium is at 3000 pCi/L; values for the East Seep Weir are about 2700 pCi/L for tritium and 15 pCi/L for $^{233/234}$U	Follows soil/bedrock interface to seeps/streams	WOC via West Seep, East Seep, and WC-Trib	• Does flow from the Pits and Trenches area migrate under the West Seep tributary
MV-1e	Shallow Groundwater Contamination at WAG 9 (^{90}Sr and ^{3}H in Rutledge Limestone)	Variable; up to 300 × 400 ft	10 to 20 ft	Sr-90: <10 to 10,000 pCi/L in groundwater; typically 150 to 200 pCi/L in downgradient surface water	Follows soil/bedrock interface to seeps/streams	WOC via HRT tributary	• Uncertainty exists regarding undocumented events that may have resulted in contaminant discharges to soil/groundwater and the north prong of the HRE Tributary
MV-2	Hydrofracture Area: Deep contamination of fission products (including ^{137}Cs and ^{90}Sr) in Pumpkin Valley Shale	Variable; up to 3500 × 2000 ft for minimum extent of contaminated brine	~600 to 1100 ft	High levels of fission products in injected grout and separated grout filtrate	Unknown/speculative deep to shallow circulation or strike-west migration; speculative pressure driven up-dip	Unknown	• Uncertainty as to vertical (along borehole traces) or horizontal travel of separated grout filtrate • Data gaps related to Hydrofracture in the NW portion of MV in Rutledge Limestone • Uncertainty as to vertical or horizontal extent of dissolved-phase contamination • Leaching of constituents from grout • What is the head profile in the brine • What is the connection between the Rutledge Limestone and the Pumpkin Valley Shale • What is the tri-party agreement on the approach and strategy for a future hydrofracture decision, including long-term stewardship

Table H.6. Consolidated description of Oak Ridge Reservation groundwater plumes, data gaps, and uncertainties (cont.)

Plume No.	Name	Description: Length (ft down valley)	Depth (ft bgs)	Concentration	Flowpaths	Groundwater exit points	Data gaps and uncertainties
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	Unknown; if source is SWSA 4 (speculative) then >5000 ft	200	Alpha max 25 pCi/L, Beta max 116 pCi/L in Port 1 @ 450 ft bgs	Along-strike flow in formations	Clinch River; speculation of deeper flow path	• Unknown source for contamination in well 4537–whether local or distant travel from MV waste units further to the east • Routine exceedances of fluoride in picket wells; sporadic exceedances of other non-rad metals • What is the 3-D model of pH all the way across the Clinch River • Need well across river in Rutledge limestone

BCK = Bear Creek kilometer.
BCV = Bear Creek Valley.
BG = Burial Ground.
bgs = below ground surface.
BV = Bethel Valley.
BVGWES = Bethel Valley Groundwater Engineering Study.
BY/BY = Boneyard/Burnyard.
CH33 = Corehole 33.
COC = contaminant/chemical of concern.
CR = Chestnut Ridge.
CRSP = Chestnut Ridge Security Pits.
CT = carbon tetrachloride.
DCA = dichloroethane.
DCE = dichloroethene.
DNAPL = dense non-aqueous phase liquid.
DOE = U.S. Department of Energy.
EEVOC = East End Volatile Organic Compound.
ETTP = East Tennessee Technology Park.
FY = fiscal year.
HCDA = Hazardous Chemical Disposal Area.
HRE = Homogenous Reactor Experiment.
HRT = Homogenous Reactor Test.
mg/L = milligrams per liter.
µg/L = micrograms per liter.
MV = Melton Valley.
NA = not applicable.
NT = North Tributary.
NW = northwest.
ORR = Oak Ridge Reservation.
PCE = tetrachloroethene.
pCi/L = picocuries per liter.
PWT = Process Waste Treatment.
RI = Remedial Investigation.
SCR = Scarboro.
SWSA = solid waste storage area.
TCA = trichloroethane.
TCE = trichloroethene.
U = uranium.
UEFPC = Upper East Fork Poplar Creek.
USGS = U.S. Geological Survey.
VC = vinyl chloride.
VOC = volatile organic compound.
WAC = waste acceptance criteria.
WAG = Waste Area Grouping.
WOC = White Oak Creek.
WOL = White Oak Lake.
Y-12 Complex = Y-12 National Security Complex.

Table H.7. Overall ranking of ORR groundwater plumes

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Weighted total	Pathway	Receptor	Total	
MV-2	Hydrofracture Sites	15	7	10	18.3	5	7.5	12.5	31
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	9	10	10	16.6	7.5	5	12.5	29
BCV-1a	S-3 Shallow contamination in Nolichucky Shale and Bear Creek (Pathways 1, 2, and 3)	12	7	10	16.6	7.5	5	12.5	29
BCV-2	Uranium in the Maynardville Limestone	5	5	10	11.4	10	7	17	28
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	7	5	2	8.0	10	10	20	28
UEFPC-7	East End VOC Plume	10	10	6	14.9	10	3	13	28
BV-2	Corehole 8, ^{90}Sr, U, ^{137}Cs	15	5	2	12.6	7.5	7	14.5	27
UEFPC-6	Localized Mercury Sources to Groundwater	12	3	10	14.3	7.5	5	12.5	27
ETTP-9	Mitchell Branch Commingled Plumes	15	3	6	13.7	7.5	5	12.5	26
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	4	10	1	8.6	10	7	17	26
BCV-6	Various near surface uranium signatures in Nolichucky Shale	7	10	10	15.4	5	5	10	25
BV-3	7000 Area VOC Plume	12	3	6	12.0	7.5	5	12.5	25
BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky and Maynardville	9	5	6	11.4	7.5	5	12.5	24
ETTP-1	K-1070-A Burial Ground	7	3	3	7.4	7.5	9	16.5	24
ETTP-5	K-720 Fly Ash Pile	5	1	10	9.1	5	9	14	23
ETTP-11	K-27/K-29 Area	8	1	6	8.6	7.5	7	14.5	23
BV-1	Main Plant ^{90}Sr, ^{3}H, mercury	13	3	2	10.3	5	7	12	22
ETTP-2	Contractor's Spoil Area	4	3	3	5.7	7.5	9	16.5	22
UEFPC-5	Uranium Sources in Maynardville Limestone	7	3	10	11.4	7.5	3	10.5	22
BCV-4	BG-A Shallow/deep (DNAPL) VOC in Nolichucky Shale	13	3	6	12.6	5	3	8	21
ETTP-7	K-1200 Area	8	3	3	8.0	7.5	5	12.5	21
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	5	3	10	10.3	5	5	10	20
BV-4	SWSA 3 ^{90}Sr	6	3	2	6.3	5	9	14	20
CR-1	Chestnut Ridge Security Pits	5	5	3	7.4	7.5	5	12.5	20
ETTP-4	Duct Island/K-1070-F	4	3	3	5.7	5	9	14	20
MV-1	Shallow groundwater contamination emanating from buried waste operations overlying the Conasauga Group formations	10	3	2	8.6	5	5	10	19
ETTP-8	K-1004 Area	4	3	3	5.7	7.5	5	12.5	18
ETTP-3	K-1085 Old Firehouse Burn Area	7	3	3	7.4	5	5	10	17
CR-2	United Nuclear Corporation Disposal Site	5	1	2	4.6	7.5	5	12.5	17
UEFPC-2	Western and Central Y-12 Area VOC Plume	9	3	3	8.6	5	3	8	17
ETTP-10	K-1064 Peninsula	2	1	3	3.4	7.5	5	12.5	16
ETTP-6	K-770 Scrap Metal Yard	5	1	4	5.7	1	9	10	16
BCV-5	BG-C West Shallow VOCs in Nolichucky Shale	9	3	3	8.6	1	1	2	11
CR-3	South Campus Facility	2	3	3	4.6	5	1	6	11
UEFPC-4	Former East End Fuel Station Plume and Garage Tanks	9	1	1	6.3	1	3	4	10

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

BCV = Bear Creek Valley.
BV = Bethel Valley.
BYBY = Boneyard/Burnyard.
CR = Chestnut Ridge.
Cs = Cesium.
DNAPL = dense non-aqueous phase liquid.
ETTP = East Tennessee Technology Park.
H = hydrogen (H^3 = tritiated hydrogen or tritium).
HCDA = Hazardous Chemical Disposal Area.
MV = Melton Valley.
Sr = strontium.
U = uranium.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.

- In fact, many of the highest ranking plumes also had very high Hazard scores due to their high contaminant concentrations, large masses, and long-half-lives. Two high-ranking plumes that had relatively low Hazard scores are the BCV Maynardville nitrate plume (BCV-1b) and MV-3, the contamination in the Melton Valley (MV) Picket wells. These scored low in the Hazard category due to their very low concentrations of contaminants and relatively short half-lives.

- For the most part plumes that scored low are smaller, with low contaminant concentrations and short half-lives, and many are situated over tighter aquitard formations.

The following sections discuss results by watershed.

H.4.2 BEAR CREEK VALLEY

The six BCV groundwater plumes are shown on Table H-8. The high-ranked plumes are those with evidence of past and ongoing releases to the Maynardville Limestone, and include:

- The S-3 Pond nitrate, uranium and technetium-99 (^{99}Tc) secondary source in the Nolichucky Shale (BCV-1a) that continues to release to both Bear Creek and the Maynardville Limestone. The current extension of this plume is BCV-1b.

- The uranium plume in the Maynardville Limestone (BCV-2), whose likely source is former activity at the Boneyard/Burnyard (BYBY), and/or ongoing releases from the S-3 Pond secondary source.

- Uranium releases to Bear Creek (and possibly into the Maynardville down creek) from the Bear Creek Burial Grounds (BCBG) [BCV-6].

Table H.8. Bear Creek Valley rankings

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Weighted total	Pathway	Receptor	Total	
	Bear Creek Valley								
BCV-1a	S-3 Shallow contamination in Nolichucky Shale and Bear Creek	12	7	10	16.6	7.5	5	12.5	29
BCV-1b	S-3 Deep nitrate in Maynardville Limestone	4	10	1	8.6	10	7	17	26
BCV-2	Uranium in the Maynardville Limestone	5	5	10	11.4	10	7	17	28
BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky and Maynardville	9	5	6	11.4	7.5	5	12.5	24
BCV-4	BG-A Shallow/deep (DNAPL) VOC in Nolichucky Shale	13	3	6	12.6	5	3	8	21
BCV-5	BG-C West Shallow VOC in Nolichucky Shale	9	3	3	8.6	1	1	2	11
BCV-6	Various near surface uranium signatures in Nolichucky Shale	7	10	10	15.4	5	5	10	25

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

BCV = Bear Creek Valley.

BG-A = Burial Ground A.
BG-C = Burial Ground C.
BYBY = Boneyard/Burnyard.
DNAPL = dense non-aqueous phase liquid.
HCDA = Hazardous Chemical Disposal Area.
VOC = volatile organic compound.

The next set of plumes (medium-ranked plumes) represents:

- Volatile organic compound (VOC) dense non-aqueous phase liquids (DNAPLs) at BCBG (BCV-4) and possibly DNAPL at the Hazardous Chemical Disposal Area (HCDA) [BCV-3] sources in the Nolichucky Shale.

- The relatively high-volume, but low-toxicity, nitrate plume in the Maynardville Limestone (BCV-1b).

The small VOC plume emanating from the BCBG-C West (BCV-5) received a Low ranking.

Note: The S-3 Plume is unusual in its variety of COCs. In this case multiple COCs, including cadmium, were considered as the key ecological COCs since cadmium is a greater ecological concern. However, cadmium plume concentrations are so low (maximum detection was 2.8 mg/L), and uranium so high (>10,000 mg/L), that uranium was still a more conservative COC for use in the ecological c/t.

One challenge encountered in ranking the BCV plumes was that flow between Bear Creek and the Maynardville Limestone unit is highly complex, and is the primary location on the ORR that this interaction occurs between a naturally flowing creek and a karst unit. It was difficult to apply pathway scores to some of the BCV plumes that lie in the Nolichucky Limestone but discharge contaminants to Bear Creek. In general, it is possible to tell where large masses of contamination hit a losing reach in Bear Creek and enter the Maynardville, but there is still much uncertainty. The one location where this appears to result in a significant mass of contamination moving from the Nolichucky to Bear Creek to the Maynardville is directly downstream of S-3, in a losing reach of Bear Creek prior to BYBY, and thus to account for this, BCV-1a received a score of 7.5. All other Nolichucky plumes received "5, or medium" scores for the pathway criteria.

It is important to note that for BCV the land use designations negotiated in the BCV Interim Record of Decision (ROD) are used to define the off-site receptor location (i.e., off-site is not considered the current ORR boundary; rather it is assumed to be the area identified as Zone 2 in the ROD, which is identified as future unrestricted land use long-term). Picket A is identified as the hypothetic plane marking the boundary of Zone 2 with Zone 3, which is identified as future controlled industrial land use (historical waste management area) [Table H.4]. If current off-site locations were used in the Pathway/Receptor scoring, BCV plumes would have scored lower.

H.4.3 UPPER EAST FORK POPLAR CREEK

The seven Upper East Fork Poplar Creek (UEFPC) Watershed groundwater plumes are shown on Table H.9. The high-ranked plumes are those with evidence of past and/or ongoing releases to the Maynardville Limestone, in particular off-site releases through groundwater migration pathways east of the ORR into Union Valley. High-ranked plumes include the following:

- The East End Volatile Organic Compound (EEVOC) Plume (UEFPC-7) scored high for three primary reasons: carbon tetrachloride levels as high as 800 times the MCLs have been detected in the plume; the verified presence of DNAPL-equivalent levels results in a relatively high score for "longevity"; and the plume's presence in the Maynardville at Picket J results in a high pathway score (10). Picket J is a line of Westbay wells located near the downgradient boundary of the Reservation in the UEFPC Watershed, several hundred feet from Scarboro Road.

- The plumes emanating from the S-3 and S-2 areas (UEFPC-1) scored high for the same three reasons; however, the pathway score is less since the plume has not reached Picket J, but the longevity score is higher since uranium is a major COC in the plume.

Table H.9. UEFPC ranking results

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Total	Pathway	Receptor	Total	
Upper East Fork Poplar Creek									
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	9	10	10	16.6	7.5	5	12.5	29
UEFPC-2	Western and Central Y-12 Area VOC Plume	9	3	3	8.6	5	3	8	17
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	5	3	10	10.3	5	5	10	20
UEFPC-4	Former East End Fuel Station Plume and Garage Tanks	9	1	1	6.3	1	3	4	10
UEFPC-5	Uranium Sources in Maynardville Limestone	7	3	10	11.4	7.5	3	10.5	22
UEFPC-6	Localized Mercury Sources to Groundwater	12	3	10	14.3	7.5	5	12.5	27
UEFPC-7	East End VOC Plume	10	10	6	14.9	10	3	13	28

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

UEFPC = Upper East Fork Poplar Creek.

VOC = volatile organic compound.

- The mercury source areas (UEFPC-6) that feed shallow groundwater and surface water rank high due to mercury concentrations that are 500 times the MCL and over 19,000 times the AWQC for organisms only.

The following two plumes received mid-level rankings: Uranium in the Maynardville Limestone (UEFPC-5) and uranium in the Nolichucky Shale (UEFPC-3). In both cases the longevity of uranium contributes to a high hazard rank. The plume in the Maynardville receives a relatively high pathway rank; however, it has not reached Picket J. The Nolichucky plume exits via surface water that is not a drinking source.

The lowest ranked plumes in UEFPC are the relatively contained organic plumes within the Nolichucky Shale—the Former East End Fuel Station Plume and Garage Tanks (UEFPC-4) and the Western and Central Y-12 Area VOC Plume (UEFPC-2).

None of the plumes in UEFPC scored as high as the BCV plumes in regard to plume size, and none of the plumes received high scores in regard to potential drinking water receptors since administrative controls are in place to prevent potable groundwater use in Union Valley.

The receptor scoring approach for the UEFPC Watershed contains two unique characteristics. First, currently there are groundwater use restrictions in place in Union Valley downgradient of the Y-12 National Security Complex (Y-12 Complex) site. A scoring of "3" has been developed to address a plume that could migrate to this area. Also, the Y-12 Complex storm drain and surface water conveyance system was determined to be an industrial drainage area in the remedial investigation and thus assumed to

not be an area for protection of ecological habitat. Sites that discharge into this industrial drainage area receive a receptor score of 3 (this is the case for uranium sources [UEFPC-5] that discharge to UEFPC); however, if historical and current data show related contaminants at Station 17, the point that the system changes from an industrial conveyance to a potential sensitive habitat, the site receives a receptor score of 5 (this is the case for mercury sources that discharge to UEFPC [UEFPC-6]).

H.4.4 CHESTNUT RIDGE AND OFF-SITE

The Chestnut Ridge and South Campus plumes were scored as shown on Table H.10. Based on the Total Plume scores (sum of the scores from Hazard identification and Pathway/Receptor analysis), the Chestnut Ridge Security Pits (CRSP) plumes ranked medium and the United Nuclear Corporation (UNC) Disposal Site and South Campus Facility (SCF) plume ranked low. In general, the Chestnut Ridge and SCF plumes scored low relative to groundwater plumes in other watersheds, primarily because the Hazard scores were low (e.g., the plumes are low concentration, relatively small, and their COCs are not long-lived). At the UNC site no groundwater plume has been delineated; there are simply low-level detections in a well. At SCF the contamination has been reduced to non-detected levels. The scoring does account for the fact that the CRSP and UNC sites overlie the karst Knox Formation (and received a Pathway score of 7.5 as a result). As with UEFPC, groundwater use restrictions to the northeast of the Y-12 Complex are accounted for in the receptor scoring.

Table H.10. Chestnut Ridge ranking results

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Weighted total	Pathway	Receptor	Total	
	Chestnut Ridge								
CR-1	Chestnut Ridge Security Pits	5	5	3	7.4	7.5	5	12.5	20
CR-2	United Nuclear Corporation Disposal Site	5	1	2	4.6	7.5	5	12.5	17
CR-3	South Campus Facility	2	3	3	4.6	5	1	6	11

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

CR = Chestnut Ridge.

H.4.5 EAST TENNESSEE TECHNOLOGY PARK

Rankings for the 11 ETTP groundwater plumes are provided in Table H.11. For this ranking exercise, several conservative assumptions were made:

- If the extent of the plume is uncertain, it is assumed the plume length extends from the contaminated well or seep to the assumed contaminant source, even if that connection has not been verified.

- Chlorinated ethene degradation ratings are based on conservative values for abiotic degradation, with 3 and 4 chlorine chemicals (tetra- and tri-) reflecting the highest reported U.S. Geological Survey (USGS) half-life (380 years) and 2 chlorine chemicals (di) reflecting a reported value of approximately 70 years (USGS 2006).

- It was assumed that the Clinch River is a drinking water source, while Poplar Creek, Mitchell Branch, and the interior ponds are not drinking water sources but are considered sensitive ecological habitats.

Table H.11. ETTP ranking results

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Total	Pathway	Receptor	Total	
East Tennessee Technology Park									
ETTP-1	K-1070-A Burial Ground	7	3	3	7.4	7.5	9	16.5	24
ETTP-2	Contractor's Spoil Area (CSA)	4	3	3	5.7	7.5	9	16.5	22
ETTP-3	K-1085 Old Firehouse Burn Area	7	3	3	7.4	5	5	10	17
ETTP-4	Duct Island/K-1070-F	4	3	3	5.7	5	9	14	20
ETTP-5	K-720 Fly Ash Pile	5	1	10	9.1	5	9	14	23
ETTP-6	K-770 Scrap Metal Yard	5	1	4	5.7	1	9	10	16
ETTP-7	K-1200 Area	8	3	3	8.0	7.5	5	12.5	21
ETTP-8	K-1004 Area	4	3	3	5.7	7.5	5	12.5	18
ETTP-9	Mitchell Branch Commingled Plumes	15	3	6	13.7	7.5	5	12.5	26
ETTP-10	K-1064 Peninsula	2	1	3	3.4	7.5	5	12.5	16
ETTP-11	K-27/K-29 Area	8	1	6	8.6	7.5	7	14.5	23

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

ETTP = East Tennessee Technology Park.

The highest scored plume and the only plume ranked in the "High" category is the comingled contaminant signatures throughout the Mitchell Branch subwatershed, ETTP-9. Although these plumes do not directly impact a drinking water source, they have a very high "hazard" ranking due to two factors: Very high groundwater concentrations [e.g., the trichloroethene (TCE) maximum detected was 230,000 µg/L relative to the 5 µg/L MCL], and the verified presence of DNAPL. There is also the potential for deep flow from the area to the Clinch River. The highest ranked plumes in the "Medium" category are those with evidence of high measured contaminant concentrations in groundwater and ongoing releases to nearby surface water receptors, and include:

- The K-1070A Burial Ground, based on its relatively high concentrations and the presence of a direct flowpath to the Clinch River.

- The K-27/K29 VOC plume, based on its high concentrations, including suspect DNAPL, and its proximity to receptors in Poplar Creek.

- The K-720 Fly Ash pile, which received a high ranking based on its proximity to the Clinch River, and the longevity of the metals in the fly ash.

Three other plumes ranked in the "Medium" category: the Contractor's Spoil Area (CSA), K-1200, and Duct Island/K-1070-F Areas due to possible flowpaths off-site, and the K-1200 Area due to high detected concentrations.

H.4.6 BETHEL VALLEY

The four Bethel Valley groundwater plumes scores are presented in Table H.12. For the Hazard ranking, one plume is assumed to involve potential DNAPL—the 7000 Area VOC plume—and thus received a longevity score of 6.

Table H.12. Bethel Valley ranking results

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Weighted Total	Pathway	Receptor	Total	
	Bethel Valley								
BV-1	Main Plant ^{90}Sr, ^{3}H, mercury	13	3	2	10.3	5	7	12	22
BV-2	Corehole 8, ^{90}Sr, U, ^{137}Cs	15	5	2	12.6	7.5	7	14.5	27
BV-3	7000 Area VOC Plume	12	3	6	12.0	7.5	5	12.5	25
BV-4	SWSA 3 ^{90}Sr	6	3	2	6.3	5	9	14	20

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

BV = Bethel Valley.
Cs = Cesium.
H = Hydrogen.
Sr = Strontium.
SWSA = Solid Waste Storage Area.
U = Uranium.
VOC = Volatile organic compound.

The highest scored plume is the Corehole 8 Plume dominated by ^{90}Sr contamination. It scores high based on two factors: its extremely high historical contaminant concentrations, and its relatively high “pathway” and “receptor” scores. Also scoring high was the 7000 Area VOC Plume. Although it did not score as high as the Corehole 8 Plume on the toxicity or receptor score, the potential for DNAPL to be present at the plume results in a relatively high longevity score, and its presence within the Little Lime Limestone formation results in a high Pathway score.

The commingled plumes in the main plant area receive a medium ranking, and the Solid Waste Storage Area (SWSA) 3 plume receives a medium ranking due to the fact that – based on available data – it does not appear to have migrated to deeper flowpaths.

H.4.7 MELTON VALLEY

The MV scoring results are presented in Table H.13. The MV plumes are a challenge to score for several key reasons. First, the broad list of COCs—which range from short-lived radionuclides to transuranics to metals and to VOCs—makes the hazard (toxicity and longevity) scoring more difficult. Some key assumptions were made for this scoring exercise:

- The shallow groundwater contamination remains in the Conasauga – even though there is some speculation that contamination may be moving westward, especially in the Rutledge, plume MV-1 gets a score of 5 for pathway. The uncertainty about the contamination in the Rutledge picket well is picked up under plume MV-3.

- Although the Hydrofracture Site (MV-2) scores very high in the Hazard ranking, it is not in a karst or highly transmissive formation and has not reached the MV Picket. Because of that it receives a 5 for the pathway score.

- The Exit Pathway (MV-3) plume scores low on the Hazard side because of the very low concentrations in all picket wells and off-site wells, but it scores very high on the pathway/receptor side. This pathway/receptor score assumes that contamination is in off-site wells to account for the current uncertainty related to this issue.

As indicated in Table H.13, the Hydrofracture Site (MV-2) received a high score of 31 based on its extreme toxicity and longevity, and its location near to the ORR boundary. The Exit Pathway plume (MV-3) also received a high score with a score of 28 based on sporadic contaminant detections across the Clinch River, suggesting that it may have migrated to off-site areas. The shallow groundwater plume (MV-1) received a low score of 19. This plume was the focus of the capping, excavation, and stabilization efforts required by the MV Interim ROD.

Table H-13. Melton Valley Watershed groundwater plumes scoring

Plume No.	Groundwater plume	Hazard score				Pathway score			Total Plume Score[a]
		Toxicity	Area	Longevity	Weighted Total	Pathway	Receptor	Total	
Melton Valley									
MV-1	Shallow groundwater contamination emanating from buried waste operations overlying the Conasauga Group formations	10	3	2	8.6	5	5	10	19
MV-2	Hydrofracture Sites	15	7	10	18.3	5	7.5	12.5	31
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	7	5	2	8.0	10	10	20	28

[a] Total Plume Scores are rounded. Shading: The list of ranked plumes was divided into three general groupings: high (25–31, red), medium (20–24, yellow), and low (10–19, green). However, because several plumes scored within one point of the higher or lower grouping, these groupings should be used with caution.

MV = Melton Valley.

H.5 REFERENCES

EPA (U.S. Environmental Protection Agency) 1992. *Hazard Ranking System Guidance Manual*, EPA 540-R-92-026, Office of Solid Waste and Emergency Response, Washington, D.C., November.

EPA 1997. *Terms of Environment – Glossary, Abbreviations, and Acronyms*, EPA 175-B-97-001, Communications, Education, and Public Affairs, Washington, D.C., December

USGS (U.S. Geological Survey) 2006. *Description, Properties, and Degradation of Selected Volatile Organic Compounds Detected in Ground Water – A Review of Selected Literature*, by Stephen J. Lawrence, Open File Report 2006-1338, U.S. Department of the Interior, U.S. Geological Survey, Reston, VA.

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ATTACHMENT H.1
RESPONSE TO STAKEHOLDER INPUT ON SCORING APPROACH

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Attachment H.1. Response to Stakeholder Input on Scoring Approach

Comment #	Stakeholder input	Response
Comments received at Workshop 1 as documented in meeting minutes		
WS-1	The toxicity score should reflect not just absolute toxicity but also toxicity relative to concentration of a contaminant (lower score for lower concentration)	Use EPA's "toxicity/concentration" screen approach, as outlined in EPA RAGS Part A (1989)[a] [see Table H.1].
WS-2	Need to account for ecological toxicity	Agreed. Although humans are the primary receptor for direct groundwater use, ecological receptors may be exposed to groundwater that resurfaces to the creek. The HRS guidance states: • "Evaluate whether the ground water to surface water component should be scored. Note that no specific guidance on this component is provided in this manual (p. 24)." • Guidance is provided for the surface water pathway and indicates that a site could receive "a relatively high score if an observed release to a fishery of sensitive environment is established" (p. 35). This guidance is accounted for in the "receptor" scoring approach (see Table H.5). The guidance also directs the scorer to place more emphasis on contamination in surface water that could bioaccumulate up the food chain (see Table H.5).
WS-3	Ranking should reflect the deep flow pathway being more of a concern up the valley	Agreed. Under the Pathway score, groundwater plumes in the Maynardville, or with the potential to enter the Maynardville, score higher than plumes that are in the aquitard formations (see Table H.4).
WS-4	An uncertainty factor needs to be applied to plume ranking	See response to Comment #EPA-1 regarding conservative assumptions about contaminant mobility and plume migration in plume ranking. Also, the magnitude of existing uncertainties can be accounted for as part of the "implementability" evaluation at the project categorization stage (e.g., if there are significant uncertainties about a given plume, an additional characterization project may be implementable, but an early action project would not be implementable).
WS-5	Take into consideration Reference Doses and Slope Factors	Agreed. However since it is not possible to directly compare a reference dose to a slope factor, or a cancer slope factor to a radiation slope factor, we will use MCLs (and RSLs if necessary) for the comparisons. MCLs are comparable (in the same units) and account for all types of health effects.

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response
WS-6	Scaling of 1 to 10 may imply more precision than there is vs. using High, Medium, or Low	Numeric scoring is useful when combining diverse criteria into an overall score; however, the final outcome of the scoring will be "high," medium," and "low" final prioritization categories.
WS-7	Scoring does not account for differences in longevity of dissolved-phase plume of VOCs vs. DNAPL	Consideration of DNAPL in the plume is included in the "volume" scoring. A DNAPL or possible DNAPL source is ranked at least 6, even in the case of small masses.
WS-8	Consider consolidating plumes from the same source area for plume identification and ranking	Agreed. The 10 preliminary plumes for Bear Creek Valley have been consolidated down to 6 key secondary groundwater sources/plumes. The 6 secondary sources/plumes basically represent plumes from 6 unique primary sources.
WS-9	Consider contaminant mobility	Contaminant mobility is considered in both the hazard/area scoring (see plume length on Table H.3) and the pathway score (the documented downgradient migration on Table H.4).
	Comments received from EPA in February 2013	
EPA-1	**Plume Scoring Process:** The hazard scoring needs to better incorporate a contaminant migration factor. If a plume is confirmed to be static and not "daylighting" in surface water or extending beyond an area where exposure can be controlled, it would have a lower migration score than if the plume is expanding or daylights into one or more surface water bodies. This score could either appear as a fourth column in the hazard score or could be used to modify one of the other columns. For example, if there is no plume mobility (or more generally, no contaminant mobility) and the plume is in close proximity to the source area, then the effective toxicity of the plume would be lowered. This modification to incorporate a migration element to hazard scoring is not identical to any migration component to the pathway scoring for groundwater because (1) a plume could be in karst and be immobile or relatively immobile (the pathway receptor scoring sheet indicates that if contamination is in the Maynardville Ls, it is migrating downgradient); and (2) the distance to a receptor well or spring from the plume is not necessarily a consideration (e.g., a plume moving 100 ft per year and 1000 ft away from a well is of more concern than a plume moving 1 ft per year and 200 ft away from the well); and (3) the migration component does have a moderating or	The approach introduced at the January 29, 2013, Workshop and presented in more detail in this Attachment H.1 has the advantages of keeping the process simple and generally aligned with the HRS scoring guidance (EPA 1992)[b] The approach also places the greatest focus on groundwater contamination that may be migrating off-site over long distances and potentially impacting human health vs. contaminants that quickly resurface to surface water. As shown in Table H.4, the pathway scoring conservatively assumes the worst case in terms of whether a plume is mobile with potential for off-site migration and the distance to the receptor. Plumes with the potential to move off-site to a residential drinking water well receptor are given the highest scores, and plumes that are likely to remain on-site in the aquitard formations in Bear Creek (the Nolichucky shale and the Maryville Limestone) are given the lowest scores. The plume length captured in the Hazard Scoring (see Table H.3) inherently accounts for dilution and attenuation of a contaminant that can impact effective toxicity. Also, many plumes appear to be in essentially steady-state condition with concentration fluctuations (and inferred mass transport) that respond to seasonal and longer term climatic stressors on groundwater recharge. In

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response
	exacerbating effect on the toxicity component, which is not necessarily captured in the pathway scoring. The migration component is also not identical to the volume component of the hazard scoring, because the volume of a plume is not necessarily correlated with current plume dynamics. There are likely to be other ways to incorporate the migration factor into the overall scoring process in addition to those suggested in the previous paragraph. Since it is at least partly addressed by the draft scoring system, it might best be considered as an improvement to that system, rather than being a new element.	some areas plume mass increases are observed based on rising concentration trends, and conversely many areas show apparent mass decreases based on falling concentration trends. The plume volume criterion as used in the HRS provides a very high-level metric indicating relative magnitude. In assigning scoring a conservative approach is used to encompass uncertainty of plume extent. Maximum scoring is applied when a plume occurs in a recognized zone of potential rapid, off-site transport. The Groundwater Receptor Score shown in Table H.5 is a new element of the Pathway/Receptor scoring that has been added since the January 29, 2013, Workshop. Table H.5 shows the highest scores for groundwater receptor wells or surface drinking water sources with actual contamination, with decreasing scores the farther away actual receptors are from the source.
EPA-2	The longevity factor in the hazard score probably needs to be adjusted to more realistic time periods. For example, if VOC groundwater contamination is being fed by DNAPL and (left unremediated) the VOC plume is expected to persist in unacceptable concentrations for 5000 years, how different is that condition, in a practical sense, from uranium groundwater contamination that may persist for much longer?	As shown in the Hazard Criterion discussion and Table H.3, the Longevity ranking has been revised to reflect a score of 6 out of 10 for DNAPL source. The score of 10 reflects the uranium decay of over 4 billion years.
EPA-3	The pathway/receptor scoring needs to account for the possibility that contaminated groundwater in the Nolichucky is discharging to surface water and causing unacceptable surface water contamination.	As shown in Table H.4, plumes outside of the Maynardville that are currently discharging to Bear Creek or North Tributaries are assigned a score of 5 vs. a score of 1 for contamination that remains in the Nolichucky Shale or Maryville Limestone. The Groundwater Receptor Score shown in Table H.5 reflects consideration of groundwater releases to surface water.
EPA-4	There may be a basis for adding in an uncertainty adjustment factor to the volume and/or migration hazard criterion to account for potential underestimation of contaminant plume size and migration. The less degree of certainty about the size of the plume, the higher the score (similar consideration should be given to the migration criterion).	See response to Comment #EPA-1.

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response
EPA-5	**Ecological Considerations for Prioritization of Groundwater Plumes:** The toxicity assessment for the constituents detected in groundwater plumes should also consider the toxicity to aquatic organisms. A sum toxic unit approach should be used to estimate the toxicity of a mixture of volatile organic compounds detected in the shallow groundwater well nearest the location where a groundwater plume is expected to daylight. EPA Region 4 should be contacted for the surface water screening values to use in the sum toxic unit approach. Screening values for chronic and acute exposures will be provided. The result will be a numerical value for the toxic unit. Sum toxic unit values below 1 for chronic screening values in groundwater are considered of minor concern. Values above 1 for chronic screening values are considered of greater concern to aquatic life. Sum toxic units above 1 for acute exposures will be considered of even greater concern, even if groundwater discharges are localized or intermittent. The volume of the groundwater discharge relative to the capacity for dilution within the surface water body should be factored into the prioritization. If a groundwater plume is discharging into a wetland, this is of special concern due to the sensitivity of the wetland habitat and limited dilution potential. If the groundwater plume has daylighted and the Sum Toxic Unit in groundwater is above 1 for either acute or chronic exposure, the concentrations in the surface water body should also be screened. If the sum toxic units in surface water are above 1 for the chronic screening values, the exposure pathway should be considered complete. Given the complexity of groundwater at the ORR, determining where a groundwater plume might daylight may not be trivial. This discussion does not attempt to describe how to determine where the groundwater might daylight. If there are no data in the surface water body in the vicinity of where the groundwater will daylight or no shallow wells in the area, the prioritization should capture this uncertainty.	See response to Comment #WS-2 regarding HRS guidance and ecological receptors. While the suggested Sum Toxic Unit Approach is applicable to ecological considerations for a future groundwater RI and could be noted as such in the GW Strategy Document, the approach proposed in this Attachment H.1 is recommended. The proposed approach accounts for ecological considerations in a variety of ways without requiring a large amount of additional data collection and analysis. The proposed approach is a concentration/toxicity score using AWQC, fish and aquatics, organisms only values, and is discussed in the Hazard Criterion discussion and Table H.3. The AWQC element reflects potential impact of GW contamination to surface water resources and aligns with goals in the existing Bear Creek Valley Phase I ROD (DOE 2000).[c] The approach mimics the human health approach while focusing on a primary objective of the ORR GW Strategy to address potential off-site releases to groundwater well users. Similar to other watersheds on the ORR, it should be noted that CERCLA monitoring in Bear Creek Valley is aligned with goals of the existing decision document (Bear Creek Valley Phase I ROD [DOE 2000]),[c] including the goal to attain applicable AWQC for protection of surface water resources through Bear Creek and its tributaries within 5 years after implementation of all ROD actions. Results of AWQC monitoring throughout the Bear Creek Watershed were recently reported and evaluated in the 2011 Third Reservation-wide CERCLA Five-Year Review (DOE 2012).[d]

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response
	Scoring − 1 Plume currently does not daylight and has a very low probability of daylighting to surface water in the future. − 2 Plume currently daylights, or has a reasonable chance of daylighting in the future, and the sum toxic unit for organic compounds detected in the shallow well closest to the waterbody is less than 1 for chronic screening exposures and surface water data are available for the waterbody that also has either non-detected concentrations of organic compounds or a sum toxic unit also less than 1 for chronic exposures. − 3 Plume currently daylights and the concentrations of organic compounds in groundwater are less than a sum toxic unit of 1 for chronic exposures, but groundwater characterization is limited and/or limited surface water data are available in the likely path of the plume. − 4 Plume daylights, or may be expected to daylight in the future, and concentrations in the nearest shallow groundwater well are above a sum toxic unit of 1 for chronic exposures and below a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are below the chronic sum toxic unit of 1 for organic compounds. − 5 Plume daylights and concentrations in the nearest shallow groundwater well are above the sum toxic unit of 1 for chronic exposure and below a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are below the chronic sum toxic unit of 1 for organic compounds. − 6 Plume daylights, or may be expected to daylight in the future, and concentrations in the nearest shallow groundwater well are occasionally above a sum toxic unit of 1 for acute exposures.	

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response
	Concentrations in the impacted surface water are below the chronic sum toxic unit of 1 for organic compounds. The volume of the groundwater plume, the estimated discharge flux to the surface water, or the data uncertainty suggest a potential for greater concern.	
	− 7 Plume daylights and concentrations in the nearest shallow groundwater well are above the sum toxic unit of 1 for chronic exposure and either are above or below a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are unknown or data limited.	
	− 8 Plume daylights and concentrations in the nearest shallow groundwater well are above the sum toxic unit of 1 for chronic exposure and are above a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are available and are determined to be above the chronic sum toxic unit for organic compounds.	
	− 9 Plume daylights and concentrations in the nearest shallow groundwater well are above the sum toxic unit of 1 for chronic exposure and are above a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are unavailable, unknown, or data are limited. The volume of the plume and an estimate of its discharge flux relative to the dilution provided by the surface water body suggest the concentrations delivered to the surface water body may be above the sum toxic unit of 1 for either acute or chronic exposures.	
	− 10 Plume daylights and concentrations in the nearest shallow groundwater well are above the sum toxic unit of 1 for chronic exposure and are above a sum toxic unit of 1 for acute exposures. Concentrations in the impacted surface water are also detected above the sum toxic unit of 1 for acute exposures in one or more sampling events.	

Attachment H.1. Response to Stakeholder Input on Scoring Approach (continued)

Comment #	Stakeholder input	Response

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

[b] EPA 1992. *Hazard Ranking System Guidance Manual*, EPA 540-R-92-026, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

[c] DOE 2000. *Record of Decision for the Phase I Activities in Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee*, DOE/OR/01-1750&D4, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

[d] DOE 2012. *2011 Third Reservation-wide CERCLA Five-Year Review for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee*, DOE/OR/01-2516&D2, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

AWQC = ambient water quality criteria.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
DNAPL = dense non-aqueous phase liquid.
EPA = U.S. Environmental Protection Agency.
GW = groundwater.
HRS = Hazard Ranking System.
MCL = maximum contaminant level.
ORR = Oak Ridge Reservation.
RAGS = Risk Assessment Guidance for Superfund.
RI = Remedial Investigation.
ROD = Record of Decision.
RSL = Regional Screening Level.
VOC = volatile organic compound.

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APPENDIX I
PROJECT IDENTIFICATION AND RANKING FOR THE OAK RIDGE RESERVATION GROUNDWATER STRATEGY

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CONTENTS

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TABLES

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ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CSM	conceptual site model
DQO	data quality objective
ETTP	East Tennessee Technology Park
FY	fiscal year
HRS	Hazard Ranking System
MV	Melton Valley
ORR	Oak Ridge Reservation

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I.1 INTRODUCTION

This Appendix provides the results of project identification and ranking by the Groundwater Strategy Team. In addition to supporting selection of an early action project called for in the charter, the list provides candidate projects for longer-term implementation. The list is a starting catalog based on Strategy Team efforts; it is not inclusive of every project that may be needed to achieve strategy objectives.

The process for identifying and ranking projects and the selection of a near-term groundwater project based on the ranking results are described below.

I.1.1 PROJECT IDENTIFICATION AND RANKING

I.1.1.1 Identification of Potential Projects

During review of conceptual site models (CSMs) and recent trend data, the Strategy Team identified a list of groundwater plumes on the Oak Ridge Reservation (ORR) and major data gaps and uncertainties in understanding plume characteristics (Appendices B through G). The groundwater plumes were ranked using a modified Hazard Ranking System (HRS) approach (Appendix H). A list of potential projects to address the plumes and uncertainties was also identified and ranked.

In order to mobilize a project by the 9/30/2014 Construction Start milestone, the following constraints were identified by the Strategy Team:

- The project must be implementable within an existing, approved Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) decision document; there would not be sufficient time for preparation/review/approval of a new decision document to support project mobilization.

- The project cost must be within available funding identified in the charter:

  — $1.5M per year in fiscal year (FY) 2014 through FY 2016 ($4.5M total).

- The project must be selected early enough in FY 2013 to allow time for applicable CERCLA work plan preparation/review/approval needed for project mobilization.

Many of the identified projects are relatively low-cost characterization projects that fall within these constraints. Some of the projects are complex and costly projects that fall outside these constraints and are candidates for longer-term strategy implementation.

Each project was assigned a project number with the first part of the project number corresponding to the project plume it addresses (e.g., project ETTP-9-1 East Tennessee Technology Park [ETTP] Sitewide Groundwater Treatability Study [K-1401 Area] relates to groundwater plume ETTP-9 Mitchell Branch Commingled Plumes). After identifying projects for plumes in each watershed, the project lists were combined into a list of 60 projects shown in Table I.1. The corresponding groundwater plume for each project is also shown in Table I.1 along with plume scores and data gaps and uncertainties. Remedial action projects (projects that involve active remediation) are indicated in the table in red font. As indicated by a “Y” in the “Multiple Related Plumes” column on the table, in some cases a single project relates to more than one groundwater plume. In some cases, no project was identified for a plume.

Table I.1. ORR groundwater plumes and potential groundwater projects

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
BCV-1a	S-3 Ponds; S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3) discharging to Maynardville	• Ongoing releases from nitrate plume/secondary source in Nolichucky • Quantified estimates of total U mass that left S-3 compared to mass in current plumes • What is the extent of the U plume (bottom in Maynardville) • How much of the plume is currently being monitored • Water chemistry as related to potential actions • Few deep wells in Maynardville downgradient of S-3	16.6	12.5	29	BCV-1a-1 – Sample Additional Existing On-site and Off-site Wells; increase monitoring of existing wells to better define trends	Y
						BCV-1a-2 – Install/sample Additional Wells – Bear Creek/Grassy Creek Divide; should reduce uncertainties regarding Maynardville discharge off-site and help define flow system	Y
						BCV-1a-3 – Install/sample Additional Wells – Nolichucky Shale – Zone 2; would help address uncertainties around BCV integration point (BCK 9.2)	Y
						BCV-1a-4 – Implement future action for S-3 Ponds Pathways 1–3	
						BCV-1a-5 – Investigation to determine best locations and implementation of wells for pumping and treating groundwater plumes in BCV	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

			Plume scores				
Plume No.	Description	Data gaps and uncertainties	Weighted total hazard score	Total pathway score	Total plume score*	Potential groundwater action projects	Multiple related plumes
BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone	• Uncertain nitrate mass as secondary source in Maynardville • Nitrate degradation processes and rates; ammonia data • Bottom of Maynardville plume	8.6	17	26	BCV-1b-1 – Sample Additional Existing On-site and Off-site Wells; increase monitoring of existing wells to better define trends	Y
						BCV-1b-2 – Install/sample Additional Wells – Bear Creek/Grassy Creek Divide; should reduce uncertainties regarding Maynardville discharge off-site and help define flow system	Y
						BCV-1b-3 – Install/sample Additional Wells – Nolichucky Shale – Zone 2	Y
						BCV-1b-4 – DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	Y
						BCV-1b-5 – Groundwater Use Restrictions/Policies across Clinch River - TBD	Y
BCV-2	Uranium in the Maynardville Limestone	• Shallow plume source since BYBY action • What has happened to U in Maynardville since BYBY action • Is the BYBY the primary source of U in Maynardville downgradient of BYBY (or S 3)	11.4	17	28	BCV-2-1 – BYBY uranium source characterization; soil sampling and well installation/sampling on north hill side of BYBY	
						BCV-2-2 – Install/sample Additional Wells – Nolichucky Shale – Zone 2; would help address uncertainties around BCV integration point (BCK 9.2)	Y
						BCV-2-3 – Implement NT-8 Early Action	Y

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
BCV-3	HCDA Shallow/deep VOCs (DNAPL) in Nolichucky Shale and Maynardville	• Is there a DNAPL source at the Hazardous Chemical Disposal Area (HCDA) and, if so, how deep • Is the conceptual model for transfer from Nolichucky to Maynardville well understood • VOC degradation rates in BCV • What is the nature of the primary HCDA source	11.4	12.5	24	BCV-3-1 – HCDA DNAPL source characterization; soil sampling and well installation/sampling at HCDA	
BCV-4	Bear Creek Burial Grounds; BG-A Shallow/deep (DNAPL) VOCs in Nolichucky Shale	• What do existing West Bay wells tell us about VOC (and other COC migration) and are they in the right place • Poorly defined bottom and west end of Plume #8	12.6	8	21	BCV-4-1 – Install/sample Additional Wells – Nolichucky Shale – Zone 2	Y
BCV-5	Bear Creek Burial Grounds; BG-C West Shallow VOCs in Nolichucky Shale	• Is DNAPL at Burial Ground A the source of contamination “moving” toward NT-8 • What is DNAPL mass at Burial Ground A • How far west has the VOC plume moved	8.6	2	11	BCV-5-1 – Install/sample Additional Wells – Nolichucky Shale – Zone 2	Y
BCV-6	Bear Creek Burial Grounds; various near-surface uranium signatures in Nolichucky Shale NT-8 discharging to Maynardville	• Gaining/losing reaches of Bear Creek	15.4	10	25	BCV-6-1 – Long-term, dry-season tracer test, combined with Install/sample Additional Wells – Bear Creek/Grassy Creek Divide and Install/sample Additional Wells – Nolichucky Shale – Zone 2, would help address uncertainties in the uranium plume in Maynardville flowpath and SW/GW interactions	Y
						BCV-6-2 – Implement NT-8 Early Action	Y

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
BV-1 (a–e)	Main Plant Area; various areas of groundwater contamination across four quadrants and the 4000 Area in the ORNL main plant area	• Investigations have not been able to delineate contamination around and under active facilities to determine if groundwater plumes have active and continuing sources around infrastructure, piping, appurtenances, etc., or if one-time spills or former operations were responsible • Depth of some contamination is unknown • Full list of COCs is uncertain • Distribution of mercury contamination is poorly defined; also not listed as a primary COC in the BV RI • Nature and extent of contamination from Bldg. 3019 and other source areas on its outcrop belt in 2000 and 3000 areas not well understood • Not sure of the CH33 plume source or plume depth • What is the extent of Hg in groundwater around Bldg. 4501 • Are there historical data or monitoring wells around the old SWSA 2 • The gradient is in many directions in both shallow and deep zones • There is a limited head data set with lots of inference in analysis; limited understanding of flow in BV and its impact to off-site sources • Need more deep wells and wells in same formation to test the strata-bound flow concept • Down-gradient extent of Central Plant Area plumes – is it First Creek • Need water-balance update	10.3	12	22	BV-1-1 – Sample additional existing wells in the main plant area; attempt to better delineate extent of contamination	
						BV-1-2 – Install and sample additional bedrock wells in the main plant area; assess probable groundwater flow regime and nature and extent of groundwater contamination beneath site facilities	
						BV-1-3 – Sample additional existing bedrock wells in the Rockdell formation; attempt to better delineate extent of contamination	
						BV-1-4 – Install additional bedrock wells in Rockdell west of existing well 2541; assess potential groundwater flow directions and nature and extent of contamination at the watershed divide near SWSA 3; this task should be implemented in combination with BV-4-1	Y
						BV-1-5 – Project to address mercury contamination, e.g., Bldg. 3592	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
BV-2	Corehole 8 Plume; ^{90}Sr, uranium, and ^{137}Cs in shallow/deep Benbolt limestones and siltstones	• Extent of plume migration down-dip (vertically) and into formations adjacent to the Benbolt is uncertain (various versions of the BVGWES show migration into Rockdell Formation underlying limestone formation located north of Tank W-1A) • There is not much data-bounding of the Corehole 8 Plume • What happens if DOE shuts down central process treatment facilities (e.g., long-term availability of treatment capability) • Assumption that plume direction is not toward the east (Fifth Creek) • Need deep well down-strike of 4570 (is the plume beyond First Creek) • Unknown mid- to long-term effect of upgrades to Corehole 8 Plume capture system • Can we currently pump and treat more water or are we limited by PWT WAC and have we optimized ^{90}Sr mass removal, location, and pumping rates	12.6	14.5	27	BV-2-1– Install/sample a Bethel Valley Picket Well transect near Hwy. 95; help reduce uncertainties about extent of plume migration	
						BV-2-2 – Install/sample picket wells near the Clinch River	
						BV-2-3 – Define extent of CH 8 plume in all directions, including depth	
						BV-2-4 – Install/sample wells downgradient of CH 8 plume as appropriate based on flow in Benbolt, Rockdell	
						BV-2-5 – Groundwater Use Restrictions/Policies across Clinch River - TBD	Y
						BV-2-6 – DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	Y
BV-3	7000 Area VOC Plume; VOCs, primarily TCE and daughters, in Witten shaley siltstones and limestones; relatively minor VOCs in shallow/deep Benbolt limestones and siltstones	• Bottom and west end of plume somewhat poorly defined (limited TCE data at depth) • Existence and mass/distribution of DNAPL are unknown, possibly bringing into question the effectiveness of bioremediation • Degradation of all daughter products down to ethane is uncertain • What is the best injection location	12	12.5	25	BV-3-1 – Design and implement a full-scale bioremediation system; implement 7000 Area plume remediation (BV ROD action)	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
BV-4	SWSA 3 ^{90}Sr Plume; Sr-90 in Witten shaley siltstones and limestones migrating both east (to Northwest Tributary) and west (Raccoon Creek)	• Bottom and both east and west ends of plume are somewhat poorly defined • There is ^{99}Tc in off-site wells RWA-97	6.3	14	20	BV-4-1 – Install and sample additional bedrock wells to east, west, and on the apparent watershed divide, assess probable groundwater flow directions and nature and extent of contamination	Y
CR-1	Chestnut Ridge Security Pits	• Lateral and vertical extent of VOC contamination and exit pathways in the Knox Group are not well understood • What is the remaining mass of VOCs in the source	7.4	12.5	20	CR-1-1 – Monitor “bootlegger” spring downgradient of the site; attempt to determine potential exit pathway	
CR-2	United Nuclear Corporation Site	• No significant documented groundwater contamination; however, potential exit pathways in the Knox Group are not well understood • There is no monitoring in the southwest portion of the CR watershed	4.6	12.5	17		
CR-3	South Campus Facility	• No significant data gaps identified	4.6	6	11		
ETTP-1	K-1070-A Burial Ground	• Mass and distribution of residual source are uncertain • There is uncertainty about the flowpath in the Knox at depth (e.g., west or east) • The depth of VOC contamination is unknown	7.4	16.5	24	ETTP-1-1 – Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y
						ETTP-1-2 – DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	Y
						ETTP-1-3 – Groundwater Use Restrictions/Policies across Clinch River - TBD	Y
ETTP-2	Contractor's Spoil Area	• Source of TCE at spring (USGS 10-895) is unknown	5.7	6.5	22		

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
ETTP-3	K-1085 Old Firehouse Burn Area	• Full extent of plume and remaining source mass is uncertain	7.4	10	17	ETTP-3-1 – Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y
ETTP-4	Duct Island/K-1070-F	• Source of TCE at PCO spring is unknown (could be K-1070-F or K-27 or other source)	5.7	14	20	ETTP-4-1 – Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y
ETTP-5	K-770 Fly Ash Pile	• Discharge of elevated metals to Clinch River is uncertain	9.1	14	23		
ETTP-6	K-770 Scrap Metal Yard	• Vertical extent into bedrock is unknown	5.7	10	16	ETTP-6-1 – Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y
ETTP-7	K-1200 Area	• Source of VOCs is uncertain and extent in bedrock is unknown	8	12.5	21		
ETTP-8	K-1004 Area	• Source of VOCs is uncertain	5.7	12.5	18		
ETTP-9	Mitchell Branch Commingled Plumes	• Vertical extent of plumes is uncertain • Source of Cr that exits to Mitchell Branch is unknown	13.7	12.5	26	ETTP-9-1 – ETTP Sitewide Groundwater Treatability Study (K-1401 Area)	
ETTP-10	K-1064 Peninsula	• Source of TCE is uncertain	3.4	12.5	16		
ETTP-11	K-27/K-29 Area	• Source of VOCs is uncertain and vertical and horizontal extent of plumes is uncertain	8.6	14.5	23	ETTP-11-1 – Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
MV-1 (a–e)	Shallow Groundwater Contamination emanating from buried waste operations overlying the Conasauga Group formations	• It is uncertain if there is along-strike flow and if transport to the west in more transmissive portions of Rutledge Limestone is occurring • Failure in attainment of water level targets in some monitoring wells brings into question isolation on all waste • Unknown if there is along-strike transport toward the west in more transmissive portions of Maryville Limestone • Groundwater level targets mostly met in FY 2010 (three wells exceeded target), but some uncertainty remains as to completeness of hydraulic isolation; FY 2012 (Fig. H.12) shows that two wells did not meet the target (4127, 0850) • Is there along-strike flow moving west in the Maryville of Nolichucky • Does flow from the Pits and Trenches area migrate under the West Seep tributary • Uncertainty exists regarding undocumented events that may have resulted in contaminant discharges to soil/groundwater and the north prong of the HRE Tributary	8.6	10	19	MV-1-1 – Install/sample wells in the Rutledge Limestone exit pathway close to sources (SWSA 4)	Y

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
MV-2	Hydrofracture Sites	• Uncertainty as to vertical (along borehole traces) or horizontal travel of separated grout filtrate • Data gaps related to Hydrofracture in the NW portion of MV in Rutledge Limestone • Uncertainty as to vertical or horizontal extent of dissolved-phase contamination • Leaching of constituents from grout • What is the head profile in the brine • What is the connection between the Rutledge Limestone and the Pumpkin Valley Shale • What is the tri-party agreement on the approach and strategy for a future hydrofracture decision, including long-term stewardship	18.3	12.5	31	MV-2-1 – Install/sample deep wells to investigate brine mobility	Y
						MV-2-2 – DQO session to determine an approach for addressing hydrofracture issues	
MV-3	Exit Pathway/Picket Wells contamination from undetermined sources	• Unknown source for contamination in well 4537– whether local or distant travel from MV waste units further to the east • Routine exceedances of fluoride in picket wells; sporadic exceedances of other non-rad metals • What is the 3-D model of pH all the way across the Clinch River • Need well across river in Rutledge limestone	8	20	28	MV-3-1 – Install/sample wells in the Rutledge Limestone exit pathway close to sources (SWSA 4)	Y
						MV-3-2 – Install/sample deep wells to investigate brine mobility	Y
						MV-3-3 – DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	Y
						MV-3-4 – Groundwater Use Restrictions/Policies across Clinch River - TBD	Y

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume	• Central Y-12 Maynardville Limestone Exit Pathway: A limited number of wells exist in the central portion of the complex within the Maynardville Limestone, particularly in the intermediate and deep groundwater intervals; lateral and vertical extent of contamination in the exit pathway in the western and central portions of the Y-12 Complex is not well understood • Where is the groundwater divide between UEFPC and BCV • Do the reducing conditions in UEFPC (VOCs) result in nitrate reductions to ammonia	16.6	12.5	29	UEFPC-1-1 – Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	Y
						UEFPC-1-2 – Tracer tests in GW-251 to monitor flow direction near BCV/UEFPC Divide	
UEFPC-2	Western and Central Y-12 Area VOC Plume	• Same as plume UEFPC-1 • What are/were the sources of VOCs, operations, leaks, and spills • Are there secondary DNAPL sources • Vertical and horizontal delineation of VOCs and potential DNAPL sources in the Nolichucky Shale near former production facilities in the western Y-12 area (e.g., Bldgs. 9201-5, 9201-4, and WCPA)	8.6	8	17	UEFPC-2-1 – Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	Y
						UEFPC-2-2 – Install/sample Additional Wells in the Nolichucky in western portion of Y-12 Complex; investigate vertical and horizontal delineation and DNAPL sources	
UEFPC-3	Western Y-12 Area Uranium Sources in Nolichucky Shale	• Same as plume UEFPC-1	10.3	10	20		
UEFPC-4	Former East End Fuel Station and Garage Tanks	• No significant data gaps identified	6.3	4	10	UEFPC-4-1 – In-situ bioremediation; potential mass reduction of plume	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
UEFPC-5	Uranium Sources in Maynardville Limestone	• Same as plume UEFPC-1	11.4	10.5	22	UEFPC-5-1 – Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	Y
						UEFPC-5-2 – Characterization of GW-605/606 Source Area; soil sampling and well installation	
						UEFPC-5-3 – Pending UEFPC-5-1 characterization results, implement source removal/control at GW-605/606 Source Area; potential reduction of U plume	
UEFPC-6	Localized Mercury Sources to Groundwater	• Same as plume UEFPC-1 • Is there an actual Hg plume in the shallow or deeper zones	14.3	12.5	27	UEFPC-6-1 – Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	Y
						UEFPC-6-2 – Install well in shallow karst east of Big Spring; perform dye trace; investigate potential downstream conduit for GW to UEFPC	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores: Weighted total hazard score	Plume scores: Total pathway score	Plume scores: Total plume score*	Potential groundwater action projects	Multiple related plumes
UEFPC-7	East End VOC Plume	• What is the source of the carbon tetrachloride (CT) plume • A limited number of wells exist in the intermediate and deep groundwater intervals of the Nolichucky Shale at the ORR boundary and no wells exist in these intervals off of the ORR in Union Valley to the east; the potential for EEVOC Plume migration along strike-parallel fracture pathways is not well understood • Is there discharge at SCR 7.18, Cattail Spring, or Picket J • Wells in UEFPC water gap should be sampled for current VOC concentrations • Existing wells in the eastern portion of the Y-12 Complex do not define the full vertical extent of VOC contamination (particularly CT) within the Maynardville Limestone and provide only partial definition of the lateral extent of the VOC plume within the eastern portion of the complex	14.9	13	28	UEFPC-7-1 – Install/sample Additional Wells in the Nolichucky Shale near eastern Y-12 Complex boundary/Scarboro Road; increase understanding of plume migration	
						UEFPC-7-2 – Characterization of CT and TCE sources at east end of Y-12 Complex; soil sampling and well installation	
						UEFPC-7-3 – Pending UEFPC-7-2 characterization results, remediate CT and TCE sources at east end of Y-12 Complex	

Table I.1. ORR groundwater plumes and potential groundwater projects (cont.)

Plume No.	Description	Data gaps and uncertainties	Plume scores			Potential groundwater action projects	Multiple related plumes
			Weighted total hazard score	Total pathway score	Total plume score*		

* Total Plume Scores are rounded.
Red font = Remedial Action Project.
3-D = three-dimensional.
^{99}TC = technetium-99.
AM = Action Memorandum.
BCK = Bear Creek kilometer.
BCV = Bear Creek Valley.
BG = Burial Ground.
BV = Bethel Valley.
BVGWES = Bethel Valley Groundwater Engineering Study.
BYBY = Boneyard/Burnyard.
CH = Corehole.
COC = chemical/contaminant of concern.
CR = Chestnut Ridge.
CT = carbon tetrachloride.
DNAPL = dense non-aqueous phase liquid.
DOE = U.S. Department of Energy.
DQO = data quality objective.
EEVOC = East End Volatile Organic Compound.
ETTP = East Tennessee Technology Park.
FY = fiscal year.
GW = groundwater.
HCDA = Hazardous Chemical Disposal Area.
Hg = mercury.
HRE = Homogenous Reactor Experiment.
MV = Melton Valley.
NT = North Tributary.
NW = northwest.
ORNL = Oak Ridge National Laboratory.
ORR = Oak Ridge Reservation.
PWT = Process Waste Treatment.
RI = remedial investigation.
ROD = Record of Decision.
SW = surface water.
SWSA = Solid Waste Storage Area.
TBD = to be determined.
TCE = trichloroethene.
TDEC = Tennessee Department of Environment and Conservation.
U = uranium.
UEFPC = Upper East Fork Poplar Creek.
USGS = U.S. Geological Survey.
VOC = volatile organic compound.
WAC = Waste Acceptance Criteria.
WCPA = Waste Coolant Processing Area.
Y = yes.
Y-12 Complex = Y-12 National Security Complex.

I.1.1.2 Project Scores and Ranking of Potential Projects

In order to eliminate redundancies due to similar projects that relate to multiple plumes, the original list of 60 projects shown in Table I.1 was collapsed to 36 projects shown in Table I.2. For each project with a "Y" in the "Multiple Related Plumes" column in Table 1.2, there is a listing in Table I.3 of the groundwater project and the multiple related groundwater plumes.

I.1.1.2.1 Project score criteria

Once a project was identified, the following criteria supporting selection of a near-term project were used to determine a project score:

- **Time** required to plan and implement.
- **Implementability** of the project – is there a degree of confidence that the technical aspects of the selected project are implementable.
- **Cost** – is the project cost within the available funding.

For the **Time** criteria, short-term projects (<3 years) received a score of 2 and longer-term projects (>3 years) received a score of 1.

For the **Implementability** criteria, projects that are highly implementable received a score of 3; a medium effort to implement received a score of 2; and uncertain, or low implementability, received a score of 1.

For the **Cost** criteria, low-cost projects (<$4.5M) are assigned a score of 3; medium-cost projects (<$20M and >$4.5M) are assigned a score of 2; and high-cost projects (>$20M) are assigned a score of 1.[1]

When all three scoring criteria are added together, the highest possible Project Score of 8 represents a project that is highly implementable in the short-term (over the next 3 years) within the available $4.5M funding. As shown in Table I.2, many of the identified projects received a score of 8.

I.1.1.2.2 Ranking of potential projects

Once Project Scores were developed, sorting was performed to determine which projects would be considered priority for a near-term project. For this exercise, the results of the Plume Scores shown in Table I.1 were combined with the Project Scores.

Table I.2 shows a ranking comparison of the projects using the three different sorting methods shown in Table I.4. The top 10-ranked projects using each sorting method are shaded. The sorting methods correspond with the Pathway ranking and Overall ranking methods described in the groundwater strategy (Vol. 1, Sects. 5.1.3 and 6.2). Until uncertainties regarding exit pathways are addressed, the Pathway ranking is the more appropriate guide for the strategy focus. After exit pathway data gaps are filled, the Overall ranking can be used to prioritize ORR interior plumes and corresponding projects for longer-term sequencing.

[1] "High," "Medium," and "Low" cost ranges are unverified, rough order of magnitude estimates for preliminary planning use only.

Table I.2. Ranking comparison for potential groundwater projects

						Project score criteria			
Pathway ranking* (sort #1)	**Overall ranking* (sort #2)**	**Overall ranking w/o project score* (sort #3)**	**Plume No.(s)**	**Potential groundwater action project**	**Multiple related plumes (Table 1.3)**	**Time**	**Implement-ability**	**Cost****	**Project score**
1	11	13	MV-3, BCV-1b, BV-2, ETTP-1	DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	Y	Short-term	High	Low	8
2	12	14	MV-3, BCV-1b, BV-2, ETTP-1	Groundwater Use Restrictions/Policies across Clinch River - TBD	Y	Short-term	High	Low	8
3	10	12	MV-3, MV-1(a-e)	Install/sample wells in the Rutledge Limestone exit pathway close to sources (SWSA 4)	Y	Short-term	High	Low	8
4	2	1	MV-3, MV-2	Install/sample deep wells to investigate brine mobility	Y	Long-term	High	Medium	6
5	5	5	BCV-2, BCV-1a, BCV-1b, BCV-4, BCV-5, BCV-6	Install/sample Additional Wells Nolichucky Shale – Zone 2; would help address uncertainties around BCV integration point (BCK 9.2)	Y	Short-term	High	Low	8
6	15	11	BCV-2, BCV-6	Implement NT-8 Early Action	Y	Long-term	High	Medium-High	5.5
7	16	10	BCV-2	BYBY Uranium source characterization; soil sampling and well installation/sampling on north hill side of BYBY		Long-term	High	Low	7

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	
8	3	3	BCV-1b, BCV-1a	Sample Additional Existing On-site and Off-site Wells; increase monitoring of existing wells to better define trends	Y	Short-term	High	Low	8
9	4	4	BCV-1b, BCV-1a, BCV-6	Install/sample Additional Wells – Bear Creek/Grassy Creek Divide; should reduce uncertainties regarding Maynardville discharge off-site and help define flow system	Y	Short-term	High	Low	8
10	25	26	ETTP-1, ETTP-3, ETTP-4, ETTP-6, ETTP-11	Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	Y	Short-term	High	Low	8
11	18	18	BV-2	Install/sample a Bethel Valley Picket Well transect near Hwy. 95; help reduce uncertainties about extent of plume migration		Short-term	High	Low	8
12	19	19	BV-2	Install/sample picket wells near the Clinch River		Short-term	High	Low	8
13	20	21	BV-2	Install/sample wells downgradient of CH 8 plume as appropriate based on flow in Benbolt, Rockdell		Short-term	High	Low	8
14	22	20	BV-2	Define extent of CH 8 plume in all directions, including depth		Long-term	High	Medium	6

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	
15	30	30	BV-4, BV-1(a-e)	Install and sample additional bedrock wells to east, west, and on the apparent watershed divide; assess probable groundwater flow directions and nature and extent of contamination	Y	Long-term	High	Medium	6
16	13	15	UEFPC-7	Install/sample Additional Wells in the Nolichucky Shale near eastern Y-12 Complex boundary/Scarboro Road; increase understanding of plume migration		Short-term	High	Low	8
17	14	16	UEFPC-7	Characterization of carbon tetrachloride (CT) and TCE sources at east end of Y-12 Complex; soil sampling and well installation		Short-term	High	Low	8
18	17	17	UEFPC-7	Pending UEFPC-7-2 characterization results, remediate CT and TCE sources at east end of Y-12 Complex		Long-term	Medium	Medium	5
19	1	2	MV-2	DQO session to determine an approach for addressing hydrofracture issues		Short-term	High	Low	8
20	6	9	UEFPC-1	Tracer tests in GW-251 to monitor flow direction near BCV/UEFPC Divide		Short-term	High	Low	8

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	
21	7	6	BCV-1a	Implement future action for S-3 Ponds Pathways 1–3		Long-term	Medium	Medium	5
22	8	7	BCV-1a	Investigation to determine best locations and implementation of wells for pumping and treating groundwater plumes in BCV		Long-term	Medium	Medium	5
23	9	8	UEFPC-1, UEFPC-2, UEFPC-5, UEFPC-6	Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	Y	Long-term	Medium	Medium	5
24	21	22	UEFPC-6	Install well in shallow karst east of Big Spring; perform dye trace; investigate potential downstream conduit for GW to UEFPC		Short-term	High	Low	8
25	23	23	ETTP-9	ETTP Sitewide Groundwater Treatability Study (K-1401 Area)		Long-term	High	Medium	6

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	
26	24	24	BV-3	Design and implement a full-scale bioremediation system; implement 7000 Area plume remediation (BV ROD action)		Short-term	High	Low	8
27	26	25	BCV-3	HCDA DNAPL source characterization; soil sampling and well installation/sampling at HCDA		Long-term	High	Low	7
28	34	34	CR-1	Monitor "bootlegger" spring downgradient of the site; attempt to determine potential exit pathway		Short-term	High	Low	8
29	27	27	BV-1 (a–e)	Sample additional existing wells in the main plant area; attempt to better delineate extent of contamination		Short-term	High	Low	8
30	28	29	BV-1 (a–e)	Sample additional existing bedrock wells in the Rockdell formation; attempt to better delineate extent of contamination		Short-term	High	Low	8
31	29	28	BV-1 (a–e)	Install and sample additional bedrock wells in the main plant area. Assess probable groundwater flow regime and nature and extent of groundwater contamination beneath site facilities.		Short-term	High	Medium	7

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	
32	31	31	BV-1 (a–e)	Project to address mercury contamination (e.g., Bldg. 3592)		Long-term	High	Medium	6
33	32	32	UEFPC-5	Characterization of GW-605/606 Source Area; soil sampling and well installation		Long-term	High	Medium	6
34	33	33	UEFPC-5	Pending UEFPC-5-1 characterization results, implement source removal/control at GW-605/606 Source Area; potential reduction of U plume		Long-term	Medium	Medium	5
35	35	35	UEFPC-2	Install/sample additional Wells in the Nolichucky in western portion of Y-12 Complex; investigate vertical and horizontal delineation and DNAPL sources		Long-term	Medium	Medium	5
36	36	36	UEFPC-4	In situ bioremediation; potential mass reduction of plume		Long-term	High	Low	7

Table I.2. Ranking comparison for potential groundwater projects (cont.)

Pathway ranking* (sort #1)	Overall ranking* (sort #2)	Overall ranking w/o project score* (sort #3)	Plume No.(s)	Potential groundwater action project	Multiple related plumes (Table 1.3)	Project score criteria			Project score
						Time	Implement-ability	Cost**	

Shaded cell = Top 10 in Ranking.
Red font = Remedial Action Project.
*Sorting Methods for Ranking (see Table I.4):

- Pathway ranking (Sort #1) – Total Pathway Score/Weighted Total Hazard Score/Project Score.
- Overall ranking (Sort #2) – Total Plume Score/Project Score.
- Overall ranking without Project Score (Sort #3) – Total Plume Score.

**"High," "Medium," and "Low" cost ranges are unverified, rough order of magnitude estimates for preliminary planning use only.

^{99}Tc = technetium-99.
BCK = Bear Creek kilometer.
BCV = Bear Creek Valley.
BV = Bethel Valley.
BYBY = Boneyard/Burnyard.
CH = Corehole.
CR = Clinch River.
CT = carbon tetrachloride.
DNAPL = dense non-aqueous phase liquid.
DOE = U.S. Department of Energy.
DQO = data quality objective.
ETTP = East Tennessee Technology Park.
GW = groundwater.
HCDA = Hazardous Chemicals Disposal Area.
MV = Melton Valley.
NT = North Tributary.
ORNL = Oak Ridge National Laboratory.
ROD = Record of Decision.
SWSA = Solid Waste Storage Area.
TBD = to be determined.
TCE = trichloroethene.
TDEC = Tennessee Department of Environment and Conservation.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
Y = yes.
Y-12 Complex = Y-12 National Security Complex.

Table I.3. List of potential groundwater action projects and multiple related plumes

Watershed	Groundwater action project	Plume No.	Description
Multiple	DQO session to evaluate existing DOE and TDEC off-site data, including downgradient spring inventory, and determine additional monitoring needed	BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone
		BV-2	Corehole 8 Plume; ^{90}Sr, uranium, and ^{137}Cs in shallow/deep Benbolt limestones and siltstones
		ETTP-1	K-1070-A Burial Ground
		MV-3	Exit Pathway/Picket Wells
Multiple	Groundwater Use Restrictions/Policies across Clinch River - TBD	BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone
		BV-2	Corehole 8 Plume; ^{90}Sr, uranium, and ^{137}Cs in shallow/deep Benbolt limestones and siltstones
		ETTP-1	K-1070-A Burial Ground
		MV-3	Exit Pathway/Picket Wells
Melton Valley	Install/sample wells in the Rutledge Limestone exit pathway close to sources (SWSA 4)	MV-1 (a–e)	Shallow Groundwater Contamination emanating from buried waste operations overlying the Conasauga Group formations
		MV-3	Exit Pathway/Picket Wells
Melton Valley	Install/sample deep wells to investigate brine mobility	MV-2	Hydrofracture Sites
		MV-3	Exit Pathway/Picket Wells
Bear Creek Valley	Install/sample Additional Wells – Nolichucky Shale – Zone 2; would help address uncertainties around BCV integration point (BCK 9.2)	BCV-1a	S-3 Ponds; S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3) discharging to Maynardville
		BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone
		BCV-2	Uranium in the Maynardville Limestone
		BCV-4	Bear Creek Burial Grounds; BG-A Shallow/deep (DNAPL) VOCs in Nolichucky Shale
		BCV-5	Bear Creek Burial Grounds; BG-C West Shallow VOCs in Nolichucky Shale
		BCV-6*	Bear Creek Burial Grounds; various near-surface uranium signatures in Nolichucky Shale; NT-8 discharging to Maynardville
Bear Creek Valley	Implement NT-8 Early Action	BCV-2	Uranium in the Maynardville Limestone
		BCV-6	Bear Creek Burial Grounds; various near-surface uranium signatures in Nolichucky Shale; NT-8 discharging to Maynardville
Bear Creek Valley	Sample Additional Existing On-site and Off-site Wells; increase monitoring of existing wells to better define trends	BCV-1a	S-3 Ponds; S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3) discharging to Maynardville
		BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone
Bear Creek Valley	Install/sample Additional Wells – Bear Creek/Grassy Creek Divide; should reduce uncertainties regarding Maynardville discharge off-site and help define flow system	BCV-1a	S-3 Ponds; S-3 Shallow/deep contamination (nitrate, uranium, and ^{99}Tc) in Nolichucky Shale (Pathways 1, 2, and 3) discharging to Maynardville
		BCV-1b	S-3 Ponds; S-3 Deep nitrate in Maynardville Limestone
		BCV-6*	Bear Creek Burial Grounds; various near-surface uranium signatures in Nolichucky Shale; NT-8 discharging to Maynardville

Table I.3 List of potential groundwater action projects and multiple related plumes (cont.)

Watershed	Groundwater action project	Plume No.	Description
ETTP	Install/sample deep well picket near the Clinch River; attempt to determine lateral and vertical extent of contamination	ETTP-1	K-1070-A Burial Ground
		ETTP-3	K-1085 Old Firehouse Burn Area
		ETTP-4	Duct Island/K-1070-F
		ETTP-6	K-770 Scrap Metal Yard
		ETTP-11	K-27/K-29 Area
Bethel Valley	Install and sample additional bedrock wells to east, west, and on the apparent watershed divide; assess probable groundwater flow directions and nature and extent of contamination	BV-1 (a–e)**	Main Plant Area; various areas of groundwater contamination across four quadrants and the 4000 Area in the ORNL main plant area
		BV-4	SWSA 3 ^{90}Sr Plume; ^{90}Sr in Witten shaley siltstones and limestones migrating both east (to Northwest Tributary) and west (Raccoon Creek)
Upper East Fork Poplar Creek	Install/sample Additional Wells in the Maynardville in central portion of Y-12 Complex; investigate lateral and vertical extent of contamination	UEFPC-1	S-3 Site Eastern Plume/S-2 Site Plume
		UEFPC-2	Western and Central Y-12 Area VOC Plume
		UEFPC-5	Uranium Sources in Maynardville Limestone
		UEFPC-6	Localized Mercury Sources to Groundwater

Red font = Remedial Action Project.
*Project BCV-6-1 is a long-term, dry-season tracer test, combined with:

- Install/sample Additional Wells – Bear Creek/Grassy Creek Divide (also relates to plumes BCV-1a and BCV-1b), and
- Install/sample Additional Wells – Nolichucky Shale – Zone 2 (also relates to plumes BCV-1a, BCV-1b, and BCV-2).

**Project BV-1-4 is installation of additional bedrock wells in the Rockdell west of existing well 2541. This task should be implemented in combination with a project to install and sample additional bedrock wells to the east, west, and on the apparent watershed divide (also relates to plume BV-4).

^{99}Tc = technetium-99.
AM = Action Memorandum.
BCK = Bear Creek kilometer.
BCV = Bear Creek Valley.
BG = Burial Ground.
BV = Bethel Valley.
DNAPL = dense non-aqueous phase liquid.
DOE = U.S. Department of Energy.
DQO = data quality objective.
ETTP = East Tennessee Technology Park.
FY = fiscal year.
MV = Melton Valley.
NT = North Tributary
ORNL = Oak Ridge National Laboratory.
SWSA = Solid Waste Storage Area.
TBD = to be determined.
TDEC = Tennessee Department of Environment and Conservation.
UEFPC = Upper East Fork Poplar Creek.
VOC = volatile organic compound.
Y-12 Complex = Y-12 National Security Complex.

Sort #1 (Pathway ranking) was used to select the near-term project. This sorting method gives primary weight to the Total Pathway Score in order to focus on potential off-site migration. Both Sort #2 and Sort #3 use the Overall ranking method to focus on interior plumes and longer-term sequencing, which gives primary weight to the Total Plume Score. For Sort #3 (Overall ranking without Project Score), the Project Score is not used, eliminating consideration of near-term project constraints such as funding.

Table I.4. Sorting methods used in project ranking

Sort #	Description	Primary weight	Secondary weight	Tertiary weight
1	**Pathway Ranking** • **Focus on potential off-site migration**	**Total Pathway Score*** ➡	**Weighted Total Hazard Score*** ➡	**Project Score****
2	Overall Ranking • Focus on interior plumes and longer-term sequencing	Total Plume Score* ➡	Project Score**	
3	Overall Ranking without Project Score • Focus on interior plumes and longer-term sequencing • Project Score not considered (no near-term project constraints)	Total Plume Score*		

Bold font = Sort #1 was used to select near-term project.
*See Table I.1.
**See Table I.2.

I.2 SELECTION OF A NEAR-TERM PROJECT

Using the Pathway ranking (Sort #1), potential projects to address the groundwater plume MV-3 Exit Pathway/Picket Wells contamination from undetermined sources, ranked highest. The MV-3 plume ranked high due to uncertainty related to the potential for off-site migration of ORR groundwater contamination. There have been sporadic, low-concentration radionuclide and volatile organic compound detections in off-site locations downgradient of Melton Valley (MV).

As shown in Table I.2, three potential projects identified for the MV-3 plume have a Project Score of “8” and are, therefore, top-ranked in terms of near-term implementability. A project that includes a data quality objective (DQO) session to evaluate existing off-site data and a follow-on field monitoring effort was selected as the near-term project. Results of the monitoring will be evaluated to assess the potential threat of off-site migration. Other top-ranked projects will be considered for future implementation based on results of the DQO and monitoring project and other strategy findings.

The DQO and monitoring project may also reduce uncertainties about other plumes with exit pathways on the western portion of the ORR (Table I.3). The selected project is referred to in the strategy as an Off-site Groundwater Quality Assessment.

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APPENDIX J
HYDRAULIC AND GEOCHEMICAL BOUNDARIES IN THE DEEP FLOW SYSTEM UNDERLYING THE ORR

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CONTENTS

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FIGURES

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ACRONYMS

amsl	above mean sea level
BCV	Bear Creek Valley
bgs	below ground surface
BV	Bethel Valley
DOE	U.S. Department of Energy
ETTP	East Tennessee Technology Park
MV	Melton Valley
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PNAS	Proceedings of the National Academy of Science
PVC	polyvinyl chloride
SWSA	Solid Waste Storage Area
TDS	total dissolved solids
TVA	Tennessee Valley Authority
UEFPC	Upper East Fork Poplar Creek
USGS	U.S. Geological Survey

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J.1 INTRODUCTION

This Appendix presents information about hydraulic and geochemical boundaries in the deep flow system underlying the Oak Ridge Reservation (ORR). The geologic and hydrologic setting of the ORR is described below. Analysis of potential boundaries to deep groundwater flow is provided in Sect. J.2. Conclusions of the analysis are summarized in Sect. J.3. References used in the appendix are listed in Sect. J.4.

J.1.1 GEOLOGIC AND HYDROLOGIC SETTING

The ORR is located in the Valley and Ridge Physiographic Province, which extends from New York to central Alabama. The alternating ridges and valleys characteristic of this province have formed by the erosion of folded sedimentary rocks that consist of alternating sequences of weakly resistant shales and shaley limestones and strongly resistant sandstones and cherty dolostones. These rocks are generally oriented in a northeast–southwest direction and dip to the southeast. An exception to this is the area in the vicinity of the East Tennessee Technology Park (ETTP) where complex folding and thrust faulting has produced a wide range of bedrock orientations. The Copper Creek thrust fault comes to the surface on Haw Ridge, and several branches of the Whiteoak Mountain thrust fault occur in the valley between Pine Ridge and East Fork Ridge. Northwest of the Whiteoak Mountain fault, the rocks are part of the Kingston thrust sheet (Moore and Toran 1992). Figure J.1 provides the geologic map of the ORR.

The groundwater zone of the ORR has been divided into the water table interval; the intermediate interval; the deep interval, which extends down to the base of fresh water; and the aquiclude (Moore and Toran 1992). Saline water, having total dissolved solids (TDS) ranging from 2000 to 275,000 milligrams per liter (mg/L) delineates the aquiclude (Solomon et al. 1992). The groundwater in the aquiclude is assumed to be nearly stagnant and not included in the active subsurface circulation (Solomon et al. 1992). The stagnancy of the aquiclude groundwater has been inferred from its very high salinity and the low permeability of the host rocks (Nativ et al. 1997).

These hydrological zones are gradational vertically and are defined on the basis of water flux, which decreases with depth, but varies with lithology. Thus, their boundaries do not coincide with the stratigraphic boundaries. Their vertical extent and properties are locally influenced by the nature of the hydrostratigraphic units (Nativ et al. 1997). Although much has been done by the U.S. Department of Energy (DOE) to investigate groundwater, until relatively recently, most work has been within the confines of the ORR and, in most cases, only at moderate depths (300 to 600 ft below ground surface [bgs]) with the deeper wells being characterized by more saline waters or brines (Davies et al. 2012).

Nativ et al. (1997) state that some evidence exists that supports the concept of stagnant brine at depth and its hydraulic disconnection from the overlying shallow, fresh and active flow zone. The slow recovery of water levels in some wells following purging suggests restricted flow and the high salinity could not be preserved under intensive, deep groundwater circulation. Large, spatial variations in salinity also may support an extremely restricted flow in at least portions of the aquiclude. However, other evidence supports the potential for some groundwater flow in the aquiclude. This evidence includes presence of fractures at great depths, some exhibiting temperature anomalies, which suggests they may be hydraulically active, and the preferential dilution of the brine through discrete fractures may account for the spatial variations in salinity observed.

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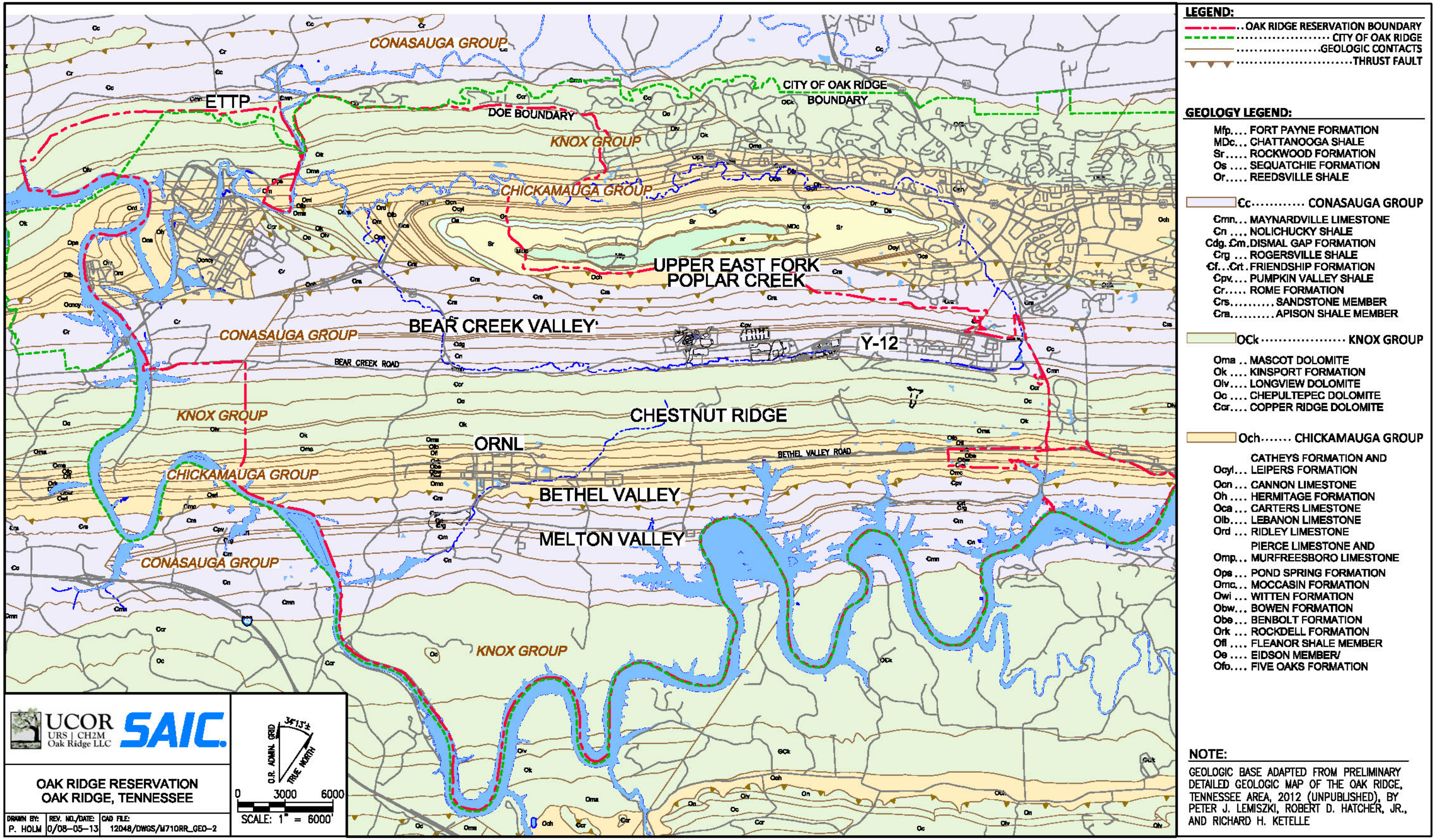


Fig. J.1. Geology of the Oak Ridge Reservation.

J.2 POTENTIAL BOUNDARIES TO DEEP FLOW

Groundwater boundaries identified on the ORR may be due to topographic elevation where recharge on higher elevation ridges causes hydraulic gradients influencing groundwater flow, formational differences where permeability differences between various lithologies influence flowpaths, structural differences where folding and faulting can influence fracture permeability and flowpath orientation, and geochemistry of the formation water (i.e., groundwater density differences). It has long been recognized on the ORR that permeability and, therefore, groundwater flow potential decreases with depth. This is evidenced in hydraulic conductivity data from wells in Melton Valley (MV) and adjacent off-site locations shown in Fig. J.2. This is not to discount differences in potential flowpath depth generated by variations in lithology (e.g., carbonate vs clastic bedrock).

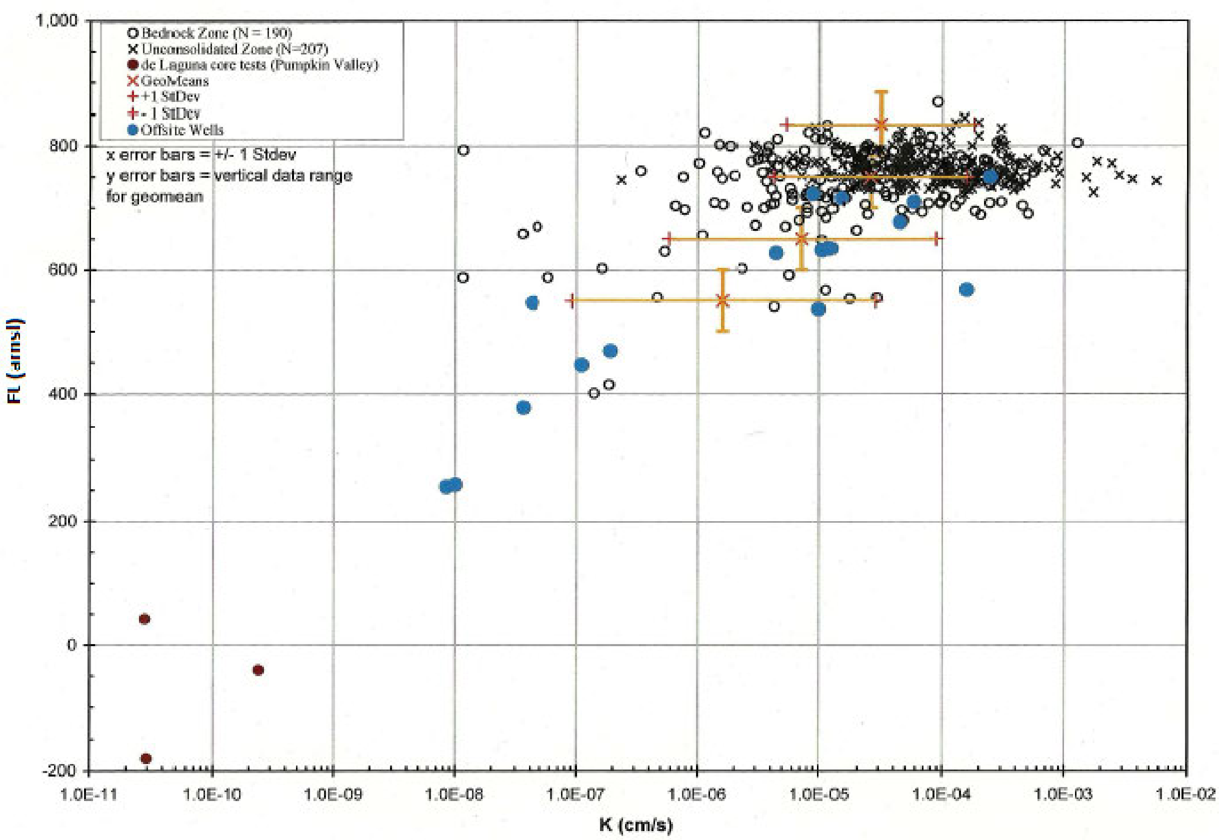


Fig. J.2. Hydraulic conductivity vs elevation for wells in Melton Valley and adjacent off-site locations.

At the boundaries of the ORR, the Clinch River has been considered to be a barrier to groundwater flow. However, data from some of the deeper ORR wells show contamination and meteoric water are mixing with saline water, and there are indications of flow. Off-site wells also show potential ORR-related signatures, but a problem both on and off the Reservation is that there are few deeper wells available for sampling (Davies et al. 2012).

Nativ et al. (1997) cite conflicting data for determining the hydraulic continuity of the aquiclude and in the relationship between the aquiclude and the shallower system. For example, Nativ et al. state that the

hydraulic head values observed in adjacent deep wells suggest the potential for lateral hydraulic continuity; however, salinity variations in nearby wells suggest the opposite. Both upward and downward flow potential were deemed possible based on observed water levels and geochemistry, but potential flow beneath the Clinch River was not specifically addressed by the study. To monitor for the potential off-site migration of contaminants, a series of wells were installed to above the non-potable highly saline water zone at the western end of MV. These exit pathway and off-site monitoring wells provide hydraulic head and groundwater chemistry data from both sides of the Clinch River. Monitoring results from these wells are discussed in the following sections.

J.2.1 WATER LEVEL FLUCTUATIONS

As mentioned above, there are uncertainties related to deep groundwater flow on the ORR. In order to better understand the flow system, water level monitoring is being conducted at DOE off-site monitoring wells adjacent to MV. Figure J.3 shows the well cluster locations, the locations of the rain gage and Melton Hill Dam tailwater gage, as well as well 0936 (to be discussed later) located in the Solid Waste Storage Area 6 (SWSA 6) on the DOE site in MV. Well hydrograph data for the date range of July 2010 through April 2013 are presented in Figs. J.4 through J.7. Hydrograph data from all wells in each well cluster are provided on single pages to allow easy comparison of groundwater level behavior within all zones per cluster. All the hydrographs are annotated with symbols showing the groundwater elevation at the date and time of groundwater sampling events. Also shown on each page are the daily total rainfall measured at the Oak Ridge National Laboratory (ORNL) site approximately 2.3 miles to the north and the level of Watts Bar Reservoir, as measured by the Tennessee Valley Authority (TVA), at the Melton Hill Dam tailwater located approximately 2 miles to the east.

Well hydrographs constructed for these wells show daily average groundwater elevations for 15 instrumented monitoring wells located in the 4 well clusters and weekly manual measurements for 1 well. The OMW-1D well has been monitored weekly because initially its groundwater level was approximately 500 ft below ground surface (bgs). All other wells are instrumented with In Situ Level Troll pressure transducers. All wells are visited once per week for a groundwater level calibration check and transducers are adjusted when differences greater than 0.05 ft occur between the manually measured depth to groundwater and the transducer-indicated depth to groundwater. Groundwater sampling of these wells is conducted periodically using low-flow purging methods and attempts are made to minimize well drawdown consistent with the U.S. Environmental Protection Agency procedure (EPA 2007). Even at purge and sample rates less than 100 cubic centimeters per minute (cc/min), significant drawdown occurs on some wells and is visible on the hydrographs.

The OMW-1 and OMW-2 well clusters each include four separate boreholes with centralized polyvinyl chloride (PVC) casing and screen construction. In each of the clusters, the shallowest two monitoring wells (OMW-1A and OMW-1AA, and OMW-2A and OMW-2AA) are nested, 2-in.-diameter PVC wells in single boreholes. Each of the other wells per location is a 4-in.-diameter PVC screen and casing well constructed in separate boreholes. At these well cluster locations, the deepest wells, which reached depths of ~600 ft bgs in both cases [~200 ft above mean sea level (amsl)], were drilled first to allow borehole logging and packer testing prior to selection of zones that would be monitored both in the deepest portion of the deepest well and in offset, shallower wells. The shallower wells were drilled and constructed subsequent to installation of casings in the deepest well per cluster. Wells OMW-3 and OMW-4 were nested wells consisting of three, separate, 1.5-in.-diameter PVC casings and screens retrofitted into two existing residential wells. Both wells were geophysically logged and packer tests were attempted to provide some estimate of potential zone yields prior to monitoring zone selection. Borehole

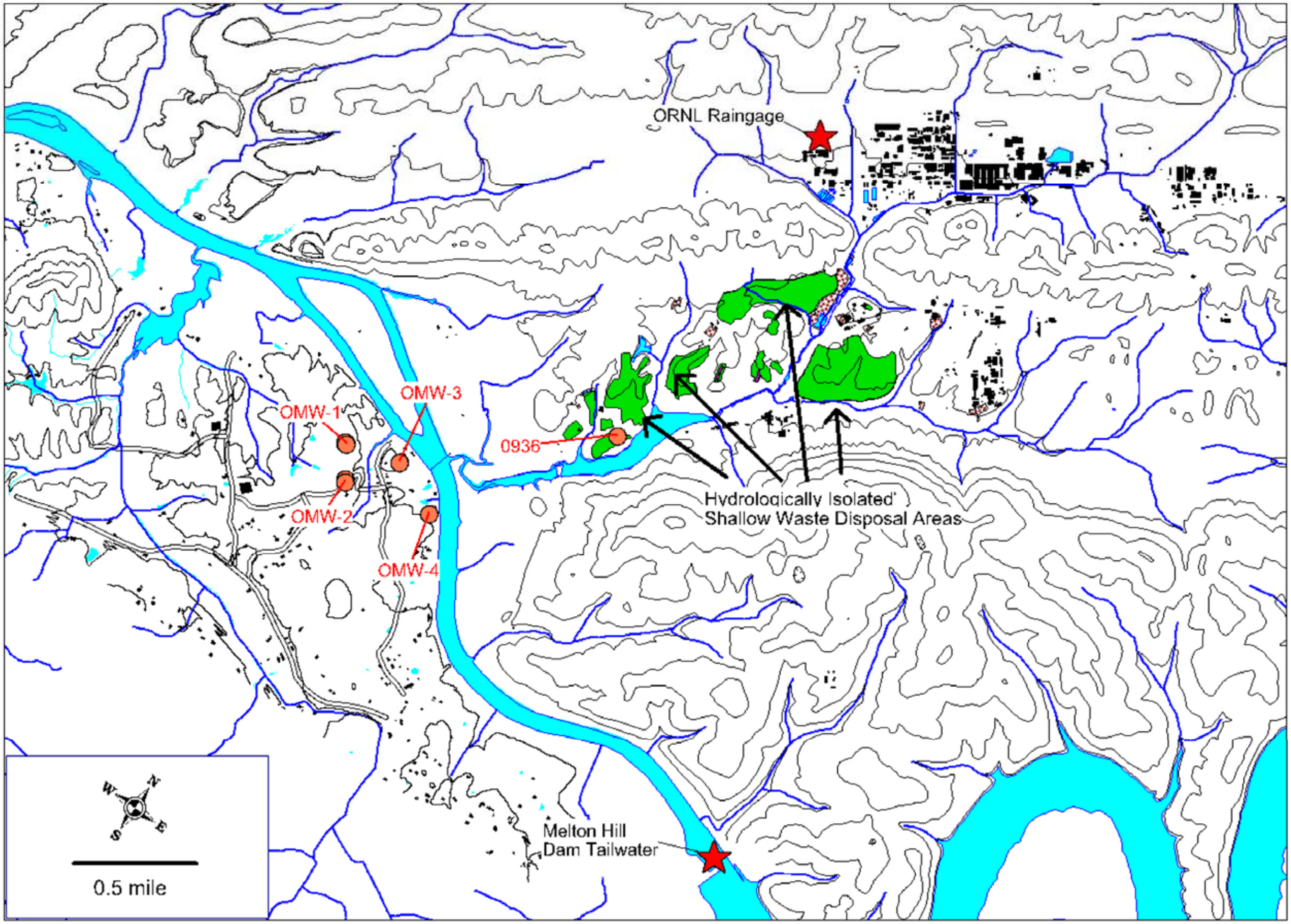


Fig. J.3. Locations of wells, rain gage, and Melton Hill Dam tailwater.

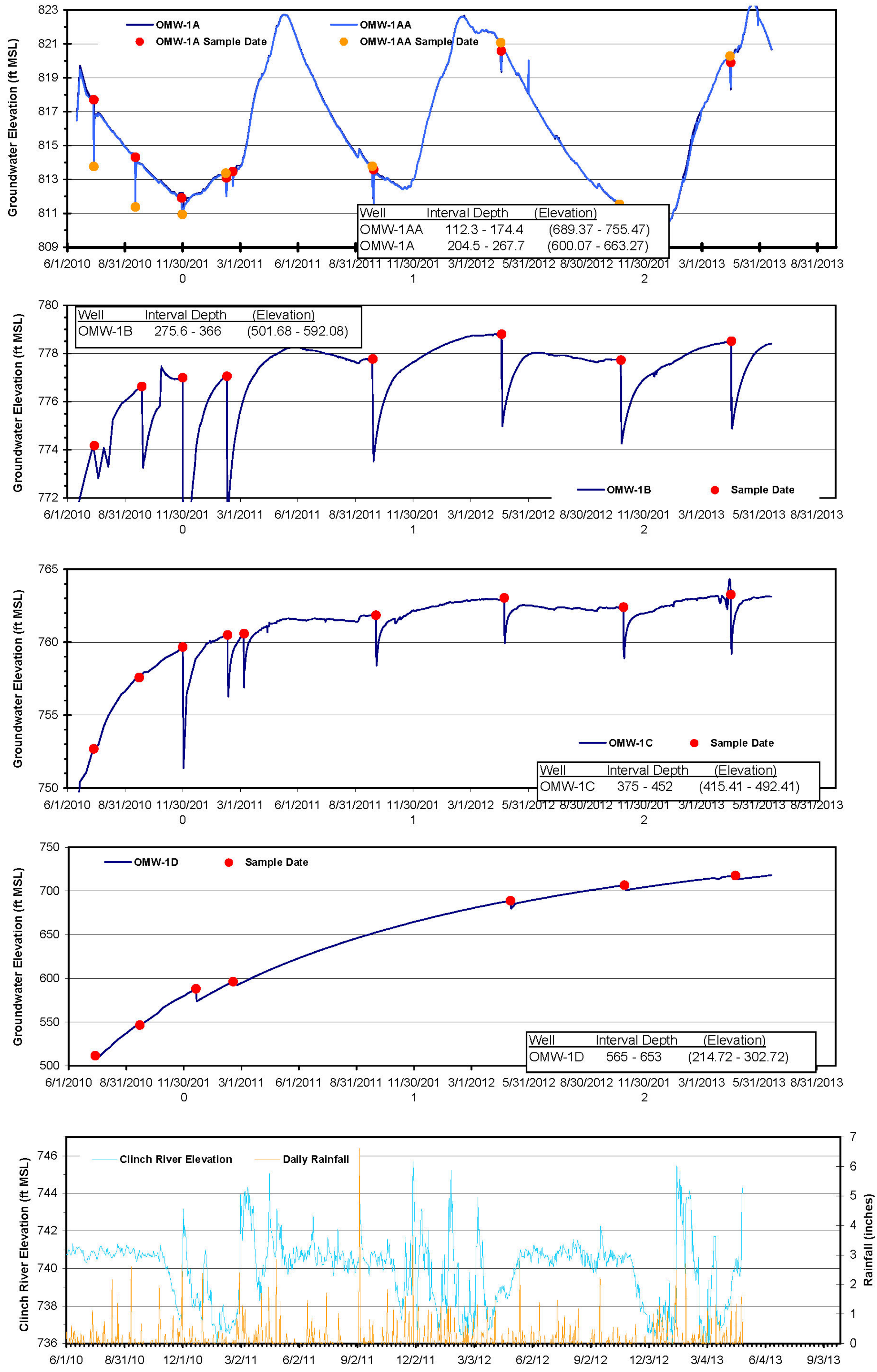


Fig. J.4. Hydrographs for wells in cluster OMW-1, daily total rainfall at ORNL, and daily average Clinch River elevation at Melton Hill Dam tailwater.

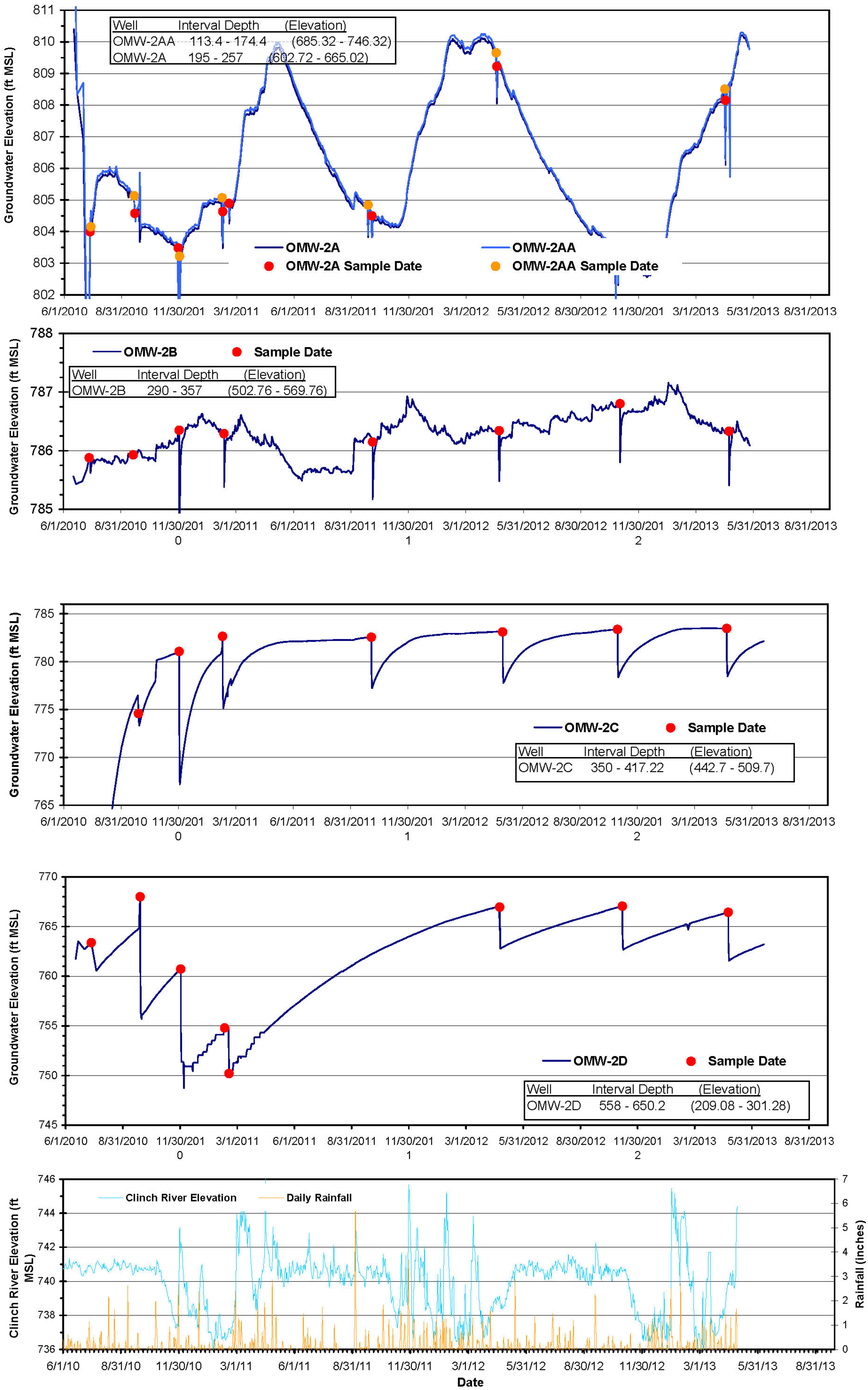


Fig. J.5. Hydrographs for wells in cluster OMW-2, daily total rainfall at ORNL, and daily average Clinch River elevation at Melton Hill dam tailwater.

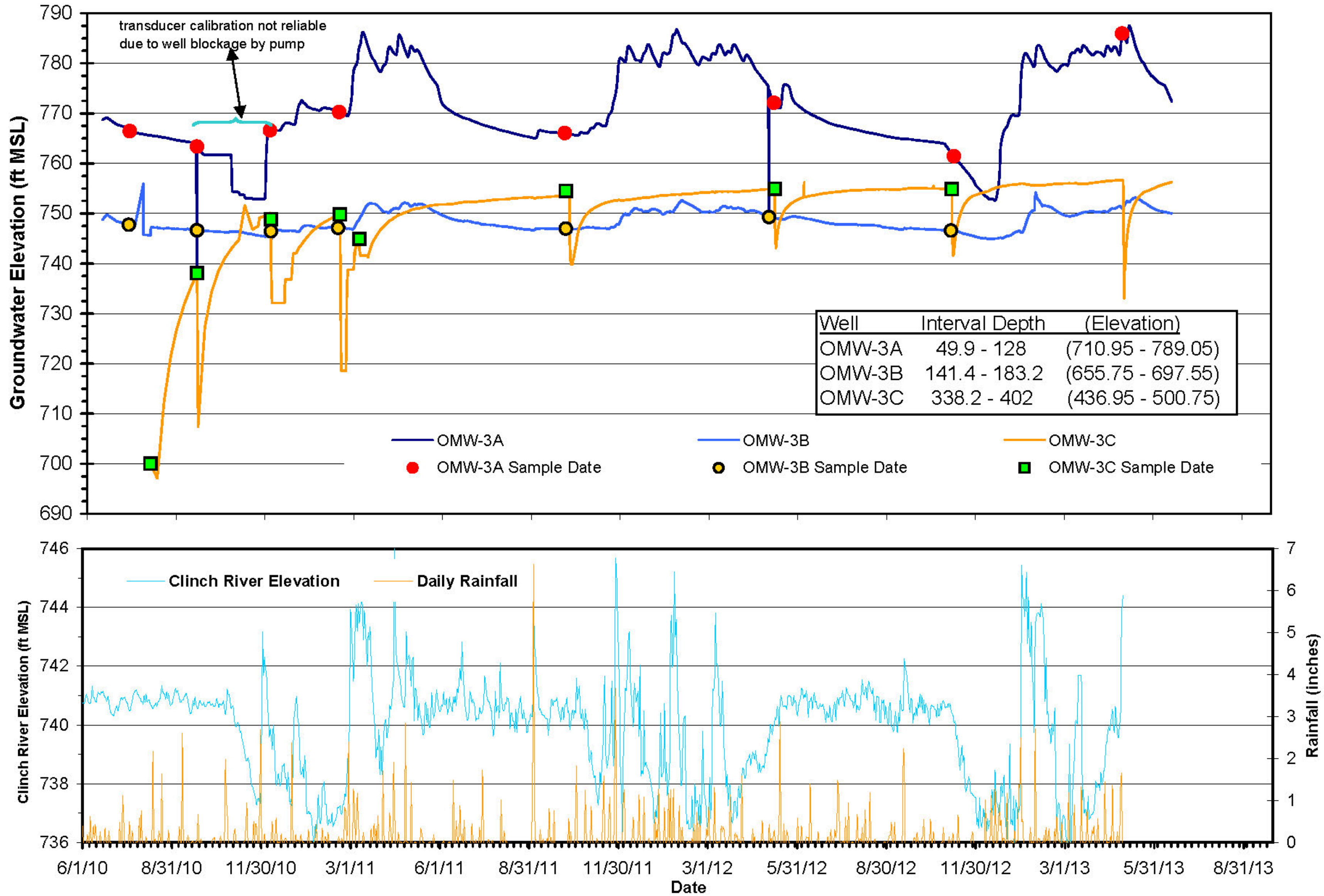


Fig. J.6. Hydrographs for wells in cluster OMW-3, daily total rainfall at ORNL, and daily average Clinch River elevation at Melton Hill Dam.

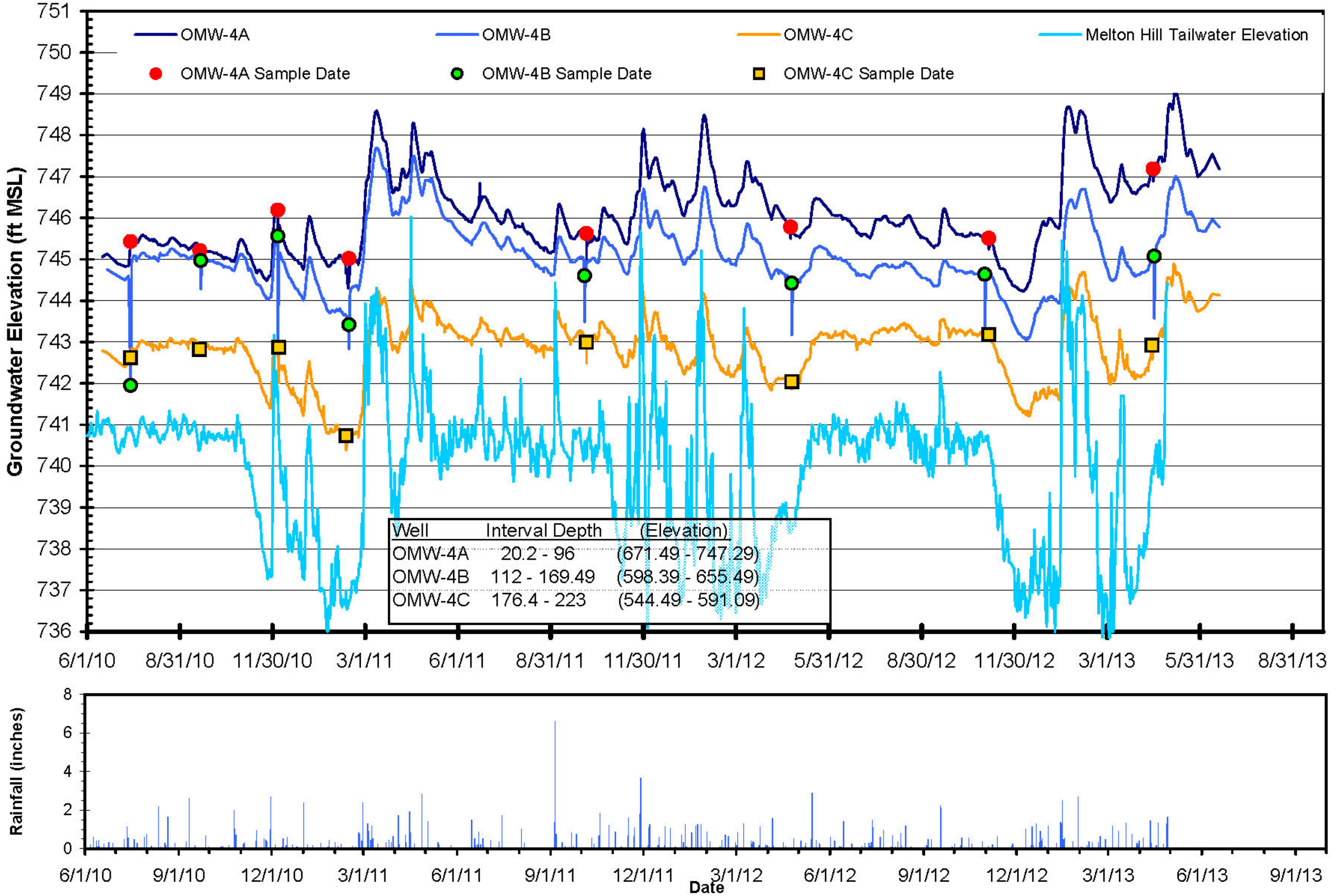


Fig. J.7. Hydrographs for wells in cluster OMW-4, daily total rainfall at ORNL, and daily average Clinch River elevation at Melton Hill Dam.

packer testing in all the wells was problematic because of borewall roughness and difficulty obtaining adequate packer seals against borewalls.

Figures J.4 and J.5 show the hydrographs for well clusters OMW-1 and OMW-2. The hydrographs for well clusters OMW-1 and OMW-2 show several general similarities and a couple of differences. Similarities include:

- The greater responsiveness to annual seasonal cycles of recharge and discharge in the zones completed above about 600 ft amsl than in deeper zones.

- Generally slow recovery from minor drawdowns caused by sampling in wells completed at elevations lower than about 600 ft amsl.

- Extremely slow recovery of the deepest wells completed at elevations below about 300 ft amsl.

The primary difference between the hydrographs in clusters OMW-1 and OMW-2 is the behavior of well OMW-2B, which exhibits a noisy response. The monitored interval in this well may connect via fractures to a near-surface variable head boundary such as a nearby stream valley where head fluctuations may be erratic.

The overall observations regarding heads in the wells in the OMW-1 and OMW-2 clusters are that head gradients are downward and all head results in fully recovered wells are 40 ft or more greater than the maximum recorded daily average water level for the Clinch River between July 2010 and April 2013. Heads in the wells completed above the 600 ft amsl datum are more than 50 ft higher than maximum recorded daily average water level for the Clinch River between July 2010 and April 2013. Although well OMW-2D has never been allowed to fully recover to a stable head condition because of sampling-related drawdowns, the head in this unrecovered well typically does recover to greater than 765 ft amsl between sampling events. This partially recovered head is approximately 20 ft higher than the maximum recorded daily average water level for the Clinch River between July 2010 and April 2013.

Wells OMW-3 and OMW-4 are located at lower elevations and closer to the Clinch River than OMW-1 and OMW-2, which are located atop a ridgeline further west of the river. Well hydrographs for the three complete zones in each of wells OMW-3 and OMW-4 are shown in Figs. J.6 and J.7, respectively.

The shallowest zone in well OMW-3 shows responses to periods of high rainfall as well as interactions with fluctuations in river level. The intermediate zone shows a more subdued hydrograph than the shallowest zone and also fairly consistently exhibits the lowest head of the three zones with levels consistently higher than river level. The upper two zones show little drawdown behavior during sampling. All three zones maintain groundwater elevations higher than Clinch River elevations except the deepest zone, which is drawn down several feet from normal levels during sampling events. The deepest zone has the most subdued hydrograph and, as noted, is drawn down several feet during sampling with recovery times of several weeks, which is reflective of low bedrock transmissivity below elevation 500 ft amsl.

Well OMW-4 is the off-site well located closest to the Clinch River. The vertical gradient is consistently downward from the shallowest zone to the deepest zone. Groundwater elevations are consistently higher than Clinch River water elevations except on occasions when the river rises extremely fast in response to large storm events and the TVA river management activities. The well was constructed to a bottom elevation of about 545 ft amsl, which was the total depth of the homeowner's well. All three zones appear to fluctuate in relation to the Watts Bar Reservoir level with additional responses to rain events. The

intermediate depth sample zone shows brief drawdown responses to sampling event groundwater withdrawals. The shallow and deep zones are sampled without significant drawdown.

Figure J.8 provides recovery curves for one of the off-site wells (OMW-1D) and well 0936 located on the east side of the Clinch River in MV (see Fig. J.3). The water level recovery at these two deep wells illustrates the protracted time for water levels to reach static conditions in some wells completed at depths well below the bottom of the Clinch River. This figure shows that well OMW-1D is still in recovery; however, its head has risen to an elevation of nearly 718 ft amsl, which is less than 30 ft below the maximum recorded daily average water level for the Clinch River between July 2010 and April 2013.

The slow recovery of well OMW-1D (which has an 86-ft-long screened interval) is similar to recovery measured in a somewhat shallower well 0936 with a shorter completion interval located in the SWSA 6 area in DOE's MV Waste Disposal area (location shown on Fig. J.3). Well 0936 (which has a 20-ft-long open interval) required more than 7 years to fully recover from drilling and well development purging. Two logarithmic projections of the measured recovery behavior of well OMW-1D are shown on Fig. J.8. Neither projection is truly a reliable indicator of final stable head in the well; however, their similarity to the measured recovery characteristic of well 0936 suggests that fully recovered head in well OMW-1D is likely to be well above the head of the Clinch River. Full recovery could take several more years. Continued sampling stresses on well OMW-1D may produce a behavior similar to those observed in OMW-2D, described previously, and a fully recovered head may never be observed if sampling continues.

In addition to the off-site wells, water levels are collected at various monitoring wells throughout Bethel and Melton valleys. Hydraulic head data for the intermediate to deep wells completed in these two valleys show a very complex head field. Some of the hydraulic head relationships suggest limitations to depth of circulation of near-surface contaminants based on the observed upward gradients. Figure J.9 shows the locations of representative cross-sections constructed for BV (A-A'), MV (B-B'), and the MV Picket wells (C-C'). Hydraulic head relationships in BV are shown in Fig. J.10. This figure illustrates some of the complexities with both upward and downward local hydraulic gradients observed, especially at the deeper elevations (e.g., near and below ~500 ft amsl). In contrast, with the exception of wells that have not reached static conditions, upward local hydraulic gradients generally predominate in MV (Fig. J.11).

Figure J.12 shows the hydraulic head relationships observed in the MV Picket wells. This figure illustrates the complex nature of the local vertical gradients observed in these wells with both upward and downward vertical gradients dominating within individual wells. It is also important to note that the lowest hydraulic head for the MV Picket wells (~744 ft amsl) is higher than the normal stage of the Clinch River.

J.2.2 GEOCHEMICAL CHARACTERISTICS

Rarely considered in the groundwater basin flow boundary discussion is the depth boundary potentially indicated by groundwater chemistry, in this case, high-density brines ubiquitous to the Appalachian Basin. The following discussion will attempt to incorporate brine chemistry at depth on the ORR into consideration as a dimensional boundary for deep groundwater flow in the vicinity of the ORR. Data from deep wells are limited to those areas investigated for potential contamination and, as such, do not provide a geographic distribution of information across the ORR.

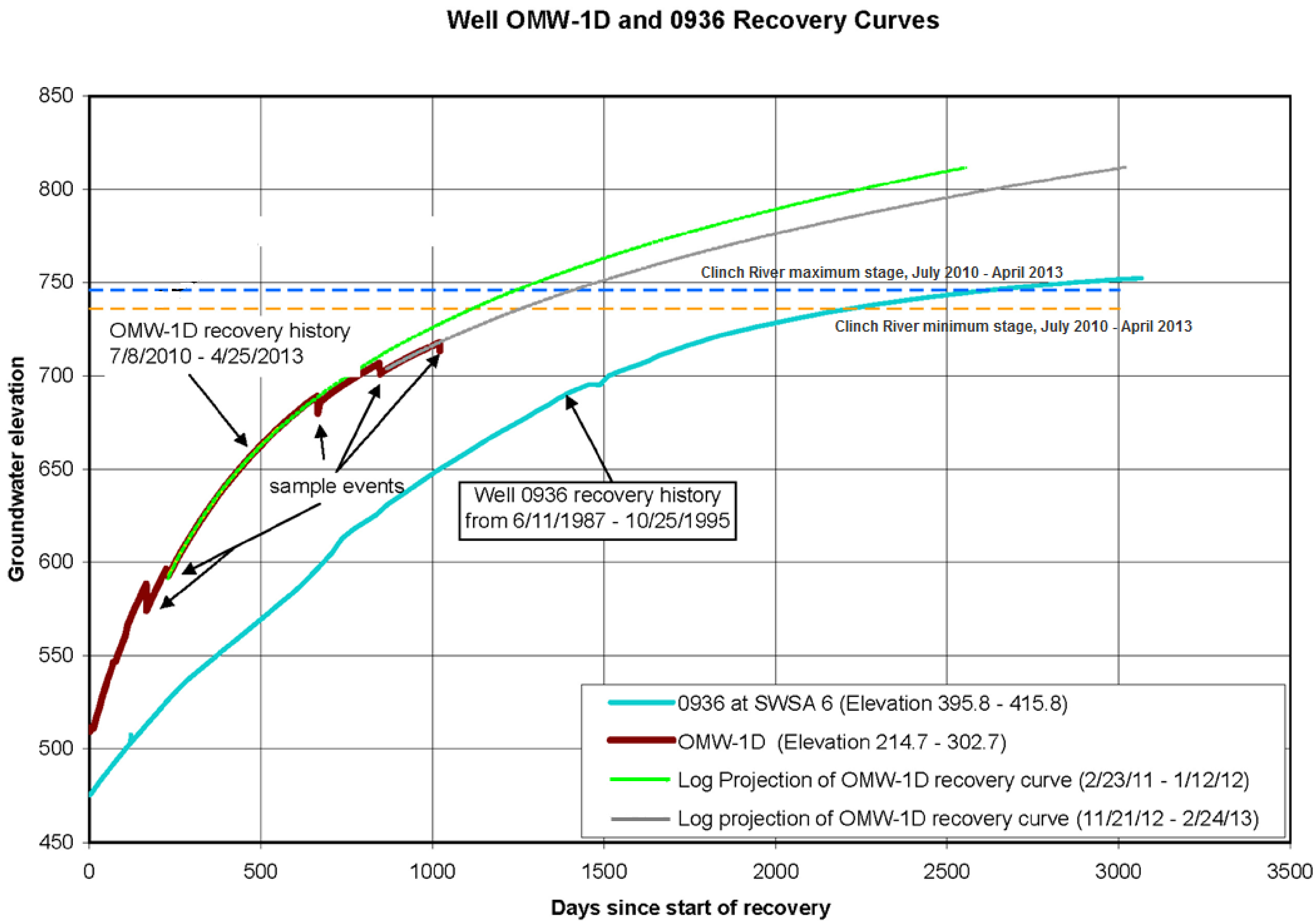


Fig. J.8. Recovery curves for off-site well OMW-1D and well 0936 in SWSA 6 located in Melton Valley.

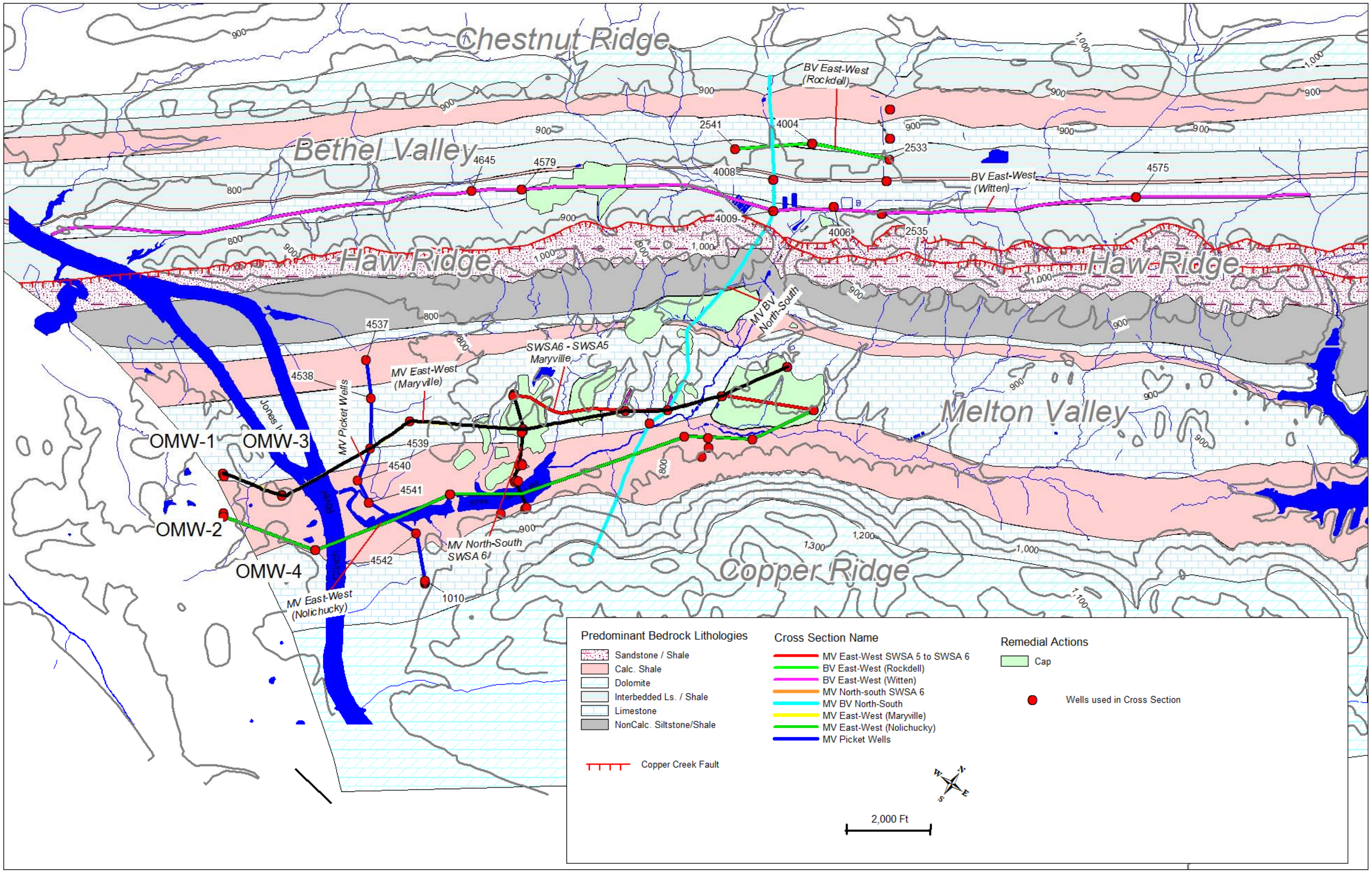
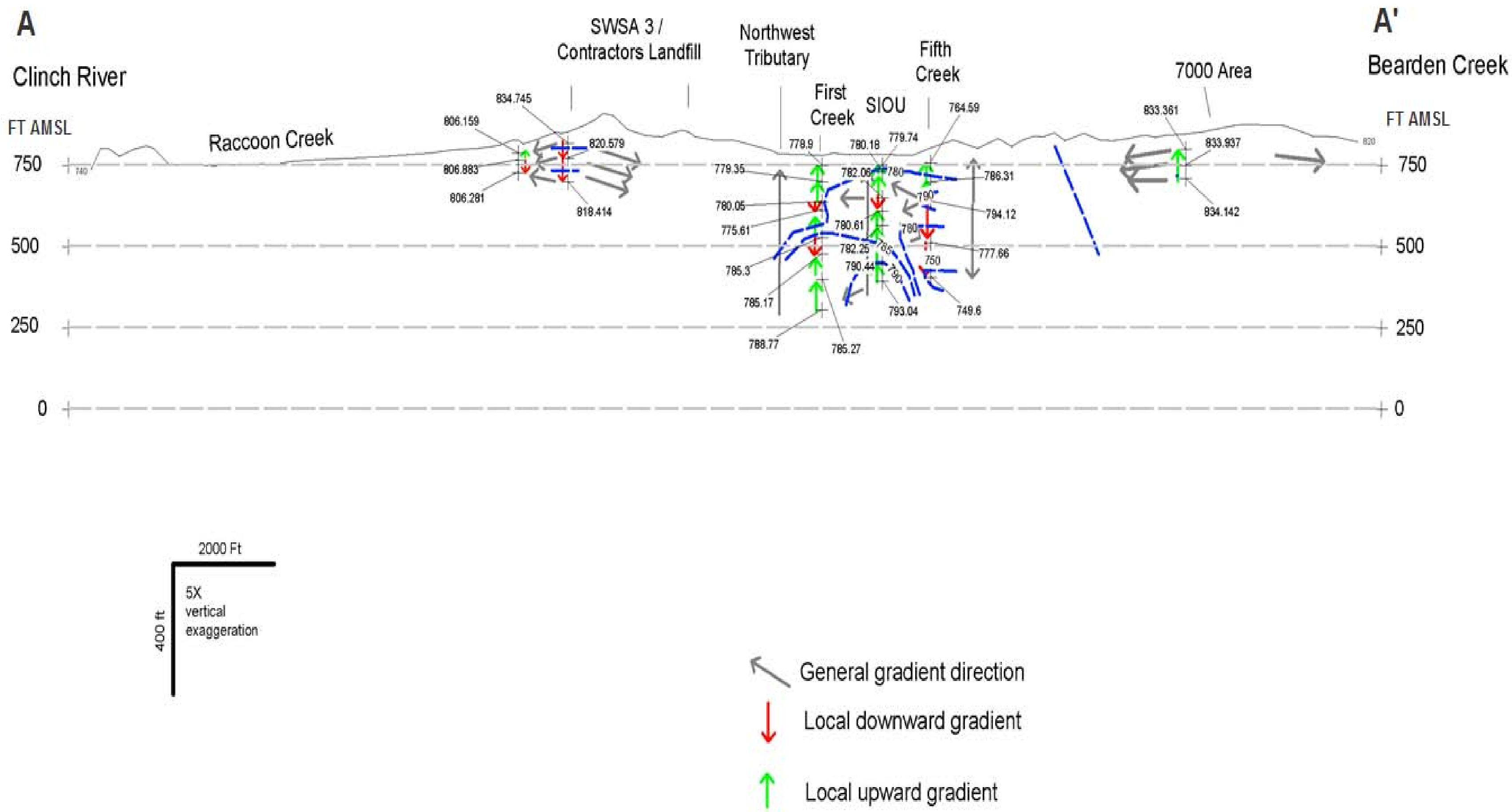
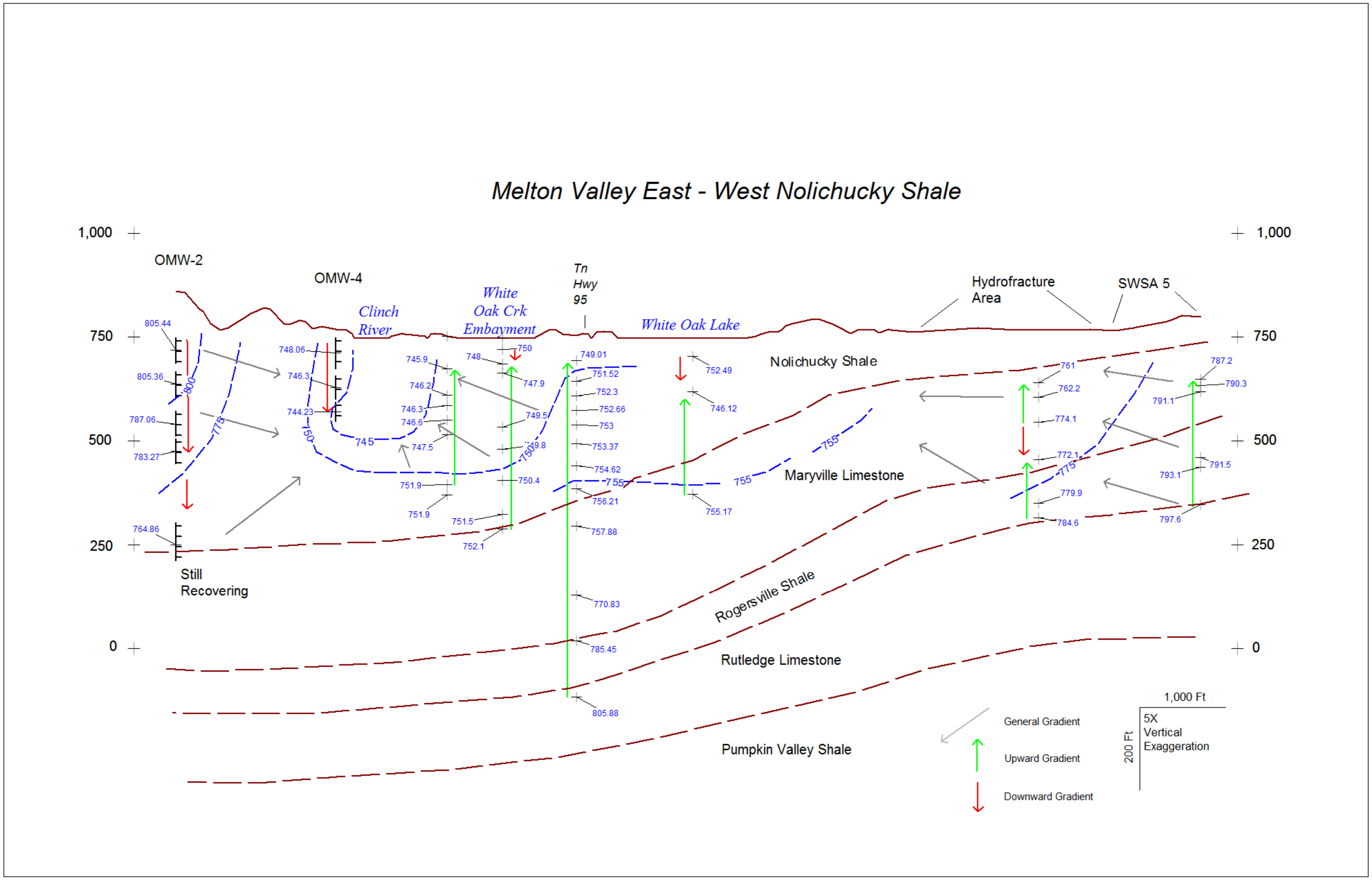


Fig. J.9. Bethel Valley and Melton Valley cross-section locations.



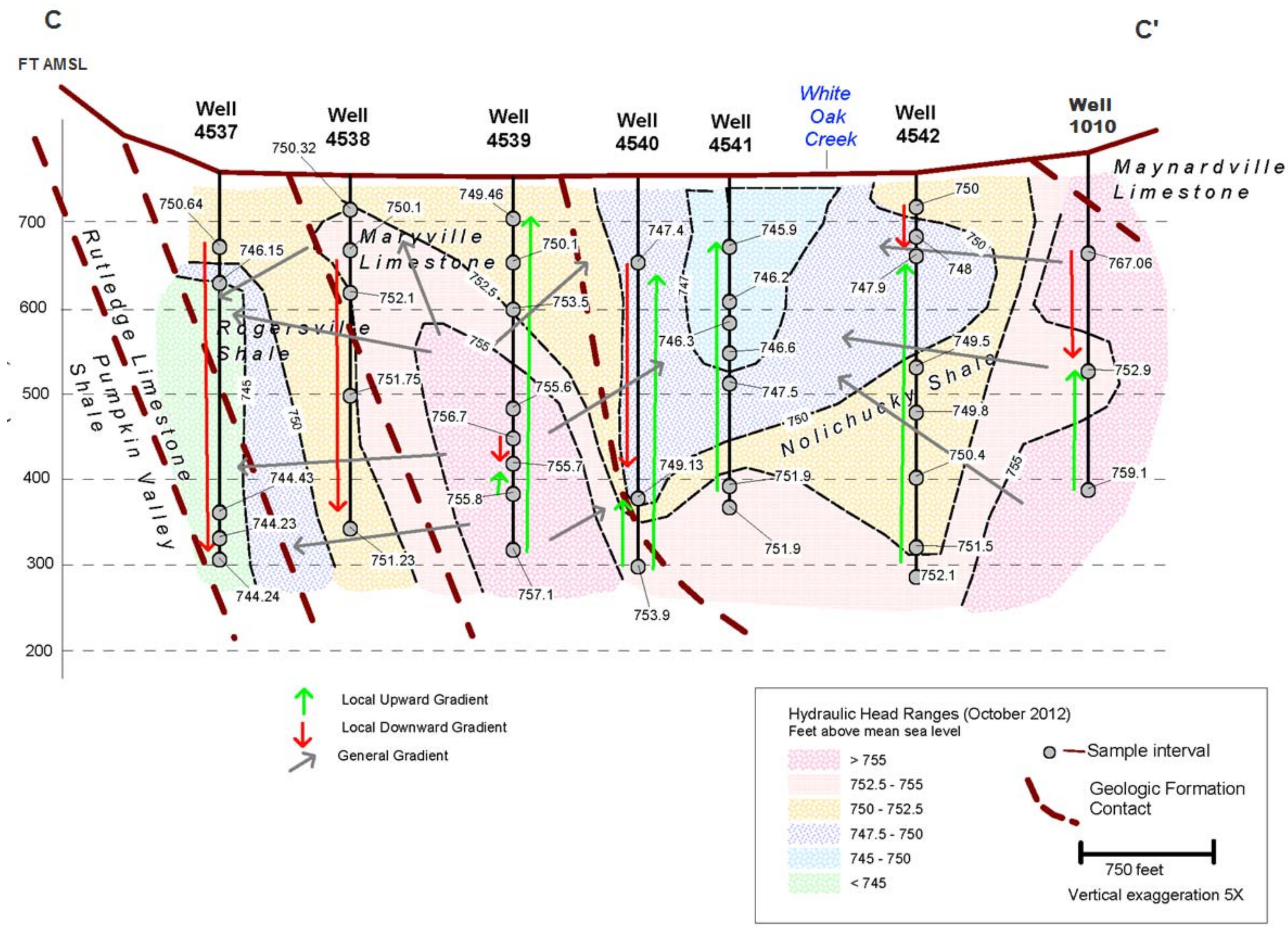
Based on most recent available data

Fig. J.10. Hydraulic head relationships in Bethel Valley along cross-section A-A' in Witten Limestone.



Based on most recent available data.

Fig. J.11. Hydraulic head relationships beneath Melton Valley along cross-section B-B'.



Based on most recent available data

Fig. J.12. Hydraulic head relationships in Melton Valley Picket Wells along cross-section C-C'.

J.2.2.1 Regional Groundwater Geochemical Setting

While the entire East Tennessee region is underlain by fresh water at relatively shallow depths, much of eastern Tennessee is underlain by dense, highly saline brine that is encountered at varying elevations (depths) based on hydrogeologic setting. Increase in salinity of sediment pore fluids may be initiated by evaporation in basins having restricted communication with fresher water bodies. Some evidence exists that during the Cambrian Period, evaporative processes progressed to the point of halite precipitation. This evidence is based on halite crystal casts and molds as primary depositional features in the Rome Formation. Even without evaporation driven salinity increase the concentrations of the most soluble constituents (such as chloride, bromide, sodium, lithium, etc.) may become very high compared to most shallow groundwaters through diagenetic chemical reactions. These waters are referred to as connate brines and are most commonly encountered in deep drilling such as in petroleum exploration and production. Connate brine composition is dominated by high chloride concentrations and the dominant cation may be sodium or calcium. Magnesium, lithium, potassium, and strontium are usually also present as subordinate cations, and bromide is usually present as a subordinate anion along with variable concentrations of bicarbonate and sulfate.

That bedrock in the Oak Ridge area has been influenced by brines similar to oil field brines as demonstrated by the presence of crude petroleum in small quantities in bedrock core of the Chickamauga Group at ORNL in Bethel Valley (BV). The origin (source rock for the hydrocarbons) of this petroleum is unknown. In West Virginia and Eastern Kentucky, the Cambrian-age Rogersville Shale, which also occurs in the Conasauga Group beneath MV and elsewhere on the ORR, has been determined to be a likely source for the oil and gas produced from the Rome Formation in the Rome Trough (USGS 2005). Also, oil and gas produced from the Cambrian-age Knox Dolomite, Rose Run Sandstone, and Lower and Middle Ordovician strata in West Virginia and Eastern Kentucky have been attributed to the Ordovician Utica Shale (USGS 2005).

Connate brine solutions and petroleum hydrocarbons are known to be mobile on the geologic time scale. The fluid density of the highly saline fluid (from 1.1 to >1.25 grams per cubic centimeter [g/cc]) is sufficient to induce gravity-driven flow under conditions where adjacent or deeper zones contain fluid of lower density. In addition, connate brines were the source of dissolved constituents that influenced sediment diagenesis, provided the source materials for formation of the major Mississippi Valley-type base metal (lead–zinc) ore deposits of the eastern and central United States, including East Tennessee, and carried petroleum from source rocks to reservoirs (Bethke and Marshak 1990). Additionally, tectonic forces (such as classic mountain-building orogenies) have been identified as causative forces for brine movement at regional scales (Bethke and Marshak 1990).

J.2.2.2 Melton Valley Investigations

Most of the investigations related to brines on the ORR have been conducted in MV primarily because that is where radioactive waste was disposed by hydrofracturing mixtures of cement grout with radioactive liquid and sludge wastes into the Pumpkin Valley Shale at depths of 800 to 1000 ft bgs (elevations of ~-250 to 0 ft referenced to mean sea level). This is a low-permeability formation with TDS in groundwater above 200,000 mg/L. In addition to deep well monitoring in MV, several deep monitoring wells have been installed in the Conasauga Group formations in Bear Creek Valley (BCV).

Geologic and groundwater investigations at the ORNL site date back to about 1950 when a geologic investigation of BV was undertaken to select sites for waste disposal. During the 1960s and 1970s, additional investigations were initiated to study groundwater seepage issues related to liquid and solid waste disposal sites. Extensive groundwater sampling and analysis has been conducted through various scientific and environmental compliance-related programs. Numerous reports have been prepared

by personnel at ORNL and subcontractors that describe groundwater flow and solute transport, and several over-arching reports stand out that capture large-scale concepts of groundwater conditions in MV.

The U.S. Geological Survey (USGS) conducted a substantial amount of groundwater investigative work in MV from the mid-1970s through the mid-1980s. The work included installation and sampling of an array of wells that included unconsolidated zone and bedrock wells to a depth of about 200 ft bgs. The studies included the collection of groundwater elevation data and evaluation of groundwater responses to precipitation stresses, as well as sampling and analysis of groundwater for determination of general chemical characteristics and contaminant detection.

Groundwater chemical data presented and interpreted in the USGS summary report (USGS 1988) show increasing sodium and increasing pH with depth in the upper 200 ft of the bedrock groundwater system at SWSA 5. Six of 7 wells sampled with screens at depths of 100 ft or deeper (in the 500- to 600-ft elevation range) had pH values of 9 or greater and three had pH values greater than 10. The water type in these wells was sodium bicarbonate dominated. The USGS noted the high solubility of sodium and potassium and their early removal during the rock-weathering process. Part of the USGS general conceptual model for bedrock groundwater flow is based on the observation that sodium and potassium concentrations increase with depth as a result of decreasing fresh groundwater seepage with increasing depth bgs. They note the change in principal ion composition of groundwater from calcium bicarbonate to sodium bicarbonate at the 40- to 100-ft depth beneath Conasauga Group valleys and comment that most of the recharging groundwater flows through the system at depths less than about 100 ft. Others (Toran and Saunders 1999; Boyle and Chagnon 1995; Parkhurst et al. 1996) describe geochemical and water–rock mechanisms that cause increases in pH and dissolved sodium in sedimentary rock settings.

The USGS also conducted groundwater modeling in MV and they conducted field investigations to support that effort (USGS 1992). The model domain included all of MV from the Clinch River to the west to Melton Hill Reservoir to the east, and from the crest of Haw Ridge to the north to the crest of Copper Ridge to the south. The modeled area incorporated a drainage divide and an area of MV that drains northeast toward Melton Hill Lake. The purpose of their modeling was to evaluate water balance and estimate the areal and vertical distribution of groundwater recharge and flow. The model was discretized in four layers extending from land surface to a depth of 600 ft. The results of their work indicate that most groundwater recharge occurs on upland areas including Haw Ridge, the mid-valley knolls underlain by the Maryville Limestone, and Copper Ridge. They concluded that about 91 to 96% of groundwater flow occurs in the upper 50 ft below the water table, about 97% of groundwater flow occurs within the upper 100 ft, and about 99.7% of groundwater flow occurs in the upper 250 ft bgs, and groundwater flow is negligible at depths greater than 550 ft below surface. The groundwater geochemical transition from $CaHCO_3$ in wells less than about 100 ft deep to $NaHCO_3$ below that depth was confirmed in this report and the relationship of groundwater geochemistry to “time-in-contact” with bedrock material was suggested as the explanation. In this concept, more chemical evolution occurs in groundwater that has had longer contact with incompletely weathered rock. This chemical evolution alters the nature of dissolved constituents through processes related to the gradual chemical weathering of bedrock on fracture surfaces and within rock matrix between fractures.

Beneath MV, relatively fresh groundwater extends from the water table downward to an elevation of approximately 350 to 400 ft amsl. In the freshwater interval, bicarbonate is the dominant anion and calcium and sodium are the dominant cations with sodium concentrations increasing with increasing depth. Beneath the fresh water zone, groundwater contains rapidly increasing concentrations of dissolved solids that include residual components of the naturally occurring ancient brine contained in the bedrock. This deep groundwater is non-potable because of natural salinity and wells constructed in the bedrock at

these elevations produce very little water. At elevations ranging from about 250 to 300 ft amsl beneath MV (450 to 500 ft below the level of the Clinch River), the groundwater is saline brine that contains extremely high dissolved solids concentrations dominated by sodium and chloride but also containing calcium, magnesium, potassium, barium, lithium, strontium, and other metal ions. Monitoring data show that there is a transition zone of rapidly increasing chloride concentrations from about 1000 mg/L at about the 300-ft elevation to 100,000 mg/L or more at about the 200-ft elevation. The brine has a high density (from 1.2 to 1.3 g/cc compared to densities near 1.0 g/cc for the overlying groundwater) because of the high concentrations of dissolved ions. This strong density contrast between the brines at depth and the overlying fresher groundwater and reduced permeability with depth inhibit the mixing of constituents between the two zones.

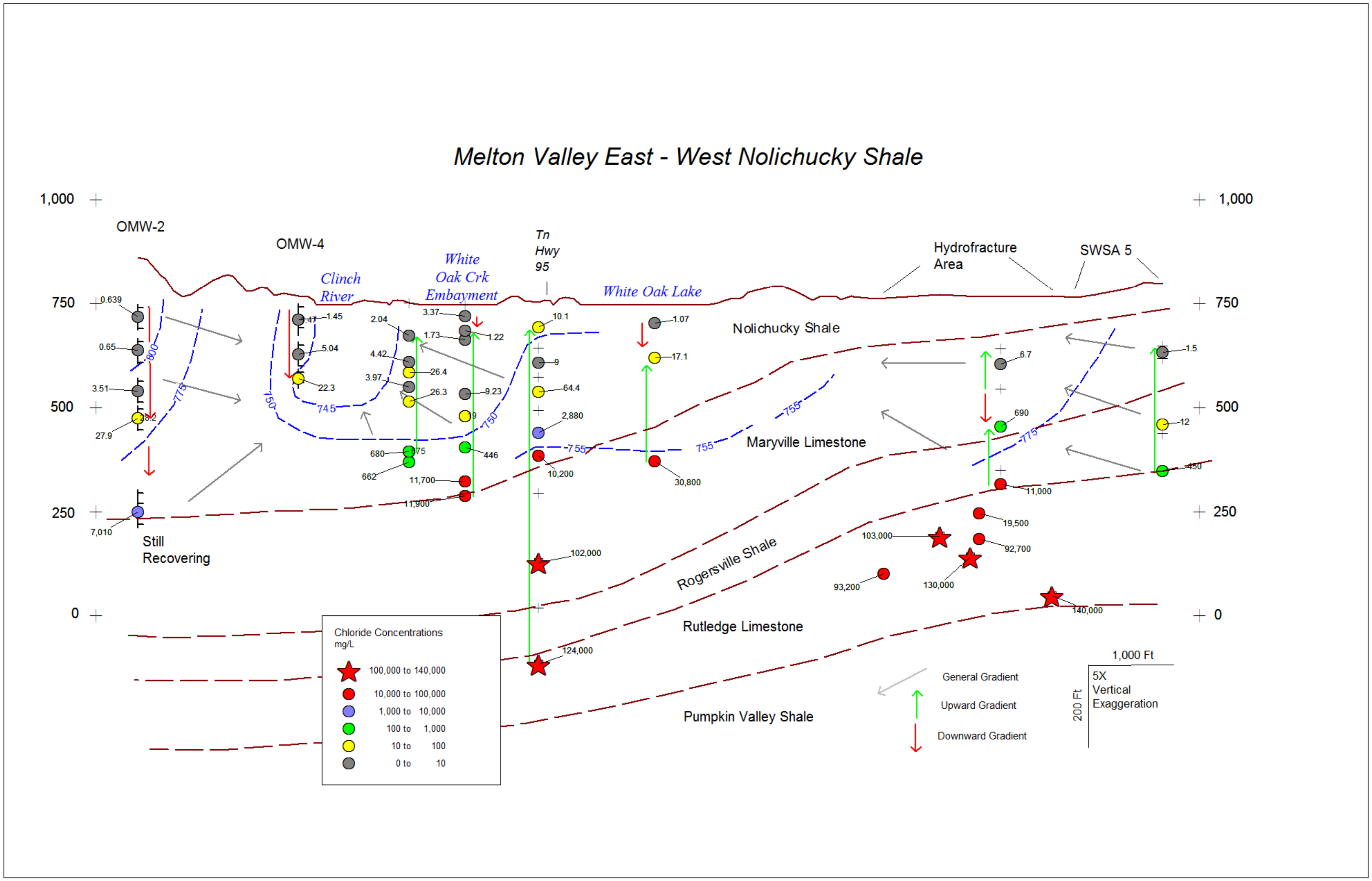
The cross-section in Fig. J.13 provides data for chloride concentrations in groundwater at various depths in monitoring wells located in MV. It is evident that chloride concentrations greater than 100,000 mg/L are widespread in the carbonate formations (Maryville Limestone and Rutledge Limestone) at elevations below 250 ft amsl.

Signature contaminants of concern (COCs) for MV (i.e., tritium and ^{90}Sr) are not widely distributed in the intermediate to deep zones. Figure J.14 shows the ^{90}Sr concentrations in groundwater beneath MV along cross-section B-B'. Strontium-90 is measured consistently in several wells constructed in the Rutledge Limestone directly overlying the hydrofracture grout injection area at elevations below 250 ft amsl. In addition, ^{90}Sr has been detected several times in the Rutledge Limestone in the MV Picket well 4537 near the Clinch River (see Fig. J.9). At this well, ^{90}Sr occurs in a fresh water type that is atypical of the connate brine into which the hydrofracture injections were performed. However, a definitive source for the ^{90}Sr at well 4537 has not been identified.

J.2.2.3 Chloride-Elevation Relationships

Analysis of recent chemical analytical data from the limited number of deep wells in MV and other portions of the ORR provide the basis for establishing a brine-elevation relationship in the primary areas of groundwater concern on the ORR. It is acknowledged that the elevation of any brine-fresh water transition will vary based on hydrogeologic setting (i.e., shales vs carbonates) and with geologic structure. MV is a logical first step to looking at this relationship, as most of the previous investigative work relative to brine presence has been done here and most of the deeper wells are located here. Figure J.15 shows the relationship of chloride concentration to elevation amsl for wells in the MV and BV areas of the ORR. There is a definite break between brine and more dilute waters at the 300 ft amsl elevation. This suggests that there is some degree of interaction between fresh water circulation above 300 ft amsl but very little below that elevation. It is noted that there are no wells in BV that penetrate beneath the 300 ft amsl elevation. There are also several carbonate-rich units in BV that could provide deeper transport pathways.

To compare the chloride vs elevation relationship between MV and BCV, chloride concentration data from well 2369 (WOL-2) in MV was plotted along with those from well GW-729 in BCV (Fig. J.16). Both wells are Westbay Multilevel System installations. As is evident, chloride concentration in the BCV well exceeds 100,000 mg/L at a significantly lower elevation than comparable concentration in MV. This is explained by the presence of the Maynardville Limestone, a major carbonate formation component of the Knox aquifer system underlying BCV. The Maynardville Limestone provides conditions conducive to potentially deeper fresh groundwater flow that has effectively flushed the brine water out of the bedrock.



Based on most recent available data.

Fig. J.13. Groundwater chloride concentrations beneath Melton Valley along cross-section B-B'.

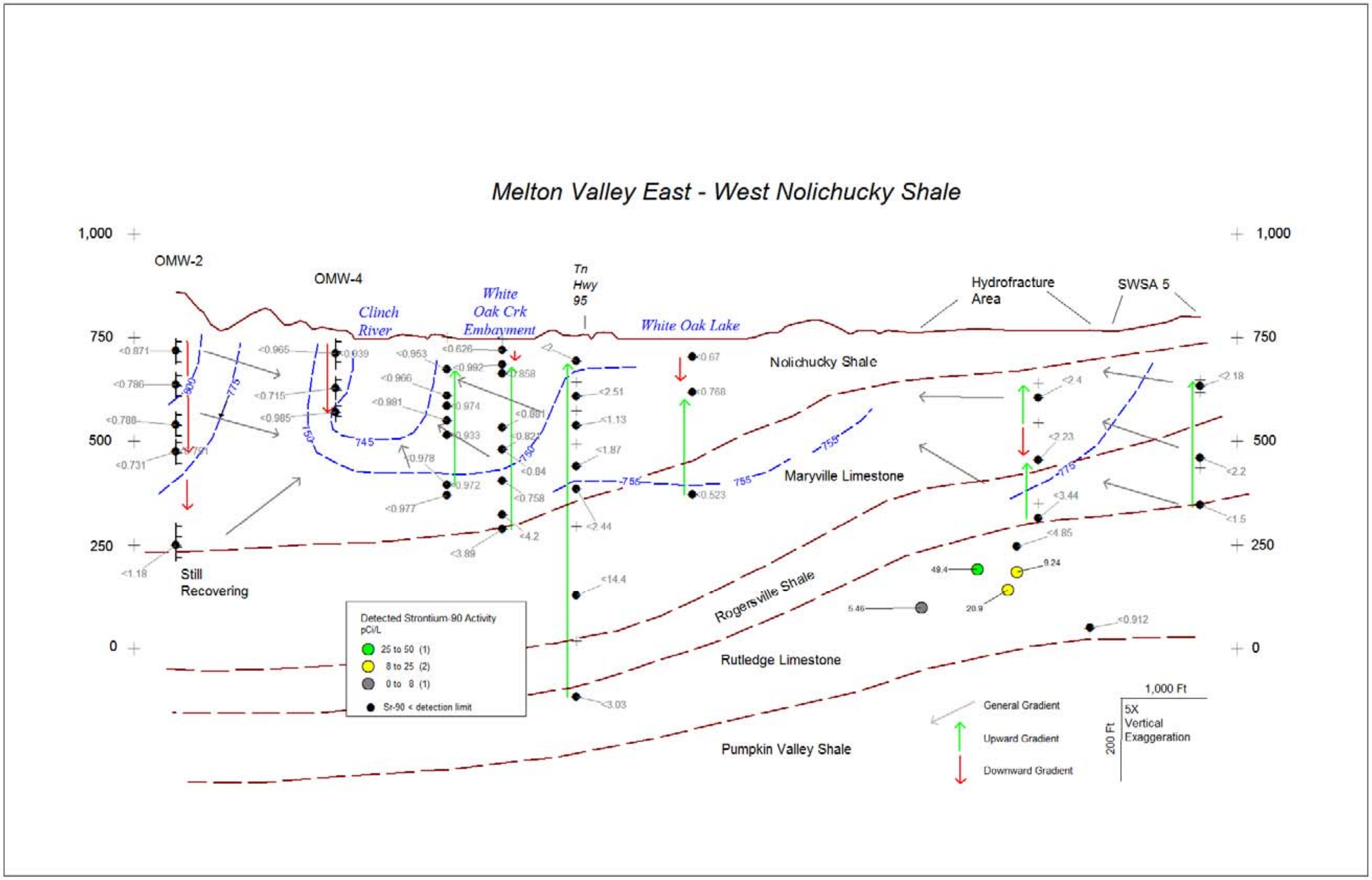


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Fig. J.14. Strontium-90 concentrations in groundwater beneath Melton Valley along cross-section B-B'.

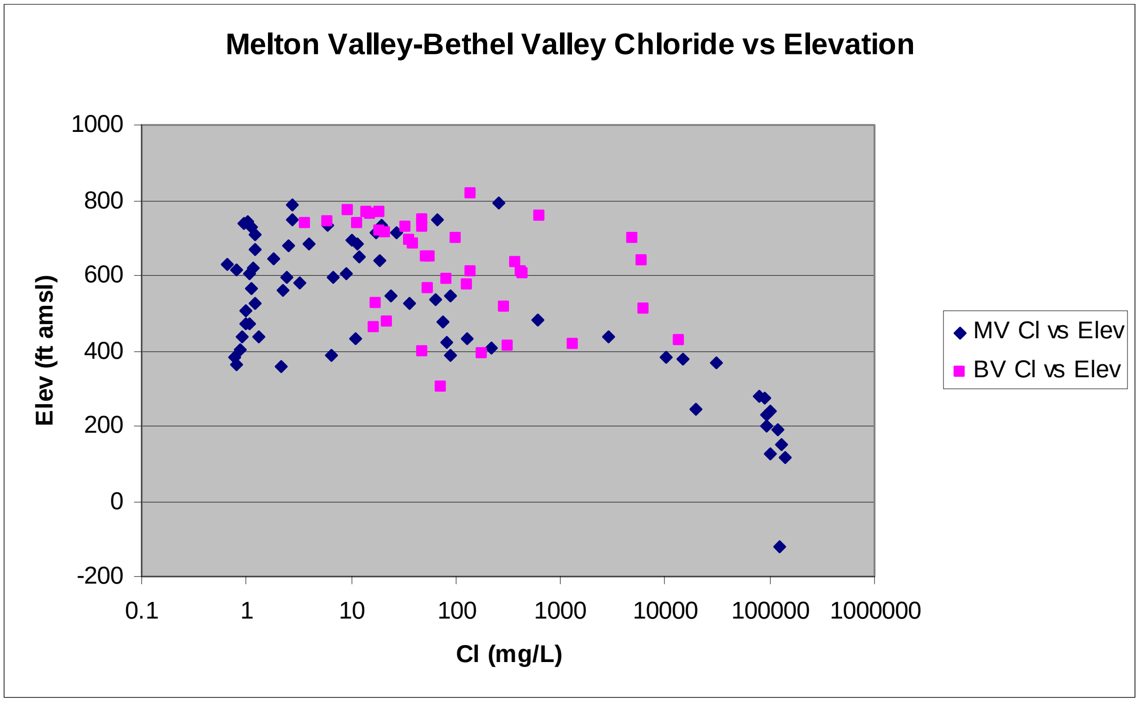


Fig. J.15. Chloride vs elevation for wells in Melton Valley and Bethel Valley, ORR.

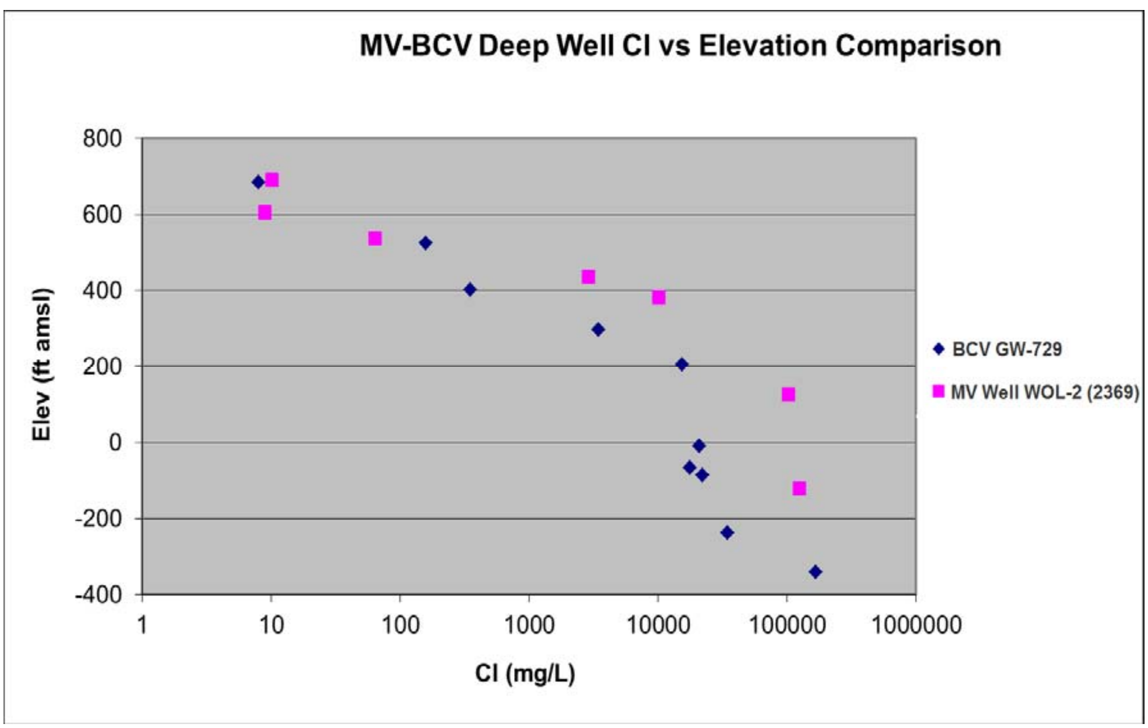


Fig. J.16. Chloride vs elevation relationship comparison for Westbay wells in Melton Valley and Bear Creek Valley.

Figure J.17 presents a similar plot for all deep wells on the ORR to show how the chloride–elevation relationship varies in Westbay wells between MV, BV, BCV, and Upper East Fork Poplar Creek (UEFPC). Note that, as shown by the comparison on Fig. J.16, BCV reaches brine concentrations at elevations lower than that of MV. UEFPC does not approach brine concentration at elevations nearing -100 ft amsl in the only two deep Westbay installations in the area. While there are very few Westbay wells in UEFPC, both BCV and the UEFPC area are underlain by the Maynardville Limestone, which is a recognized groundwater sink to undetermined elevations. This plot suggests the potential for deeper fresh water flow paths in UEFPC than in BCV and deeper flow paths in BCV than in MV.

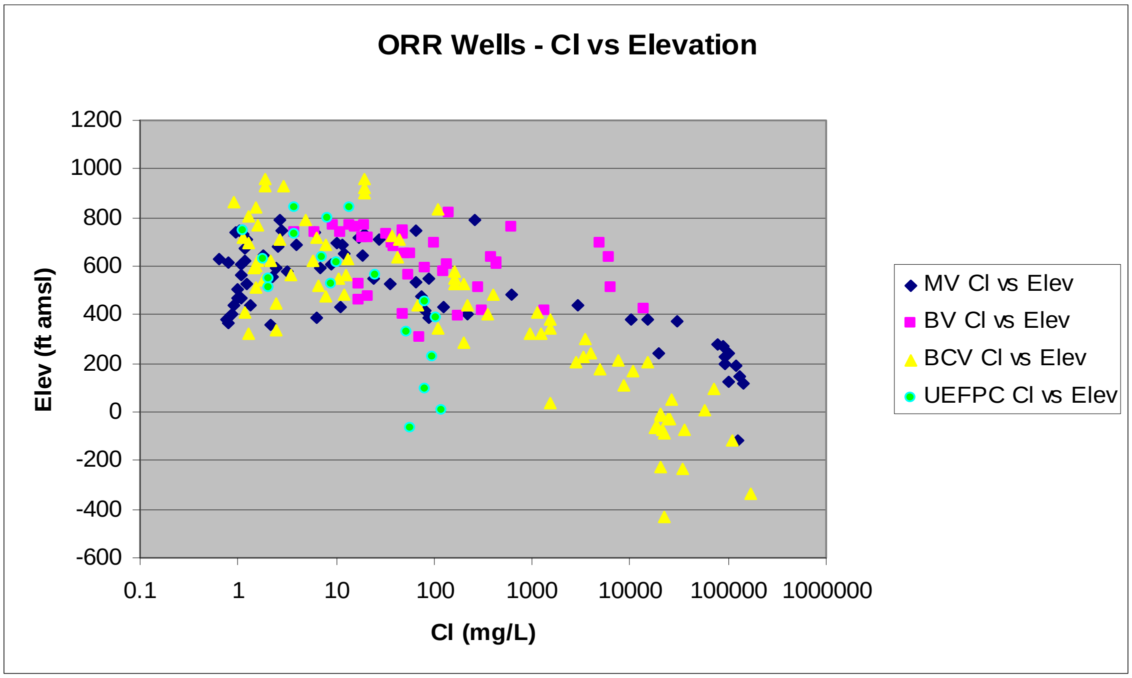


Fig. J.17. Chloride vs elevation relationships for Westbay Wells in the major ORR watersheds.

J.2.2.4 Brine–Fresh Water Relationships

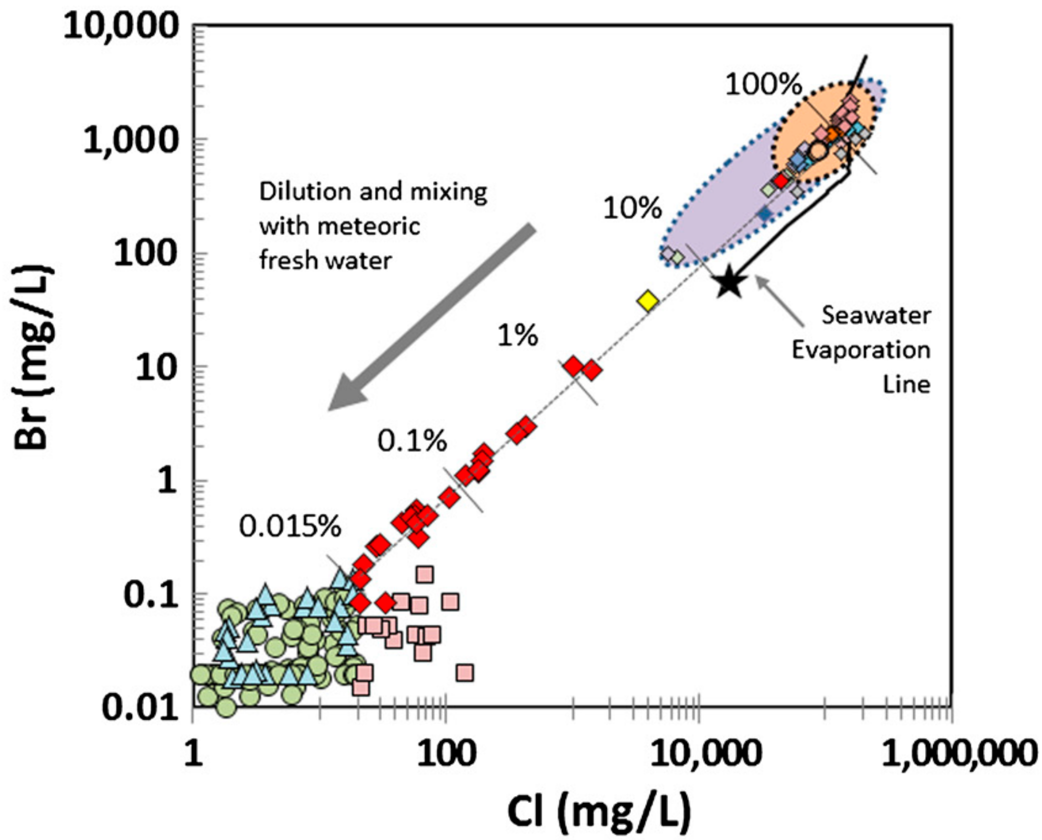
Nativ (1996) and Nativ et al. (1997) state that the presence of low levels of ^{14}C and ^{3}H, and the isotopic ratio of deuterium to oxygen-18 ($D/^{18}O$) in wells sampled for their ORR study indicate the influence of meteoric water at depth. While true, with one exception (well WOL-2), the wells sampled were at elevations higher than 300 ft amsl and are not indicative of brine geochemistry. It is noted that the chloride observed by Nativ in WOL-2 at an elevation of -128.15 ft amsl prior to installation of the Westbay system was reported at 64,900 mg/L in November 1992. More recent sampling of a Westbay port at the same elevation interval in December 2008 yielded 160,000 mg/L of chloride. Analysis of other chemical constituents shows similar increases in concentration. Neither ^{14}C nor ^{3}H were detected in any post-1992 sampling of WOL-2 deep intervals. This data discrepancy suggests that the groundwater chemistry in the well had not stabilized when sampled in 1992. These reports also included analytical results of oil field brines from wells located to the west on the Cumberland Plateau and at greater depth. These brines are believed to be representative of Appalachian Basin brines and provide a useful comparison with ORR and more distant brine chemistries.

Additional Appalachian Basin brine data are provided by two recently published studies on brines in Pennsylvania. Dresel and Rose (2010) present chemical analyses of western Pennsylvania oil- and gas-field brines and conclude the following:

- Saline water is found at depths of "a few thousand feet or less in most parts of western Pennsylvania."
- Data show a mixture of two end members: composition A – seawater evaporated beyond the point of halite precipitation (Cl ~185,700 mg/L); composition B – "fresh" water.
- Most brines are composed of 80 to 90% composition A. Oil well brines are generally more dilute than gas well brines.
- Brines originated as residual fluids in halite evaporates and were mobilized during compaction by overlying beds or during late Paleozoic deformation.
- Because brines are much more dense than seawater, they tend to displace normal connate water from underlying formations.
- Surface water has mixed with brines at some time post-evaporation, possibly as early as Devonian non-marine Catskill sedimentation.
- Some trends between composition and stratigraphic unit or geographic location appear to exist.
- Brines from oil wells always have lower TDS than gas wells ($<$130 g/L vs $>$150 g/L).
- Preservation of brines interpreted to have formed in the mid-Paleozoic time indicates that these brines form a stable "layer" having a density appreciably higher than that of surface water. This density stratification has enabled the brines to persist since Paleozoic time.

A second study (Warner et al. 2012) was initiated in an attempt to understand the potential natural migration of brines from the Marcellus Shale into shallow aquifers and how this process might influence the shale hydrofracturing controversy. The study showed that natural migration does occur from brines to fresh water aquifers and provides chemical evidence to document the process. Log–log plots of major ions versus chloride (in mg/L) show the relationship of brines to overlying fresh waters. A representative plot of bromide vs chloride is shown in Fig. J.18. The linear relationship between these conservative elements demonstrates that the majority of the higher salinity samples are derived from dilution of these Appalachian brines.

In addition to Br vs Cl, Na vs Cl, Sr vs Cl, Ba vs Cl, and Li vs Cl were also plotted and present the same linear relationship demonstrating the relatively conservative and nonreactive behavior of these constituents and that the salinity in these shallow aquifers is most likely derived from mixing of deeper formation brines (Warner et al. 2012).



Orange Envelope – Brines from Middle Devonian or Older Formations.
Purple Envelope – Appalachian Basin Brines from Devonian, Ordovician, and Silurian Formations.
Source: Warner et al. 2012

Fig. J.18. Bromide vs chloride concentrations showing relationship between shallow groundwaters in Northeast Pennsylvania and Appalachian Brines.

Figure J.19 presents a plot of the limited bromide vs chloride data for wells in Melton and Bethel valleys showing a similar linear pattern to that observed in Fig. J.18. The MV and BV data sets are the only ones on the ORR that include bromide analyses. Included on this plot are samples considered to be end-member Appalachian Basin oil field brines from several locations. The Nativ (1996, 1997) samples are from oil wells on the Cumberland Plateau of east-central Tennessee, the west Pennsylvania brines represent the highest chloride wells presented in the Dresel and Rose (2010) report, and the Marcellus brines are those taken from the Warner et al. (2012) report excepting those it gleaned from Dresel and Rose (2010). All of these brine analyses fall within a tight envelope that also includes the highest concentration MV brine samples. This indicates that the brines in MV are a part of the broader, high-density Appalachian Basin brine, which underlies major portions of the region.

The Warner (2012) study suffered from the same problem evident on the ORR as bromide was not a regularly analyzed constituent in many sample suites. Figure J.20 is a plot of strontium vs chloride from the Warner et al. (2012) study. For discussions of ORR brines, the strontium vs chloride relationship was chosen as, generally, both constituents are included in most analytical suites.

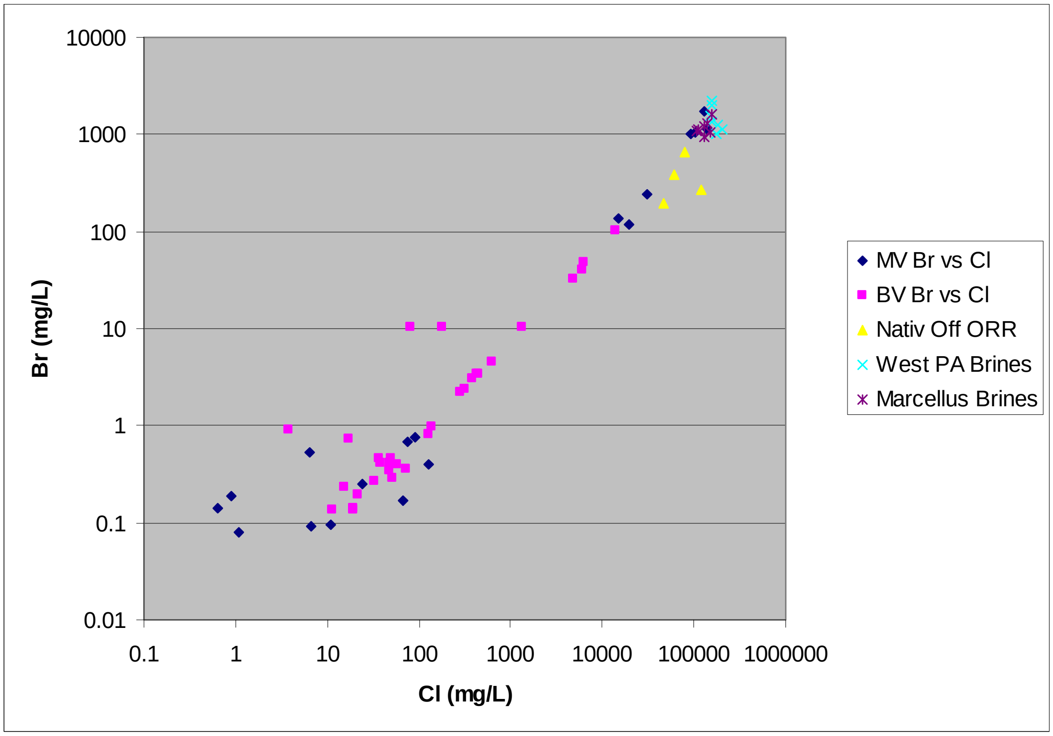
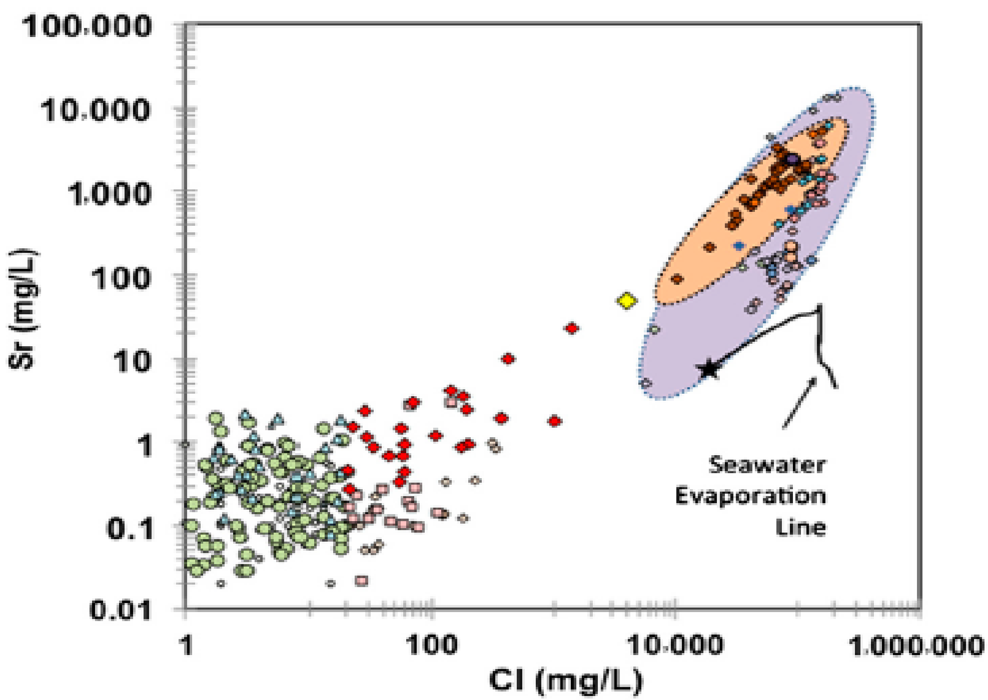


Fig. J.19. Bromide–chloride relationship for ORR wells and identified Appalachian Basin oil field brines.



Orange Envelope – Brines from Middle Devonian or Older Formations.
Purple Envelope – Appalachian Basin Brines from Devonian, Ordovician, and Silurian Formations.
Source: Warner et al. 2012

Fig. J.20. Strontium vs chloride concentrations showing relationship between shallow groundwaters in Northeast Pennsylvania and Appalachian Brines.

Figure J.21 shows the strontium vs chloride concentration relationship between shallow MV and BV groundwaters and the ORR/Appalachian Basin brines. Data from Nativ (1996, 1997) for oil field brine samples did not include strontium analyses. The linear dilution relationship is apparent through the higher concentration samples from both MV and BV with an obvious divergence at lower concentrations of both strontium and chloride at elevations correlative with the introduction of higher levels of shallow groundwater. Figure J.22 shows the same strontium vs chloride relationship for all ORR deep wells and the Appalachian Basin brines. The linear relationship holds most strongly for waters from MV and BCV with a few higher concentration samples from BV included in the more diluted part of the linear trend.

Where deep wells exist that penetrate massive carbonate units such as the Maynardville Limestone, brine, if present, has been encountered at depths below sea level (e.g., GW-135-03: Na-Cl water with TDS 45,000 mg/L), although high TDS groundwaters dominated by carbonate/bicarbonate and/or sulfate have been encountered. The difference in top-of-brine elevations between predominantly clastic vs carbonate lithologies is attributed to the deeper circulation of fresh water in the carbonate lithologies, which is presumed to have flushed the connate fluids away. The restricted depth of circulation in the predominantly clastic lithologies is attributed to decreasing bulk hydraulic conductivity at lower elevations, which slows the removal rate of connate fluids.

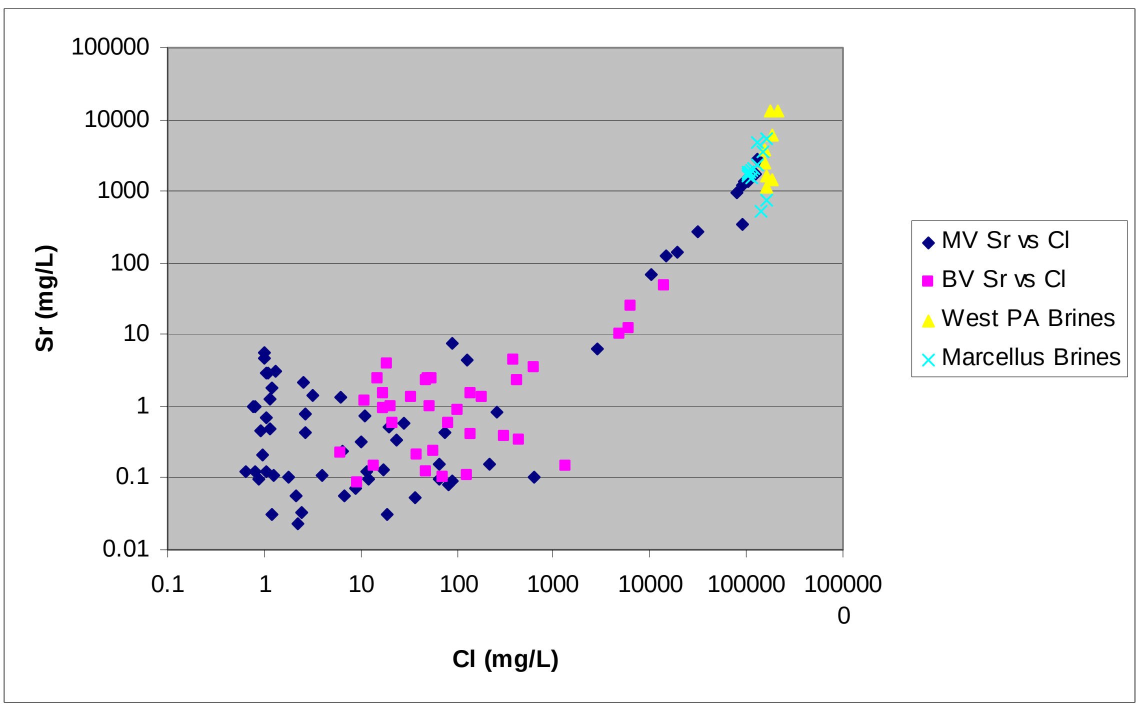


Fig. J.21. Strontium vs chloride relationship for wells in Melton Valley and Bethel Valley and Pennsylvania Appalachian Basin Brines.

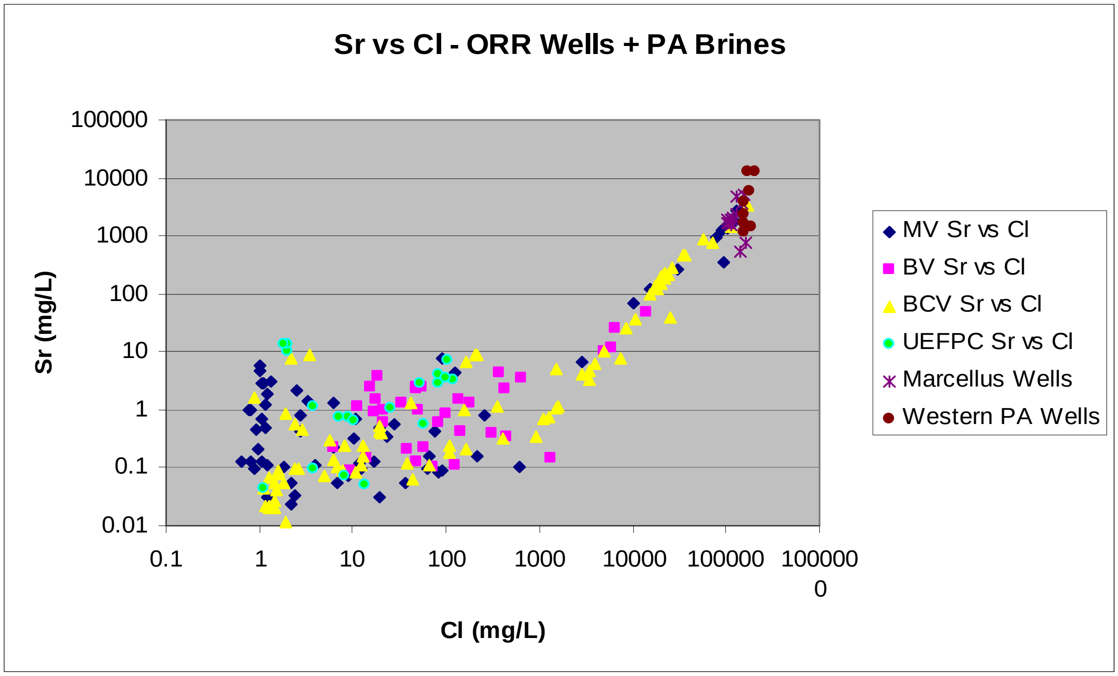


Fig. J.22. Strontium vs chloride relationship for ORR deep wells and Appalachian Basin Brines.

J.2.2.5 Off-site Well Comparisons

Plots of data from the MV Picket (exit pathway) wells and their off-site counterparts on the opposite side of the Clinch River (see Fig. J.9) show the same data spread observed in most of the other shallow groundwater situations. The exit pathway wells and off-site monitoring wells were designed and installed to sample groundwater above the non-potable, highly saline brine zone. There is an obvious trend toward higher chloride concentration with lower elevation in both data sets, but neither approaches brine concentrations at the elevations penetrated (Fig. J.23). Note that, as of summer 2013, the two deepest off-site monitoring wells have not yet achieved geochemical stability as indicated by steadily increasing chloride and TDS concentrations.

The plot of strontium vs chloride for these data sets (Fig. J.24) shows relatively high concentrations of both constituents for the deepest sample zones in each location. The three high-strontium–low-chloride data points in the Picket Well set are from the deepest zones in Picket Well 4537, which samples the Rutledge Limestone at the western end of MV. Groundwater in this well has a high sulfate concentration related to the geochemistry of the Rutledge Limestone/Rogersville stratigraphic zone. This local geochemistry is unique within the broad area sampled by the Picket Wells. There is no off-site well accessible to sample a similar setting on the west side of the river.

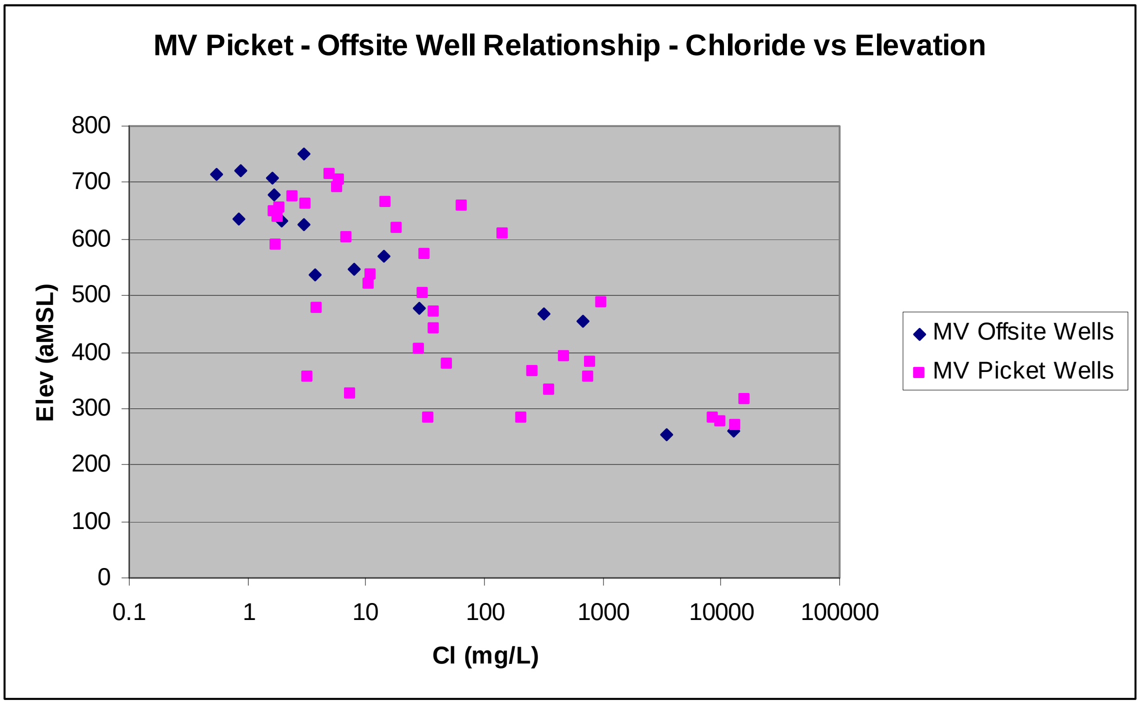


Fig. J.23. Chloride vs elevation plot for Melton Valley picket wells and off-site correlative monitoring locations.

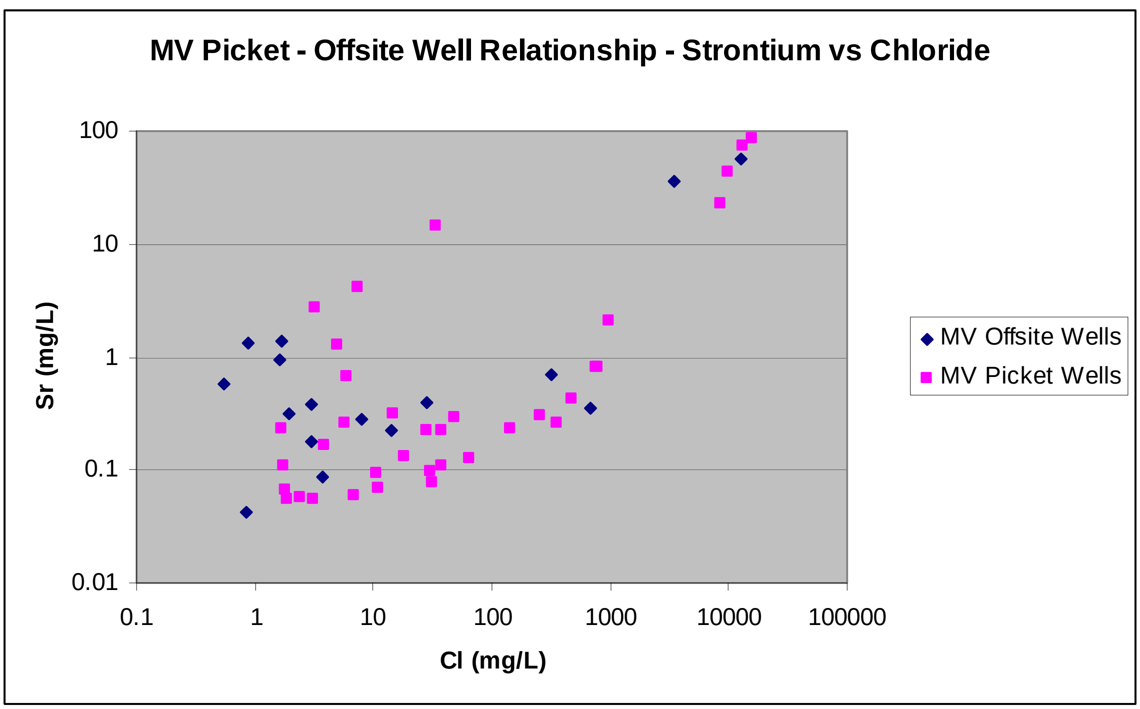


Fig. J.24. Strontium vs chloride plot for Melton Valley picket wells and off-site correlative monitoring locations.

Figure J.25 shows the chloride concentrations in groundwater in the Picket wells along cross-section C-C'. It can be seen that chloride concentrations of greater than 1000 mg/L are present at elevations below about 350 ft amsl in the Nolichucky Shale and the Maryville Limestone. Data from the Rogersville Shale exhibit elevated chloride concentrations at much shallower depths (>1000 mg/L at ~500 ft amsl) despite the local downward gradient observed at well 4538.

J.3 CONCLUSIONS

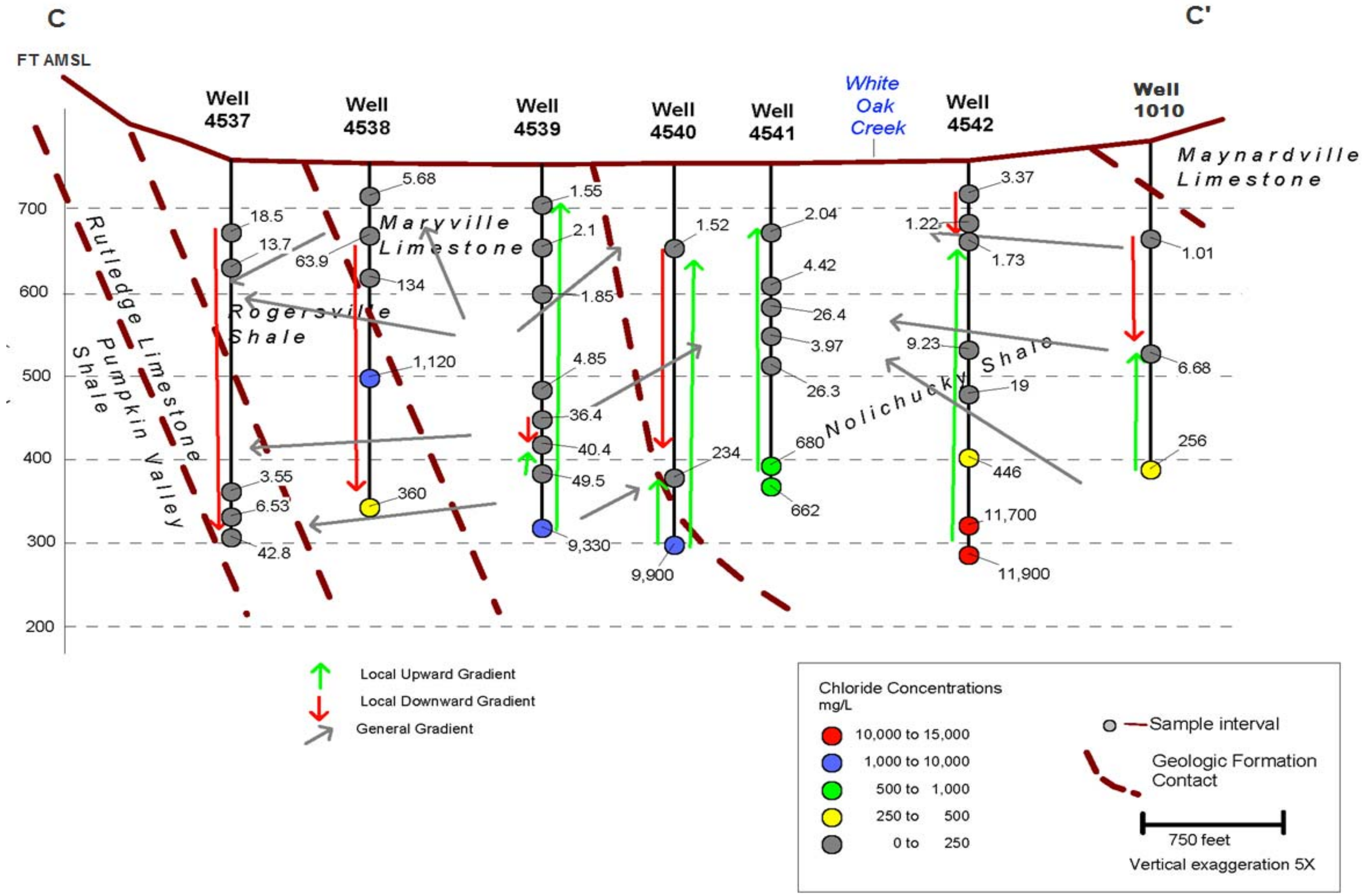
The overall observations regarding heads in the DOE off-site wells are that, generally, head gradients are downward and all head results in fully recovered wells are greater than the maximum recorded daily average water level for the Clinch River. In general, the shallowest zone wells show responses to periods of high rainfall as well as interactions with fluctuations in river level. The DOE off-site well located closest to the Clinch River (well OMW-4) exhibits groundwater elevations in all three zones that are consistently higher than Clinch River water elevations except during short periods when the river rises rapidly in response to storm events and reservoir management activities. All three zones at this location appear to fluctuate in relation to the Watts Bar Reservoir level with additional responses to rain events.

Generally, the intermediate and deep zones at the off-site well clusters show a more subdued hydrograph than the shallowest zone wells. For the most part the shallowest zones show less of an impact during sample collection than the intermediate and deep zone wells. The deepest zones tend to exhibit recovery times of several weeks following sample collection, which is reflective of low bedrock transmissivity below elevation 500 ft amsl.

In addition, hydraulic head data show a very complex head field in the intermediate and deep intervals. With both upward and downward gradients present, some of the head relationships suggest limitations to depth of circulation of near-surface contaminants based on the upward gradients. The continuous presence of brine beneath MV suggests the existence of an elevation beneath the area below which fresh water is not circulating. The same cannot be said for other areas of the ORR because of the paucity of deep wells. Data from BCV indicate that high-density brines are present and, at a minimum, underlie some of the eastern portion of the valley. There is insufficient deep well data from BV; however, plotting of some of the strontium vs chloride data on the dilution trend line suggests deeper wells may encounter brine. Determination of the fresh water/brine interface elevation beneath UEFPC requires further investigation.

Signature COCs for MV (i.e., tritium and ^{90}Sr) are not widely distributed in the intermediate and deeper zones. Strontium-90 is measured consistently in several wells constructed in the Rutledge Limestone directly overlying the hydrofracture grout injection area.

The agreement in analysis of brines from the ORR with those from the Cumberland Plateau oil fields and the oil and gas fields in Pennsylvania indicates that the brines are all regionally related as part of the broadly disseminated high-density Appalachian Basin brine system that has been identified in many areas as limiting the vertical movement of less dense waters. Data from existing deep wells on the ORR suggest the existence of a high-density brine boundary at elevations near sea level elevation beneath the ORR.



Based on most recent available data

Fig. J.25. Groundwater chloride concentrations in Melton Valley Picket Wells along cross-section C-C'.

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APPENDIX K
FEEDBACK FROM THE FEDERAL FACILITY AGREEMENT PARTIES ON KEY ORR GROUNDWATER STRATEGY ISSUES

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ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
FFA	Federal Facility Agreement
FY	fiscal year
GW	groundwater
NPL	National Priorities List
ORR	Oak Ridge Reservation
TDEC	Tennessee Department of Environment and Conservation
TI	Technical Impracticability

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A list of questions about groundwater strategy issues was discussed at the August 2013 workshop. The Federal Facility Agreement (FFA) participants have provided a written response to each question. The questions were designed to open tri-party (U.S. Environmental Protection Agency, Tennessee Department of Environment and Conservation, and U.S. Department of Energy) dialogue about some of the key regulatory and technical challenges on the Oak Ridge Reservation. The questions and FFA party responses are as follows:

1) **When are alternate ground water risk management measures acceptable as a sole means of managing risks posed by ground water contamination?**

   EPA: Land Use Controls (i.e., risk management measures) may be used in combination with active response measures to achieve protection to human health and the environment. Land Use Controls as a sole means of managing risk posed by groundwater contamination across the DOE Oak Ridge Reservation is not an acceptable singular option [*300.430(a)(iii)(D) - "The use of institutional controls shall not substitute for active response measures... ...as the sole remedy unless such active measures are determined not to be practicable..."*].

   TDEC: When meeting established criteria proves to be technically and economically infeasible.

   DOE: When meeting established criteria proves to be technically and economically infeasible.

2) **What groundwater contamination situations on the ORR are strong candidates for Technical Impracticability waivers?**

   EPA: A Treatability Study was initiated between DOE, EPA, and TDEC at the East Tennessee Technology Park (ETTP) 1401 Area to answer this important question. Because this work was never completed the regulators do not have sufficient data to provide a definitive answer. The completion of the Treatability Study at the 1401 Area should provide the data which would determine the appropriateness of a waiver for contaminated groundwater at ETTP and inform future evaluations across the reservation.

   TDEC: At this time, without further characterization, it is not possible to make this determination. However, a TI waiver will still mean monitoring, 5 year reviews, and characterization of the plumes showing there is no pathway for human exposure and restoration is unattainable.

   DOE: A number of plumes on the ORR have typical features found in Technical Impracticability waivers. Additional characterization is needed to make a TI waiver determination for specific plumes.

   Under CERCLA all remedies are subject to Five-Year Reviews of performance and protectiveness. In this regard all CERCLA TI decisions are interim measures subject to future revision. Should new technologies or remediation approaches be developed that could significantly reduce the time and cost to attain unrestricted use of the affected groundwater resource, a Five-Year Review could require DOE to re-open the decision and implement a new remedial action.

3) **The current ORR DOE Life Cycle Baseline assumes that final groundwater remedies on the Oak Ridge Reservation focus primarily on monitoring and preventing use of contaminated GW, with limited active restoration. Are changes to this scope assumption requested at this time?**

EPA: Yes. DOE ORR has been identified as an NPL Site that does not meet the goal of "Groundwater Migration Under Control." Changes to the DOE Oak Ridge Reservation Life Cycle Baseline are necessary to show the plan toward meeting this goal and the Site-Wide Groundwater Strategy Document should support an update to the current baseline. During scoping meetings for the reservation-wide Groundwater Strategy document, the Project Team identified several individual areas and specific watersheds that are currently poorly characterized and are contributing to the uncontrolled release of unacceptable levels of contamination to groundwater. The movement of that contamination within the subsurface has not been sufficiently characterized at present to understand the potential impact of the uncontrolled contaminant migration, both on the Reservation and offsite.

TDEC: Yes. The State requests a commitment from DOE to put a line item in the baseline and commit funding to that item from the present to the final groundwater remediation decision. The funding would be used to characterize current groundwater conditions and proceed with the intent of moving forward groundwater decisions as needed.

DOE: Yes. DOE plans to budget annual funding for an ongoing ORR Groundwater Program to systematically prioritize and investigate groundwater plumes and data gaps. The first project planned under the program is the Off-site Groundwater Quality Assessment. Future baseline changes will become better defined as characterization of plumes proceeds under the Program.

4) **Are changes to the ORR DOE Life Cycle Baseline requested with regard to the *timing* of groundwater activities in the baseline?**

EPA: Yes. Changes to the ORR Life Cycle Baseline are necessary at this time to achieve a balanced approach to groundwater characterization and remedial decision making in a coordinated, timely, and orderly manner. The current baseline appears to defer all costs for this work to many years in the future, without any plans for phased implementation. The extended deferral without phased implementation may add to the eventual cost and complexity of conducting this work. Alternatively, initiating a groundwater program sooner, consistent with the Site-wide Groundwater Strategy Document, will yield more realistic long-term project and budget planning and potentially significantly reduce overall costs. EPA's priorities for the strategic plan to address groundwater contamination include subsurface characterization to identify and address secondary sources, as a part of a phased implementation strategy to reach final decisions (e.g., Record of Decision). The effectiveness and finality of conducting some of this work would begin with finishing the groundwater Treatability Study at the ETTP 1401 Area and taking the lessons learned and decisions made to other secondary sources and contaminate plumes across the reservation.

TDEC: Yes. See above.

DOE: Yes. See response to Question #3.

5) **Under the current understanding of GW conditions, are additional near-term off-site monitoring measures needed to assess potential off-site risks?**

EPA: Yes. The current state of knowledge regarding possible offsite risk to human health and the environment is deficient and will be addressed in the upcoming offsite groundwater sampling work. However, at this time, there is nothing known that requires the DOE Oak Ridge Reservation to initiate additional offsite actions (e.g., monitoring, alternative water supply) from those already taken.

TDEC: Yes. The State would like to see immediate characterization efforts of residential wells immediately off-site of the ORR.

DOE: Yes. An Off-site Groundwater Quality Assessment project that includes additional off-site groundwater sampling is planned for FY 14 through FY 16. The project prioritizes early resources toward assessing the potential threat of off-site contamination.

6) **Under the current understanding of GW conditions, are immediate off-site use controls (beyond those already in place) needed?**

EPA: No. See response to #5 above.

TDEC: No, but it must be recognized that there are numerous off-site residential wells that lack sufficient characterization to make this determination. This position could change based on characterization results that should be collected soon.

DOE: No. However, this assessment could change based on characterization results of the Off-site Groundwater Quality Assessment project.

A groundwater strategy recommendation is to use a portion of the annual funding to be budgeted for the ORR Groundwater Program to improve the tracking of groundwater uses and restrictions. Setting up a DOE interface with TDEC program to allow DOE to be notified of new well installation activity is a specific recommended improvement.

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