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JAN 2 0 2010

Ms. Jennifer Tufts
U.S. Environmental Protection Agency, Region 4
Federal Facilities Branch
61 Forsyth Street
Atlanta, Georgia 30303

PPPO-02-303-10

Mr. Edward Winner, FFA Manager
Kentucky Department for Environmental Protection
Division of Waste Management
200 Fair Oaks Lane, 2nd Floor
Frankfort, Kentucky 40601

Dear Ms. Tufts and Mr. Winner:

TRANSMITTAL OF D2 FOCUSED FEASIBILITY STUDY FOR THE SOUTHWEST GROUNDWATER PLUME VOLATILE ORGANIC COMPOUND SOURCES (OIL LANDFARM AND C-720 NORTHEAST AND SOUTHEAST SITES) AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY (DOE/LX/07-0186&D2)

Please find enclosed the certified D2 Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, (DOE/LX/07-0186&D2), for your review. Also enclosed is a red-lined version of the document and a comment response summary in response to comments received on October 21, 2009, and the comment resolution meetings held in Nashville, Tennessee, on December 7 and 8, 2009.

If you have any questions or require additional information, please contact David Dollins at (270) 441-6819.

Sincerely,

Reinhard Knerr
Paducah Site Lead
Portsmouth/Paducah Site Office

Enclosures:
1. Certification Page
2. D2 FFS for the SW Plume
3. Red-lined D2 FFS for the SW Plume
4. Comment Response Summary

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CERTIFICATION

Document Identification: **Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plan (DOE/LX/07-0186&D2)**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Paducah Remediation Services LLC

Paul Wellette for | 1/25/2010

Dennis Ferrigno, PM, Site Manager | Date Signed

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

U.S. Department of Energy (DOE)

1/26/10

Reinhard Knerr, Paducah Site Lead | Date Signed

DOE/LX/07-0186&D2
PRIMARY DOCUMENT

Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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DOE/LX/07-0186&D2
PRIMARY DOCUMENT

Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued–January 2010

Prepared for the
U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Environmental Management Activities at the
Paducah Gaseous Diffusion Plant
Paducah, Kentucky 42001

managed by
Paducah Remediation Services, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC30-06EW05001

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PREFACE

This *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0186&D2, was prepared to evaluate remedial alternatives for potential application at the U.S. Department of Energy's Paducah Gaseous Diffusion Plant. This work was prepared in accordance with the requirements of the *Federal Facility Agreement for the Paducah Gaseous Diffusion Plant* (FFA) (EPA 1998a) and the "Resolution of the Environmental Protection Agency Letter of Non-Concurrence for the Site Investigation Report for the Southwest Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/OR/07-2180&D2/R1, and Notice of Informal Dispute Dated November 30, 2007, McCracken County, Kentucky KY 8-890-008-982" (referred to as the Resolution) (EPA 2008). In accordance with Section IV of the FFA, this integrated technical document was developed to satisfy applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 *USC* 9601 *et seq.* 1980) and the Resource Conservation and Recovery Act (42 *USC* 6901 *et seq.* 1976). As such, the phases of the investigation process are referenced by CERCLA terminology within this document to reduce the potential for confusion.

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TABLES

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FIGURES

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ACRONYMS

ALARA	as low as reasonably achievable
AOC	area of contamination
ARAR	applicable or relevant and appropriate requirement
ARD	anaerobic reductive dechlorination
bgs	below ground surface
BHHRA	baseline human health risk assessment
BMP	best management practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
cis-1,2-DCE	*cis*-1,2-dichloroethene
COC	contaminant of concern
COE	U.S. Army Corps of Engineers
CPT	cone penetrometer
CRMP	*Cultural Resources Management Plan for the Paducah Gaseous Diffusion Plant, Paducah Gaseous Diffusion Plant, McCracken County, Kentucky*
CSM	Conceptual Site Model
CWA	Clean Water Act
DCE	dichloroethene
D&D	decontamination and decommissioning
DNAPL	dense nonaqueous-phase liquid
DOE	U.S. Department of Energy
DPT	direct-push technology
ECD	electron capture detector
EDE	effective dose equivalent
ELCR	excess lifetime cancer risk
E/PP	excavation/penetration permit
EPA	U.S. Environmental Protection Agency
ERH	electrical resistance heating
FFA	Federal Facility Agreement
FFS	focused feasibility study
FML	flexible membrane liner
FR	*Federal Register*
FS	feasibility study
FY	fiscal year
GAC	granular-activated carbon
GC-ECD	gas chromatography-electron capture detector
GC-MS	gas chromatography-mass spectrometry
GRA	general response action
HASP	health and safety plan
HDPE	high-density polyethylene
HI	hazard index
HRC	Regenesis Hydrogen Release Compound®
HTTD	high temperature thermal desorption
HU	hydrogeologic unit
ISB	*in situ* bioremediation
ISB-ARD	*in situ* bioremediation-anaerobic reductive dechlorination
ISCO	*in situ* chemical oxidation
ISRM	*in situ* redox manipulation

ITRD	Innovative Treatment and Remediation Demonstration
KAR	*Kentucky Administrative Rules*
K_d	soil/water partition coefficient
KDEP	Kentucky Department for Environmental Protection
K_H	Henry's Law constant value
K_{oc}	soil organic carbon partition coefficient
K_{ow}	octanol-water partition coefficient
KOW	Kentucky Ordnance Works
KPDES	Kentucky Pollutant Discharge Elimination System
LCD	Lower Continental Deposits
LDR	land disposal restriction
LLW	low-level waste
LTTD	low temperature thermal desorption
LUC	land use control
MCL	maximum contaminant level
MDL	method detection limits
MIP	membrane interface probe
MMO	methane monooxygenase
MNA	monitored natural attenuation
MW	monitoring well
NAPL	nonaqueous-phase liquid
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act of 1969
NHPA	National Historic Preservation Act
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
NRCS	Natural Resources Conservation Service
NV	no value
NWP	Nationwide Permit
OH	hydroxyl free radicals
O&M	operation and maintenance
O&M&M	operation, maintenance, and monitoring
ORP	oxidation reduction potential
OU	operable unit
PCB	polychlorinated biphenyl
PCE	perchloroethene (tetrachloroethene)
PFM	passive fluxmeter
PGDP	Paducah Gaseous Diffusion Plant
pH	hydrogen-ion concentration
PID	photoionization detector
PITT	Partioning Interwell Tracer Test
POE	point of exposure
PPE	personal protective equipment
PRB	permeable reactive barrier
PTW	principal threat waste
PVC	polyvinyl chloride
RA	removal action
RAO	remedial action objective
RAWP	remedial action work plan
RCRA	Resource Conservation and Recovery Act
RD	remedial design

RDSI	remedial design site investigation
RG	remediation goal
RGA	Regional Gravel Aquifer
RI	remedial investigation
RNS	Ribbon NAPL Sampler
ROD	record of decision
RPO	representative process option
SERA	screening ecological risk assessment
SI	site investigation
SMP	Site Management Plan
SPH	six-phase heating
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWMU	solid waste management unit
^{99}Tc	technetium-99
TBC	to be considered
TCA	trichloroethane
TCE	trichloroethene
TDR	time domain reflectometry
T&E	threatened and endangered
TOC	total organic carbon
trans-1,2-DCE	*trans*-1,2-dichloroethene
TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authority
UCD	Upper Continental Deposits
UCRS	Upper Continental Recharge System
USC	*United States Code*
USFWS	U. S. Fish and Wildlife Service
VC	vinyl chloride
VOC	volatile organic compound
WAC	waste acceptance criteria
WAG	waste area grouping
WCP	waste characterization plan
WKWMA	West Kentucky Wildlife Management Area
WMP	waste management plan
ZVI	zero-valent iron

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EXECUTIVE SUMMARY

This *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0186&D2, (FFS) was prepared to evaluate remedial alternatives for potential application at the U.S. Department of Energy's (DOE's) Paducah Gaseous Diffusion Plant (PGDP). This work was prepared in accordance with the requirements of the *Federal Facility Agreement for the Paducah Gaseous Diffusion Plant* (FFA) (EPA 1998a) and the "Resolution of the Environmental Protection Agency Letter of Non-Concurrence for the Site Investigation Report for the Southwest Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky (DOE/OR/07-2180&D2/R1) and Notice of Informal Dispute Dated November 30, 2007, McCracken County, Kentucky, KY 8-890-008-982" (referred to as the Resolution) (EPA 2008).

The Southwest Groundwater Plume refers to an area of groundwater contamination at PGDP in the Regional Gravel Aquifer (RGA), which is south of the Northwest Groundwater Plume and west of the C-400 Building. The plume was identified during the Waste Area Grouping (WAG) 27 Remedial Investigation (RI) in 1998. Additional work to characterize the plume [Solid Waste Management Unit (SWMU) 210] was performed as part of the WAG 3 RI and Data Gaps Investigations, both in 1999. As discussed in these reports, the primary groundwater contaminant of concern (COC) for the Southwest Groundwater Plume (hereinafter referred to as the Southwest Plume) is trichloroethene (TCE). Other contaminants found in the plume include additional volatile organic compounds (VOCs), metals, and the radionuclide, technetium-99 (^{99}Tc). The PGDP is posted government property and trespassing is prohibited. Access to PGDP is controlled by guarded checkpoints, a perimeter fence, and vehicle barriers and is subject to routine patrol and visual inspection by plant protective forces.

DOE conducted a Site Investigation (SI) in 2004 to address the uncertainties with potential source areas to the Southwest Plume that remained after previous investigations. The SI further profiled the current level and distribution of VOCs in the dissolved-phase plume along the west plant boundary. Results of the SI were reported in the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1 (DOE 2007). This FFS is based on the SI (DOE 2007) as well as previous investigations identified below.

The potential source areas investigated in the SI (DOE 2007) included the C-747-C Oil Landfarm (Oil Landfarm); C-720 Building Area near the northeast and southeast corners of the building (C-720 Northeast Site and C-720 Southeast Site); and the storm sewer system between the south side of the C-400 Building and Outfall 008 (Storm Sewer). As a result of the Southwest Plume SI, the storm sewer subsequently was excluded as a potential VOC source to the Southwest Plume. Respective SWMU numbers for each potential source area investigated in the SI are provided in Table ES.1.

Table ES.1. Summary of Potential Source Areas and SWMU Numbers

Description	SWMU No.
C-747-C Oil Landfarm	1
Plant Storm Sewer	Part of 102
C-720 TCE Spill Sites Northeast and Southeast	211 A&B

In November 2007, the U.S. Environmental Protection Agency (EPA) invoked an informal dispute on the Southwest Plume SI. In March 2008, DOE signed the Resolution which required, among other things, that DOE conduct an FFS for addressing source areas to the Southwest Plume, in view of developing remedial

alternatives and undertaking a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 *USC* 9601 *et seq.* 1980) remedial action and Record of Decision (ROD). The source areas subject to the FFS included the Oil Landfarm, C-720 Northeast and Southeast Sites, and Storm Sewer. The FFS was to address contamination in the shallow groundwater and could be based upon the Southwest Plume SI data, previous documents, and additional information, as necessary. The FFS was required to contain, among other information, a remedial action objective (RAO) for addressing source areas, including treatment and/or removal of principal threat waste (PTW) consistent with CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (including the preamble) and pertinent EPA guidance. The Southwest dissolved-phase plume in the Groundwater Operable Unit (OU) Dissolved-Phase Plumes would include the RAO of returning contaminated groundwater to beneficial use(s) and attaining chemical-specific applicable or relevant and appropriate requirements (ARARs), and/or attaining risk-based concentrations for all identified COCs throughout the plume (or at the edge of the waste management area depending on whether the waste source was removed), consistent with CERCLA, the NCP (including the preamble), and pertinent EPA guidance.

EPA typically describes sources as material that includes hazardous substances, pollutants, or contaminants that act as a reservoir for the groundwater, surface water, or air or act as a source of direct exposure. EPA considers sources or source materials to be principal threats when they are highly toxic or highly mobile and generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (EPA 2004a). Previous investigations of FFS source areas to 55 ft below ground surface (bgs) identified the potential presence of TCE dense nonaqueous-phase liquid (DNAPL), which would constitute PTW.

SCOPE OF THE SOUTHWEST PLUME FFS IN THE SITEWIDE GROUNDWATER OU

This FFS will support a final action to mitigate the migration of VOCs from the Oil Landfarm and the C-720 Building Area to the Southwest Plume and to treat or remove PTW. Based on results from the Southwest Plume SI, the Storm Sewer no longer is considered a source of VOC contamination to the Southwest Plume. Risks posed by direct contact with contaminated surface soil or sediment at the Oil Landfarm and C-720 Building Area or remaining risks from potential use of contaminated groundwater from VOC and non-VOC contaminants will be addressed later as part of the decisions for the Surface Water, Soils, or Groundwater OUs.

These VOC source areas are assigned to the Groundwater OU at PGDP, which is one of five media-specific sitewide OUs being used to evaluate and implement remedial actions. Consistent with EPA guidance (EPA 2004a), the Groundwater OU is being implemented in a phased approach consisting of sequenced remedial and removal actions designed to accomplish the following goals:

(1) Prevent human exposure to contaminated groundwater;
(2) Prevent or minimize further migration of contaminant plumes;
(3) Prevent, reduce, or control contaminant sources contributing to groundwater contamination; and
(4) Restore the groundwater to its beneficial uses, wherever practicable.

This FFS and ensuing final VOC remedial action will support the phased groundwater goals represented in goals 3 and 4 above by controlling VOC migration (including DNAPL) that contribute to groundwater contamination, thereby promoting the restoration of groundwater to beneficial use, as practicable. The remedial action also is anticipated to substantially reduce the risk and hazard from hypothetical groundwater use associated with releases from these source areas.

Evaluation of a final remedial action for additional COCs (non-VOCs) associated with direct contact exposure risks will be addressed by the Soils Operable Unit, as described in the 2009 Site Management Plan. Groundwater contamination will be addressed through the Dissolved-Phase Plumes Remedial Action.

PREVIOUS INVESTIGATIONS

This FFS is based on findings from the multiple investigations summarized in Table ES.2.

Table ES.2. Summary of Investigations and Areas Investigated

Date	Title	Southwest Plume	Oil Landfarm	C-720 Building Area	Storm Sewer	SWMU 4*
1989–1990	Phase I SI		✓		✓	✓
1990–1991	Phase II SI		✓	✓	✓	✓
1996	Site-specific sampling		✓			
1997	WAG 6 Remedial Investigation				✓	
1998	WAG 23 Removal Action		✓			
1998	WAG 27 Remedial Investigation	✓	✓	✓		
1999	Sitewide Data Gaps Investigation	✓				
1999	WAG 3 Remedial Investigation	✓				✓
2001	Groundwater OU Feasibility Study	✓	✓	✓	✓	
2007	Southwest Plume Site Investigation	✓	✓	✓	✓	✓

*SWMU 4 is a component of the Burial Ground Operable Unit and will be remediated as necessary under that operable unit.

SOURCE AREAS AND NATURE AND EXTENT OF CONTAMINATION

C-747-C Oil Landfarm (SWMU 1)

Between 1973 and 1979 the Oil Landfarm was used for landfarming waste oils contaminated with TCE, uranium, polychlorinated biphenyls (PCBs), and 1,1,1-trichloroethane (TCA). These waste oils are believed to have been derived from a variety of PGDP processes. The landfarm consisted of two 104.5-m^2 (1,125- ft^2) plots that were plowed to a depth of 0.305 to 0.61 m (1 to 2 ft). Waste oils were spread on the surface every 3 to 4 months; then the area was limed and fertilized.

Investigations of the Oil Landfarm include the Phase I and Phase II SI (CH2M HILL 1991; CH2M HILL 1992), additional sampling performed to support the WAG 23 Feasibility Study and resulting Removal Action (RA) (DOE 1998a), and the WAG 27 RI (DOE 1999a). These investigations and actions identified VOCs, PCBs, dioxins, semivolatile organic compounds, heavy metals, and radionuclides as COCs. As part of the WAG 23 RA, 17.58 m^3 (23 yd^3) of dioxin-contaminated soil was excavated and removed from the unit. Samples collected to support the WAG 23 RA indicated the presence of *cis*-1,2-dichloroethene (*cis*-1,2-DCE) concentrations as high as 2,400 milligrams per kilogram (mg/kg). During the WAG 27 RI, the maximum detected TCE concentration was 439 mg/kg at 4.6 m (15 ft) below ground surface (bgs) with most TCE concentrations less than 100 mg/kg.

During the Southwest Plume SI, five soil borings were placed within and adjacent to the contaminated area defined in the WAG 27 RI. No RGA groundwater samples were collected at this unit. The highest levels of total VOCs detected in a single sample included TCE (3.5 mg/kg) and degradation products *cis*-1,2-DCE (1.5 mg/kg) and vinyl chloride (VC) (0.02 mg/kg), TCA (0.05 mg/kg), and 1,1-DCE (0.07 mg/kg). Some or all of these products were detected in samples from all sample intervals at the location collected down to a total depth of 18.1 m (59.5 ft). The high TCE concentration (3.5 mg/kg) was detected at 14.3 m (47 ft) bgs. Significant levels of TCE (1.8 mg/kg) and *cis*-1,2-DCE (0.086 mg/kg) were detected in a second location from all intervals collected to a depth of 17.07 m (56 ft), with the highest level of TCE detected at 17.07 m (56 ft) bgs. A third location exhibited lower levels of TCE and its degradation products, with the highest level of TCE (0.98 mg/kg) detected at 9.1 m (30 ft) bgs together with TCA (0.0034 mg/kg). Low levels of TCE (0.37 mg/kg) and *cis*-1,2-DCE (0.2 mg/kg) were detected at 13.8 m (45.5 ft) in a fourth sample location. The fifth location did not contain any detectable concentrations of TCE or its degradation products, but had a slight detection of carbon disulfide (0.014 mg/kg) at 10.1 m (33 ft), which was the only contaminant above the method detection limit (MDL).

C-720 Building Area

The WAG 27 RI identified areas of TCE contamination at the C-720 Building Area. This FFS addresses two areas that were identified in the Resolution. One area was underneath the parking lot and equipment storage area at the northeast corner of the building. The second area was located underneath the parking lot adjacent to the loading docks at the southeast corner of the building.

C-720 Northeast Site (SWMU 211A). Contamination found to the northeast of the C-720 Building is believed to have been released during routine equipment cleaning and rinsing performed in the area. Solvents were used to clean parts, and the excess solvent may have been discharged on the ground. Spills and leaks from the cleaning process also may have contaminated surface soils in the area. Solvents may have migrated as dissolved contamination, leached by rainfall or facility water percolating through the soils and migrating to deeper soils and the shallow groundwater, or as DNAPL, migrating to adjacent and underlying soils. Soils and groundwater containing TCE will be considered a RCRA listed hazardous waste until the materials can be characterized. In the WAG 27 RI, the maximum TCE concentration detected (8.1 mg/kg) was in a sample located immediately north of the parking lot at 9.1 m (30 ft) bgs.

During the Southwest Plume SI, six borings were placed between the north edge of the parking lot and a storm sewer to which all surface runoff for the parking lot flows. Results indicated that soils containing very low levels of VOC contamination were detectable in the subsurface of the northeast corner of the C-720 Building Area. The highest level of TCE (0.98 mg/kg) was detected at 15.1 m (49.5 ft) bgs, with low-levels of *cis*-1,2 DCE (0.05 mg/kg) and 1,1-DCE (0.02 mg/kg) detected. Carbon disulfide (0.005 mg/kg) was detected at this location as well, but not detected at any other location during investigation of the northeast corner source area. The second highest sample identified a maximum TCE concentration of 0.63 mg/kg at 17.2 m (56.5 ft), with no degradation products detected above the MDLs. A third location had a similar maximum detected TCE level of 0.6 mg/kg at 14 m (46 ft) and included *cis*-1,2-DCE (0.019 mg/kg). The remaining three locations had low-levels of TCE (0.01 to 0.06 mg/kg) and degradation products and other VOCs including tetrachloroethene, 1,2-dichloroethane, 1,1-DCE, carbon tetrachloride, and chloroform detected. The results confirmed that dissolved contamination had migrated to the area's deeper soil.

Samples from a well cluster completed in the Upper Continental Recharge System (UCRS) and the RGA were the only groundwater samples collected during the investigation of this unit. The TCE levels declined from the UCRS to the RGA wells (280 to 99 μg/L).

C-720 Southeast Site (SWMU 211B). The source of VOC contamination found southeast of the C-720 Building is not certain. The VOCs found in this area may have originated from spills that occurred within the building, with subsequent discharge to storm drains leading to the southeast corner of the building or from spills or leaks on the loading dock or parking lot located to the southeast of the building. The area of concern discovered during the WAG 27 RI is near the outlet to one of the storm drains for the east end of the building. A storm sewer inlet for the southeast parking lot also is located in the vicinity. The north edge of the parking lot, where the contamination occurs, is the location of one of the loading docks for the C-720 Building, an area where chemicals, including solvents, may have been loaded or unloaded. In the WAG 27 RI, the maximum TCE concentration detected was 68 mg/kg at 6.4 m (21 ft) bgs.

During the Southwest Plume SI, two borings were placed through the parking lot adjacent to the C-720 Building loading dock. No groundwater samples were collected during investigation of this unit. Samples had low-levels of TCE [maximum 0.20 mg/kg at 8.84 m (29 ft) bgs] with no associated degradation products. The results indicated that the locations sampled were at the periphery of the source area defined in the WAG 27 RI.

Plant Storm Sewer (SWMU 102)

During the WAG 6 RI (DOE 1999b), VOC contamination of subsurface soils was identified near two of the lateral lines that feed into the main storm sewer that runs south of the C-400 Building to Outfall 008 on the west side of PGDP. At one time, the eastern lateral appears to have been connected to the TCE degreaser sump inside the C-400 Building. The TCE that leaked from the sump/storm sewer connection to the surrounding soils had been identified as a potential source of groundwater contamination. There was a possibility that TCE was transported down the lateral to the main storm sewer line running to Outfall 008, encountered an undetermined breach in the storm sewer, and leaked to the surrounding soils to become a source of TCE to the Southwest Plume.

Soil sample results from the Southwest Plume SI indicated that low-levels of VOCs were present in the backfill at the Storm Sewer (DOE 2007). No groundwater samples were taken during the investigation of this unit. A video survey that confirmed the integrity of the Storm Sewer, combined with the soil sampling results, demonstrated that the Storm Sewer was not a source of contamination to the Southwest Plume; therefore, the Storm Sewer was not carried forward in the FFS for alternative evaluation.

PREVIOUS BASELINE RISK ASSESSMENT

The Southwest Plume SI (DOE 2007) used historical information and newly collected data to develop a site model for each source area and presented a baseline human health risk assessment (BHHRA) and a screening ecological risk assessment (SERA). In the BHHRA, information collected during the Southwest Plume SI and results from previous risk assessments were used to characterize the baseline risks posed to human health and the environment resulting from contact with contaminants in groundwater drawn from the Southwest Plume in the RGA at the source areas. In addition, fate and transport modeling of selected VOCs (TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC) in subsurface soils to RGA groundwater was conducted. These results were used to estimate the future baseline risks that might be posed to human health and the environment through contact with groundwater impacted by contaminants migrating from the Oil Landfarm and C-720 Building Area to four points of exposure (POEs). The POEs assessed were at the source, the plant boundary, DOE property boundary, and near the Ohio River. The modeling was initiated after it was observed that cleanup levels determined to be protective of a rural resident using groundwater drawn from a well at a PGDP property boundary were similar to or less than the average concentrations of TCE in the Oil Landfarm and C-720 Building Area sources (DOE 2007). EPA disagreed with the use of multiple POEs (especially the Plant and Facility boundaries) for purposes of

determining unacceptable risk to hypothetical residential users due to contaminated groundwater and that widespread exceedances of maximum contaminant levels (MCLs) and/or risk-based concentrations in the groundwater warranted a response action for the Southwest Plume.

Inhalation of vapor released from the groundwater into home basements was modeled quantitatively for rural residents based on measured TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC concentration at the Oil Landfarm and the C-720 Building Area, as well as modeled TCE concentrations at the plant and property boundaries. The potential air concentrations also were used for estimating excess lifetime cancer risk (ELCR) and hazard for the hypothetical future on- and off-site rural resident.

Because data collected during the SI focused on the collection of subsurface soil and groundwater data to delimit the potential sources of contamination to the Southwest Plume, the new material developed in the BHHRA and SERA was limited to risks posed by contaminants migrating from potential source areas to RGA groundwater and with direct contact with contaminated groundwater in the source areas.

BASELINE RISK ASSESSMENT CONCLUSIONS

For both the Oil Landfarm and the C-720 Building Area, the cumulative human health ELCR and hazard index (HI) exceeded *de minimis* levels [i.e., a cumulative ELCR of 1×10^{-6} or a cumulative HI of 1] in the PGDP Risk Methods Document for one or more scenarios (DOE 2001a). Additionally, risks from household use of groundwater by a hypothetical on-site rural resident also exceeded those standards. The land uses and media assessed for ELCR and HI to human health for each potential source area were taken from earlier assessments with the exception of groundwater use and vapor intrusion by the hypothetical future on- and off-site rural resident. These were newly derived in the BHHRA from measured and modeled data collected during the Southwest Plume SI and previous investigations.

In the BHHRA, it was determined that the hypothetical rural residential use of groundwater scenario and vapor intrusion is of concern for both ELCR and HI at each source area, except the Storm Sewer, which is of concern for ELCR only. The exposure routes of ingestion of groundwater, inhalation of gases emitted while using groundwater in the home, and vapor intrusion from the groundwater into basements account for about 90% of the total ELCR and HI.

For groundwater use by the hypothetical adult resident at the Oil Landfarm, VOC COCs include TCE; *cis*-1,2-DCE; chloroform; and 1,1-DCE; all of which are "Priority COCs" (i.e., chemical-specific HI or ELCR greater than or equal to 1 or 1 × 10-4 respectively), except for 1,1-DCE. The VOCs make up 78% of a cumulative ELCR of 6.8 × 10-4 and 76% of a cumulative HI of 26. For groundwater use by the hypothetical child resident, VOC COCs include TCE; *cis*-1,2-DCE, and chloroform, all of which are "Priority COCs." These VOCs make up 85% of a cumulative HI of 99.

At the C-720 Building Area, the VOC COCs for groundwater use by the hypothetical adult resident include TCE; *cis*-1,2-DCE; VC; and 1,1-DCE, with all except VC being "Priority COCs." The VOCs make up 93% of a cumulative ELCR of 1.8 × 10-3 and 57% of the cumulative HI of 23. For groundwater use by the hypothetical child resident, VOC COCs include TCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and 1,1-DCE, all of which are "Priority COCs," except for *trans*-1,2-DCE. The VOCs make up 76% of a cumulative HI of 102.

At the Storm Sewer, the adult residential COCs include TCE and 1,1-DCE, neither of which is a "Priority COC." The VOCs make up 100% of a cumulative ELCR of 7.9 × 10-6. The HI for the storm sewer was less than 1 and, therefore, not of concern. For groundwater use by the hypothetical child resident at the

Storm Sewer, COCs include TCE and 1,1-DCE, neither of which is a "Priority COC." The VOCs make up 100% of a cumulative HI of 0.6 for the child resident.

At the property boundary for the hypothetical adult resident, the migrating COCs from the Oil Landfarm are TCE and VC with no "Priority COCs." The VOCs make up 100% of the total ELCR of 1.4×10^{-6} and the HI is less than 0.1. For the hypothetical child resident at the property boundary the COCs are TCE and *cis*-1,2-DCE with no "Priority COCs." The VOCs make up 85% of a cumulative HI of 0.4 for the child resident.

The COC migrating from the C-720 Building Area to the hypothetical adult resident at the property boundary is VC, which is not a "Priority COC." The VC makes up greater than 95% of the total ELCR of 1.1×10^{-6} and the HI is less than 0.1. For the hypothetical child resident at the property boundary, the HI is less than 1. Based on results of previous and current modeling reported in the SI BHHRA, neither metals nor radionuclides are COCs for contaminant migration from the Oil Landfarm or C-720 Building Area.

The SERA, which used results taken from the Baseline Ecological Risk Assessment completed as part of the WAG 27 RI, concluded that a lack of suitable habitat in the industrial setting at the Oil Landfarm and the C-720 Building Area precluded exposures of ecological receptors under current conditions; therefore, it was determined during problem formulation that an assessment of potential risks under current conditions was unnecessary.

REMEDIAL ACTION OBJECTIVES

The Resolution (EPA 2008) required that the FFS include an RAO for addressing source areas, including treatment and/or removal of PTW consistent with CERCLA, the NCP (including the preamble), and pertinent EPA guidance. RAOs were developed collaboratively with the EPA and Kentucky and are focused on VOCs in soils. The resulting RAOs were used in screening technologies and developing and evaluating alternatives for the Oil Landfarm and C-720 Northeast and Southeast Sites:

- Treat and/or remove PTW consistent with the NCP.

- Prevent exposure to VOC contamination in the source areas that will cause an unacceptable risk to excavation workers (<10 ft).

- Prevent exposure to non-VOC contamination through interim land use controls within the Southwest Plume source areas (i.e., SWMU 1, SWMU 211-A and SWMU 211-B), pending remedy selection as part of the Soils OU.

- Reduce VOC migration from contaminated subsurface soils in the source areas to the RGA groundwater to the extent they do not contribute contamination exceeding MCLs in the area of attainment at the Oil Landfarm and C-720 Northeast and Southeast Sites.

Two types of RGs were developed to support the RAOs. Worker protection remediation goals (RGs) are VOC concentrations in soils present at depths of 0-10 ft that would meet RAO #2a with no other controls necessary. Groundwater protection RGs are VOC concentrations in subsurface soils that would meet RAO #3 with no other controls necessary.

For purposes of the FFS, the area of attainment encompasses the RGA directly below and within the boundaries of the Oil Landfarm and C-720 Northeast and Southeast Sites. Groundwater protection RGs

were based on subsurface soil concentrations above the area of attainment that would not result in exceedance of the MCL in the area of attainment (RGA).

Alternatives were evaluated with respect to their effectiveness at attaining RGs and meeting the RAOs based on previous source removal demonstrations at PGDP; literature reports of previous actions at other sites; modeling of VOCs to determine exceedances of MCLs; and engineering judgment. After final remedy selection, further definition for completion criteria will be stated in the ROD and quantified as appropriate in the Remedial Action Work Plan.

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

CERCLA Section 121(d) and the NCP require compliance with ARARs as one of the threshold criteria. Also, per the NCP at 40 *CFR* § 300.430(e)(9)(iii)(B), remedial alternatives shall be assessed to determine whether they attain ARARs under federal environmental laws and state environmental or facility siting laws or provide grounds for invoking a CERCLA waiver. ARARs do not include occupational safety or worker protection requirements. Additionally, per 40 *CFR* § 300.405(g)(3), other advisories, criteria, or guidance may be considered in determining remedies [to be considered (TBC) category]. The CERCLA 121(d)(4) provides several ARAR waiver options that may be invoked, provided that human health and the environment are protected.

ARARs typically are divided into three categories: (1) chemical-specific, (2) location-specific, and (3) action-specific. Chemical-specific ARARs provide health- or risk-based concentration limits or discharge limitations in various environmental media (i.e., surface water, groundwater, soil, or air) for specific hazardous substances, pollutants, or contaminants. Location-specific ARARs establish restrictions on permissible concentrations of hazardous substances or establish requirements for how activities will be conducted because they are in special locations (e.g., floodplains or historic districts). Action-specific ARARs include operation, performance, and design of the preferred alternative based on waste types and/or media to be addressed and removal/remedial activities to be implemented.

There are no chemical-specific ARARs for remediation of the contaminated subsurface soils at the source areas; however, Kentucky drinking water standard MCLs at 401 *KAR* 8:420 for VOCs were used for calculation of soil RGs. Location- and action-specific ARARs have been identified and evaluated for each alternative in Section 4.

ALTERNATIVES

A primary objective of the FFS is to identify remedial technologies and process options that potentially meet the RAOs and then combine them into a range of remedial alternatives. CERCLA requires development and evaluation of a range of responses, including a No Action Alternative, to ensure that an appropriate remedy is selected. The selected final remedy must comply with ARARs and must protect human health and the environment. The technology screening process consists of a series of steps that include the following:

- Identifying general response actions (GRAs) that may meet RAOs, either individually or in combination with other GRAs;
- Identifying, screening, and evaluating remedial technology types for each GRA; and
- Selecting one or more representative process options (RPOs) for each technology type.

GRAs potentially applicable to the Southwest Plume source areas were identified. These GRAs include land use controls, monitoring, monitored natural attenuation, containment, removal, treatment, and disposal. Technology types and process options representative of the GRAs then were identified, screened, and evaluated. The criteria for identifying, screening, and evaluating technologies are provided in EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988) and the NCP. The initial technology screening eliminated some technologies on the basis of technical impracticability.

Following the technology screening, RPOs were identified for each technology type. RPOs were selected on the basis of effectiveness, technical and administrative implementability, and cost, relative to other technologies in the same technology type. Alternatives then were developed by combining RPOs into a range of comprehensive strategies to meet the RAOs.

The following alternatives were developed:

Alternative 1: No Action
Alternative 2: *In Situ* Bioremediation and Land Use Controls
Alternative 3: Source Removal and *Ex Situ* Thermal Treatment
Alternative 4: Soil Vapor Extraction Source Treatment, Containment and Land Use Controls
Alternative 5: *In Situ* Thermal Treatment and Land Use Controls

Alternatives 2 and 3 were screened out on the basis of uncertain effectiveness and low technical implementability, respectively, in comparison to other alternatives. Alternatives 1, 4, and 5 were advanced to detailed analysis. Alternatives are discussed, with the assumption that each would be applied to the Oil Landfarm and the C-720 Northeast and Southeast Sites. Decision makers could apply different alternatives to individual sites, depending on regulator preferences or public response to the Proposed Plan. Sufficient information is provided to allow for this type of alternative selection in the Proposed Plan and ROD.

Alternatives are analyzed in detail and compared based on the CERCLA evaluation criteria. Overall protection of human health and the environment and compliance with ARARs are categorized as threshold criteria that any viable alternative must meet. Long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost are considered balancing criteria upon which the detailed analysis is primarily based. State and community acceptance are evaluated following comment on the RI/Feasibility Study report and the Proposed Plan and are addressed as a final decision is made and the ROD is prepared.

The comparative analysis identifies the relative advantages and disadvantages of each alternative, so that the key tradeoffs that risk managers must balance can be identified. Alternatives are ranked with respect to the evaluation criteria, and the overall detailed and comparative evaluations are summarized. Results of the detailed and comparative analysis form the basis for preparing the Proposed Plan. Table ES.3 summarizes the results of the comparative analysis where a ranking of 1 least meets the criteria, and 3 best meets the criteria.

Table ES.3. Summary of the Comparative Analysis of Alternatives

Evaluation Criteria	Alternative 1: No Action	Alternative 4: SVE Source Treatment, Containment and Land Use Controls	Alternative 5: *In Situ* Thermal Treatment and Land Use Controls
Overall Protection of Human Health and the Environment	Does not meet the threshold criterion	Meets the threshold criterion	Meets the threshold criterion
Compliance with ARARs	Does not meet the threshold criterion	Meets the threshold criterion	Meets the threshold criterion
Long-Term Effectiveness and Permanence	1	2	3
Reduction of Toxicity, Mobility, or Volume through Treatment	1	2	3
Short-Term Effectiveness	1	2	3
Implementability	3	1	2
Total Project Cost (Escalated)	0	$24.5M	$21.5M
Total Project Cost (Unescalated)	0	$19.2M	$17.6M
Total Project Cost (Present Worth)	0	$17.6M	$16.8M

ARAR = applicable or relevant and appropriate regulation
FY = fiscal year
SVE = soil vapor extraction

1. INTRODUCTION

This section provides a brief introduction to the Paducah Gaseous Diffusion Plant (PGDP) and an explanation of the purpose and organization of the report. Background information, including the site background and regulatory setting, is summarized. Site and area-specific descriptions including land use, demographics, climate, air quality, noise, ecological resources, and cultural resources are summarized. An overview is provided of the topography, surface water hydrology, geology, and hydrogeology of the region and the study area. A conceptual site model summarizing the nature and extent of contamination and fate and transport modeling of volatile organic compound (VOC) contaminants of concern (COCs) are discussed.

1.1 PURPOSE AND ORGANIZATION

This *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0186&D2, was prepared to evaluate remedial alternatives for potential application at the U.S. Department of Energy's (DOE's) PGDP. This work was prepared in accordance with the requirements of the *Federal Facility Agreement for the Paducah Gaseous Diffusion Plant* (FFA) (EPA 1998a) and the "Resolution of the Environmental Protection Agency Letter of Non-Concurrence for the Site Investigation Report for the Southwest Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky (DOE/OR/07-2180&D2/R1) and Notice of Informal Dispute Dated November 30, 2007, McCracken County, Kentucky, KY 8-890-008-982*"* (referred to as the Resolution) (EPA 2008). In accordance with Section IV of the FFA, this integrated technical document was developed to satisfy applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 *USC* 9601 *et seq.* 1980) and the Resource Conservation and Recovery Act (RCRA) (42 *USC* 6901 *et seq.* 1976). In addition to the U.S. Environmental Protection Agency (EPA) requirements, National Environmental Policy Act of 1969 (NEPA) values, consistent with the DOE's Secretarial Policy Statement on NEPA in June 1994 (DOE 1994), are evaluated and documented in this focused feasibility study (FFS).

This FFS also has been prepared in accordance with the Integrated Feasibility Study (FS)/Corrective Measures Study Report outline prescribed in Appendix D of the FFA for PGDP. As such, this FFS is considered a primary document. All subsections contained in the referenced outline have been included for completeness. Additional subsections have been added to the outline, as appropriate, and have been included to provide clarity and enhance the organization of the document.

1.2 BACKGROUND INFORMATION

The following section presents information concerning the site background and regulatory setting at the PGDP. It also provides a site description of the PGDP region and source areas, as well as a summary of the process history, nature and extent of contamination, contaminant fate and transport, and the risks associated with the source areas.

1.2.1 Site Description

PGDP is located approximately 10 miles west of Paducah, Kentucky, (population approximately 26,000), and 3.5 miles south of the Ohio River in the western part of McCracken County (Figure 1.1). The plant is located on a DOE-owned site, approximately 650 acres of which are within a fenced security area, approximately 800 acres are located outside the security fence, and the remaining 1,986 acres are licensed to Kentucky as part of the West Kentucky Wildlife Management Area (WKWMA). Bordering the PGDP Reservation to the northeast, between the plant and the Ohio River, is a Tennessee Valley Authority (TVA) reservation on which the Shawnee Steam Plant is located (Figure 1.2). All plant and process water at PGDP is drawn from the Ohio River.

Before the PGDP was built, a munitions-production facility, the Kentucky Ordnance Works (KOW), was operated at the current PGDP location and at an adjoining area southwest of the site. Munitions, including trinitrotoluene, were manufactured and stored at the KOW between 1942 and 1945. The KOW was shut down immediately after World War II. Construction of PGDP was initiated in 1951 and the plant began operations in 1952. Construction was completed in 1955 and PGDP became fully operational in 1955, supplying enriched uranium for commercial reactors and military defense reactors.

PGDP was operated by Union Carbide Corporation until 1984, when Martin Marietta Energy Systems, Inc. (which later became Lockheed Martin Energy Systems, Inc.), was contracted to operate the plant for DOE. On July 1, 1993, DOE leased the plant production/operations facilities to the United States Enrichment Corporation; however, DOE maintains ownership of the plant and is responsible for environmental restoration and waste management activities. On April 1, 1998, Bechtel Jacobs Company LLC, replaced Lockheed Martin Energy Systems, Inc., in implementing the Environmental Management Program at PGDP. On April 23, 2006, Paducah Remediation Services, LLC, replaced Bechtel Jacobs Company LLC, in implementing the Environmental Management Program at PGDP.

Trichloroethene (TCE), a chlorinated solvent that is a VOC, is the most widespread groundwater contaminant associated with PGDP. The TCE degradation products *cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-dichloroethene (*trans*-1,2-DCE), and vinyl chloride (VC) also are present in some areas. These contaminants have resulted in three dissolved-phase plumes that are migrating from PGDP toward the Ohio River. These groundwater plumes are the Northwest Groundwater Plume [Solid Waste Management Unit (SWMU) 201], the Northeast Groundwater Plume (SWMU 202), and the Southwest Groundwater Plume (SWMU 210) (Figure 1.3).

1.2.1.1 Source area description

The Southwest Groundwater Plume refers to an area of groundwater contamination at PGDP in the Regional Gravel Aquifer (RGA), which is south of the Northwest Groundwater Plume and west of the C-400 Building. The plume was identified during the Waste Area Grouping (WAG) 27 Remedial Investigation (RI) in 1998. Additional work to characterize the plume (SWMU 210) was performed as part of the WAG 3 RI and Data Gaps Investigations, both in 1999. As discussed in those reports, the primary groundwater COC for the Southwest Groundwater Plume (hereinafter referred to as the Southwest Plume) is TCE. Appendix D contains a discussion of COCs and other contaminants found in the plume including additional VOCs, metals, and the radionuclide, technetium-99 (^{99}Tc).

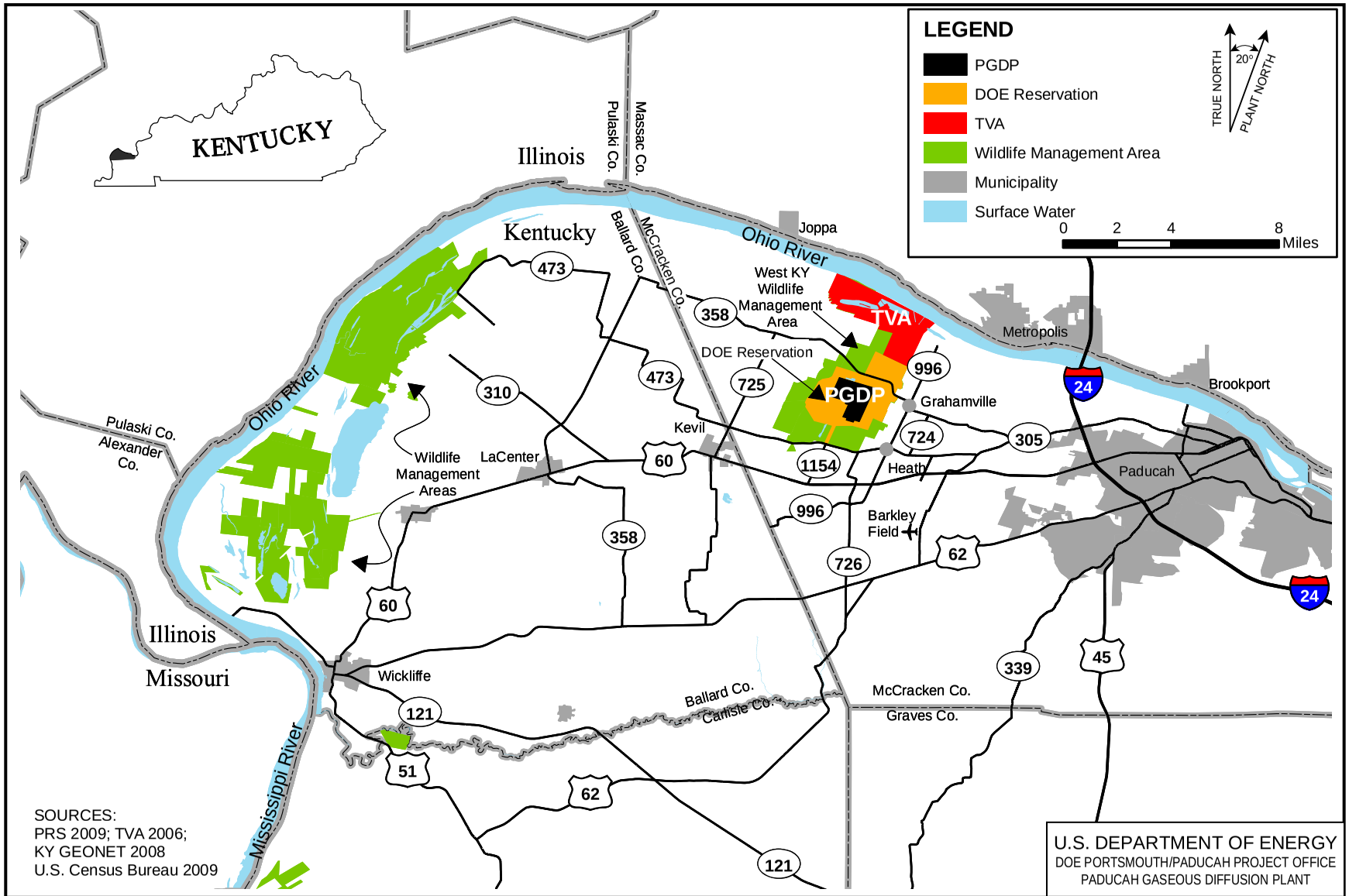

Figure 1.1 PGDP Site Location

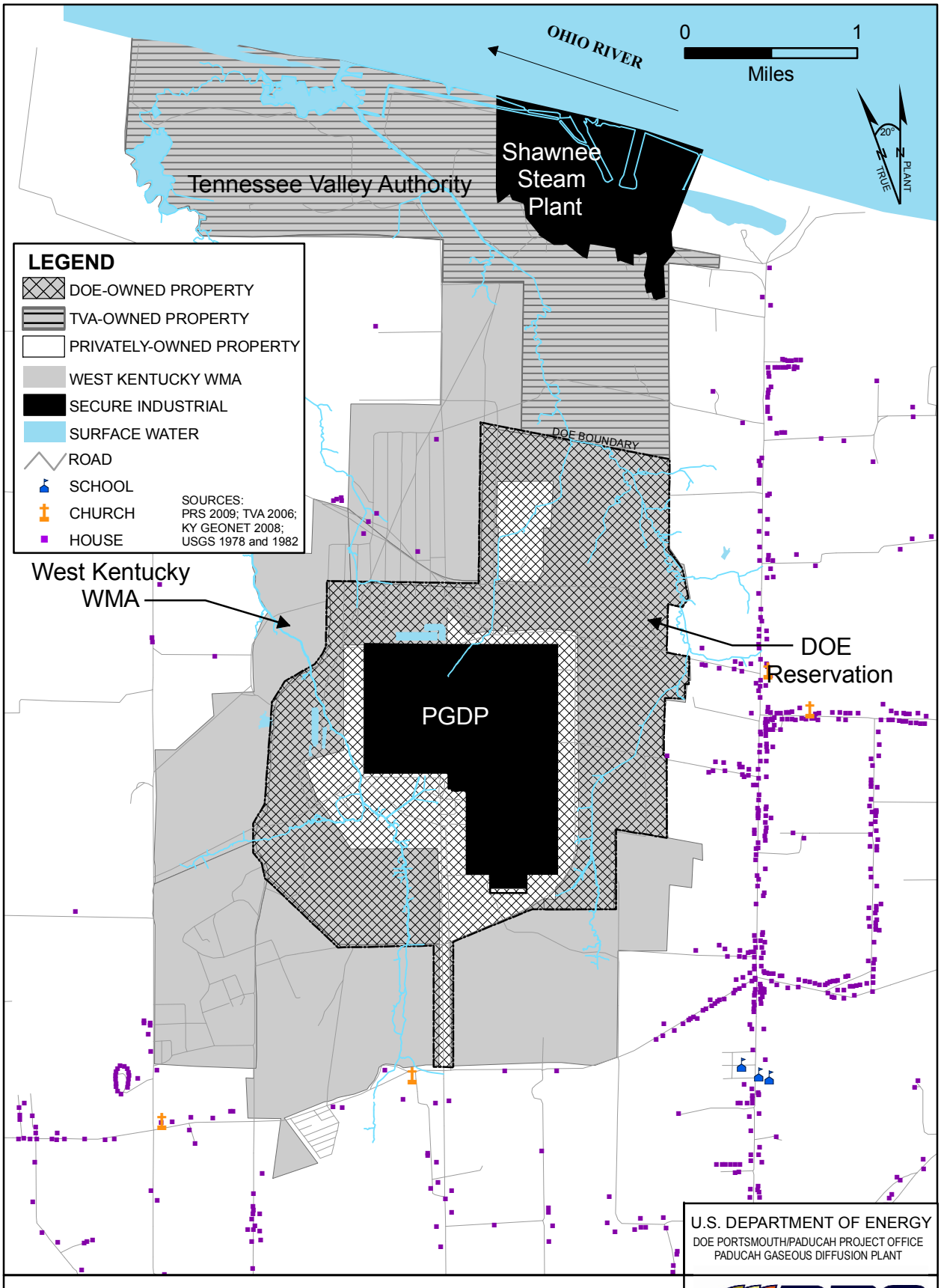

Figure 1.2. PGDP Land Ownership

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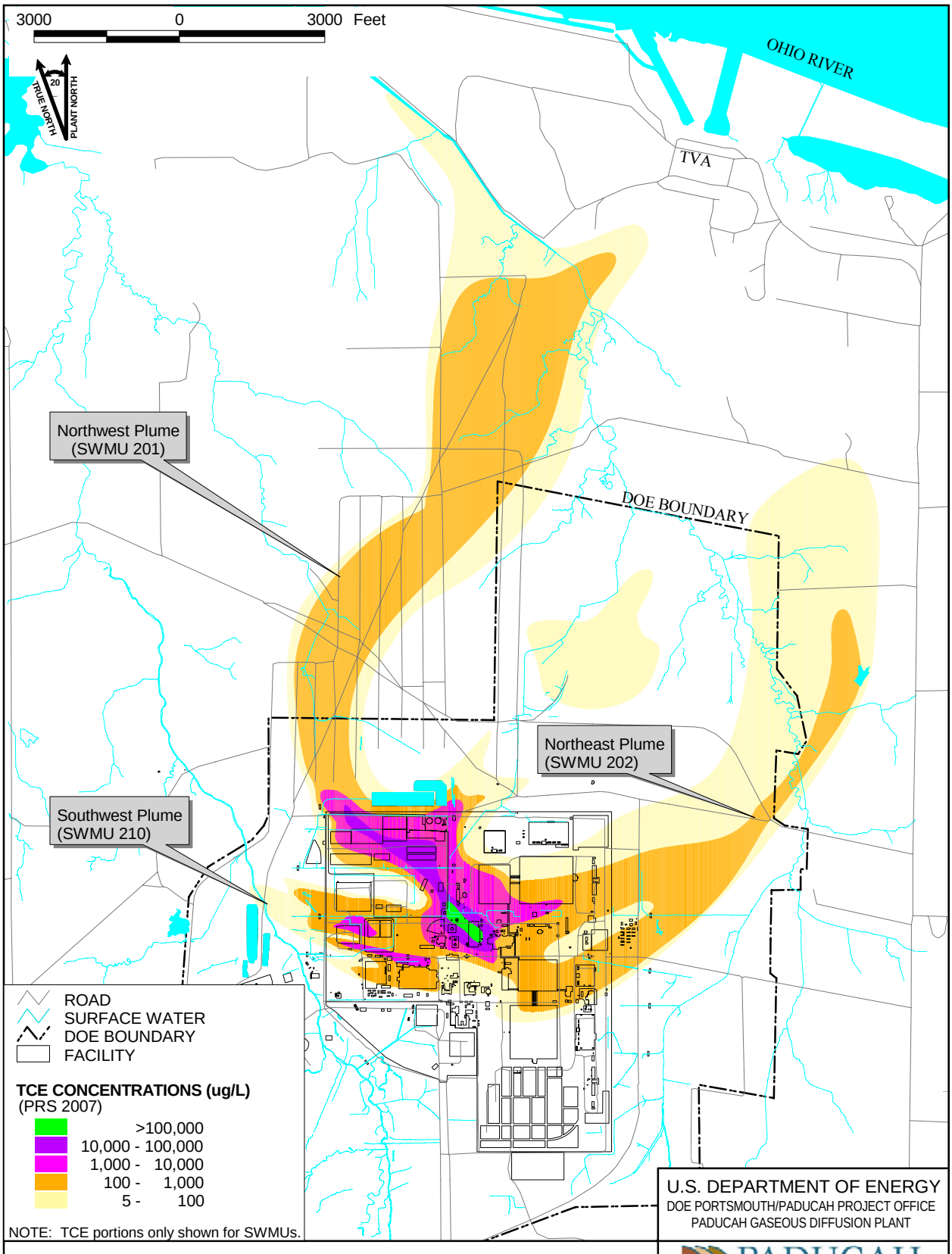

Figure 1.3. Trichloroethene Plume Locations

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DOE conducted a Site Investigation (SI) in 2004 to address the uncertainties with potential source areas to the Southwest Plume that remained after previous investigations. The SI evaluated potential source areas of contamination to the Southwest Plume and profiled the current level and distribution of VOCs in the dissolved-phase plume along the west plant boundary. Results of the SI were reported in the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1 (DOE 2007). The FFS is based on the SI as well as previous investigations discussed below.

The potential source areas investigated in the SI included part of the C-747-C Oil Landfarm (Oil Landfarm); C-720 Building areas near the northeast and southeast corners of the building (C-720 Northeast Site and C-720 Southeast Site); and the storm sewer system between the south side of the C-400 Building; Outfall 008 (Storm Sewer). As a result of the Southwest Plume SI, the storm sewer subsequently was excluded as a potential VOC source to the Southwest Plume. SWMU 4 is a major source to the Southwest Plume that was not investigated in the SI, but will be addressed as part of the Burial Ground Operable Unit (OU).

Respective SWMU numbers for each potential source area investigated in the SI are provided in Table 1.1. The potential source areas investigated in the Southwest Plume SI are identified in Figure 1.4.

Table 1.1. Summary of Potential Source Areas and SWMU Numbers

Description	SWMU No.
C-747-C Oil Landfarm	1
Plant Storm Sewer	Part of 102
C-720 TCE Spill Sites Northeast and Southeast	211 A&B
C-747 Contaminated Burial Yard	4

1.2.1.2 Regulatory setting

This section summarizes the framework for environmental restoration at PGDP, including the major acts and accompanying regulations driving response actions, such as the CERCLA, RCRA, and NEPA. It also describes environmental programs and the documents controlling response actions, such as the FFA, the Site Management Plan (SMP) (DOE 2009a), and the Resolution (EPA 2008). The scope of this action within the overall response strategy for PGDP is described.

Major Laws, Regulations, and Controlling Documents. Section 105(a)(8)(B) of CERCLA, as amended by the Superfund Amendments and Reauthorization Act, requires EPA to promulgate a list of national priorities among the known or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States. On June 30, 1994, EPA placed PGDP on the National Priorities List (NPL) [59 *Federal Register* (*FR*) 27989 (May 31, 1994)]. The NPL lists sites across the country that are designated by EPA as high priority sites for remediation under CERCLA. As the lead agency under CERCLA, DOE is responsible for conducting cleanup activities at PGDP in compliance with CERCLA, the FFA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), and relevant DOE and EPA guidance. The CERCLA is not the only driver for cleanup at PGDP. RCRA requires corrective action for releases of hazardous constituents from SWMUs.

Section 120 of CERCLA requires federal facilities listed on the NPL to enter into an FFA. The purpose of an FFA is to coordinate the CERCLA response action and RCRA corrective action process into a set of comprehensive requirements for site remediation. The FFA requires that DOE develop and submit an annual SMP to EPA and Kentucky Department for Environmental Protection (KDEP). The SMP is intended to provide details necessary or useful in implementing the FFA.

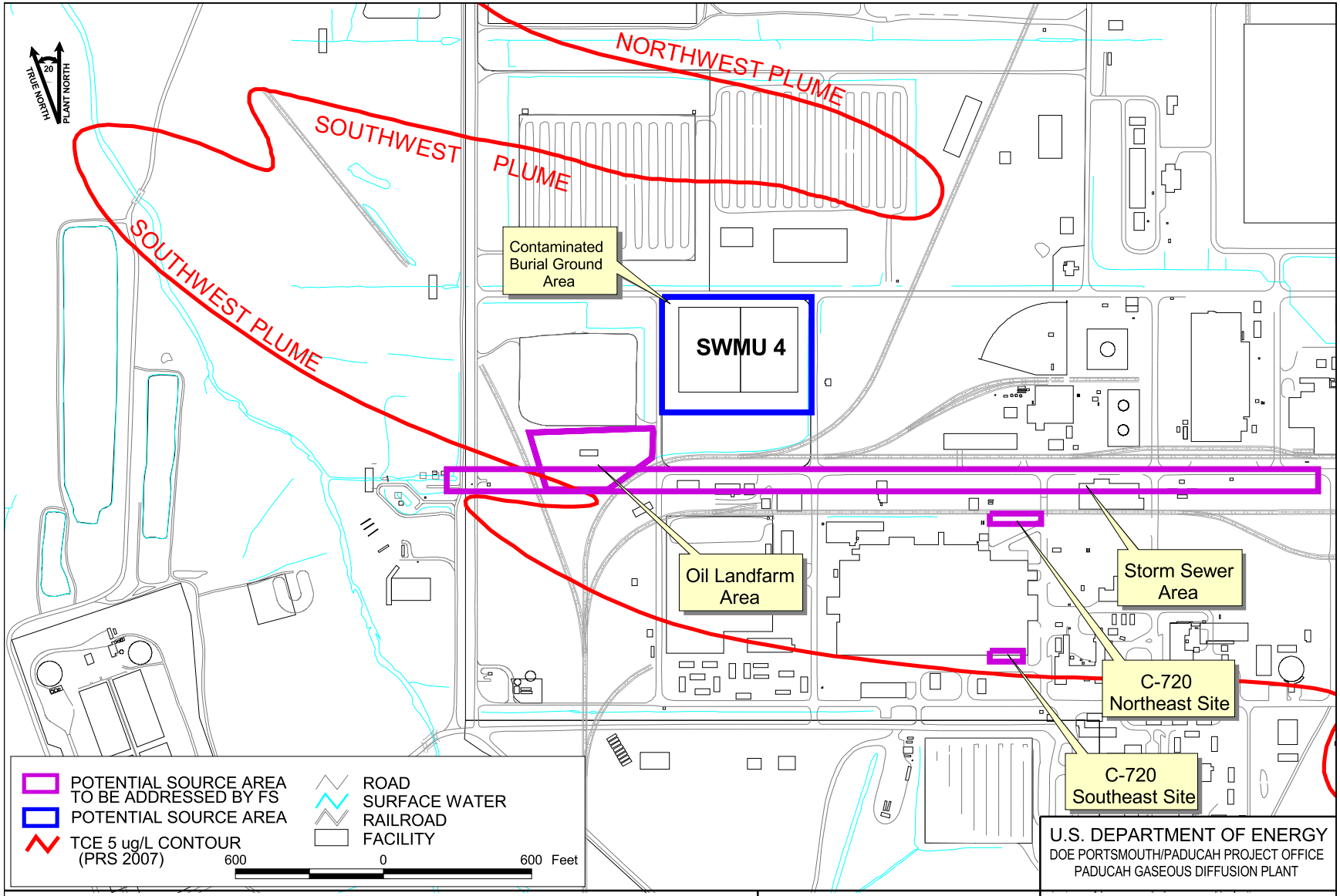

Figure 1.4. Southwest Plume Potential Source Areas

Environmental Programs. Environmental sampling at PGDP is a multimedia (air, water, soil, sediment, direct radiation, and biota) program of chemical, radiological, and ecological monitoring. Environmental monitoring consists of two activities: effluent monitoring and environmental surveillance. As part of the ongoing environmental restoration activities, SWMUs and areas of concern have been identified. Characterization and/or remediation of these sites will continue pursuant to the CERCLA and Hazardous and Solid Waste Amendments corrective action conditions of the RCRA Permit.

National Environmental Policy Act. The intent of the NEPA is to promote a decision making process that results in minimization of adverse impacts to human health and the environment. On June 13, 1994, the Secretary of Energy issued a Secretarial Policy (Policy) on NEPA that addresses NEPA requirements for actions taken under CERCLA. Section II.E of the Policy indicates that DOE CERCLA documents will incorporate NEPA values, to the extent practicable, such as analysis of cumulative, off-site, ecological, cultural, and socioeconomic impacts.

Resolution on the Southwest Plume Site Investigation Informal Dispute. In November 2007, EPA invoked an informal dispute on the Southwest Plume SI. In March 2008, DOE signed the Resolution, which required, among other things, that DOE conduct an FFS for addressing source areas to the Southwest Plume in view of developing remedial alternatives and undertaking a CERCLA remedial action and Record of Decision (ROD) (42 *USC* 9601 *et seq.* 1980). The source areas subject to the FFS included the Oil Landfarm, C-720 Northeast and Southeast Sites, and Storm Sewer. The FFS was to address contamination in the shallow groundwater and could be based upon the Southwest Plume SI data, previous documents, and additional information, as necessary. The FFS was required to contain, among other information, a remedial action objective (RAO) for addressing source areas, including treatment and/or removal of principal threat waste (PTW) consistent with CERCLA, the NCP (including the preamble), and pertinent EPA guidance. The Southwest dissolved-phase plume in the Groundwater OU Dissolved-Phase Plumes would include the RAO of returning contaminated groundwaters to beneficial use(s) and attaining chemical-specific applicable or relevant and appropriate requirements (ARARs) [e.g., maximum contaminant levels (MCLs) established under the Safe Drinking Water Act] and/or risk-based concentrations for all identified COCs throughout the plume (or at the edge of the waste management area, depending on whether the waste source is removed, consistent with the NCP (including the preamble) and pertinent EPA guidance.

EPA typically describes sources as material that includes hazardous substances, pollutants, or contaminants that act as a reservoir for the groundwater, surface water, or air or act as a source of direct exposure. EPA considers sources or source materials to be principal threats when they are highly toxic or highly mobile and generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (EPA 2004a). Previous investigations of FFS source areas to 55 ft below ground surface (bgs) identified the potential presence of TCE dense nonaqueous-phase liquid (DNAPL), which would constitute PTW.

Scope of the Southwest Plume FFS within the Sitewide Groundwater OU. This FFS will support a final action to mitigate the migration of VOCs at the Oil Landfarm and the C-720 Building Area to the Southwest Plume and to treat or remove PTW. Based on results from the SI further discussed below, the Storm Sewer no longer is considered a source of VOC contamination to the Southwest Plume. Risks posed by direct contact with contaminated surface soil or sediment at the Oil Landfarm and C-720 Building Area or remaining risks from potential use of contaminated groundwater will be addressed later as part of the decisions for the Surface Water, Soils, or Groundwater OUs.

These VOC source areas are assigned to the Groundwater OU at PGDP, which is one of five media-specific sitewide OUs being used to evaluate and implement remedial actions. Consistent with EPA guidance (EPA 2004a), the Groundwater OU is being implemented in a phased approach consisting of sequenced remedial and removal actions designed to accomplish the following goals:

(1) Prevent human exposure to contaminated groundwater;
(2) Prevent or minimize further migration of contaminant plumes;
(3) Prevent, reduce, or control contaminant sources contributing to groundwater contamination; and
(4) Restore the groundwater to its beneficial uses, wherever practicable.

This FFS and ensuing final VOC remedial action will support the phased groundwater goals represented in goals 3 and 4 above by controlling VOC migration (including DNAPL) that contribute to groundwater contamination, thereby promoting the restoration of groundwater to beneficial use, as practicable. The remedial action also is anticipated to substantially reduce the risk and hazard from hypothetical groundwater use associated with releases from these source areas. Non-VOC soil contamination at the source areas will be addressed by the Soils Operable Unit, as described in the 2009 SMP. Groundwater contamination will be addressed through the Dissolved-Phase Plumes Remedial Action.

The remedial action alternatives presented were developed based on the information contained in the SI. Uncertainties associated with the extent of VOC contamination that would be subject to remedial action are intended to be addressed during post-ROD/remedial design site investigation (RDSI). The results of the RDSI will provide the detailed basis for remedial action design.

1.2.1.3 Land use, demographics, surface features, and environment

Land Use. The PGDP is heavily industrialized; however, the area surrounding the plant is mostly agricultural and open land, with some forested areas. TVA's Shawnee Steam Plant, adjacent to the northeast border of the DOE Reservation, is the only other major industrial facility in the immediate area. The PGDP is posted government property and trespassing is prohibited. Access to the PGDP site is controlled by guarded checkpoints, a perimeter fence, and vehicle barriers and is subject to routine patrol and visual inspection by plant protective forces. The PGDP site includes 1,986 acres licensed to the Commonwealth of Kentucky Department of Fish and Wildlife Resources. This area is part of the WKWMA and borders PGDP to the north, west, and south. The WKWMA is an important recreational resource for western Kentucky and is used by more than 10,000 people each year. Major recreational activities include hunting, field trials for dogs and horses, trail riding, fishing, and skeet shooting.

Demographics. Total population within an 50-mile radius of PGDP is approximately 500,000. Approximately 50,000 people live within 10 miles of PGDP, and homes are scattered along rural roads around the plant. The population of Paducah, based on the 2000 U.S. Census, is 26,307; the total population of McCracken County (251 square miles) is approximately 65,000. The closest communities to PGDP are the unincorporated towns of Grahamville 1 mile to the east and Heath 1 mile southeast. Current and anticipated future land use for PGDP and surrounding areas is depicted in Figure 1.5, taken from the PGDP SMP (DOE 2009a).

Surface Features and Topography. PGDP lies in the Jackson Purchase Region of western Kentucky between the Tennessee and Mississippi Rivers, bounded on the north by the Ohio River. The confluence of the Ohio and Mississippi Rivers is approximately 35 miles downstream (southwest) from the site. The confluence of the Ohio and Tennessee Rivers is approximately 15 miles upstream (east) from the site.

Local elevations range from 88.41 m (290 ft) above mean sea level (amsl) along the Ohio River to 137.2 m (450 ft) amsl in the southwestern portion of PGDP near Bethel Church Road. Generally, the topography in the PGDP area slopes toward the Ohio River at an approximate 5.11 m per kilometer (m/km) [27 ft per mile (ft/mile)] gradient (CH2M HILL 1992). Within the plant boundaries, ground surface elevations vary from 109.75 m (360 ft) to 118.9 m (390 ft) amsl. The terrain in the vicinity of the plant is slightly modified by the dendritic drainage systems associated with the two principal streams in the area, Bayou Creek and Little Bayou Creek. These streams have eroded small valleys, which are about 6.09 m (20 ft) below the adjacent plain.

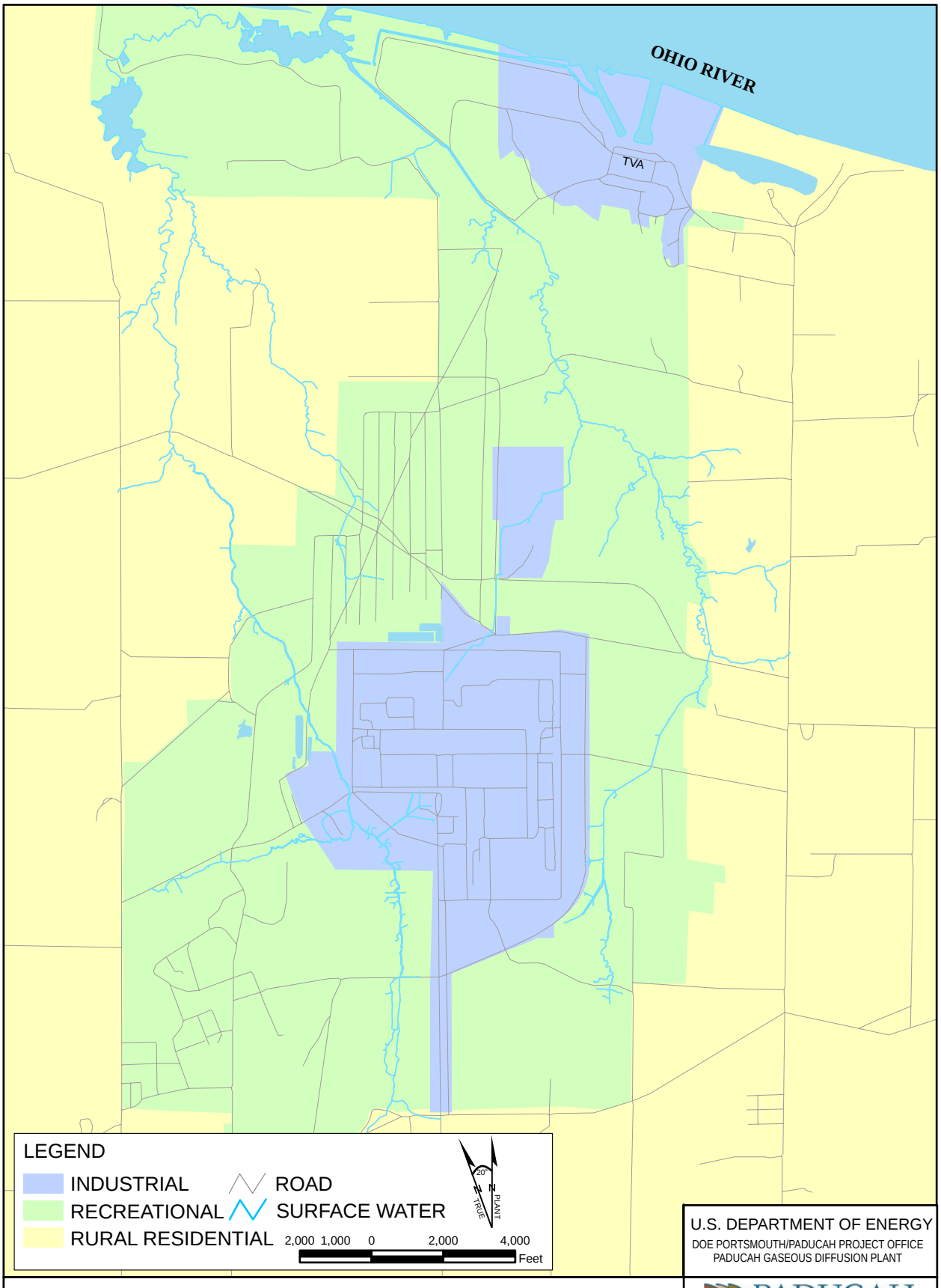

Figure 1.5. Anticipated Future Land Use

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The average pool elevation of the Ohio River is 88.41 m (290 ft) amsl, and the high water elevation is 104.26 m (342 ft) amsl (TCT-St. Louis 1991). Approximately 100 small lakes and ponds exist on DOE property (TCT-St. Louis 1991). A marsh covering 165 acres exists off-site of DOE property, immediately south of the confluence of Bayou Creek and Little Bayou Creek (TCT-St. Louis 1991).

Climate. The climate of the region may be broadly classified as humid-continental. The term "humid" refers to the surplus of precipitation versus evapotranspiration that normally is experienced throughout the year. The 22-year average monthly precipitation is 4.00 inches, varying from an average of 2.73 inches in August (the monthly average low) to an average of 4.58 inches in April (the monthly average high). The total precipitation for 2007 was 43.33 inches, compared to the average of 49.24 inches.

The "continental" nature of the local climate refers to the dominating influence of the North American landmass. Continental climates typically experience large temperature changes between seasons. The mean annual temperature for the Paducah area for 2007 was 57.1 °F. The 22-year average monthly temperature is 58.0°F, with the coldest month being January with an average temperature of 35.1°F and the warmest month being July with an average temperature of 79.2 °F.

The average mean prevailing wind speed is 10 miles per hour. Historically, stronger winds are recorded when the winds are from the southwest.

Air Quality. PGDP is located in the Paducah-Cairo Interstate Air Quality Control Region of Kentucky, which includes McCracken County and 16 other counties in western Kentucky. Data from the state's air monitors are used to assess the region's ambient air quality for the criteria pollutants (ozone, nitrogen oxides, carbon monoxide, particulates, lead, and sulfur dioxide) and to designate nonattainment areas (i.e., those areas for which one or more of the National Ambient Air Quality Standards are not met). McCracken County is classified as an attainment area for all six criteria pollutants [*Fiscal Year 2008 Annual Report* (KDAQ 2008)]. In addition, the United States Enrichment Corporation, which operates PGDP, operates an ambient air monitoring system to assess the impact of various air contaminants emitted by PGDP on the surrounding environment. Ambient air monitoring of radioactive particulates (gross alpha and gross beta) is accomplished by six continuous samplers. Ten additional ambient air sampling stations are operated by the Kentucky Radiation Health Branch to monitor airborne radionuclides from PGDP.

Noise. Noises associated with plant activities generally are restricted to areas inside buildings located on-site. Currently, noise levels beyond the security fence are limited to wildlife, hunting, traffic moving through the area, and operation and maintenance activities associated with outside waste storage areas located close to the security fence.

1.2.1.4 Ecological, cultural, archeological, and historical resources

The following sections give a brief overview of the soils, terrestrial and aquatic systems, wetlands, and cultural resources at PGDP. A more detailed description, including an identification and discussion of sensitive habitats and threatened and endangered (T&E) species, is contained in the *Investigation of Sensitive Ecological Resources Inside the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (CDM 1994) and the *Environmental Investigations at the Paducah Gaseous Diffusion Plant and Surrounding Area, McCracken County, Kentucky* (COE 1994).

Soils and Prime Farmland. Six soil types are associated with PGDP as mapped by the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (USDA 1976). These are Calloway silt loam, Grenada silt loam, Loring silt loam, Falaya-Collins silt loam, Vicksburg silt loam, and Henry silt loam.

The dominant soil types, the Calloway and Henry silt loams, consist of nearly level, somewhat poorly drained to poorly drained soils that formed in deposits of loess and alluvium. These soils tend to have low organic content, low buffering capacity, and acidic hydrogen-ion concentration (pH) ranging from 4.5 to 5.5. The Henry and Calloway series have a fragipan horizon, a compact and brittle silty clay loam layer that extends from 66 centimeters (26 inches) below ground surface (bgs) to a depth of 127 centimeters (50 inches) or more. The fragipan reduces the vertical movement of water and causes a seasonally perched water table in some areas at PGDP. In areas within the PGDP where past construction activities have disturbed the fragipan layer, the soils are best classified as "urban."

Prime farmland, as defined by the NRCS, is land that is best suited for food, feed, forage, fiber, and oilseed productions, excluding "urban built-up land or water" [7 *CFR* §§ 657 and 658]. The NRCS determines prime farmland based on soil types found to exhibit soil properties best suited for growing crops. These characteristics include suitable moisture and temperature regimes, pH, drainage class, permeability, erodibility factor, and other properties needed to produce sustained high yields of crops in an economical manner. Prime farmland is located north of the PGDP plant area. The prime farmland north of the plant is predominantly located in areas having soil types of Calloway, Grenada, and Waverly.

Terrestrial Systems. The terrestrial component of the PGDP ecosystem includes the plants and animals that use the upland habitats for food, reproduction, and protection. The upland vegetative communities consist primarily of grassland, forest, and thicket habitats with agricultural areas. The main crops grown in the PGDP area include soybeans, corn, tobacco, and sorghum.

Most of PGDP has been cleared of vegetation at some time, and much of the grassland habitat currently is mowed by PGDP personnel. A large percentage of the adjacent WKWMA is managed to promote native prairie vegetation by burning, mowing, and various other techniques. These areas have the greatest potential for restoration and for establishment of a sizeable prairie preserve in the Jackson Purchase area (KSNPC 1991).

Canopy species of the forested areas include oaks, hickories, maples, elms, and sweetgum. Understory species include snowberry, poison ivy, trumpet creeper, Virginia creeper, and Solomon's seal.

Thicket areas consist predominantly of maples, black locust, sumac, persimmon, and forest species in the sapling stage with herbaceous ground cover similar to that of the forest understory.

Wildlife commonly found in the PGDP area consists of species indigenous to open grassland, thicket, and forest habitats. The species documented to occur in the area are discussed in the following paragraphs.

Small mammal surveys conducted on WKWMA documented the presence of southern short-tailed shrew, prairie vole, house mouse, rice rat, and deer mouse (KSNPC 1991). Large mammals commonly present in the area include coyote, eastern cottontail, opossum, groundhog, whitetail deer, raccoon, and gray squirrel.

Typical birds of the area include European starling, cardinal, red-winged blackbird, mourning dove, bobwhite quail, turkey, killdeer, American robin, eastern meadowlark, eastern bluebird, bluejay, red-tail hawk, and great horned owl.

Amphibians and reptiles present include cricket frog, Fowler's toad, common snapping turtle, green tree frog, chorus frog, southern leopard frog, eastern fence lizard, and red-eared slider (KSNPC 1991).

Mist netting activities in the area have captured red bat, little brown bat, Indiana bat, northern long-eared bat, evening bat, and eastern pipistrelle (KSNPC 1991).

Aquatic Systems. The aquatic communities in and around PGDP area that could be contaminated by plant discharges include two perennial streams (Bayou Creek and Little Bayou Creek), the North-South

Diversion Ditch, a marsh located at the confluence of Bayou Creek and Little Bayou Creek, and other smaller drainage areas. The dominant taxa in all surface waters include several species of sunfish, especially bluegill and green sunfish, as well as bass and catfish. Shallow streams, characteristic of the two main area creeks, are dominated by bluegill, green and longear sunfish, and stonerollers.

Threatened and Endangered Species. Potential habitat for federally listed T&E species was evaluated for the area surrounding PGDP during the 1994 U.S. Army Corps of Engineers (COE) environmental investigation of the PGDP (COE 1994) and inside the fence of the PGDP during the 1994 investigation of sensitive resources at the PGDP (CDM 1994). Investigation inside the PGDP security fence did not detect any T&E species or their preferred habitats, and the U.S. Fish and Wildlife Service (USFWS) has not designated critical habitat for any species within DOE property.

Cultural, Archaeological, and Historic Resources. In accordance with the National Historic Preservation Act (NHPA), a Programmatic Agreement among the DOE Paducah Site Office, the Kentucky State Historic Preservation Officer, and the Advisory Council on Historic Preservation Concerning Management of Historical Properties was signed in January 2004. DOE developed the *Cultural Resources Management Plan for the Paducah Gaseous Diffusion Plant, Paducah Gaseous Diffusion Plant, McCracken County, Kentucky* (CRMP) (BJC 2006) to define the preservation strategy for PGDP and direct efficient compliance with the NHPA and federal archaeological protection legislation at PGDP. PGDP facilities are documented with survey forms and photographs in the *Cultural Resources Survey for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, BJC/PAD–688/R1. No archaeological resources have been identified within the vicinity of the facilities identified as sources for the Southwest Groundwater Plume. If portions of the project remove soils that previously have been undisturbed, in accordance with the CRMP, an archaeological survey will be conducted. If archaeological properties are identified and will be affected adversely, appropriate mitigation measures will be employed.

1.2.1.5 Surface water hydrology, wetlands, and floodplains

Surface Water Hydrology. PGDP is located in the western portion of the Ohio River drainage basin, approximately 24 km (15 miles) downstream of the confluence of the Ohio River with the Tennessee River and approximately 56 km (35 miles) upstream of the confluence of the Ohio River with the Mississippi River. Locally, the PGDP is within the drainage areas of the Ohio River, Bayou Creek (also known as Big Bayou Creek), and Little Bayou Creek.

The plant is situated on the divide between the two creeks. Surface flow is east-northeast toward Little Bayou Creek and west-northwest toward Bayou Creek. Bayou Creek is a perennial stream on the western boundary of the plant that flows generally northward, from approximately 2.5 miles south of the plant site to the Ohio River along a 14.5-km (9-mile) course. The Little Bayou Creek drainage originates within WKWMA and extends northward and joins Bayou Creek near the Ohio River along a 10.5-km (6.5-mile) course.

Most of the flow within Bayou and Little Bayou Creeks is from process effluents or surface water runoff from PGDP. Plant discharges are monitored at the Kentucky Pollutant Discharge Elimination System (KPDES) outfalls prior to discharge into the creeks.

Wetlands. The 1994 COE environmental investigations identified 1,083 separate wetland areas and grouped them into 16 vegetative cover types encompassing forested, scrub/shrub, and emergent wetlands (COE 1994). Wetland vegetation consists of species such as sedges, rushes, spikerushes, and various other grasses and forbs in the emergent portions; red maple, sweet gum, oaks, and hickories in the forested portions; and black willow and various other saplings of forested species in the thicket portions.

Five acres of potential wetlands were identified inside the fence at PGDP (COE 1995). The COE made the determination that these areas are jurisdictional wetlands. Wetlands inside the plant security fence are confined to portions of drainage ditches traversing the site. These areas provide some groundwater recharge, floodwater retention, and sediment retention. While the opportunity for these functions and values is high, the effectiveness is low due to water exiting the area quickly through the drainage system. Other functions and values (e.g., wildlife benefits, recreation, diversity, etc.) are very low.

Floodplains. Floodplains were evaluated during the 1994 COE environmental investigation of PGDP (COE 1994). This evaluation used the Hydrologic Engineering Center Computer Program-2 model to estimate 100- and 500-year flood elevations. Flood boundaries from the Hydrologic Engineering Center Computer Program-2 model were delineated on topographic maps of the PGDP area to determine areal extent of the flood waters associated with these events.

Flooding is associated with the Ohio River, Bayou Creek, and Little Bayou Creek. The majority of overland flooding at PGDP is associated with storm water runoff and flooding from Bayou and Little Bayou Creeks. A floodplain analysis performed by COE (1994) found that much of the built-up portions of the plant lie outside the 100- and 500-year floodplains of these streams. Drainage ditches inside the PGDP security fence can contain nearly all of the expected 100- and 500-year flood discharges (COE 1994). It should be noted that precipitation frequency estimates for the 100- and 500-year events were updated in 2004 in the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 (NOAA 2004). In the updated report, the mean precipitation estimate for the 100-year, 24-hour event in Atlas 14 for the Paducah area is 10.1% to 15% greater than the mean estimate in previous publications. As stated in Atlas 14, in many cases, the mean precipitation estimate used previously still is within the confidence limits provided in Atlas 14; therefore, it is assumed the plant ditches still will contain the 100- and 500-year discharges.

1.2.1.6 Regional and study area geology and hydrogeology

Regional Geology. PGDP is located in the Jackson Purchase Region of Western Kentucky, which represents the northern tip of the Mississippi Embayment portion of the Coastal Plain. The Jackson Purchase Region is an area of land that includes all of Kentucky west of the Tennessee River. The stratigraphic sequence in the region consists of Cretaceous, Tertiary, and Quaternary sediments unconformably overlying Paleozoic bedrock. Figure 1.6 summarizes the geologic and hydrogeologic systems of the PGDP region.

Within the Jackson Purchase Region, strata deposited above the Precambrian basement rock attain a maximum thickness of 3,659 to 4,573 m (12,000 to 15,000 ft). Exposed strata in the region range in age from Devonian to Holocene. The Devonian stratum crops out along the western shore of Kentucky Lake.

Mississippian carbonates form the nearest outcrop of bedrock and are exposed approximately 14.5 km (9 miles) northwest of PGDP in southern Illinois (Clausen *et al.* 1992). The Coastal Plain deposits unconformably overlie Mississippian carbonate bedrock and consist of the following: the Tuscaloosa Formation; the sand and clays of the Clayton/McNairy Formations; the Porters Creek Clay; and the Eocene sand and clay deposits (undivided Jackson, Claiborne, and Wilcox Formations). Continental Deposits unconformably overlie the Coastal Plain deposits, which are, in turn, covered by loess and/or alluvium.

Relative to the shallow groundwater flow system in the vicinity of PGDP, the Continental Deposits and the overlying loess and alluvium are of key importance. The Continental Deposits resemble a large low-gradient alluvial fan that covered much of the region and eventually buried the erosional topography. A principal geologic feature in the PGDP area is the Porters Creek Clay Terrace, a subsurface terrace that

SYSTEM	SERIES	FORMATION	THICKNESS (IN FEET)	DESCRIPTION	HYDROGEOLOGIC SYSTEMS
QUATERNARY	PLEISTOCENE AND RECENT	ALLUVIUM	0-40	Brown or gray sand and silty clay or clayey silt with streaks of sand.	Upper Continental Recharge System
	PLEISTOCENE	LOESS	0-43	Brown or yellowish-brown to tan unstratified silty clay.	
	PLEISTOCENE	CONTINENTAL DEPOSITS	3-121	Upper Continental Deposits (Clay Facies) - mottled gray and yellowish brown to brown clayey silt and silty clay, some very fine sand, trace of gravel. Often micaceous.	
TERTIARY	PLIOCENE-MIOCENE (?)			Lower Continental Deposits (Gravel Facies) - reddish-brown clayey, silty and sandy chert gravel and beds of gray sand.	Regional Gravel Aquifer
	EOCENE	JACKSON, CLAIBORNE, AND WILCOX FORMATIONS	0-200+	Red, brown or white fine to coarse grained sand. Beds of white to dark gray clay are distributed at random.	McNairy Flow System
			0-100+	White to gray sandy clay, clay conglomerates and boulders, scattered clay lenses and lenses of coarse red sand. Black to dark gray lignitic clay, silt or fine grained sand.	
	PALEOCENE	PORTERS CREEK CLAY	0-200	Dark gray, slightly to very micaceous clay. Fine grained clayey sand, commonly glauconitic in the upper part. Glauconitic sand and clay at the base.	
		CLAYTON FORMATION	Undetermined	Lithologically similar to underlying McNairy Formation.	
UPPER CRETACEOUS		McNAIRY FORMATION	200-300	Grayish-white to dark gray micaceous clay, often silty, interbedded with light gray to yellowish-brown very fine to medium grained sand with lignite and pyrite. The upper part is interbedded clay and sand, and the lower part is sand.	
		TUSCALOOSA FORMATION	Undetermined	White, well rounded or broken chert gravel with clay.	
MISSISSIPPIAN		MISSISSIPPIAN CARBONATES	500+	Dark gray limestone and interbedded chert, some shale.	

Figure 1.6. Generalized Lithostratigraphic Column of the PGDP Region

trends approximately east to west across the southern portion of the plant. The Porters Creek Clay Terrace represents the southern limit of erosion or scouring of the ancestral Tennessee River. Thicker sequences of Continental Deposits, as found underlying PGDP, represent valley fill deposits and can be informally divided into a lower unit (gravel facies) and an upper unit (clay facies). The Lower Continental Deposit (LCD) is the gravel facies consisting of chert gravel in a matrix of poorly sorted sand and silt that rests on an erosional surface representing the beginning of the valley fill sequence. In total, the gravel units average approximately 9.14 m (30 ft) thick, but some thicker deposits [as much as 15.25 m (50 ft)] exist in deeper scour channels. The Upper Continental Deposit (UCD) is primarily a sequence of fine-grained, clastic facies varying in thickness from 4.6 to18.3 m (15 to 60 ft) that consist of clayey silts with lenses of sand and occasional gravel. The UCRS is comprised of alluvial deposits, which vary considerably in grain size and porosity. Based on geologic logs, the lithology reflects facies changes that range from silt to sand to clay. Some logs indicate clay is present from land surface to the top of the RGA, which confines the aquifer. Other logs indicate there are areas where only silt and sand are present from land surface to the top of the RGA, so the RGA is unconfined in these areas. The RGA receives recharge most readily in the unconfined areas. These areas may serve as pathways for contaminant migration from the UCRS to the RGA.

The area of the Southwest Plume lies within the buried valley of the ancestral Tennessee River in which Pleistocene Continental Deposits (the fill deposits of the ancestral Tennessee River Basin) rest unconformably on Cretaceous marine sediments. Pliocene through Paleocene formations in the area of the Southwest Plume have been removed by erosion from the ancestral Tennessee River Basin. In the area of the Southwest Plume and its sources, the upper McNairy Formation consists of 18.3 to 21.3 m (60 to 70 ft) of interbedded units of silt and fine sand and underlies the Continental Deposits. Total thickness of the McNairy Formation is approximately 68.6 m (225 ft).

The surface deposits found in the vicinity of PGDP consist of loess and alluvium. Both units are composed of clayey silt or silty clay and range in color from yellowish-brown to brownish-gray or tan, making field differentiation difficult.

Regional Hydrogeology. The local groundwater flow system at the PGDP site occurs within the sands of the Cretaceous McNairy Formation, Pliocene terrace gravels, Plio-Pleistocene lower continental gravel deposits and upper continental deposits, and Holocene alluvium (Jacobs EM Team 1997; MMES 1992). Four specific components have been identified for the groundwater flow system and are defined as follows from lowest to uppermost.

(1) **McNairy Flow System.** Formerly called the deep groundwater system, this component consists of the interbedded and interlensing sand, silt, and clay of the Cretaceous McNairy Formation. Sand facies account for 40% to 50% of the total formation's thickness of approximately 68.6 m (225 ft). Groundwater flow is predominantly north.

(2) **Terrace Gravel.** This component consists of Pliocene(?)-aged gravel deposits (a question mark indicates uncertain age) and later reworked sand and gravel deposits found at elevations higher than 97.5 m (320 ft) amsl in the southern portion of the plant site; they overlie the Paleocene Porters Creek Clay and Eocene sands. These deposits usually lack sufficient thickness and saturation to constitute an aquifer. Terrace Gravel is not present in the area of the Southwest Plume sources.

(3) **RGA.** This component consists of the Quaternary sand and gravel facies of the LCDs and Holocene alluvium found adjacent to the Ohio River and is of sufficient thickness and saturation to constitute an aquifer. These deposits are commonly thicker than the Pliocene(?) gravel deposits, having an average thickness of 9.1 m (30 ft), and range up to 15.24 m (50 ft) in thickness along an axis that trends east–west through the plant site. Prior to 1994, the RGA was the primary aquifer used as a drinking water source by nearby residents. The RGA has not been formally classified, but likely would be considered

a Class II groundwater under EPA Groundwater Classification guidance (EPA 1986). Groundwater flow is predominantly north toward the Ohio River.

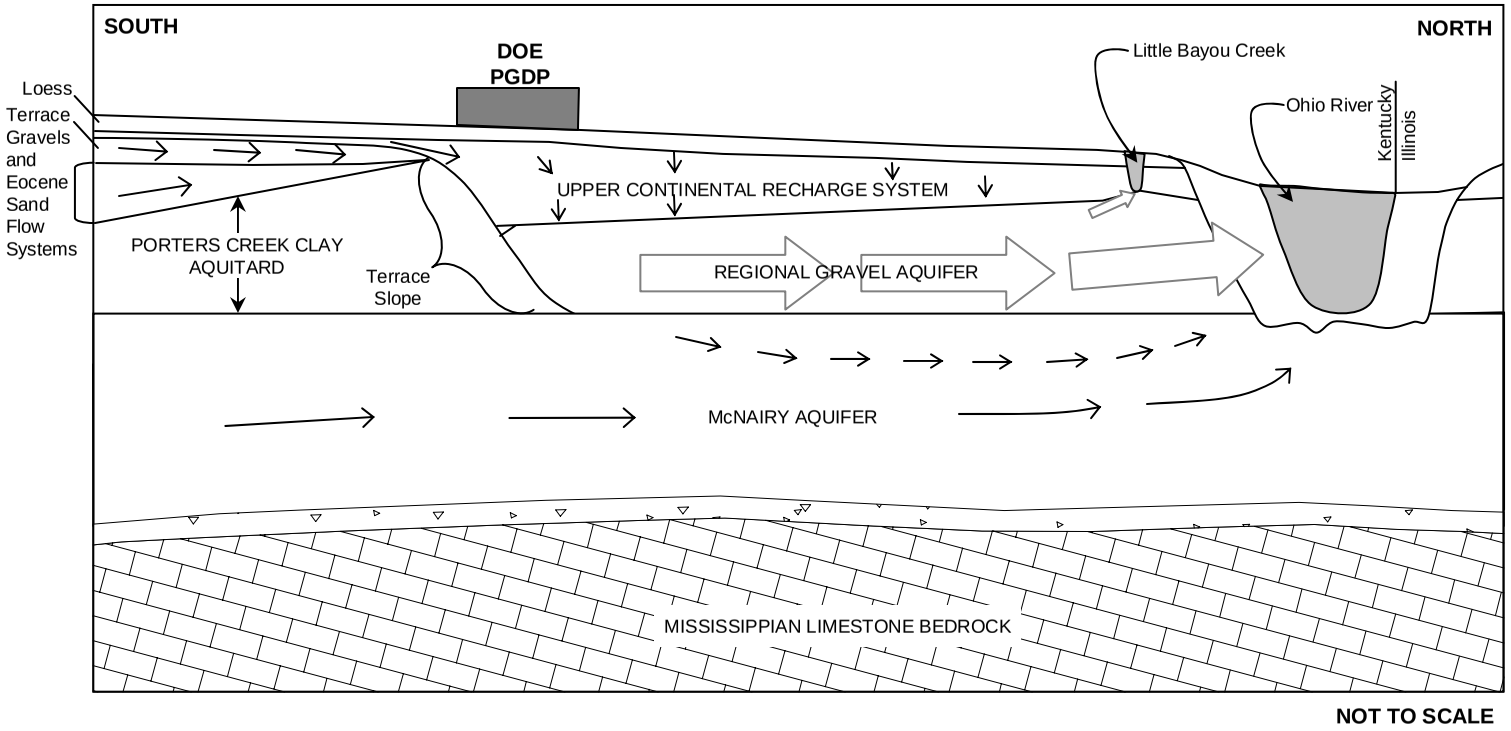
(4) **Upper Continental Recharge System.** Formerly called the shallow groundwater system, this component consists of the surficial alluvium and UCDs. Sand and gravel lithofacies appear relatively discontinuous in cross-section, but portions may be interconnected. The most prevalent sand and gravel deposits occur at an elevation of approximately 105.2 to 106.9 m (345 to 351 ft) amsl; less prevalent deposits occur at elevations of 102.7 to 103.9 m (337 to 341 ft) amsl. Groundwater flow is predominantly downward into the RGA from the Upper Continental Recharge System (UCRS), which has a limited horizontal component in the vicinity of PGDP. The UCRS is comprised of alluvial deposits, which vary considerably in grain size and porosity. Based on geologic logs, the lithology reflects facies changes that range from silt to sand to clay. Some logs indicate clay is present from land surface to the top of the RGA, which confines the aquifer. Other logs indicate there are areas where only silt and sand are present from land surface to the top of the RGA, so the RGA is unconfined in these areas. The RGA receives recharge most readily in the unconfined areas. These areas may serve as pathways for contaminant migration from the UCRS to the RGA.

The primary groundwater flow systems associated with the Southwest Plume are the UCRS and the RGA. Figure 1.7 shows the different water-bearing zones and their relationships in the PGDP area. In the area of the Southwest Plume, groundwater flow and contaminant migration through the upper 13.7 to 16.76 (45 to 55 ft) of subsurface soil (UCD) is predominantly downward with little lateral spreading. This flow system is termed the UCRS. Locally, the UCRS consists of three hydrogeologic units (HUs), an upper silt interval (HU1), an intermediate horizon of sand and gravel lenses (HU2), and a lower silt and clayey silt interval (HU3). Groundwater flow rates in the UCRS tend to be on the order of 0.03 m per day [0.1 ft per day (ft/day)]. The silts and clays of the UCRS readily adsorb some contaminants, such as many metals and radionuclides, retarding the migration of these contaminants in groundwater from the source areas. Moreover, laterally extensive silt and clay horizons in the UCRS may halt the downward migration of DNAPLs, but foster the development of DNAPL pools in the subsurface.

Groundwater occurrence in the UCRS is primarily the result of infiltration from natural and anthropogenic recharge. Flow is predominantly downward. Groundwater in the UCRS provides recharge to the underlying RGA. The water table in the UCRS varies both spatially and seasonally due to lithologic heterogeneity and recharge factors (infiltration of focused run-off from engineered surfaces, seepage due to variations in cooling water line integrity, rainfall and evapotranspiration), and averages approximately 5.2 m (17 ft) in depth with a range of 0.61 to 15.25 m (2 to 50 ft).

Downward vertical hydraulic gradients generally range from 0.15 to 0.30 m per m (0.5 to 1 ft per ft) where measured by monitoring wells (MW) completed at different depths in the UCRS. Monitoring wells in the south-central area of PGDP (south of the C-400 Building and east of the C-720 Building) have lower water level elevations than monitoring wells in other areas of the plant (DOE 1997). Hydraulic conductivity in the UCRS has been determined from numerous slug tests in a previous investigation (CH2M HILL 1992). Hydraulic conductivity ranges from 1.0E-08 to 6.9E-04 centimeters per second (cm/s) [3.9E-09 to 2.7E-04 inches/second (in/s)] with a geometric mean of 1.4E-05 cm/s (5.5E-06 in/s).

A thick interval of late Pleistocene sand and gravel from a depth interval of 18.3 to 27.4 m (60 to 90 ft) (LCD) represents the shallow, uppermost aquifer underlying most of PGDP, referred to as the RGA. The RGA consists of a discontinuous upper horizon of fine to medium sand (HU4) and a lower horizon of medium to coarse sand, and gravel (HU5). The RGA is the main pathway for lateral flow and dissolved contaminant migration off-site. Variations in hydraulic conductivity and the location of discrete sources of recharge govern the local direction of groundwater flow. However, overall flow within the RGA trends north-northeast toward the Ohio River, which represents the regional hydraulic base level.



U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

PADUCAH
Remediation Services
A Portage Shaw Joint Venture Company

Figure 1.7. Water-Bearing Zones Near the PGDP

Appendix C describes the process used for this FFS to determine the location of the HU3/HU4 contact at the SW Plume source areas, based on lithologic logs for boreholes and monitoring wells provided in the WAG 27 RI (DOE 1999a) and the SI Report (DOE 2006). The location of the contact was used in modeling migration of contaminants from the source areas to the RGA. The location of the contact was determined using the following evaluation steps:

(1) Locate the gravel layer in the RGA in the well logs,

(2) Locate the sand layers above the gravel layer.

(3) The top of the HU4 layer, where present, is considered to be the top of the saturated sand unit, not containing significant silts or clays, immediately overlying the HU5 gravel layer. If the HU4 is not present then the top of the HU5 gravel is considered to be the contact.

The methodology for choosing the HU3/HU4 contact considers the clay content of the sand layer because significant clay content would reduce the capacity of the sand to the extent that its hydraulic properties would be more similar to the HU3 unit. Table 1 and Figure 1 of Appendix C provide the Oil Landfarm location of the HU3/HU4 contact location based on the well logs. The average location of the HU3/HU4 contact is at 53 ft below the surface at the Oil Landfarm. Table 2 and Figure 2 of Appendix C provide the C-720 location of the HU3/HU4 contact location based on the well logs. The average location of the HU3/HU4 contact is at 58.4 ft below the surface at C-720.

The RGA typically has a high hydraulic conductivity with a range from 1.9E-02 to 2.0E+00 cm/s (7.5E-03 to 7.9E-01 in/s) as determined from aquifer testing. RGA horizontal hydraulic gradients range between 1.84×10^{-4} and 2.98×10^{-3} ft/ft and have average and median values of 7.81×10^{-4} and 4.4×10^{-4} ft/ft, respectively. Groundwater flow rates within the RGA average approximately 1 to 3 ft/day. Contaminant migration tends to be less retarded in the coarse sediments of the RGA due to its high groundwater flow rate and also due to the low fraction of organic carbon (0.02%).

Study Area Geology. The geologic layers at the Oil Landfarm consist primarily of silt/sandy/silty sand with some clay (DOE 2007). This is indicative of the UCD overlaid with surface soil. In general, the subsurface soils typically are silts to a depth of 7.6 to 9.14 m (25 to 30 ft). Sand is common below a depth of 9.14 m (30 ft). The lower portion of the UCD often exhibits a noticeable increase in grain size and a significant increase in moisture content consistent with the contact between the UCD and the LCD.

The geologic strata found in the C-720 Building Area range from clays to silts to sands. Silt and clay are the predominant subsurface soil texture to a depth of 4.6 to 6.1 m (15 to 20 ft). Interbedded sand and clay units are commonly found below those depths. Clay and sandy clay/clayey sand are present near the bottom of most of the soil borings northeast of C-720 Building (DOE 2007).

Immediately southeast of the C-720 Building silt and clay are present to a depth of 15 ft with interbedded sand and clay layers found at deeper horizons. Medium-to-coarse-grained sand, suggestive of the contact between the UCDs and LCDs, was encountered near the bottom of borings in the southeast corner.

The Southwest Plume investigation of the Storm Sewer included 15 soil borings (DOE 2007). Each boring was placed as closely to the Storm Sewer as possible in an attempt to collect soil samples from the base of the backfill material in which the Storm Sewer rests. Borings did not exceed 6.1 m (20 ft) in depth. The soil cores consisted primarily of silt and clay with occasional lenses of sand toward the bottom of the sample interval. Because this was an area of construction, the majority of the sediments encountered bgs were possibly backfill material.

Study Area Hydrogeology. The Southwest Plume SI included soil sampling within the upper 18.3 m (60 ft) of the Oil Landfarm. Soil samples verified the presence of the HU1, HU2, and HU3 members of the UCRS. The UCRS is comprised of alluvial deposits, which vary considerably in grain size and porosity. Based on geologic logs, the lithology reflects facies changes that range from silt to sand to clay. Some logs indicate clay is present from land surface to the top of the RGA, which confines the aquifer. Other logs indicate there are areas where only silt and sand are present from land surface to the top of the RGA, so the RGA is unconfined in these areas. The RGA receives recharge most readily in the unconfined areas. These areas may serve as pathways for contaminant migration from the UCRS to the RGA. HU3 sediments tended to be coarser grained than typical. The RGA was not encountered, although the final interval sampled 16.76 to 18.3 m (55 to 60 ft) often revealed a noticeable increase in grain size and a significant increase in moisture content, consistent with trends near the top of the RGA. At the Oil Landfarm, the depth to the water table in the UCRS averages approximately 4.26 m (14 ft), but can be as shallow as 2.13 m (7 ft) due to seasonal variability. Slug tests on UCRS monitoring wells near the Oil Landfarm indicated a hydraulic conductivity of approximately 1.5E-05 in/s (3.9E-05 cm/s) (DOE 2007).

Soil sampling to a depth of 18.3 m (60 ft) was conducted at the C-702 Building Area. As in other soil borings in the C-720 Building Area, the soil textures are inconsistent with the typical HU2/HU3 contact where the top of the HU3 appears to consist predominately of silty sands. The RGA was not encountered. In the C-720 Building Area, the depth to water in the UCRS ranges from 1.83 to 13.7 m (6 to 45 ft) below surface with an average of 8.8 m (29 ft). The hydraulic conductivity of the UCRS near the C-720 Building is 1.34E-05 in/sec (3.4E-05 cm/s) (DOE 2007).

The Southwest Plume SI consisted of soil sampling to a depth of 6.1 m (20 ft) adjacent to the Storm Sewer. Because this was an area of construction, the majority of the soil encountered bgs probably was backfill material. The soils typically were silts, clays, and fine sands that were similar to the HU1 sediments (DOE 2007).

1.2.2 Contaminant History

The Southwest Plume refers to an area of groundwater contamination at PGDP in the RGA that is south of the Northwest Groundwater Plume and west of the C-400 Building. The Southwest Plume was identified during the WAG 27 RI in 1998 (DOE 1999a). Additional work to characterize the plume (SWMU 210) was performed as part of the WAG 3 RI and Data Gaps Investigations, both in 1999. The Southwest Plume SI (DOE 2007) most recently evaluated potential source areas of contamination to the Southwest Plume (see Figure 1.4) and profiled the current level and distribution of VOCs in the plume along the west plant fenceline. Confirmation of the nature and extent of contamination from the Southwest Plume SI is discussed in Section 1.2.3. Figure 1.8 presents the extent of the TCE plume for the Southwest Plume, as it was understood in 2003, prior to the Southwest Plume SI. The history of each of the source areas is presented here.

1.2.2.1 C-747-C Oil Landfarm (SWMU 1)

Between 1973 and 1979, the Oil Landfarm was used for landfarming of waste oils contaminated with TCE, uranium, polychlorinated biphenyls (PCBs), and 1,1,1-trichloroethane (TCA). These waste oils are believed to have been derived from a variety of PGDP processes. The landfarm consisted of two 104.5-m^2 (1,125-ft^2) plots that were plowed to a depth of 0.305 to 0.61 m (1 to 2 ft). Waste oils were spread on the surface every 3 to 4 months; then the area was limed and fertilized.

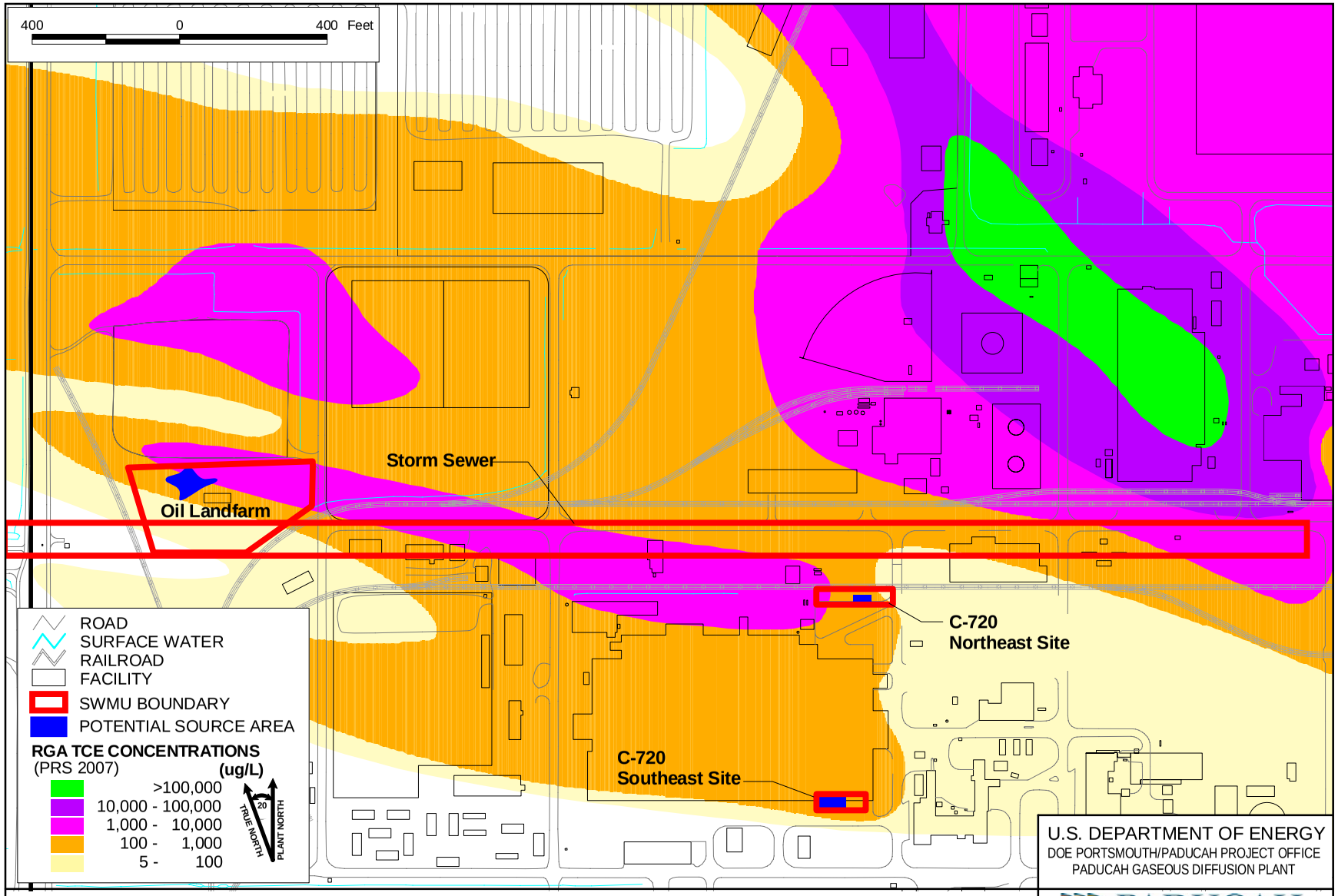


Figure 1.8. TCE Plume Within the Study Area

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1.2.2.2 C-720 Building Area (SWMUs 211A and 211B)

The C-720 Building is located in the west-central area of the PGDP, southwest of the C-400 Building. The C-720 Building consists of several repair and machine shops, as well as other support operations. The WAG 27 RI identified areas of TCE contamination at the C-720 Building Area. This FFS addresses two areas that were identified in the Resolution. One area was underneath the parking lot and equipment storage area at the northeast corner of the building. The second area was located underneath the parking lot adjacent to the loading docks at the southeast corner of the building.

C-720 Northeast Site (SWMU 211A). Contamination found to the northeast of the C-720 Building is believed to have been released during routine equipment cleaning and rinsing performed in the area. Solvents were used to clean parts, and the excess solvent may have been discharged on the ground. Spills and leaks from the cleaning process also may have contaminated surface soils in the area. Solvents may have migrated as dissolved contamination, as rainfall percolating through the soils and migrating to deeper soils and the shallow groundwater, or as DNAPL migrating to adjacent and underlying soils.

C-720 Southeast Site (SWMU 211B). The source of VOC contamination found southeast of the C-720 Building is not certain. The VOCs found in this area may have originated from spills that occurred within the building, with subsequent discharge to storm drains leading to the southeast corner of the building or from spills or leaks on the loading dock or parking lot located to the southeast of the building. The area of concern discovered during the WAG 27 RI is near the outlet to one of the storm drains for the east end of the building. A storm sewer inlet for the southeast parking lot also is located in the vicinity. The north edge of the parking lot, where the contamination occurs, is the location of one of the loading docks for the C-720 Building, an area where chemicals, including solvents, may have been loaded or unloaded.

1.2.2.3 Plant Storm Sewer (SWMU 102)

During the WAG 6 RI, VOC contamination of subsurface soils was identified near two of the lateral lines that feed into the main storm sewer that runs south of the C-400 Building to Outfall 008 on the west side of PGDP. At one time, the eastern lateral appears to have been connected to the TCE degreaser sump inside the C-400 Building. The TCE that leaked from the sump/storm sewer connection to the surrounding soils had been identified as a potential source of groundwater contamination. There was a possibility that TCE was transported down the lateral to the main storm sewer line running to Outfall 008, encountered an undetermined breach in the storm sewer, and leaked to the surrounding soils to become a source of TCE to the Southwest Plume.

The C-400 Building to Outfall 008 storm sewer drains the central west portion of the plant. Major areas and buildings that contribute storm water runoff to the system include all of the following:

- C-631 Cooling Towers
- C-331 Process Building (roof drains for northwest quadrant)
- C-310 Building (roof drains for north half)
- C-410/C-420 Complex
- C-400 Building
- C-409 Building
- C-600 Steam Plant area
- C-720 Building (roof drains for north and west sides and associated shops on north side)
- C-746-H3 Storage Pad
- C-740 Storage Yard

Construction drawings show that the Outfall 008 storm sewer begins to the east of the C-400 Building as a 15-inch-diameter pipe. The video survey of the Outfall 008 storm sewer that was part of the Southwest Plume SI revealed that the main storm sewer south of the C-400 Building is a 91.44-cm-diamter (36-inch-

diameter), reinforced-concrete pipe that enlarges to a 121.9-cm-diameter (48-inch-diameter) pipe and then a 137.16-cm-diameter (54-inch-diameter) pipe between 10th and 8th Streets. West of 8th Street, the Outfall 008 storm sewer continues as a 182.9-cm-diameter (72-inch-diameter) pipe. The video survey confirmed that the bottom of the storm sewer is between 3.96 to 4.6 m (13 and 15 ft) bgs. Construction drawings indicate that the feeder lines into the main storm sewer range from 8-inch-diameter vitreous clay pipe to 60.96-cm-diameter (24-inch-diameter) concrete pipe.

1.2.2.4 C-747 Contaminated Burial Yard (SWMU 4)

The C-747 Contaminated Burial Yard operated from 1951 through 1958 and was used for disposal of contaminated and uncontaminated trash, some of which was burned. Waste materials from the C-400 Building, originally designated for the C-404 Burial Area, may have been placed at SWMU 4 as well. Scrapped equipment with surface contamination from the enrichment process also was buried. The site consists of several pits excavated to about 15 ft. The waste was placed in the pits and was covered with 2 to 3 ft of soil. A 6-inch clay cap was installed in 1982 (DOE 2007).

The site was investigated during the Phase II SI and the WAG 3 RI. The COCs identified in these reports include radionuclides, heavy metals, solvents, semivolatile organics, and PCBs. This Southwest Plume SI focused on the RGA groundwater east and west of the unit and did not evaluate the fate and transport or risk contributions from those COCs. The Burial Ground OU RI will evaluate these areas further (DOE 2007).

1.2.2.5 Previous investigations

Investigations of the Southwest Plume and potential source areas are documented in the following reports.

- *Results of the Site Investigation, Phase I, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (CH2M HILL 1991).
- *Results of the Site Investigation, Phase II, at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky* (CH2M HILL 1992).
- *Final Remedial Action Report for Waste Area Grouping (WAG) 23 and Solid Waste Management Unit 1 of WAG 27 at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky* (DOE 1998a).
- *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky* (DOE 1999a).
- *Remedial Investigation Report for Waste Area Grouping 6 at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky* (DOE 1999b).
- *Remedial Investigation Report for Waste Area Grouping 3 at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky* (DOE 2000a).
- *Data Report for the Sitewide Remedial Evaluation for Source Areas Contributing to Off-Site Groundwater Contamination at the Paducah Gaseous Diffusion Plant*, Paducah, Kentucky (also known as Data Gaps Document) (DOE 2000b).
- *Feasibility Study for the Groundwater Operable Unit at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2001b).
- *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2007).

1.2.2.6 Southwest Plume SI

The Oil Landfarm, C-720 Building Area, and Storm Sewer most recently were investigated in the Southwest Plume SI. The objectives of the Southwest SI were to collect sufficient data to do the following:

- Determine which units are sources of contamination to the Southwest Plume;
- Determine which units are not sources of contamination to the Southwest Plume;
- Fill data gaps for risk assessment of the identified source areas; and
- Reduce uncertainties and increase the understanding of the Southwest Plume and potential sources so that appropriate response actions can be identified, as necessary.

Data collection activities were designed to answer the principal study questions that were developed for each potential source area in the SI Work Plan (DOE 2004). At the Oil Landfarm, the C-720 Building Area, and along the Storm Sewer, VOC contamination in the shallow soils of the UCD were profiled using direct-push technology (DPT) combined with a membrane interface probe (MIP). Discrete-depth soil samples were collected to approximately 18.3 m (60 ft) bgs at the Oil Landfarm and the C-720 Building Area and 6.1 m (20 ft) bgs along the Storm Sewer. These samples were sent to laboratories for analyses of VOCs (for all sites), metals, and radionuclides (only for samples from the C-720 Building Area and from along the Storm Sewer).

Groundwater samples during the Southwest Plume SI were collected at various depths within the RGA using dual-wall reverse circulation drilling equipment at the Southwest Plume (SWMU 210). At the C-720 Building Area, groundwater samples were collected from the well cluster MW203 (RGA) and MW204 (UCRS). The principal study questions of the Southwest Plume SI did not require additional groundwater sampling to address the Oil Landfarm. Moreover, groundwater samples were not required to address the principal study questions for the Storm Sewer.

Table 1.2 illustrates the investigations completed in the Southwest Plume area and potential source area to which each applies.

Table 1.2. Summary of Investigations and Areas Investigated

Date	Title	Southwest Plume	Oil Landfarm	C-720 Building Area	Storm Sewer	SWMU 4
1989–1990	Phase I SI		✓		✓	
1990–1991	Phase II SI		✓	✓	✓	
March 1996	Site-specific sampling		✓			
1997	WAG 6 Remedial Investigation				✓	
1998	WAG 23 Removal Action		✓			
1998	WAG 27 Remedial Investigation	✓	✓	✓		
1999	Sitewide Data Gaps Investigation	✓				
1999	WAG 3 Remedial Investigation	✓				✓
2001	Groundwater OU Feasibility Study	✓	✓	✓	✓	
2007	Southwest Plume Site Investigation	✓	✓	✓	✓	✓

1.2.3 Nature and Extent of Contamination

This section illustrates and interprets the nature and extent of contamination for each study area. Potential source areas, as determined by the analytical results from field activities, are examined, and potential site-related contaminants are identified. Conceptual site models (CSMs) for the Southwest Plume sources are presented and discussed. Evaluation in this section are based on data collected in the Southwest Plume SI and results from previous investigations.

The historical data of operational events that provide an explanation for the presence of contamination at each of the study areas is described in Section 1.2.2, Site History. The degree to which these events impacted the surrounding areas was determined by the analytical results of the samples collected. In some cases, the close proximity of the study areas made isolating the original source of contamination difficult.

1.2.3.1 Conceptual site model, site conditions, and plant controls

The CSM for the Southwest Plume sites is presented in this section. The discussion of contaminant sources, release mechanisms, and transport pathways provides a basis for developing the RAOs and for identifying and screening technologies and developing and analyzing alternatives. The CSM describes site conditions including nature and extent of contamination, contaminant fate and transport, and potential receptors. The CSM is described herein narratively and in the next three figures. The narrative CSM is comprised primarily of information summarized from the WAG 27 RI (DOE 1999a) and the SI Report (DOE 2007). The pictorial conceptual models, provided in Figures 1.9 and 1.10 for the Oil Landfarm and the C-720 Building Area, respectively, summarize the description, show surface and subsurface conditions, and aid in visualizing the narrative information. A pictorial CSM for the Storm Sewer is not provided. As discussed here, results of a video survey and sampling conducted during the Southwest Plume SI confirmed that the Storm Sewer was not a source of contamination to the Southwest Plume; therefore, the Storm Sewer is not carried forward in the FFS for alternative evaluation. The diagrammatic CSM detailing sources, receptors, and exposure pathways for both the Oil Landfarm and the C-720 Building area is shown in Figure 1.11.

Oil Landfarm CSM. The conceptual model of subsurface contamination for the Oil Landfarm consists of a discrete zone of soils with potential TCE DNAPL ganglia below the plow plots that extends from near the surface to the top of the RGA [approximately 16.76 m (55 ft) bgs]. The area of this contamination is estimated to be approximately 809 m^2 (8,700 ft^2or 0.2 acre). Ganglia of potential TCE DNAPL may continue to leach dissolved-phase TCE to the UCRS groundwater. Dissolved TCE levels within the source zone exceed 10,000 µg/L (which is consistent with the presence of free-phase TCE in ganglia).[1] Shallow groundwater flow is dominantly vertical in the Oil Landfarm area. The C-745-A Cylinder Yard located north and adjacent to SWMU 1 contains 10 ton cylinders of depleted uranium hexafluoride, which are not sources of VOCs or other groundwater contaminants.

TCE levels in the RGA are highest below the Oil Landfarm at the top of the RGA and directly downgradient of the source zone. Mixing of the Oil Landfarm leachate with groundwater in the RGA reduces TCE levels from the Oil Landfarm in the RGA by an order of magnitude and eventually to lesser levels downgradient. As the TCE plume migrates downgradient, area recharge from the overlying UCRS displaces the plume deeper in the RGA. Figure 1.9, adapted from the WAG 27 RI Report (DOE 1999a), illustrates the pictorial CSM for TCE contamination from the Oil Landfarm.

[1]With the exception of the lone highest value of TCE contamination reported in soil at SWMU 1 (400,000 µg/kg), the TCE-in-soil levels are easily accounted for by dissolved-phase contamination derived from a small DNAPL source zone. For further information, the reader is referred to *Feasibility Study for the Groundwater Operable Unit at Paducah Gaseous Diffusion Plant Paducah, Kentucky*, DOE/OR/07-1857&D2, Volume 4, Appendix C5 (DOE 2001b).

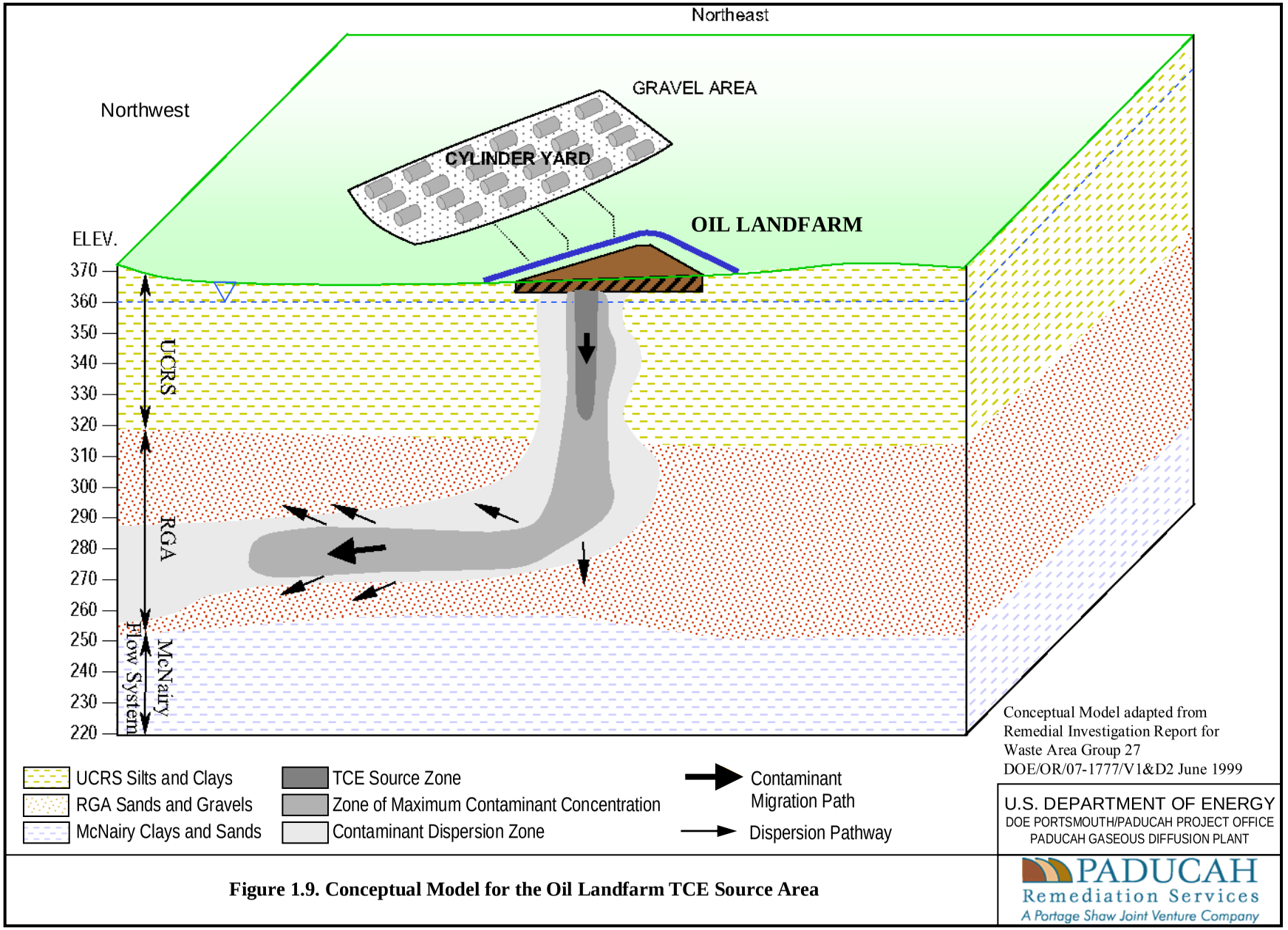

Figure 1.9. Conceptual Model for the Oil Landfarm TCE Source Area

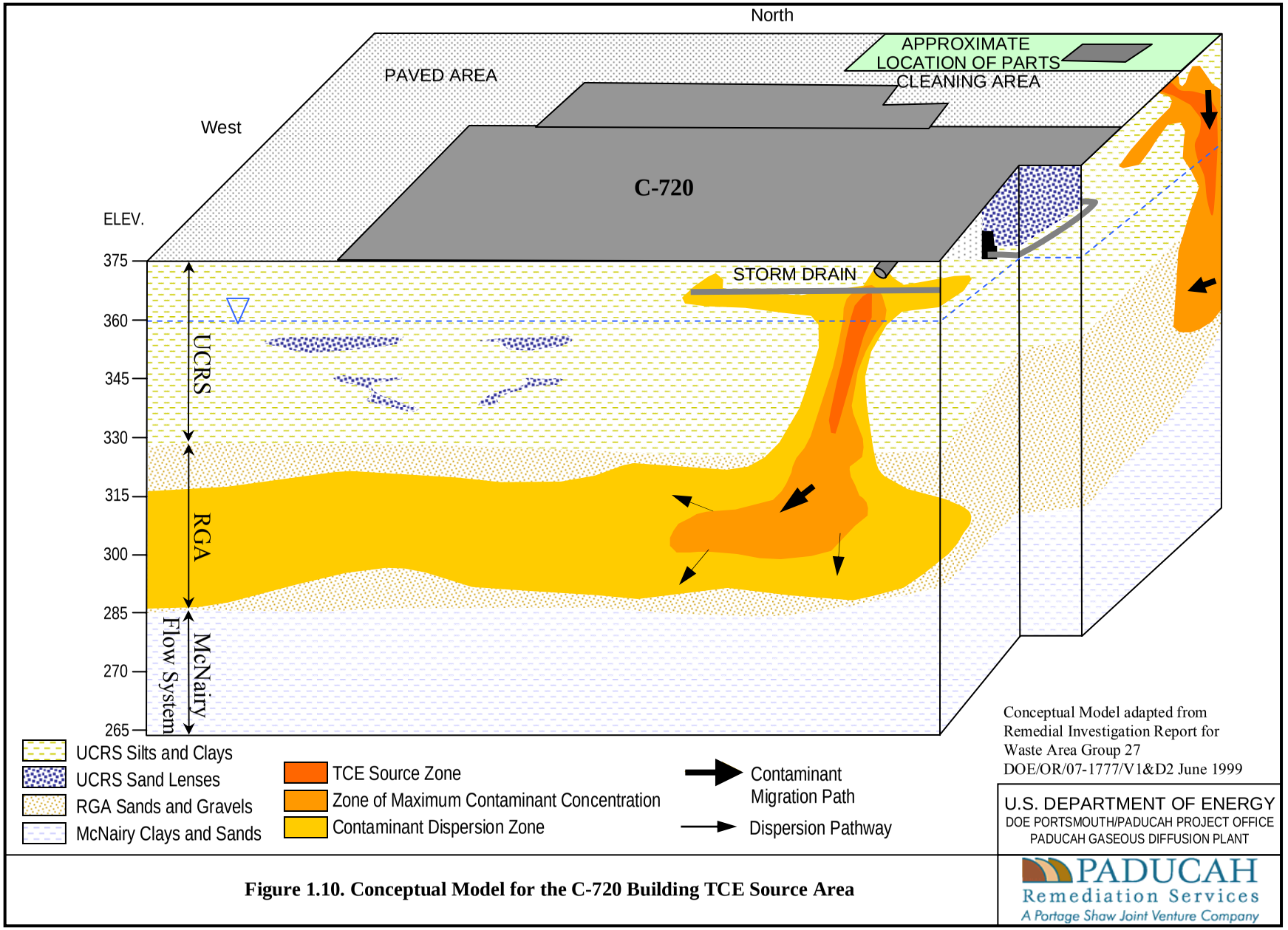

Figure 1.10. Conceptual Model for the C-720 Building TCE Source Area

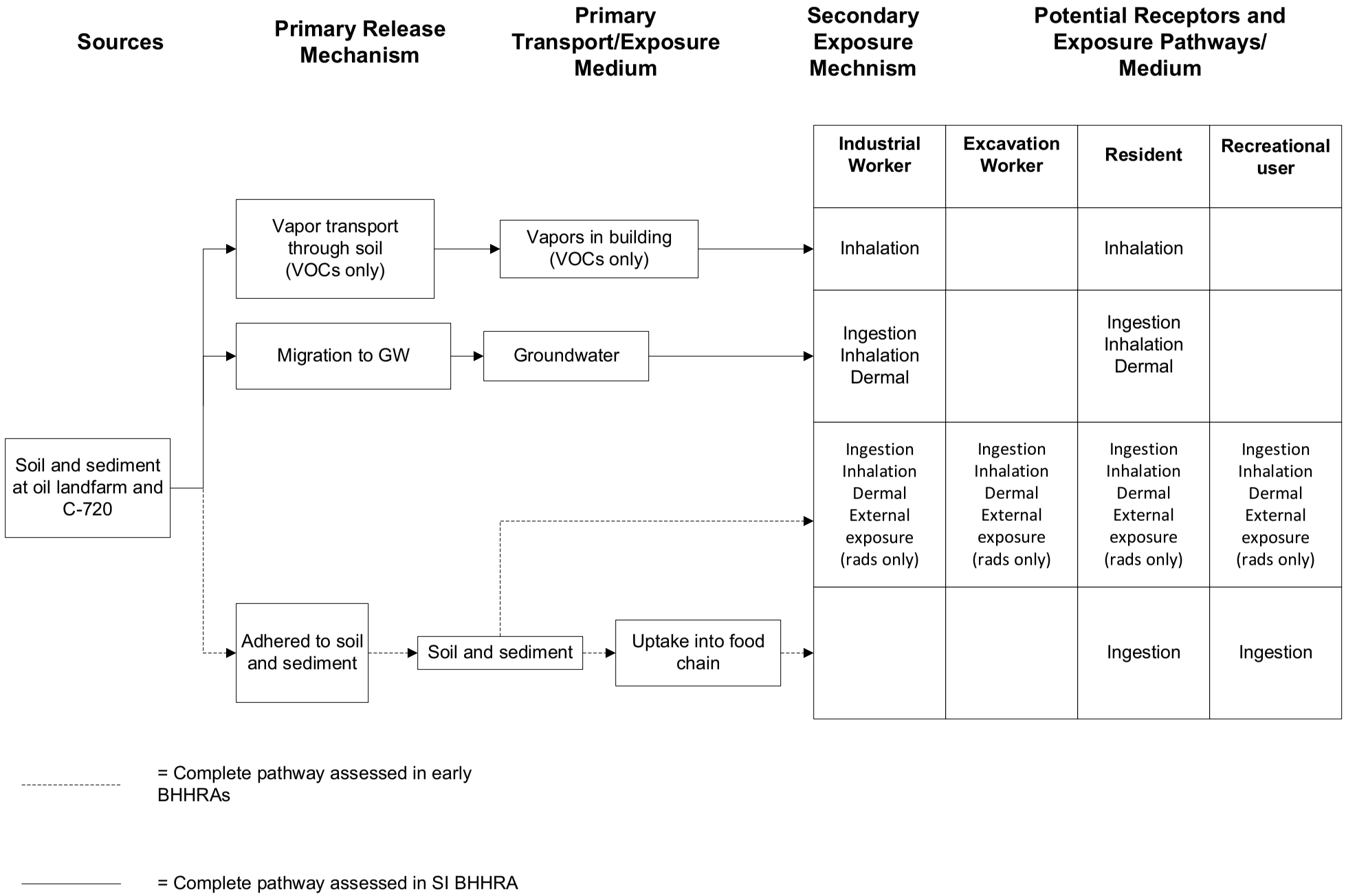

Figure 1.11. Exposure Pathway Conceptual Model for the Southwest Plume Source Areas

Oil Landfarm Site Conditions. Investigations on the Oil Landfarm include the Phase I and Phase II SIs (CH2M HILL 1991; CH2M HILL 1992), additional sampling performed to support the WAG 23 FS and resulting Removal Action (RA) (DOE 1998a), and the WAG 27 RI. These investigations and actions identified VOCs, PCBs, dioxins, semivolatile organic compounds (SVOCs), heavy metals, and radionuclides as COCs. As part of the WAG 23 RA, 17.58 m^3 (23 yd^3) of dioxin-contaminated soil was excavated and removed from the unit. Samples collected to support the WAG 23 RA indicated the presence of *cis*-1,2-DCE concentrations as high as 2,400 mg/kg. During the WAG 27 RI, the maximum detected TCE concentration was 439 mg/kg at 4.6 m (15 ft) below ground surface (bgs), with most TCE concentrations less than 100 mg/kg. Sampling locations from the WAG 27 RI are shown in Figure 1.12. TCE was not detected above method detection limits (MDLs) and any locations with the exception of the locations and results summarized in Figure 1.12.

During the Southwest Plume SI, five borings (001-201 through 001-205) were placed within and adjacent to the soil contamination area defined during the WAG 27 RI (Figure 1.12). Soil samples were collected for analysis from the vadoze zone above the RGA. Borings did not exceed 18.3 m (60 ft) and were not advanced past the UCD. Soil samples were collected at approximately 4.6-m (15-ft) intervals. Sampling intervals were modified to reflect the MIP profile. No groundwater samples were collected during the investigation of this unit. Results from SI sampling are shown in Figure 1.12.

The diagrammatic CSM in Figure 1.11 includes the pathways evaluated in the SI Baseline Human Health Risk Assessment (BHHRA) as well as pathways evaluated in earlier BHHRAs. The CSM shows that chemicals of potential concern in soil could reach receptors through direct exposure to contaminants in soil and through migration of contaminants to groundwater to which receptors could be exposed through drinking, showering, and household water use. The remaining exposure pathway shown in the CSM in Figure 1.11 involves exposure to vapors transported through soil into buildings. This vapor pathway is complete only for the VOC contaminants at these source areas. The SI BHHRA conducted a new risk assessment for this vapor pathway and for exposures to groundwater. The earlier BHHRAs evaluated direct exposure to soil and consumption of biota exposed to contaminated soil. The results of those risk assessments are summarized in Appendix D of this FFS. The earliest risk assessments included potential exposure through consumption of fish from contaminated surface water; however, the fish consumption pathway was never quantitatively evaluated for any on-site receptors and, therefore, was not included in the current CSM diagram.

The highest levels of total VOCs detected in a single sample included TCE (3.5 mg/kg) and degradation products, *cis*-1,2-DCE (1.5 mg/kg) and VC (0.02 mg/kg); TCA (0.05 mg/kg); and 1,1-dichloroethene (1,1-DCE) (0.07 mg/kg). Some or all of these products were detected in samples from all sample intervals at the location collected to a depth of 18.1 m (59.5 ft). The high TCE concentration (3.5 mg/kg) was detected at 14.3 m (47 ft) bgs. Significant levels of TCE (1.8 mg/kg) and *cis*-1,2-DCE (0.086 mg/kg) were detected in a second location from all intervals collected to a depth of 17.07 m (56 ft), with the highest level of TCE detected at 17.07 m (56 ft) bgs. A third location exhibited lower levels of TCE and its degradation products, with the highest level of TCE (0.98 mg/kg) detected at 9.1 m (30 ft) bgs together with TCA (0.0034 mg/kg). Low levels of TCE (0.37 mg/kg) and *cis*-1,2-DCE (0.2 mg/kg), were detected at 13.8 m (45.5 ft) in a fourth sample location. The fifth location did not contain any detectable concentrations of TCE or its degradation products, but had a slight detection of carbon disulfide (0.014 mg/kg) at 10.1 m (33 ft), which was the only contaminant above the MDL.

C-720 Building Area CSM. The conceptual model for the C-720 Building Area is similar to the Oil Landfarm, although the release mechanisms are dissimilar. In the C-720 Building Area model, the largest TCE source zone is below and adjacent to the outlet for the storm drain on the east end, south side of the C-720 Building, or a nearby storm sewer inlet for the parking lot. In either case, the interval of contaminated soils extends from the base of the storm sewer [1.52-m (5-ft) depth) to the base of the UCRS [18.3-m (60-ft) depth]. Soil TCE levels are elevated throughout the entire depth of the UCRS

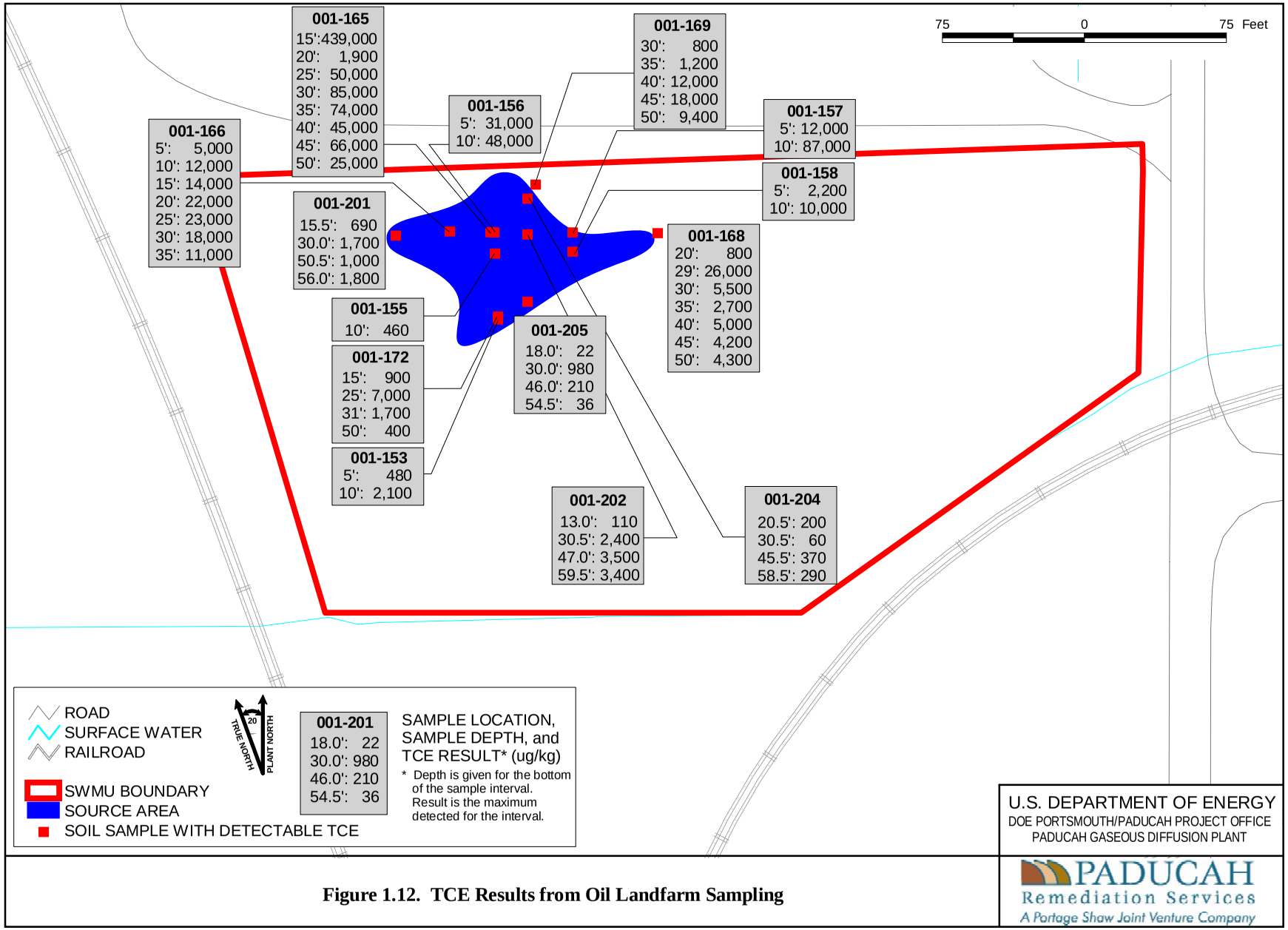

Figure 1.12. TCE Results from Oil Landfarm Sampling

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within the source zone, but the TCE levels are significantly lower in the soils above the water table, which averages a depth of 4.6 m (15 ft) bgs in this part of the C-720 Building Area.

Repeated TCE releases potentially allowed DNAPL to accumulate and eventually migrate as a free-phase liquid through the UCRS; however, sufficient time has passed to dissolve the DNAPL so that only potential ganglia of TCE DNAPL remain. The water table is at a depth of approximately 4.6 m (15 ft). Soil TCE levels are elevated throughout the entire depth of the UCRS within the source zone, but the TCE levels are significantly lower in the soils above the water table where volatilization has been more effective.

Dissolved TCE levels within the source zone exceed 10,000 µg/L (which is consistent with the presence of free-phase TCE in ganglia, as documented in other PGDP UCRS DNAPL zones). Shallow groundwater flow is dominantly vertical. Once the contamination reaches the RGA, flow becomes horizontal. TCE levels in the leachate from the C-720 Building Area are diluted by an order of magnitude when mixed with RGA groundwater, with the concentrations further declining with distance in a downgradient direction. Figure 1.10, the pictorial site conceptual model of the C-720 Building Area TCE contamination, is taken from the WAG 27 RI Report (DOE 1999a).

C-720 Northeast Site Conditions. The maximum TCE concentration detected (8.1 mg/kg) in the WAG 27 RI was in a sample 9.1 m (30 ft) bgs located immediately north of the parking lot. The WAG 27 RI sampling location is shown on Figure 1.13, with results provided on Figure 1.14. During the Southwest Plume SI (DOE 2007), investigation of soils of the C-720 Northeast Site consisted of six borings (720–101 through 720–106) placed between the north edge of the parking lot and a storm sewer to which all surface runoff for the parking lot flows (Figure 1.13). Because the conceptual release mechanism for the C-720 Northeast Site is routine equipment cleaning and rinsing performed in the area in the past, locations were selected to sample areas associated with these activities. Borings did not exceed 18.3 m (60 ft), and soil samples were collected at approximately 4.6-m (15-ft) intervals. Sampling intervals were modified to reflect the MIP profile. Analytical results below the soil background levels at PGDP were not included in the discussion of this investigation.

Results indicated that soils containing very low levels of VOC contamination were detectable in the subsurface of the northeast corner of the C-720 Building Area. The highest level of TCE (0.98 mg/kg) was detected at 15.1 m (49.5 ft) bgs, with low levels of *cis*-1,2 DCE (0.05 mg/kg) and 1,1-DCE (0.02 mg/kg) detected. Carbon disulfide (0.005 mg/kg) was detected at this location as well, but was not detected at any other locations during investigation of the northeast corner source area. The second highest sample identified a maximum TCE concentration of 0.63 mg/kg at 17.2 m (56.5 ft), with no degradation products detected above the MDLs. A third location had a similar maximum TCE level of 0.6 mg/kg at 14 m (46 ft) and included *cis*-1,2-DCE (0.019 mg/kg). The remaining three locations had low-levels of TCE (0.01 to 0.06 mg/kg) and degradation products and other VOCs including tetrachloroethene, 1,2-dichloroethane, 1,1-DCE, carbon tetrachloride, and chloroform detected. The results confirmed that dissolved contamination had migrated to the area's deeper soil. Results from SI sampling are shown in Figure 1.14.

Samples from the well cluster MW203 (RGA) and MW204 (UCRS) were the only groundwater samples collected during the investigation of this unit. The TCE levels declined from the UCRS to the RGA wells (280 to 99 µg/L).

C-720 Southeast Site Conditions. In the WAG 27 RI, the maximum TCE concentration detected was 68 mg/kg at 6.4 m (21 ft) bgs. Sampling locations are shown in Figure 1.13 with results presented in Figure 1.14. During the Southwest Plume SI, two borings were placed through the parking lot adjacent to the C-720 Building loading dock. No groundwater samples were collected during investigation of this unit. Samples had low-levels of TCE [maximum 0.20 mg/kg at 8.84 m (29 ft) bgs] with no associated degradation

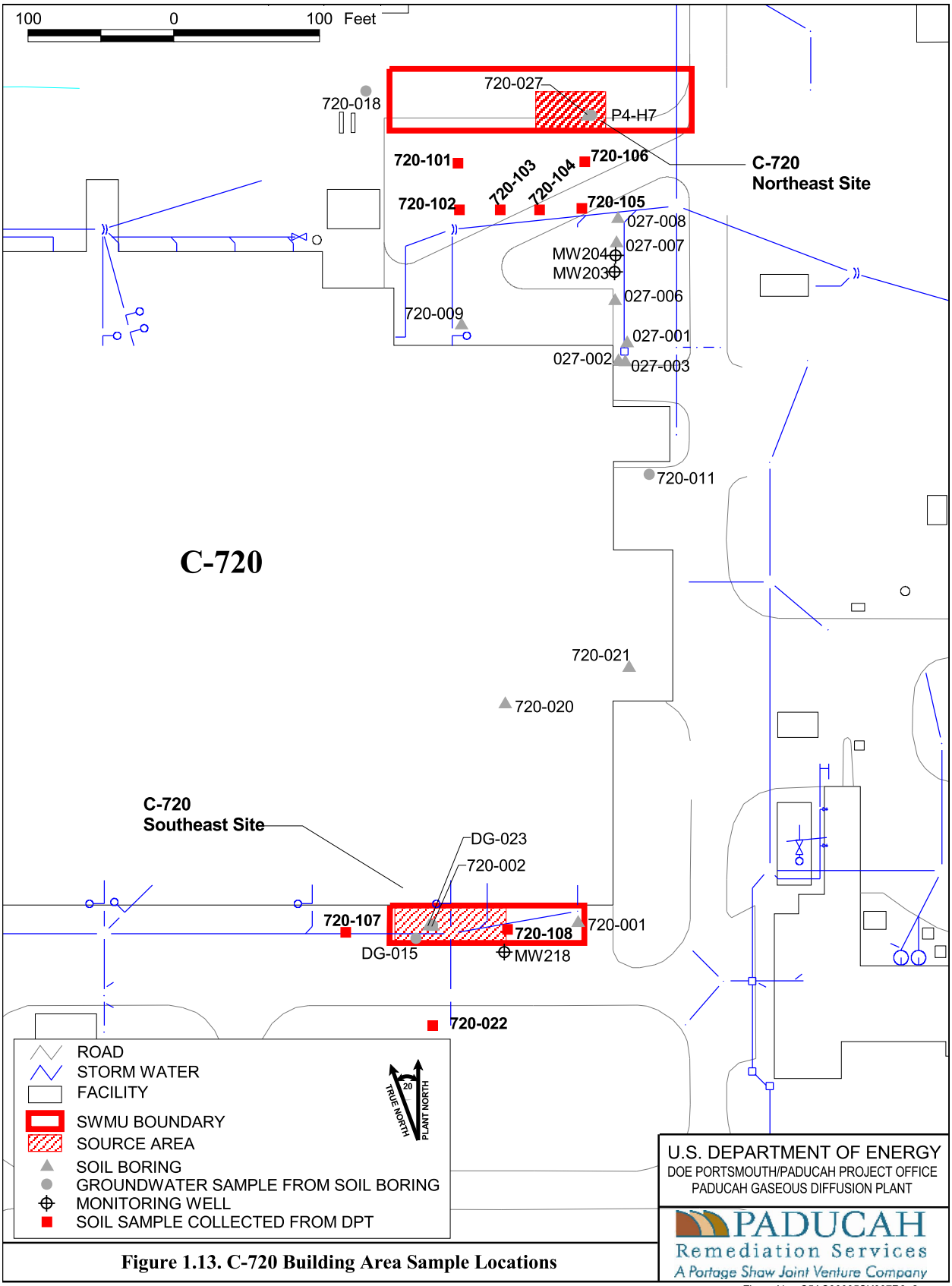

Figure 1.13. C-720 Building Area Sample Locations

products. The results indicated that the locations sampled were at the periphery of the source area defined in the WAG 27 RI. Results from SI sampling are provided on Figure 1.14.

Storm Sewer. The initial phase for the Southwest Plume SI of the Storm Sewer involved verifying the integrity of the Storm Sewer itself. Any breaks or cracks in the Storm Sewer could act as potential pathways for contamination. A video system was used to inspect approximately 914.4 m (3,000 ft) of the storm sewer from the east side of the C-400 Building to Outfall 008. The video indicated that the Storm Sewer had maintained its structural integrity. The actual physical properties of the Storm Sewer (diameter and length of pipe in sections) were different than expected in some areas, and these differences were documented for future reference. There were no significant holes or fractures visible in the Storm Sewer. The MIP/DPT samples were placed at locations near potential weaknesses in the storm sewer walls at depths of 5.73 and 6.1 m (18.8 to 20 ft) bgs, which is near but below the base of the storm sewer.

Soil sample results from the Southwest Plume SI indicated that low-levels of VOCs were present in the backfill at the Storm Sewer (DOE 2007). No groundwater samples were taken during the investigation of this unit. A video survey that confirmed the integrity of the Storm Sewer, combined with the soil sampling results, demonstrated that the Storm Sewer was not a source of contamination to the Southwest Plume; therefore, the Storm Sewer was not carried forward in the FFS for alternative evaluation.

Analytical Data. Analytical data from previous investigations that were representative of current site conditions and met the requirements of the Risk Methods Document as well as the extensive data collected during the most recent Southwest Plume SI were utilized in support of this evaluation (DOE 2001a). These datasets have been verified, validated, and assessed as documented in the respective investigations. The datasets were determined to meet the project goals and determined acceptable for use in decision making. Potential source areas, as determined by the analytical results, were examined, and potential site-related contaminants were identified.

DOE Plant Controls

Current DOE plant controls associated with the Oil Landfarm and the C-720 Area Northeast and Southeast Sites consist of the following:

- The sites are within areas protected from trespassing under the 1954 Atomic Energy Act as amended (referred to as the 229 Line). These areas are posted as “no trespassing” and trespassers are subject to arrest and prosecution. Physical access to the PGDP is prohibited by security fencing, and armed guards patrol the DOE property 24 hours per day to restrict workers entry and prevent uncontrolled access by the public/site visitors. These existing access controls are maintained outside of the requirements of CERCLA due to the nature and security needs of the facility (DOE 2008).

- Vehicle access to the sites is restricted by passage through Security Post 57 and by the plant vehicle protection barrier.

- The sites are in areas that are subject to routine patrol and visual inspection by plant protective forces, at a minimum once per shift.

- Protection of the current PGDP industrial workers is addressed under DOE’s Integrated Safety Management System/Environmental Management System program and 29 *CFR* § 1910. Interim work area access controls that may be used under these programs during implementation of a remedy include warning and informational signage, temporary fencing and/or barricades, and visitor sign-in controls. These existing access controls are implemented for protection of worker safety and health and are outside the requirements of CERCLA. The designated locations for these interim access

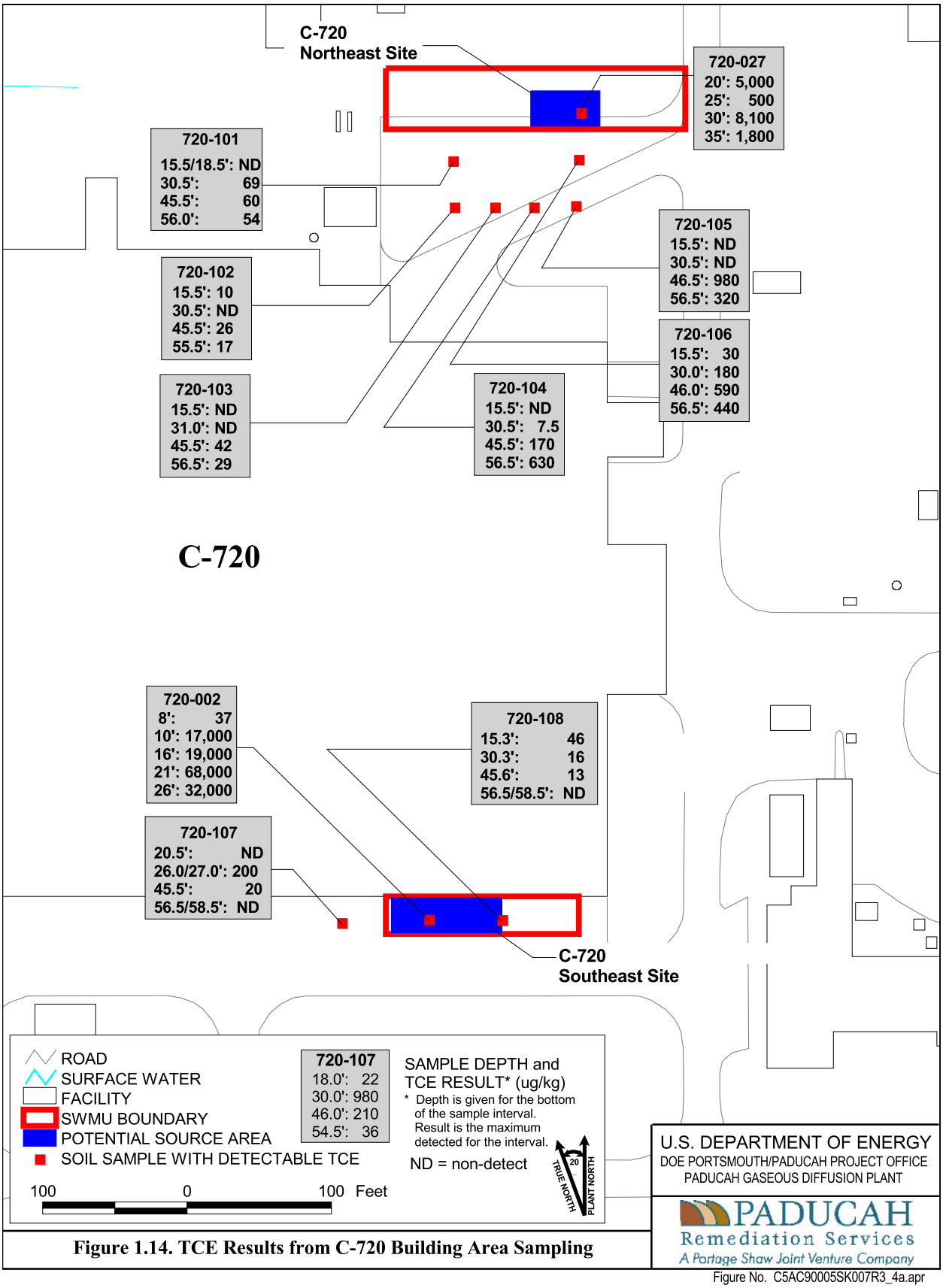

Figure 1.14. TCE Results from C-720 Building Area Sampling

Figure No. C5AC90005SK007R3_4a.apr
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- controls are provided in the Remedial Action Work Plan (RAWP) and depicted in a figure of appropriate scale. Upon completion of the remedial action, these interim controls would cease.

- Section XLII of the FFA requires the sale or transfer of the site to comply with Section 120(h) of CERCLA. In the event DOE determines to enter into any contract for the sale or transfer of any of PGDP, DOE will comply with the applicable requirements of Section 120(h) in effectuating that sale or transfer, including all notice requirements. In addition, DOE will notify EPA and Kentucky of any such sale or transfer at least 90 days prior to such sale or transfer.

1.2.4 Contaminant Fate and Transport

1.2.4.1 Previous modeling

Previous fate and transport modeling of selected VOCs (TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC) in subsurface soil to RGA groundwater was conducted as part of the Southwest Plume SI. See Appendix C, Modeling Methodology for additional information and results of the modeling. The BHHRA used these modeling results to estimate the future baseline risks that might be posed to human health and the environment through contact with groundwater impacted by contaminants migrating from the Oil Landfarm and C-720 Building Area to four points of exposure (POEs). The POEs assessed were at the source, the plant boundary, DOE property boundary, and near the Ohio River. This analysis was initiated after it was observed that cleanup levels protective of a rural resident using groundwater drawn from a well at the PGDP property boundary were similar to or less than the average concentrations of TCE in the Oil Landfarm and C-720 Building Area sources (DOE 2007).

Inhalation of vapor released from the groundwater into home basements was modeled quantitatively for rural residents based on measured TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC concentration at the Oil Landfarm and the C-720 Building area, as well as modeled TCE concentrations at the plant and property boundaries. The potential air concentrations were used for estimating excess lifetime cancer risk (ELCR) and hazard for the hypothetical future on- and off-site rural resident. Additional fate and transport modeling was conducted during the FFS to support evaluation of remedial alternatives and to calculate soil remedial goals.

1.2.4.2 Properties of site-related chemicals

Generally, the fate and transport of TCE and its degradation products (*cis*-1,2-DCE, *trans*-1,2-DCE, and VC), which are organic compounds, are functions of both site characteristics and the physical and chemical interactions between the contaminants and the environmental media with which they come into contact. The physical and chemical properties of the contaminants that influence these interactions include, but are not limited to, (1) their solubility in water, (2) their tendency to transform or degrade (usually described by an environmental half-life in a given medium), and (3) their chemical affinity for solids or organic matter (usually described by a partitioning coefficient: K_d, K_{oc}, or K_{ow}).

TCE and its Degradation Products. TCE and its degradation products may be degraded in the environment by various processes including hydrolysis, oxidation/reduction, photolysis, or biodegradation. Both aerobic and anaerobic degradation of TCE may occur. Although degradation may reduce the toxicity of a chemical, in the case of TCE, degradation may result in more toxic degradation products, such as VC. Both *cis*- and *trans*-1,2-DCE may be indicators of reductive dechlorination for this degradation pathway or contaminants of industrial grade TCE.

Degradation Rates. In a report entitled *Evaluation of Natural Attenuation Processes for Trichloroethylene and Technetium-99 in the Northeast and Northwest Plumes at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, KY/EM-113, (LMES 1997) biodegradation rates of 0.026 to 0.074 $year^{-1}$ were estimated. These biodegradation rates correspond to TCE half-lives of 26.7 and 9.4 years, respectively. The Idaho National Laboratory is one of a few aerobic aquifer settings where dissolved TCE degradation rates have been documented. *An Evaluation of Aerobic Trichloroethene Attenuation Using First-Order Rate Estimation* (Sorenson *et al.* 2000) determined that the TCE degradation half-life for Idaho National Laboratory ranged between 13 and 21 years, which compares favorably to the rates determined for PGDP. The *PGDP TCE Biodegradation Investigation Summary Report Regional Gravel Aquifer and Northwest Plume* (KRCEE 2008) provides additional information on the current understanding of aerobic degradation studies performed at PGDP.

Recently, as part of the development of response actions including the Southwest Plume SI, DOE completed fate and transport modeling for PGDP using revised biodegradation rates for the RGA. The revised biodegradation rates were developed using regulator accepted methods presented in *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (EPA 1998b) and data from the Northwest Plume, the most thoroughly characterized of the dissolved-phase plumes at PGDP. Sampling results collected from the Northwest Plume indicate that TCE concentrations decrease with distance at a faster rate than selected inorganic contaminants (i.e., chloride and ^{99}Tc). Analyses using these inorganic tracers yielded a dissolved-phase TCE degradation factor with a range of 0.0614 to 0.2149 $year^{-1}$. This degradation factor corresponds to a TCE half-life of 11.3 to 3.2 years, respectively. Appendix F of the Southwest Plume SI presents a detailed discussion of the derivation of this degradation rate.

TCE degradation rates in the UCRS have not been determined. Investigation of TCE degradation in the UCRS is an ongoing project.

Mobility. The mobility of TCE and its degradation products, like all organic compounds, is affected by its volatility, its partitioning behavior between solids and water, water solubility, and concentration. The Henry's Law constant value (K_H) for a compound is the ratio of the compound's vapor pressure to its aqueous solubility. The K_H value can be used to make general predictions about the compound's tendency to volatilize from water. Vapor pressure is a measure of the pressure at which a compound and its vapor are in equilibrium. The value can be used to determine the extent to which a compound would travel in air, as well as the rate of volatilization from soils and solution. TCE and its degradation products have high vapor pressures and Henry's Law constants, indicating a potential for volatilization; therefore, they are not expected to persist in surface soils. The rate of loss from volatilization depends on the compound, temperature, soil gas permeability, and chemical-specific vapor pressure.

Transport mechanisms for TCE include gravity-driven migration as a DNAPL. The range of K_{oc} values indicates that these chlorinated VOCs are relatively mobile through soils as dissolved constituents and tend not to partition significantly from water to soil; however, some of these compounds are retained in pore spaces in the form of DNAPLs. A DNAPL migrates principally under the influence of gravity and will migrate vertically, fingering out among available pore space. As it migrates downward, capillary forces act to retain a portion of the DNAPL within the soil matrix. This retained portion, called residual saturation, is at equilibrium with pressure, gravity, and capillary forces. DNAPL at residual saturation will remain entrapped unless the balance of forces changes. Depending upon the soil texture, entrapped residual organic saturations may vary from approximately 4% to 10% of the pore space in the unsaturated soil zone to as high as 20% of the pore space in the saturated zone (Abriola *et al.* 1998).

If a DNAPL is present in sufficient quantity, it may spread laterally along lower permeability zones it encounters and even pool there if a sufficiently large lower permeability zone exists. This type of

migration allows a DNAPL to take a highly variable path and be difficult to fully characterize in areas where the geology is spatially variable, such as in the UCRS at PGDP.

Solubility and sorption. Water solubility and the tendency to sorb to particles or organic matter can correlate with retardation in groundwater transport. In general, organic chemicals with high solubilities are more mobile in water than those that sorb more strongly to soils. The following properties dictate an organic chemical's mobility within a specific medium.

- K_{oc} (the soil organic carbon partition coefficient) is a measure of the tendency for organic compounds to be sorbed to the organic matter of soil and sediments. K_{oc} is expressed as the ratio of the amount of chemical sorbed per unit weight of organic carbon to the chemical concentration in solution at equilibrium.

- K_{ow} (the octanol-water partition coefficient), is an indicator of hydrophobicity (the tendency of a chemical to avoid the aqueous phase) and is correlated with potential sorption to soils. It is also used to estimate the potential for bioconcentration of chemicals into tissues.

- K_d (the soil/water distribution coefficient) is a measure of the tendency of a chemical to sorb to soil or sediment particles. For organic compounds, this coefficient is calculated as the product of the K_{oc} value and the fraction of organic carbon in the soils. In general, chemicals with higher K_d values sorb more strongly to soil/sediment particles and are less mobile than those with lower K_d values.

1.2.4.3 Fate of DNAPL TCE in soil and groundwater

The Southwest Plume source areas were determined as part of the Southwest Plume SI (DOE 2007) to contain residual DNAPL TCE through several lines of evidence, including the following:

- Process knowledge of use of separate-phase TCE, for example at the C-720 Northeast Site;

- Soil concentrations greater than those theoretically possible from dissolved-phase TCE in pore water only, as observed at the Oil Landfarm;

- Residual soil concentrations long after last TCE use, as observed at all of the source areas; and

Concentrations of TCE and degradation products in the upper RGA of greater than 1,000 µg/L, as observed at the C-720 Northeast Site.

-

DNAPL TCE released to soils may be redistributed into multiple phases through processes including the following (ITRC 2005):

- Formation of a continuous fluid mass of pure phase, drainable DNAPL,
- Entrapment of residual pure-phase DNAPL within pores as discontinuous globules or ganglia,
- Dissolution from the DNAPL into groundwater,
- Sorption to organic and mineral constituents of the soils, and
- Volatilization into a gas phase in the unsaturated zone.

No evidence exists that DNAPL TCE released to UCRS soils at the Southwest Plume source areas continued to migrate to the RGA; therefore, any residual DNAPL exists as discontinuous globules or ganglia. Given the end of the operational period of the Oil Landfarm in 1979 and the suspected end of practices that resulted at the C-720 Building Area in the mid-to late 1980s, TCE in UCRS soils has had sufficient time for redistribution into all phases.

The presence of VOCs in UCRS groundwater was verified during the WAG 27 RI (DOE 1999a). TCE was detected in UCRS groundwater collected at the Oil Landfarm and at the C-720 Southeast Site at concentrations up to 312 µg/L and 93 µg/L, respectively.

Soil vapor sampling has not been performed at the Southwest Plume source areas; however, VOCs are expected to be present in the UCRS soil vapor due to partitioning into the air filled porosity from the residual DNAPL and from sorbed and aqueous phase VOCs. Each of the phases may be a significant contributor to the total mass of VOCs present in the UCRS.

1.2.4.4 Vapor transport modeling

Vapor transport modeling was conducted in the Southwest Plume SI to evaluate the potential air concentrations in a residential basement from soil contamination at the Oil Landfarm and the C-720 Building Area. The Johnson and Ettinger model (1991) coded into spreadsheets by EPA (2004b) was used to assess the potential migration of VOCs into a basement. The results of the vapor transport model are presented in Table 1.3 and were used as the predicted household air concentrations for estimating ELCR and hazard for the adult rural resident. The vapor hazard and cancer risk at the Oil Landfarm were 0.7 and 4.0E-05, respectively. At C-720, the vapor hazard was 4.8, and the vapor cancer risk was 7.8E-05. A summary of the risk assessment is provided in Section 1.2.5.

Table 1.3. Basement Air Concentrations Based on Vapor Transport Modeling Results for FFS Source Areas

Source Area		On-Site
	Contaminant	Air concentration (mg/m^3)
C-720 Building Area	TCE	0.15
	cis-1,2-DCE	0.015
	trans-1,2-DCE	0.057
	Vinyl Chloride	0.008
Oil Landfarm	TCE	0.019
	cis-1,2-DCE	0.004
	trans-1,2-DCE	0.001
	Vinyl Chloride	0.0002

mg/m^3 = milligrams per cubic m

1.2.5 Previous Baseline Risk Assessment

The Southwest Plume SI (DOE 2007) used historical information and newly collected data to develop a site model for each source area and presented a BHHRA and a screening ecological risk assessment (SERA). In the BHHRA, information collected during the Southwest Plume SI and results from previous risk assessments were used to characterize the baseline risks posed to human health and the environment resulting from contact with contaminants in groundwater drawn from the Southwest Plume in the RGA at the source areas. In addition, fate and transport modeling was conducted, and the BHHRA used these

modeling results to estimate the future baseline risks that might be posed to human health and the environment through contact with groundwater impacted by contaminants migrating from the Oil Landfarm and C-720 Building Area to four POEs. The POEs assessed were at the source, the plant boundary, property boundary, and near the Ohio River. Vapor transport modeling was conducted and the potential air concentrations also used as the predicted household air concentrations for estimating ELCR and hazard for the hypothetical future on- and off-site rural resident. Additional summary of the SI Baseline Risk Assessment is provided in Appendix D.

Because data collected during the SI focused on the collection of subsurface soil and groundwater data to delimit the potential sources of contamination to the Southwest Plume, the new material developed in the BHHRA and SERA was limited to risks posed by contaminants migrating from potential source areas to RGA groundwater and with direct contact with contaminated groundwater in the source areas.

Baseline Risk Assessment Conclusions. For both the Oil Landfarm and the C-720 Building Area, the cumulative human health ELCR and hazard index (HI) exceeded *de minimis* levels [i.e., a cumulative ELCR of 1×10^{-6} or a cumulative HI of 1] in the PGDP Risk Methods Document for one or more scenarios. Additionally, risks from household use of groundwater by a hypothetical on-site rural resident also exceeded those standards. The land uses and media assessed for ELCR and HI to human health for each potential source area were taken from earlier assessments with the exception of groundwater use and vapor intrusion by the hypothetical future on- and off-site rural resident. These were newly derived in the BHHRA from measured and modeled data collected during the Southwest Plume SI and previous investigations.

In the BHHRA, it was determined that the hypothetical rural residential use of groundwater scenario and vapor intrusion are of concern for both ELCR and HI at each source area, except the Storm Sewer, which is of concern for ELCR only**.** The exposure routes of ingestion of groundwater, inhalation of gases emitted while using groundwater in the home, and vapor intrusion from the groundwater into basements account for about 90% of the total ELCR and HI.

For groundwater use by the hypothetical adult resident at the Oil Landfarm, VOC COCs include TCE; *cis*-1,2-DCE; chloroform; and 1,1-DCE, all of which are "Priority COCs" (i.e., chemical-specific HI or ELCR greater than or equal to 1 or 1×10^{-4} respectively), except for 1,1-DCE. The VOCs make up 78% of a cumulative ELCR of 6.8×10^{-4} and 76% of a cumulative HI of 26. For groundwater use by the hypothetical child resident, VOC COCs include TCE; *cis*-1,2-DCE; and chloroform, all of which are "Priority COCs." These VOCs make up 85% of a cumulative HI of 99.

At the C-720 Building Area, the VOC COCs for groundwater use by the hypothetical adult resident include TCE; *cis*-1,2-DCE; VC; and 1,1-DCE**,** with all except VC being "Priority COCs." The VOCs make up 93% of a cumulative ELCR of 1.8×10^{-3} and 57% of the cumulative HI of 23**.** For groundwater use by the hypothetical child resident, VOC COCs include TCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and 1,1-DCE, all of which are "Priority COCs," except for *trans*-1,2-DCE. The VOCs make up 76% of a cumulative HI of 102.

At the Storm Sewer, the adult residential COCs include TCE and 1,1-DCE, neither of which is a "Priority COC." The VOCs make up 100% of a cumulative ELCR of 7.9×10^{-6}. The HI for the storm sewer was less than 1 and, therefore, not of concern. For groundwater use by the hypothetical child resident at the Storm Sewer, COCs include TCE and 1,1-DCE, neither of which is a "Priority COC." The VOCs make up 100% of a cumulative HI of 0.6 for the child resident.

At the property boundary for the hypothetical adult resident, the migrating COCs from the Oil Landfarm are TCE and VC, with no "Priority COCs." The VOCs make up 100% of the total ELCR of 1.4×10^{-6} and

the HI is less than 0.1. For the hypothetical child resident at the property boundary, the COCs are TCE and *cis*-1,2-DCE with no "Priority COCs." The VOCs make up 85% of a cumulative HI of 0.4 for the child resident.

The COC migrating from the C-720 Building Area to the hypothetical adult resident at the property boundary is VC, which is not a "Priority COC." The VC makes up greater than 95% of the total ELCR of 1.1×10^{-6}, and the HI is less than 0.1. For the hypothetical child resident at the property boundary, the HI is less than 0.1. Based on the previous and current modeling results, neither metals nor radionuclides are COCs for contaminant migration from the Oil Landfarm or C-720 Building Area.

The SERA, which used results taken from the Baseline Ecological Risk Assessment completed as part of the WAG 27 RI, concluded that a lack of suitable habitat in the industrial setting at the Oil Landfarm and the C-720 Building Area precluded exposures of ecological receptors under current conditions; therefore, it was determined during problem formulation that an assessment of potential risks under current conditions was unnecessary.

Uncertainty Associated with Risk in Soils. Although previous analyses have indicated that non-VOC contaminants are present in surface and subsurface soils and may present an unacceptable risk (see Appendix D), there exists uncertainty as to whether non-VOC contaminants currently are present at levels that pose an unacceptable risk to human health. The uncertainty arises from changes in toxicity values, changes in exposure parameters, and the current level of contaminants present at the Oil Landfarm after completion of a previous removal action. The presence or absence of an unacceptable risk will be addressed as part of the Soils OU.

2. IDENTIFICATION AND SCREENING OF TECHNOLOGIES

Technology types and process options that may be applicable for remediation of Southwest Plume sources are identified, screened, and evaluated in this section. A primary objective of this FFS is to identify remedial technologies and process options that potentially meet the RAOs for this action and then combine them into a range of remedial alternatives. The potential remedial technologies are evaluated for implementability, effectiveness, and relative cost in eliminating, reducing, or controlling risks to human health. The criteria for identifying, screening, and evaluating potentially applicable technologies are provided in EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988) and the NCP.

CERCLA, the NCP, and EPA guidance require development and evaluation of a range of responses, including a No Action Alternative, to ensure that an appropriate remedy is selected. The selected final remedy must comply with ARARs and must protect human health and the environment. The technology screening process consists of a series of steps that include these:

- Identifying general response actions (GRAs) that may meet RAOs, either individually or in combination with other GRAs;
- Identifying, screening, and evaluating remedial technology types for each GRA; and
- Selecting one or more representative process options (RPOs) for each technology type.

Following the technology screening, the RPOs are assembled into remedial alternatives that are evaluated further in the detailed and comparative analyses of alternatives.

2.1 INTRODUCTION

Previous PGDP investigations and reports used to develop the conceptual site model and to identify and screen remedial technologies include the following:

- WAG 27 RI (DOE 1999a). This investigation focused on groundwater contaminant sources at the Oil Landfarm; SWMU 91 (UF_6 Cylinder Drop Test Site); SWMU 196 (C-746-A Septic Systems); and the C-720 Building Area. Geology, hydrogeology, and DNAPL source area descriptions were obtained from this source.
- *Feasibility Study for the Groundwater Operable Unit at Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2001b). This report refined the conceptual models for DNAPL distribution at source areas and identified and evaluated alternatives for remediating contaminated groundwater and source areas. Technology identification and screening were reviewed and updated as necessary and incorporated in the FFS.
- *Innovative Treatment and Remediation Demonstration* (ITRD), Paducah Groundwater Project Innovative Technology Review (Hightower *et al.* 2001). Technology identification and screening were reviewed, updated as necessary, and incorporated in the FFS.
- *Evaluation of Groundwater Management/Remediation Technologies For Application to the Paducah Gaseous Diffusion Plant* (KRCEE 2005). This report updated the previous ITRD (Hightower *et al.* 2001) in light of results of field demonstrations of soil and groundwater remedial technologies. This report was used primarily to aid in evaluation of technologies selected as RPOs.

- Southwest Plume SI (DOE 2007). This report described investigations at Southwest Plume source areas and further refined the site conditions. This report was the primary source for description of nature and extent of DNAPL source areas and source area lithology.

Other sources used in technology identification and screening, including EPA, DOE, and peer-reviewed databases and reports and journal publications, are cited and references provided.

Technologies and remedial alternatives are identified and evaluated in this FFS based on their effectiveness in reducing or eliminating contaminant sources including PTW, eliminating or mitigating the release mechanisms, or eliminating the exposure pathways for the Oil Landfarm and the C-720 Area Northeast and Southeast Sites.

2.2 REMEDIAL ACTION OBJECTIVES AND REMEDIATION GOALS

The RAOs and remediation goals (RGs) for the Southwest Plume FFS are identified in this section. RAOs consist of site-specific goals for protecting human health and the environment (EPA 1988) and meeting ARARs. The media and COCs to be addressed are discussed in Section 1 and ARARs are identified and discussed in Section 4. The following RAOs for the Southwest Plume were developed by a working group comprised of the DOE, Paducah Remediation Services, LLC, EPA, and the Commonwealth of Kentucky:

(1) Treat and/or remove PTW consistent with the NCP.

(2a) Prevent exposure to VOC contamination in the source areas that will cause an unacceptable risk to excavation workers (< 10 ft).

(2b) Prevent exposure to non-VOC contamination through interim land use controls within the Southwest Plume source areas (i.e., SWMU 1, SWMU 211-A, and SWMU 211-B) pending remedy selection as part of the Soils OU.

(3) Reduce VOC migration from contaminated subsurface soils in the source areas to the RGA groundwater to the extent they do not contribute contamination exceeding MCLs in the area of attainment at the Oil Landfarm and C-720 Northeast and Southeast Sites.

Worker protection RGs are VOC concentrations in soils present at depths of 0-10 ft that would meet RAO #2a with no other controls necessary. Worker protection RGs were obtained from the Action Levels for the excavation worker stated in Appendix A, Table A.4, of the DRAFT *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky* (DOE 2009b). Worker protection RGs for VOCs in the source areas at levels of protection ranging from ELCR of 1E-04 to 1E-06, and HIs of 1E-01 to 3 are provided in Table 2.1.

For purposes of the FFS, the area of attainment encompasses the RGA directly below and within the boundaries of the Oil Landfarm and C-720 Northeast and Southeast Sites. Groundwater protection RGs are VOC concentrations in subsurface soils above the area of attainment that would meet RAO #3 with no other controls necessary. The area of attainment and subsurface soil areas where the RGs will be met are shown in Figures 1.9 and 1.10 for the Oil Landfarm and C-720 Northeast and Southeast Sites, respectively.

Groundwater modeling was conducted deterministically using the methodology presented in Appendix C to determine the groundwater protection RGs. The groundwater protection RGs are provided in Table 2.2. The RGs were calculated for TCE half-lives in UCRS soils ranging from 5 years to 50 years to assess the

effects of high to low rates of degradation on overall remedy time frames (50 years essentially representing no observable degradation). Other VOCs were assumed not to be degraded. It is expected that as part of the ROD the RGs for RAO #3 will be revisited and assessed in detail with regard the components of the selected remedy.

Table 2.1 Worker Protection RGs for VOCs at the C-720 Area and the Oil Landfarm Source Areas, mg/kg[a]

VOC	ELCR 1E-06	ELCR 1E-05	ELCR 1E-04	HI = 0.1	HI = 1.0	HI =3.0
TCE	5.85E-02	5.85E-01	5.85E+00	1.93	19.3	57.9
1,1-DCE	6.26E-02	6.26E-01	6.26E+00	25	250	750
cis-1,2-DCE	NV	NV	NV	8.94	89.4	268.2
trans-1,2-DCE	NV	NV	NV	11.70	117	351
Vinyl chloride	1.10E-01	1.10E+00	1.10E+01	8	80	240

[a]Shaded RG values exceed the average concentration reported in Appendix C for the 0-10 ft interval at the Oil Landfarm and the C-720 Area
ELCR = excess lifetime cancer risk
HI = hazard Index
NV = no value

Table 2.2. Groundwater Protection RGs for VOCs at the C-720 Area and the Oil Landfarm Source Areas

	C-720 Northeast and Southeast Sites		
VOC	**Half-Life (yr)**	**MCL (mg/L)**	**UCRS Soil RG (mg/kg)[a]**
TCE	5	5.00E-03	9.20E-02
TCE	25	5.00E-03	8.30E-02
TCE	50	5.00E-03	7.50E-02
1,1-DCE	infinite	7.00E-03	1.37E-01
cis-1,2-DCE	infinite	7.00E-02	6.19E-01
trans-1,2-DCE	infinite	1.00E-01	5.29E+00
Vinyl Chloride	infinite	2.00E-03	5.70E-01
	Oil Landfarm		
TCE	5	5.00E-03	8.50E-02
TCE	25	5.00E-03	8.00E-02
TCE	50	5.00E-03	7.30E-02
1,1-DCE	infinite	7.00E-03	1.30E-01
cis-1,2-DCE	infinite	7.00E-02	6.00E-01
trans-1,2-DCE	infinite	1.00E-01	1.08E+00
Vinyl Chloride	infinite	2.00E-03	3.40E-02

[a]Based on a dilution attenuation factor of 59

An uncertainty analysis was conducted, using probabilistic modeling, to evaluate the soil remediation goals for TCE. Time to attainment of RGs for each alternative retained after screening in Section 3 also was modeled. The methodology and results are described in Appendix C and are summarized in Section 4.

2.3 GENERAL RESPONSE ACTIONS

GRAs are broad categories of remedial measures that produce similar results when implemented. The GRAs evaluated for this FFS include land use controls, containment, treatment, removal, and disposal. The identified GRAs may be implemented individually or in combination to meet the RAOs. Table 2.3 lists the GRAs, as well as the technology types and process options that flow down from each.

Formulation of a No Action Alternative is required by the NCP [40 *CFR* § 300.430(e)(6)]. The No Action Alternative serves as a baseline for evaluating other remedial action alternatives and generally is retained throughout the FS process. No action implies that no remediation will be implemented to alter the existing site conditions. As defined in CERCLA guidance (EPA 1988), no action may include environmental monitoring.

2.3.1 Land Use Controls

Land use controls for the CERCLA sites at PGDP are summarized in Table A.1 (see Appendix A) and discussed in the following sections.

2.3.2 Monitoring.

Technologies for monitoring are included under this GRA. Monitoring includes measurement methods to determine nature and extent of contamination, progress of cleanup, and site properties relevant to specific remediation technologies.

2.3.3 Monitored Natural Attenuation

Monitored natural attenuation (MNA) relies on natural processes to achieve site-specific remedial objectives. Processes may include physical, chemical, or biological processes that reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. Monitoring of contaminant concentrations and process-specific parameters to ensure protection of human health and the environment during implementation is a critical element of MNA.

2.3.4 Removal

RAOs potentially may be met by removing VOC-contaminated soils. Removal generates secondary wastes potentially requiring *ex situ* treatment and disposal or discharge.

2.3.5 Containment

Containment isolates contaminated media from release mechanisms, transport pathways, and exposure routes using surface and/or subsurface barriers, thereby reducing contaminant flux and reducing or eliminating exposures to receptors. Containment alone does not reduce the volume or toxicity of the contaminant source. Containment alone would not meet RAO #1, but could be an effective component of an overall alternative incorporating treatment and/or removal of PTW.

2.3.6 Treatment

Treatment reduces the toxicity, mobility, or volume of contaminants or contaminated media. Contaminant sources may be reduced or eliminated, and contaminant migration pathways and exposure routes may be eliminated. *In situ* methods treat contaminants and media in place without removal. *Ex situ* methods treat contaminants or media after removal.

2.3.7 Disposal

Disposal may include land disposal of solid wastes or discharge of liquid or vapor phase effluents generated during waste treatment processes.

2.4 IDENTIFICATION AND SCREENING OF TECHNOLOGY TYPES AND PROCESS OPTIONS

This section identifies remedial technologies and process options that potentially may meet the RAOs, and provides a preliminary screening based on implementability. The technologies are described and the potential effectiveness in meeting the RAOs and the technical implementability in the UCRS are discussed. Performance data are cited and discussed, and limitations and data needs are identified, as applicable.

The results of the technology screening are detailed in the following text and in Table A.1 (see Appendix A) and are summarized in Table 2.3. Technologies and process options that pass the preliminary screening are evaluated further in Section 2.6, based on effectiveness and relative cost. RPOs that will be used to develop the remedial alternatives are selected in Section 2.7.

Table 2.3. Results of Technology Identification and Screening

General Response Action	Technology Type	Process Options	Screening Comments[a]
Land use controls	Institutional controls	E/PP program	Technically implementable
Monitoring	Soil monitoring	Soil cores	Technically implementable
		Membrane interface probe	Technically implementable
		Soil vapor sampling	Technically implementable
		Soil moisture monitoring and sampling	Technically implementable
		Gore-sorbers	Technically implementable
		Raman spectroscopy	Technically implementable
	Groundwater monitoring	Sampling and analysis	Technically implementable
		Partitioning interwell tracer test	Low technical implementability
		Diffusion bags	Technically implementable
		Borehole fluxmeter	Technically implementable
		Ribbon NAPL Sampler	Technically implementable
		DNAPL interface probe	Technically implementable
Monitored Natural Attenuation	Monitoring and natural processes	Soil and groundwater monitoring; abiotic and biological processes	Technically implementable
Removal	Excavators	Backhoes, trackhoes	Technically implementable
		Vacuum excavation, remote excavator	Technically implementable
		Crane and clamshell	Technically implementable
Containment	Hydraulic containment	Recharge controls	Technically implementable.

Table 2.3. Results of Technology Identification and Screening (Continued)

General Response Action	Technology Type	Process Options	Screening Comments[a]
		Groundwater extraction	Technically implementable only as a secondary technology for other treatments.
	Surface barriers	RCRA Subtitle C cover	Technically implementable
		Concrete-based cover	Technically implementable
		Conventional asphalt cover	Technically implementable
		MatCon asphalt	Technically implementable
		Flexible membrane	Technically implementable
	Subsurface horizontal barriers	Freeze walls	Technically implementable
		Conventional asphalt cover	Technically implementable
		MatCon asphalt	Technically implementable
		Flexible membrane	Technically implementable
	Subsurface horizontal barriers	Freeze walls	Technically implementable
		Jet grouting	Not technically implementable
		Permeation grouting	Not technically implementable
		Soil fracturing	Technical implementability uncertain-field demonstration required
	Subsurface vertical barriers	Slurry walls	Technically implementable
		Sheet pilings	Technically implementable
		Permeable reactive barrier	Technically implementable
Treatment	Biological	Anaerobic reductive dechlorination-*in situ*	Technically implementable
		Aerobic cooxidation-*in situ*	Technically implementable
		Phytoremediation-*in situ*	Not technically implementable due to depth of VOC contamination
	Physical/Chemical	Soil vapor extraction-*in situ*	Technically implementable
		Air sparging-*in situ*	Technically implementable
		Soil flushing-*in situ*	Technically implementable
		Electrokinetics-*in situ*	Technically implementable
		Air stripping-*ex situ*	Technically implementable
		Ion exchange-*ex situ*	Technically implementable
		Granular activated carbon-*ex situ*	Technically implementable

Table 2.3. Results of Technology Identification and Screening (Continued)

General Response Action	Technology Type	Process Options	Screening Comments[a]
		Vapor condensation	Technical implementability uncertain
		Soil fracturing-*in situ*	Technical implementability uncertain
		Soil mixing-*in situ*	Technically implementable
	Thermal	Catalytic oxidation-*ex situ*	Technically implementable
		Electrical resistance heating- *in situ*	Technically implementable
		Thermal desorption-*ex situ*	Technically implementable
		Steam stripping-*in situ*	Technically implementable
	Chemical	Permanganate-*in situ*	Technically implementable
		Fenton's reagent-*in situ*	Technically implementable
		ZVI-*in situ*	Technically implementable
		Ozonation-*in situ*	Technically implementable
		Persulfate-*in situ*	Technically implementable
		Redox manipulation-*in situ*	Technically implementable
Disposal	Land disposal	Off-site permitted commercial disposal facility	Technically implementable
		NTS	Technically implementable
		PGDP C-746-U Landfill	Technically implementable
	Discharge to groundwater	Within area of contamination after treatment	Technically implementable
	Discharge to surface water	Permitted outfall after treatment	Technically implementable

[a]Gray shading indicates that the technology was screened out as not applicable or not technically implementable.

2.4.1 Identification and Screening of Technologies

Each GRA, technology type, and process option listed in Table 2.3 is discussed in the following subsections.

2.4.1.1 Land use controls

Land use controls (LUCs) include administrative restrictions on activities allowed on a property. The existing Excavation/Penetration Permit program, discussed below, is an interim LUC intended to achieve RAOs 2a and 2b.

Excavation/Penetration (E/P) Permit program—The E/P program is an interim LUC administered by DOE's contractors at PGDP and currently includes a specific permitting procedure (PRS-WCE-0026 or equivalent) designed to provide a common sitewide system to identify and control potential personnel

hazards related to trenching, excavation, and penetration. The E/P permits are issued by the Paducah Site's DOE Prime Contractor. The primary objective of the E/P permits procedure is to provide notice to the organization requesting a permit of existing underground utility lines and/or other structures and to ensure that any E/P activity is conducted safely and in accordance with all environmental compliance requirements pertinent to the area (DOE 2008).

The E/P permits procedure

- Requires formal authorization (i.e., internal permits/approvals) before beginning any intrusive activities at PGDP;
- Is reviewed annually; and
- Is implemented by trained personnel knowledgeable in its requirements.

An initial draft of an E/P permit is reviewed by project support groups to ensure that the latest updates in engineering drawings, utility drawings, and SWMU inventories are considered prior to the issuance of an E/P permit.

Existing DOE plant controls are discussed in Section 1.2.3. Accordingly, the PGDP is a federal facility with restricted access by the general public. Physical access to PGDP is prohibited by security fencing, and armed guards patrol the DOE property 24 hours per day to restrict workers entry and prevent uncontrolled access by the public/site visitors. These existing access controls are being maintained outside of the requirements of CERCLA due to the nature and security needs of the facility; nonetheless, the existing controls serve to protect against unacceptable/uncontrolled exposures.

2.4.1.2 Monitoring Technologies

Monitoring may be used in combination with other technologies to meet RAOs. Monitoring for the Oil Landfarm and the C-720 Northeast and Southeast Sites could include initial determination of the extent of VOC contamination, determination of soil contaminant concentrations during excavation, post-remedial action monitoring to determine attainment of RAOs, and long-term post-remedial action compliance monitoring. Monitoring for VOCs including DNAPL in soil and groundwater is discussed below.

Soil Monitoring. Soil monitoring may be used before, during, and after remediation to determine extent and concentrations of VOCs. Soil monitoring technologies potentially applicable to the Southwest Plume source areas are discussed below.

Soil Cores. Collection of soil cores and laboratory analysis for VOCs may be used to identify the extent and distribution of contamination and areas of TCE DNAPL residual saturation. Continuous soil cores may be obtained using DPT, hollow-stem auger or other drilling methods, and TCE extracted and measured using gas chromatography-mass spectrometry (GC-MS) or gas chromatography-electron capture detector (GC-ECD). Measured TCE concentrations may be compared to threshold values [e.g., 1% by weight (10,000 mg/kg)] as indirect evidence of presence of DNAPL. The following are other actions that can be taken to improve the overall precision of coring methods for locating chlorinated solvent DNAPL (Kram *et al.* 2001).

- Samples can be immediately immersed in methanol to inhibit the amount of volatilization due to handling and transport.

- Samples can be subject to field "shake tests" in which density differences between the relatively heavier DNAPL and water are qualitatively identified.

- Samples can be exposed to ultraviolet fluorescence with a portable meter to qualitatively identify potential fluorophores in an oil phase.

- Sudan IV or Oil Red O dye can be added to samples; these turn orange-red in the presence of nonaqueous-phase liquid (NAPL) to qualitatively identify separate phases.

- Soil vapors and cutting fluids generated while drilling can be analyzed.

- Soils, fluids, and vapors within a cavity or along a trenched wall of a test pit can be analyzed.

- A small amount of soil or water can be placed in a container that is immediately sealed, equilibrated, and a sample of the vapors that have partitioned into the headspace portion in the container can be analyzed per EPA Method 5021.

This technology is effective, technically implementable, and commercially available and is retained for further evaluation.

Membrane interface probe. The MIP technology was described in the Southwest Plume SI (DOE 2007) and the following discussion is taken from that report. The MIP is used for real-time VOC profiling and sampling. MIP sampling uses a heating element and gas permeable membrane. The element heats the material surrounding the probe, causing the VOCs contained in the material to vaporize. Vapors enter the probe through a gas permeable membrane and are transported through tubing to the surface by an inert carrier gas. The sample then is analyzed in the field with equipment appropriate to the needs of the investigation.

A photoionization detector (PID) is used for detection of VOCs, and an electron capture detector (ECD) is used for quantitation. When quantitative analysis of individual VOC species is needed, the surface analytical equipment consists of a GC-MS, direct sampling ion-trap mass spectrometer, or photo-acoustic analyzer.

This technology is effective, technically implementable using DPT, commercially available, and is retained for further evaluation.

Soil Vapor Sampling. Soil vapor sampling may be used to determine concentrations of VOCs in soil air-filled pore space, and thereby indirectly determine the presence and extent of DNAPL TCE. Drive points connected to plastic or stainless steel tubing are driven or pushed to the desired depth and soil vapor extracted and either containerized for later analysis or analyzed directly using GC-MS, ECD, or PID. This technology is effective and commercially available, but only technically implementable in the unsaturated zone. This technology is retained for further evaluation.

Soil Moisture Monitoring and Sampling. Soil moisture monitoring may be used to monitor the effectiveness of technologies aimed at restricting infiltration of water (e.g., capping). Soil moisture monitoring devices, including tensiometers and time domain reflectometry (TDR) arrays, may be installed in the soil column and moisture content and soil matrix potential monitored. These soil moisture data may be used to assess the effects of capping on mitigating infiltration and contaminant transport.

Neutron probe devices may be used to measure soil moisture in the subsurface through aluminum access tubes. The tubes are driven to the desired depth and neutron probes lowered into the tubes. Neutrons emitted by an 241-Americium source in the detector are attenuated by water, providing an *in situ*

measurement of the soil moisture content. The detector signal is transmitted to a data recorder at the surface and the soil moisture content determined relative to a calibration standard.

Soil moisture sampling using suction lysimeters may be used to determine dissolved-phase concentrations of TCE and its degradation products in soil pore water and thereby progress toward attainment of RAOs. Porous cups attached to plastic tubing are installed in silica flour in drilled or driven boreholes. Vacuum is applied to tubing causing water to flow into the porous cup. After water has collected in the cup, the vacuum is released and positive pressure is applied. The collected water then flows up a second length of tubing to a collection vessel at the surface and analyzed using GC-MS, ECD, or PID.

Soil moisture monitoring and sampling technologies are effective, technically implementable in the unsaturated zone, and commercially available. These technologies are retained for further evaluation.

Gore-Sorbers®. Passive soil gas collectors including Gore-Sorbers may be used to determine the nature of contamination. The Gore-Sorber® module is a passive soil gas sampler that consists of several separate sorbent collection units called sorbers (EPA 1998b). Each sorber contains sorbent materials selected for their broad range of VOCs and SVOCs and for their hydrophobic characteristics. The sorbers are sheathed in a vapor permeable insertion and retrieval cord constructed of inert, hydrophobic material that allows vapors to move freely across the membrane and onto the sorbent material and protects the granular adsorbents from physical contact with soil particulates and water.

The Gore-Sorber® module is installed to a depth of 0.61 to 0.91 m (2 to 3 ft). A pilot hole is created using a slide hammer and tile probe or hand drill (in paved areas). The sampler then is manually inserted into the hole using push rods. The module is left in place for about 10 days, retrieved by hand, and must be analyzed by the developer.

This technology is effective, technically implementable, commercially available, and is retained for further evaluation.

Raman Spectroscopy. Raman spectroscopy relies on the detection of light wavelength shifts from compounds of interest and is capable of direct identification of several chlorinated DNAPL constituents (Kram *et al.* 2001). Raman spectroscopy is used to detect light scattered from incident radiation, typically from a laser.

A Raman device has been coupled to a cone penetrometer (CPT) platform and successfully used to identify subsurface DNAPL constituents by their unique spectral signatures at the Savannah River Site in Aiken, South Carolina. Although confirmation samples are not required to verify a Raman detection of DNAPL, the Raman technique may require a threshold mass fraction of DNAPL for detection. As with other strategies, confirmation samples are advised.

This technology is potentially effective for DNAPL TCE detection, technically implementable, and is commercially available. This technology is retained for further consideration.

Groundwater Monitoring. Groundwater monitoring may be used in the UCRS or RGA saturated zones before, during, and after remediation to determine extent and concentrations of VOCs. Monitoring technologies potentially applicable to groundwater in the Oil Landfarm and the C-720 Northeast and Southeast Sites are discussed below.

Sampling and Analysis. Conventional groundwater sampling consists of withdrawing a representative sample of groundwater from a well or drive point, using a variety of pump types or bailers, and analyzing the contents either on-site or in a fixed-base laboratory. This technology is widely used for compliance monitoring and is effective, technically implementable, and commercially available. Vibration caused by

construction and drilling activities, in particular sonic drilling, has been observed to induce coalescing and movement of DNAPL (Payne *et al*. 2008). This technology is retained for further evaluation.

Partitioning Interwell Tracer Test. The Partioning Interwell Tracer Test (PITT) was discussed in the Innovative Technology Report (Hightower *et al.* 2001) and this discussion is taken from that source. The PITT is a proprietary technology marketed by Duke Engineering and Services that can be used prior to surfactant flushing to assess DNAPL volumes. The PITT uses injection of surfactant mixtures and numerical analysis of recovery proportions to measure the volume and describe the spatial distribution of subsurface DNAPL contamination zones. The PITT may be used in both the vadose and saturated zones, and reportedly can locate low-volume quantities [3.78 liters (1 gal)] of DNAPL.

At Paducah, the technology has most application in the RGA, due to heterogeneity and low well yields in the UCRS. The cost of the technology is high relative to other monitoring technologies. The effectiveness and technical implementability of this technology for monitoring of DNAPL TCE in the UCRS are low; therefore, this technology is screened from further consideration.

Diffusion Bags. Diffusion bags are passive groundwater sampling devices that can be hung in wells to collect VOCs or other soluble contaminants (ITRC 2002). Semipermeable diffusion bags containing deionized water are allowed to equilibrate with surrounding groundwater and eventually reach the same concentrations of soluble constituents. Diffusion bags can avoid some of the problems associated with obtaining representative groundwater samples using conventional methods and are useful in vertical profiling of contaminant distributions. Diffusion bags may be used in plume mapping and compliance monitoring. This technology is effective, technically implementable, commercially available, and is retained for further evaluation.

Borehole Fluxmeter. The passive fluxmeter (PFM) is an innovative and emerging technology that measures subsurface water and contaminant flux directly (DOD 2007). This technology can be used for process control, remedial action performance assessments, and compliance monitoring. This technology may be used to directly measure contaminant flux (i.e., mass flow rate) from NAPL areas. When deployed in a well, groundwater flows through the PFM under natural gradient conditions. The interior composition of the PFM is a matrix of hydrophobic and hydrophilic permeable sorbents that retain dissolved organic and/or inorganic contaminants present in fluid intercepted by the unit. The sorbent matrix is also impregnated with known amounts of one or more fluid soluble resident tracers, which are leached from the sorbent at rates proportional to fluid flux.

After a specified period of exposure to groundwater flow, the PFM is removed from the well or boring. Next, the sorbent is carefully extracted to quantify the masses of all contaminants intercepted by the PFM and the residual masses of all resident tracers. Contaminant masses are used to calculate cumulative time-averaged contaminant mass fluxes, while residual resident tracer masses are used to calculate cumulative or time-average groundwater fluxes.

Borehole fluxmeters have been tested in wells to depths of 60 m (196.85 ft). This technology is potentially effective for compliance monitoring for DNAPL cleanup, is technically implementable in the UCRS and RGA, and commercially available. This technology is retained for further consideration.

Ribbon NAPL Sampler. The Ribbon NAPL Sampler (RNS) is a direct sampling device that provides detailed depth discrete mapping of DNAPLs in a borehole (Riha *et al.* 1999). This qualitative method is used to complement other techniques. The RNS has been deployed in the unsaturated and saturated zones and uses the Flexible Liner Underground Technologies, Ltd. (FLUTe), membrane system (patent pending) to deploy a hydrophobic absorbent ribbon in the subsurface. The system is pressurized against the wall of the borehole and the ribbon absorbs any NAPL that it contacts.

This technology is potentially effective for DNAPL TCE detection, technically implementable, and is commercially available. This technology is retained for further consideration.

DNAPL Interface Probe. The DNAPL interface probe incorporates an infrared sensor and a conductivity sensor attached to a coaxial cable. The cable is mounted on a spool, allowing the probe to be lowered into a groundwater MW. The probe emits an audible signal upon detection of differences in electrical conductivity and infrared response that occurs when the probe passes through the interface between water and an organic liquid. The cable is marked with depth graduations, allowing the operator to determine and record the well depths at which DNAPL occurs.

This technology is potentially effective for DNAPL TCE detection, technically implementable, and is commercially available. This technology is retained for further consideration.

2.4.1.3 Monitored Natural Attenuation

EPA defines MNA as (OSWER Directive 9200.4-17, 1997): "…reliance on natural attenuation processes (within the context of a carefully controlled and monitored clean-up approach) to achieve site-specific remedial objectives within a time frame that is reasonable compared to other methods. The 'natural attenuation processes' that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. These *in situ* processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, or destruction of contaminants" (EPA 1998b).

MNA is appropriate as a remedial approach only when it can be demonstrated capable of achieving a site's remedial objectives within a time frame that is reasonable compared to that offered by other methods and where it meets the applicable remedy selection program for a particular OSWER program. EPA expects that MNA typically will be used in conjunction with active remediation measures (e.g., source control), or as a follow-up to active remediation measures that already have been implemented (EPA 1998b).

Each natural attenuation process occurs under a range of conditions that must be extensively characterized and monitored over time to determine the effectiveness of the remedy. The extent of sorption of VOCs in the UCRS and RGA at PGDP has been estimated using the organic carbon fraction of the geologic media and the K_{oc} of the individual VOCs to calculate partition coefficients. Aerobic biodegradation of TCE has been demonstrated to occur in the RGA (KRCEE 2008), and determination of rates and extents in the UCRS are ongoing. Abiotic degradation has not been verified.

Natural attenuation alone is not expected to remediate DNAPLs (EPA 1999b). Application of this technology in conjunction with source treatment, removal, containment or control potentially may be a cost-effective strategy.

Data needs for MNA are detailed in EPA 1998b and 1999a and include these:

- Soil and groundwater quality data
    - Three-dimensional distribution of residual-, free-, and dissolved-phase contaminants
    - Historical water quality data showing variations in contaminant concentrations through time
    - Chemical and physical characteristics of the contaminants
    - Geochemical data to assess the potential for biodegradation of the contaminants
- Location of potential receptors

— Groundwater wells
— Surface water discharge points

This technology is technically implementable and commercially available and is retained for further evaluation as a secondary technology.

2.4.1.4 Removal technologies

Removal, in the context of this FFS, is the excavation of UCRS soils contaminated with VOCs. Complete removal of VOCs present at the Oil Landfarm and the C-720 Northeast and Southeast Sites would require excavation to approximately 60 ft bgs. The technical complexity of excavation increases greatly with depths greater than about 20 ft (6m) (Terzaghi *et al.* 1996), and factors including slope stability, control of seepage, worker safety, management of excavated soil, shoring requirements, potential for mobilization of DNAPL, and others must be considered.

Deep excavations require extensive terracing or elaborate shoring. Piping of groundwater and entry of heaving sands into the excavation can occur and may pose complications as excavation proceeds below the water table. Excavation of the Oil Landfarm would require the largest volume of excavated soil, but likely would be less complex than excavating at the C-720 Area Southeast site, due to the proximity to the building and the associated surface loading applied by the building to the slopes or sides of the excavation, as well as the potential for damage to the building foundation and subsurface infrastructure. Excavation at the C-720 Area sites would be most feasible after the ongoing maintenance and support functions have ceased and the building has been transferred to the Decontamination and Decommissioning (D&D) OU. Currently, no date for D&D of the C-720 Building has been identified.

Ground pressure and vibration caused by construction and some drilling technologies have been observed to induce coalescing and movement of DNAPL (Payne *et al.* 2008). Downward DNAPL movement beneath an excavation could not be effectively contained and could result in migration to the RGA.

Excavation can have a large capital cost, but no operation and maintenance costs (O&M), and may have the largest probability of achieving over 99% DNAPL removal at smaller sites with contamination restricted to the upper 12.2 m (40 ft) of the soil (AFCEE 2000). Overall, experience has shown that excavation works best and is most cost-competitive at sites where confining layers are shallow, soil permeabilities are low, the volume of source materials is less than 5,000 m^3 (176,600 ft^3), and the contaminants do not require complex treatment or disposal (NRC 2004). Several types of excavation equipment that potentially could be used at the Southwest Plume sites are discussed below.

Backhoes, trackhoes, and front-end loaders can do an effective job of removing contaminated soil and overburden. Practical considerations regarding equipment limitations and sidewall stability can restrict the depth of excavation to a maximum of about 7.62 to 9.14 m (25 to 30 ft) in a single lift. Where source zone contamination lies at greater depth, excavation can require a series of progressively deeper lifts or terraces, accessed by ramps. This technique can extend the maximum depth of excavation in unconsolidated soil to over 12.2 m (40 ft); however, the unit cost of soil excavation increases rapidly with increasing depth of excavation. Additionally, implementation of methods to control or prevent the movement of groundwater into the excavation may be required if source removal extends below the water table. These methods are expensive and can require placement of caissons or driven sheet piling and dewatering (AFCEE 2000).

Vacuum excavation can be used to remove contaminated soil to depths of 10.67+ m (35+ ft) in congested areas where access, obstructions, and buried utilities prevent safe operation of conventional excavators. A combination of high-pressure air (or water) is used to break up the soil, while a high flow vacuum removes the soil and deposits it in the vacuum truck collector body. Vacuum trucks are commercially

available with capacities up to 15 yd^3. Additionally, contaminated soil and sludge can be placed directly in vacuum roll-off boxes (20 or 25 yd^3) or bags for disposal without having to decontaminate the vacuum truck (Heritage Environmental Services, Indianapolis, IN).

Effective excavation can be performed as far as 91.44 m (300 ft) from the vacuum truck, allowing work inside buildings and in highly congested areas. The high-flow vacuum eliminates the need for additional dust control measures typically required during conventional excavation activities (T-Rex Services, Houston, TX). This technology is technically implementable and commercially available and is retained for further evaluation.

Cranes and clamshells often are used in deep excavations (e.g., excavation of piers, dredging, and mining). Excavation at depths of over 100 ft are achievable.

This technology is potentially effective, technically implementable, commercially available, and is retained for further evaluation.

2.4.1.5 Containment technologies

Containment technologies may isolate source areas, reduce infiltration, and thereby minimize VOC migration to the RGA. Surface barriers potentially could meet RAO #3 by reducing or eliminating recharge through the DNAPL areas, thereby reducing the driving force for TCE flux from the UCRS to the RGA. Containment technologies alone would not meet RAO #1, but could be an effective component of an overall alternative incorporating treatment and/or removal of PTW.

Infiltrating precipitation and anthropogenic water recharge to the UCRS provide the driving force for transport of VOCs from source areas to the RGA. Surface barriers and/or recharge controls are designed to reduce or eliminate surface recharge, thereby eliminating the driving force. Subsurface barriers may reduce or eliminate flux of TCE in infiltrating water beyond the contaminated intervals. Containment technologies are summarized below and screened in Table A.1 (see Appendix A).

Hydraulic Containment

Recharge Controls. Recharge controls could reduce facility process water discharges to the UCRS, promote surface water run-off, and reduce recharge of the UCRS in the Southwest Plume TCE source areas, thereby limiting leaching of VOCs from source areas and migration to the RGA. Recharge control options are technically implementable at present using commercially available materials and equipment. Potential recharge control options include the following:

- Identifying saturated zones in the UCRS based on past investigations and determining sources;
- Installing rain gutters on the C-720 Building and other adjacent facility roofs and directing the water away from source areas or to storm drains;
- Routing runoff from roofs, roads, and asphalt parking areas to lined ditches or storm drains;
- Eliminating surface water drainage from adjacent areas onto source areas;
- Lining ditches and culverts in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites with concrete or membranes;
- Inspecting and repairing, as needed, asphalt areas to promote runoff and minimize infiltration;

- Inspection, clearing, and repairing, as needed, discharge pipes, culverts, and storm drains;

- Inspecting, metering, and repairing water lines in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites as needed; and

- Eliminating all French drains, condensate discharge, or other sources of water to the subsurface in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites.

This approach is effective, technically implementable, and commercially available, and is retained for further evaluation.

Groundwater Extraction. Groundwater pumping may be used to contain dissolved-phase contaminant plumes or may be used as a secondary technology to circulate or contain treatment amendments. Groundwater yields from wells completed in the UCRS are insufficient for sustainable pumping or for containment at the Oil Landfarm and the C-720 Northeast and Southeast Sites, which constrains the effectiveness and technical implementability of technologies that rely on groundwater pumping or circulation for removal or treatment of contaminants. Groundwater pumping is not effective for DNAPL recovery except as a secondary technology.

Pumping of RGA groundwater may be required for containment during *in situ* treatment of DNAPL TCE in the UCRS (e.g., surfactant flooding). Groundwater pumping is effective as a secondary process for other primary technologies, technically implementable, commercially available, and is retained for further evaluation.

Surface Barriers. Surface barriers reduce recharge of precipitation and/or anthropogenic water to the subsurface, thereby reducing the driving force for infiltration and leaching of VOCs from source areas. As soil moisture levels decrease in response to reduction in recharge, the unsaturated hydraulic conductivity of soils also decreases, resulting in reduction of contaminant flux rates.

EPA (2008a) identifies the following advantages and limitations of surface barriers for containment of source areas.

- Advantages of containment

    — It is a simple and robust technology.

    — Containment typically is inexpensive compared to treatment, especially for large source areas.

    — A well-constructed containment system almost completely eliminates contaminant transport to other areas and thus prevents both direct and indirect exposures.

    — In unconsolidated soils, containment systems substantially reduce mass flux and source migration potential.

    — Containment systems can be combined with *in situ* treatment and, in some cases, might allow the use of treatments that would constitute too great a risk with respect to migration of either contaminants or reagents in an uncontrolled setting.

- Limitations of containment

    — Containment does not reduce source zone mass, concentration, or toxicity unless it is used in combination with treatment technologies.

— Containment systems such as slurry walls are not impermeable and, thus, provide containment over a finite period.

— Data are not yet available concerning the long-term integrity of the different types of physical containment systems.

— Long-term monitoring of the containment system is essential for ensuring that contaminants are not migrating.

Surface barriers are commonly used to improve performance of soil vapor extraction systems by reducing airflow from the surface and forcing flow through the contaminated soil intervals. Construction at the C-720 Northeast and Southeast Sites would be constrained by surface and subsurface infrastructure. Asphalt, concrete, and geosynthetic covers have been installed and sealed around infrastructure; however, compacted clay layers cannot be as readily installed over or around surface infrastructure. Several types of surface barriers are discussed here.

RCRA Subtitle C Cover. This type of cover is designed to meet performance objectives for RCRA Subtitle C landfill closures under 40 *CFR* § 264.310. EPA guidance (EPA 1987) recommends a cover consisting of (top to bottom) an upper vegetated soil layer, a sand drainage layer, and a flexible membrane liner (FML) overlying a compacted clay barrier. A gas collection layer may be included if gas-generating wastes are capped. Nominal thickness of this type of cover is 1.5 m (4.9 ft), and addition of grading fill would increase the thickness at the crest. Figure 2.1 shows a cross-sectional schematic of a RCRA Subtitle C cover.

This type of cover is designed to be less permeable than the bottom liner of a RCRA Subtitle C landfill and meets the requirements of 40 *CFR* § 264.310. Other types of covers may be used if equivalent performance can be demonstrated through numerical modeling and/or site-specific water balance studies.

A RCRA Subtitle C cover potentially could meet RAO #3 by reducing recharge through VOC source areas. This type of cover is potentially effective, technically implementable, commercially available, and is retained for further consideration.

Concrete and Asphalt-based Covers. Concrete and asphalt cover systems may consist of a single layer of bituminous or concrete pavement over a prepared subgrade to isolate contaminated soils, reduce infiltration, and provide a trafficable surface.

An asphalt cover would be technically implementable at Oil Landfarm and the C-720 Northeast and Southeast Sites at present. The asphalt surface can be sealed around infrastructure using adhesive sealants and flexible boots; however, constructability is improved by absence of surface infrastructure.

MatCon™ asphalt has been used for RCRA Subtitle C-equivalent closures of landfills and soil contamination sites. MatCon™ is produced using a mixture of a proprietary binder and a specified aggregate in a conventional hot-mix asphalt plant. The EPA Superfund Innovative Technology Evaluation program evaluated MatCon™ in 2003 (EPA 2003) with respect to permeability, flexural strength, durability, and cost. EPA determined that the as-built permeability of <1E-07 cm/s was retained for at least 10 years with only minor maintenance and that MatCon™ had superior mechanical strength properties and durability. This technology is effective, technically implementable, commercially available, and is retained for further evaluation.

Flexible Membranes. Flexible membranes are single layers of relatively impermeable polymeric plastic [high-density polyethylene (HDPE) and others]. Flexible membranes are a component of a RCRA Subtitle C cover and, potentially, of other types and also may be used alone. Flexible membranes are laid

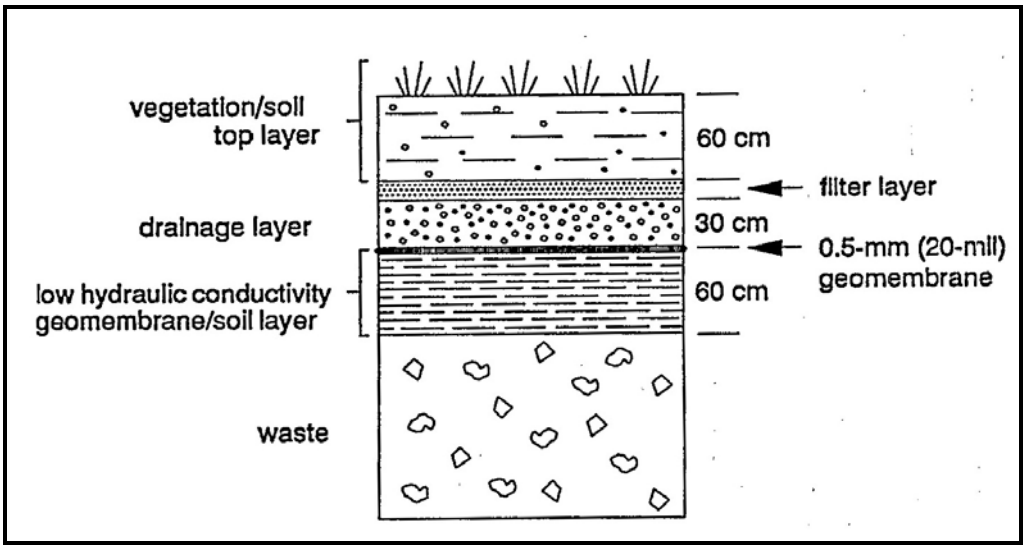


Figure 2.1. Cross-Sectional Schematic of a RCRA Subtitle C Cover

out in rolls or panels and welded together. The resulting membrane cover essentially is impermeable to transmission of water unless breached. Flexible membranes can be sealed around infrastructure using adhesive sealants and flexible boots; however, constructability is improved by absence of surface infrastructure.

Flexible membranes must be protected from damage to remain impermeable. Flexible membranes are subject to damage and/or leakage due to puncturing or abrasion, exposure to excessive heat, freezing, temperature cycling, poor welds, tearing, shearing, UV or other radiation exposure, and chemical incompatibilities. This technology is effective, technically implementable, commercially available, and is retained for further evaluation.

Subsurface Horizontal Barriers. Subsurface horizontal (hydrologic) barriers may potentially limit downward migration of contaminants in infiltrating water by formation of a physical barrier to flow. Subsurface hydrologic barriers must be co-implemented with surface hydrologic barriers to avoid accumulation of infiltrating water on the subsurface barrier, potentially resulting in the creation of perched zones of saturation and eventual degradation of the containment barrier due to increased vertical and lateral hydraulic gradients. Several types of subsurface barriers are discussed below.

Freeze Walls. Frozen barrier walls, also called cryogenic barriers or freeze walls, are constructed by artificially freezing the soil pore water, resulting in decreased permeability and formation of a low-permeability barrier. The frozen soil remains relatively impermeable and migration of contaminants thereby is reduced. This technology has been used for groundwater control and soil stabilization in the construction industry and for strengthening walls at excavation sites for many years. This technology also has been identified for contamination and dust control during excavation of buried wastes.

Implementation of this technology requires installing pipes called thermoprobes into the ground and circulating refrigerant through them. As the refrigerant moves through the system, it removes heat from the soil and freezes the pore water. Systems can be operated actively or passively depending on air temperatures (EPA 1999a).

The thermoprobes can be placed at 45-degree angles along the sides of the area to be contained to form a V-shaped or conical barrier to provide subsurface containment. This technology is considered innovative and emerging for remediation, but is commercially available through the geotechnical construction industry.
Freeze wall containment could potentially eliminate TCE flux as long as the soil remains frozen, and would therefore be effective only as a temporary containment measure. This technology is potentially effective, technically implementable, commercially available, and is retained for further evaluation.

Jet Grouting. Grout mixtures injected at high pressures and velocities into the pore spaces of the soil or rock have been used in civil construction for many years to stabilize subgrades and reduce infiltration of water. More recently, jet grouting has been tested as a potential means of creating a subsurface horizontal barrier, without disturbing overlying soils. Grouts typically are injected through drill rods. The jetted grout mixes with the soil to form a column or panel. Jet grouting can be used in soil types ranging from gravel to clay, but the soil type can alter the diameter of the grout column. Soil properties also are related to the efficiency. For instance, jet grouting in clay is less efficient than in sand (EPA 1999a).

V-shaped jet-grouted composite barriers were demonstrated at Brookhaven and the Hanford Site (Dwyer 1994) and at Fernald in 1992 (Pettit *et al.* 1996) in attempts to completely isolate contaminated soils in field trials. At Hanford and Brookhaven, V-shaped grouted barriers were created by injecting grout through the drill strings of rotary/percussion directional drilling rigs. Next, a waterproofing polymer (AC-400) was placed as a liner between the waste form and the cement v-trough, forming a composite barrier.

Technologies to determine the continuity and impermeability of the completed barrier are unavailable; therefore, the effectiveness of the completed barriers is uncertain.

EarthSaw™ is an innovative emerging jet grouting technology for construction of barriers under and around buried waste without excavating or disturbing the waste. A deep vertical slurry trench is dug around the perimeter of a site and the trench is filled with high-specific-gravity grout sealant. A horizontal bottom pathway is cut at the base of the trench with a cable saw mechanism. The large density difference between the grout and the soil allows the severed block of earth to float. The grout then cures into a relatively impermeable barrier. After the grout has cured and hardened, a final surface covering may be applied, resulting in a completely isolated monolith. This technology has only been demonstrated at the proof-of-principle stage (DOE 2002a).

Overall, jet grouted subsurface horizontal barriers have not been successfully implemented for contaminant containment at full scale; therefore, effectiveness and implementability at the PGDP Oil Landfarm and the C-720 Northeast and Southeast Sites cannot be assessed. Reliable monitoring methods to determine barrier continuity and permeability, including gas tracers, electrical resistance tomography, ground penetrating radar, seismic or acoustic methods, and others, have been tested with variable results and still are in development. Effectiveness and implementability of this technology type are uncertain, and these technologies are therefore screened from further consideration pending further technology development and demonstration.

Permeation Grout Barriers. Permeation grouting has been used extensively in construction and mining to stabilize soils and control movement of water. Low-viscosity grout is injected vertically or directionally at multiple locations into soil at sufficiently low pressure to avoid hydrofracturing while filling soil voids. Soil permeability may be reduced with minimal increase in soil volume using this method (EPA 1999a).

The extent of grout permeation is a function of the grout viscosity, grout particle size, and soil and particle size distribution. A variety of materials can be used in permeation grouting, and it is essential to select a grout that is compatible with the soil matrix. Particulate grouts are applicable when the soil permeability is greater than 1E-01 cm/s. Chemical grouts can be used with soil permeabilities greater than 1E-03 cm/s (EPA 1999a). Permeation grouting has been tested at pilot scale, resulting in formation of subsurface layers of inconsistent coverage, thickness, and permeability.

Viscous liquid barriers are a variant of permeation grouting using low-viscosity liquids that gel after injection, forming an inert impermeable barrier. Field tests have resulted in formation of subsurface layers of inconsistent coverage, thickness, and permeability.

Permeation grouting is limited to soil formations with moderate to high permeabilities. Establishing and verifying a continuous, effective subsurface barrier is difficult or impossible in heterogeneous soils or in the presence of subsurface infrastructure.

Permeation grouting is likely not technically implementable at the Oil Landfarm and the C-720 Northeast and Southeast Sites due to low saturated hydraulic conductivity in zones containing VOCs, and heterogeneous soils. This technology therefore is screened from further consideration.

Soil Fracturing. Soil fracturing may be accomplished either pneumatically, using air, or hydraulically, using liquids. Pneumatic fracturing involves the injection of highly pressurized gas (nitrogen or air) into the soil via borings to extend existing fractures and create a secondary network of subsurface channels. Hydraulic fracturing (hydrofracturing) uses water or slurry instead of gas. Soil fracturing can extend the range of treatment when combined with other primary technologies such as bioremediation, chemical oxidation/reduction or soil vapor extraction. Soil fracturing for these uses is discussed as a secondary technology in the discussion of the primary technology.

The horizontal subsurface barrier technology involves fracturing the soil matrix by creating stress points over a broad area (EPA 1999a). Soil tends to preferentially fracture along the horizontal plane. Air is injected into the boreholes at increasing pressures to cause the soil to fracture. After soil fracture formation, grouts or polymers can be injected into the fracture in an effort to create a low-permeability horizontal barrier. This technology was successfully demonstrated at pilot scale at the Savannah River Site, Aiken, SC, in 1996. Excavation of the test site showed the barrier to be continuous with a total diameter of 4.9 m (16 ft). This technique may also be used to create horizontal reactive barriers or to distribute chemical treatment amendments.

Fracturing potentially may mobilize NAPLs (ARS 2009). Recovery systems capable of capturing mobilized NAPL [i.e., soil vapor extraction (SVE) or dual-phase recovery], are necessary to ensure NAPL containment during fracturing.

Pneumatic and hydraulic fracturing was evaluated in Hightower *et al.* (2001) and KRCEE (2005) as an adjunct technology for *in situ* chemical oxidation (ISCO) and SVE at PGDP DNAPL sites and was recommended for field testing. This technology is potentially implementable, but would require an on-site demonstration to determine feasibility and effectiveness. This technology is retained for further consideration.

Subsurface Vertical Barriers. Vertical barrier technologies can be used to isolate areas of soil contamination and to restrict groundwater flow into the contaminated area or underlying zones. Subsurface vertical barriers may be used to contain or divert contaminated groundwater flow. Subsurface vertical barrier technologies must be "keyed" into an underlying low permeability layer to avoid leakage around the barrier if complete containment is required (Deuren *et al.* 2002).

Given that flow is predominantly vertically downward through the UCRS at the Oil Landfarm and the C-720 Northeast and Southeast Sites, and that no low permeability layer exists between the VOC source areas and the RGA, vertical barriers are likely effective only as adjunct technologies for other primary technologies (e.g., removal or *in situ* treatment). The following is a discussion of several different types of subsurface vertical barriers.

Slurry Walls. Slurry walls are an established and commercially available technology. Slurry walls consist of vertically excavated trenches that are kept open by filling the trench with a low permeability slurry, generally bentonite and water. The slurry forms a very thin layer of fully hydrated bentonite that is impermeable. Soil (often excavated material) then is mixed with bentonite and water to create a soil-bentonite backfill with a hydraulic conductivity of approximately 1E-07 cm/s, which is used to backfill the trench, displacing the slurry. Trench excavation is commonly completed by a backhoe or a modified boom at depths of up to 18.3 m (60 ft). A drag line or clam shell may be used for excavations greater than 18.3 m (60 ft).

Alternatively, a cement, bentonite, and water slurry that is left in the trench to harden may be used. Concrete slurry walls may have a greater hydraulic conductivity than traditional slurry walls and the excavated soil that is not used as a backfill must be disposed of properly. This technology is technically implementable, commercially available, and is retained for further evaluation.

Sheet Pilings. Sheet pilings are an established and readily available technology. Sheet pilings are long structural steel sections with a vertical interlocking system that are driven into the ground to create a continuous subsurface wall. After the sheet piles have been driven to the required depth, they are cut off at the surface. Sheet pilings are commonly used in excavations for shoring and to reduce groundwater flow into the excavation and, therefore, are a potentially useful adjunct technology for soil removal. This technology is effective, technically implementable, commercially available, and is retained for further evaluation.

Permeable Reactive Barriers. Permeable reactive barriers (PRBs) are designed and constructed to permit the passage of water while immobilizing or destroying contaminants through the use of various reactive agents. PRBs are often used in conjunction with subsurface vertical barriers, such as sheet piling, to form a funnel and gate system that directs the groundwater flow through the PRB.

PRBs have been shown to be effective for the removal of TCE and specific types are discussed in more detail. Some of these technologies also are evaluated as *in situ* treatments. Vertical PRBs would have the same constraints as other vertical barriers. They are likely effective only as adjunct technologies for other primary technologies (e.g., removal or *in situ* treatment) given that hydraulic gradients in the UCRS source areas are primarily vertically downward, and no continuous confining layer exists to key vertical walls into.

PRBs may be constructed to depths of 18.3 m (60 ft) bgs, but complexity and cost increase with depth (FRTR 2008). This technology is technically implementable, commercially available, and is retained for further evaluation.

Zero-valent iron (ZVI) is the most common reactive media used in PRBs. Halogenated hydrocarbons, such as TCE, are reductively dehalogentated by the iron, eventually reducing the compound to ethane and ethene that are amenable to biodegradation. The successful use of ZVI PRBs to remediate TCE is well documented and the technology is readily available (Tri-Agency 2002). This technology is technically implementable, commercially available, and is retained for further evaluation.

Oxidizing and reducing conditions can be generated in the subsurface by applying an electrical potential to permeable electrodes that are closely spaced to form a PRB panel. The electrical potential can be used to induce the sequential reduction of halogenated solvents such as TCE. This technology was shown to reduce TCE flux rates by as much as 95% at the pilot-scale level at the F. E. Warren Air Force Base (Sale *et al.* 2005). This technology is technically implementable, commercially available, and is retained for further evaluation.

Mulch, when used as a PRB agent, acts as a source of carbon for aerobic bacteria that lowers the dissolved oxygen concentration and creates a redox potential in the barrier. The resulting anaerobic degradation byproducts of the organic mulch, which include hydrogen and acetate, may then be used by anaerobic bacteria to reductively dechlorinate TCE and other chlorinated VOCs. TCE also may be removed from the groundwater passing though the PRB via sorption and other biotic and abiotic processes. This technology was shown to reduce successfully TCE concentrations by 95% over a 2-year period at the Offutt Air Force Base (GSI 2004). This technology is technically implementable, commercially available, and is retained for further evaluation.

2.4.1.6 Treatment technologies

Treatment technologies may destroy, immobilize, or render contaminants less toxic. Treatment technologies may be implemented *in situ*, *ex situ*, or both. The following are treatment technologies potentially applicable to the Oil Landfarm and the C-720 Northeast and Southeast Sites.

***In situ* Treatment.** *In situ* treatments destroy, remove, or immobilize VOCs without removing or extracting contaminated media. *In situ* treatment technologies may involve distributing fluids or gaseous amendments; applying thermal, pressure, or electrical potential gradients; manipulating subsurface conditions to promote biotic or abiotic contaminant degradation; or applying physical mixing in combination with other treatments. *In situ* treatments potentially applicable to VOCs in the UCRS are discussed below.

Biological Technologies. Biodegradation of chlorinated ethenes in the subsurface occurs through one or more of three different pathways, which may occur simultaneously (ITRC 2005).

(1) The contaminant is used as an electron acceptor and is reduced by the microbe, but not used as a carbon source [i.e., the anaerobic reductive dechlorination (ARD) process].

(2) The contaminant is used as an electron donor and is oxidized by the microbe, which obtains energy and organic carbon from the contaminant.

(3) The contaminant is cometabolized; this is a process where an enzyme or other factor used by the microbe for some other purpose fortuitously destroys the contaminant while providing no benefit to the microbe itself. Cooxidation is a form of cometabolism.

Bioremediation acts on dissolved aqueous phase VOCs, and does not act directly on DNAPL. Instead, the technology relies on degradation and solubilization processes that occur near the water-DNAPL interface. The DNAPL contaminant mass must transfer into the aqueous phase before it can be subjected to the dechlorination or oxidation processes.

Biodegradation of dissolved-phase VOCs in DNAPL zones or VOCs sorbed to solids increases the rate of dissolution by maintaining a relatively high concentration gradient between the DNAPL, or sorbed phase, and the aqueous phase (i.e., maintaining contaminant concentrations in the aqueous phase as low as possible). Significant destruction of contaminant mass in the source area can be achieved by increasing the rate of contaminant dissolution. Even with increased dissolution rates, however, source areas at many sites are expected to persist for many decades, due to the large amount of DNAPL mass present and the difficulty of establishing conditions favorable for biodegradation throughout the contaminated areas. Despite variation in source area characteristics, enhancing the contaminant dissolution rate remains a key process objective for bioremediation of source areas. The following is a discussion of ARD and aerobic cooxidation.

Anaerobic reductive dechlorination. Enhanced anaerobic reductive dechlorination occurs through addition of an organic electron donor and nonindigenous dechlorinating microbes, as necessary, to facilitate the sequential transformation of chlorinated ethenes as follows:

PCE → TCE → *cis*-DCE → VC → ethene

KRCEE (2008) noted that the presence of anaerobic TCE degradation products including *cis*-DCE observed in UCRS groundwater southwest of the C-400 Building and near RGA source areas is indicative of localized areas where ARD processes occur; however, rates and extent of ARD in the UCRS are not quantified.

Conditions favorable to ARD success, based on case studies, include (ITRC 2005) the following:

- Relatively low-strength residual sources characterized by nonaqueous-phase contaminants present primarily at residual saturation levels with no massive DNAPL pools.

- Relatively homogenous and permeable subsurface environment that would facilitate amendment injection and distribution throughout the contaminant zone.

- Sites with relatively long remedial time frames amenable to the achievable rate of contaminant mass destruction.

- Sites with sufficient access to facilitate the required amendment injections.

- Sites with sufficient hydraulic capture and/or downgradient buffer zone to ensure that the treatment effects, such as production of dissolvent metals and/or partial degradation products, such as VC, do not impact potential receptors.

- Sites where cost is a major driver in the technology selection process.

The Southwest Plume conceptual site model as described in Section 1.2.4 includes a favorable DNAPL distribution as residual saturation, with no DNAPL pools. The subsurface in the UCRS is relatively nonhomogenous and measured Ksat values range from 1.0E-08 to 6.9E-04 cm/s, due to depositional heterogeneities in the clays, sands, silts, and gravels that comprise the formation (DOE 1998a).

Effectiveness and technical implementability of *in situ* bioremediation-anerobic reductive dechlorination (ISB-ARD) at the PGDP Southwest Plume sites is uncertain due to the heterogeneity and variable extent of saturation in the UCRS soils, resulting in difficult conditions for injecting and circulating liquid amendments. Establishing conditions favorable for ARD also may inhibit ongoing aerobic degradation processes demonstrated to exist in the RGA (KRCEE 2008). The treatment areas would have to be saturated for the process to be implemented. ISB-ARD potentially may be effective as a polishing step after implementation of other primary technologies. Secondary effects may include color, odor, and turbidity for some time after treatment. This technology is technically implementable and commercially available and is retained for further evaluation.

Aerobic Cometabolism. TCE is not readily degraded aerobically as a primary substrate, but can be cometabolized. Cometabolism occurs when a microbe using an organic compound as a carbon and energy source produces enzymes that fortuitously degrade a second compound, without deriving energy or carbon for growth from that compound. Microbes and microbial consortia of multiple species using methane as a substrate have been demonstrated to produce methane monooxygenase (MMO), which fortuitously oxidizes TCE. This conversion has been demonstrated to occur naturally in groundwater at many sites and is part of natural attenuation processes. Aerobic cometabolism has been demonstrated to occur in the RGA at the PGDP; however, evidence of cometabolism in the UCRS has not yet been developed (KRCEE 2008).

MMO inserts molecular oxygen into TCE, removing the carbon-carbon double bond, creating TCE epoxide. The epoxide is unstable in the aqueous environment outside the cell and breaks down to formate, chlorinated acids, glyoxylate, and carbon monoxide. Methanotrophs and/or heterotrophs then can metabolize these products into final products of carbon dioxide and cell mass.

Aerobic cooxidation acts only on dissolved aqueous phase VOCs and only indirectly on DNAPL or sorbed phases, by increasing the rate of dissolution, as does ARD. This technology has been applied successfully at field scale in the saturated zone at the Savannah River National Laboratory and other sites where methane gas is sparged into groundwater containing dissolved TCE. This technology has not been demonstrated for VOCs in the unsaturated zone.

Low-permeability and heterogeneous soils limit distribution of amendments. Implementability and effectiveness for VOCs in the UCRS are uncertain, and a field demonstration would be required prior to implementation. This technology is retained for further consideration.

Phytoremediation. Phytoremediation exploits plant processes, including transpiration and rhizosphere enzymatic activity, to uptake water and dissolved-phase contaminants or to transform contaminants *in situ*. TCE may be transpired to the atmosphere or degraded in the root zone. The depth of VOC contamination at Southwest Plume sites is greater than the root zone of plants capable of transpiring or degrading TCE. Phytoremediation is not technically implementable at the PGDP Southwest Plume sites and therefore is screened from further consideration.

Physical/Chemical Technologies

Soil Vapor Extraction. SVE applies vacuum to unsaturated soils to induce the controlled flow of air through contaminated intervals, thereby removing volatile and some semivolatile contaminants from the soil. SVE can increase the rate of volatilization from DNAPL, aqueous, and sorbed VOC phases by maintaining a high concentration gradient between these phases and the air filled soil porosity.

The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and state air discharge regulations. Vertical extraction wells typically are used at depths of 1.5 m (5 ft) or greater and have been successfully applied as deep as 91 m (300 ft). Horizontal extraction vents installed in trenches or horizontal borings can be used as warranted by contaminant zone geometry, drill rig access, or other site-specific factors. SVE is defined by EPA as a presumptive remedy for VOCs in soil (EPA 2007).

Impermeable covers often are placed over soil surface during SVE operations to prevent short circuiting of air flow and to increase the radius of influence of the wells. Groundwater depression pumps may be used to reduce groundwater upwelling induced by the vacuum or to increase the depth of the vadose zone. This application, called dual-phase extraction, was evaluated and recommended by Hightower *et al.* (2001) as potentially effective and implementable for remediation of DNAPL TCE in saturated conditions in the UCRS at PGDP. Potential adjunct technologies to improve performance include fracturing, active or passive air injection, air sparging, and ozone injection, are discussed separately.

The typical target contaminant groups for *in situ* SVE are VOCs and some fuels. The technology typically is applicable only to volatile compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 mm Hg (0.02 inches Hg). Other factors, such as the moisture content, organic content, and air permeability of the soil, affect effectiveness.

Factors that may limit the applicability and effectiveness of the process include the following:

- Soil that has a high percentage of fines and a high degree of saturation will require higher vacuums (increasing costs) and hindering the operation of the *in situ* SVE system.

- Large screened intervals are required in extraction wells for soil with highly variable permeabilities or stratification, which otherwise may result in uneven delivery of gas flow from the contaminated regions.

- Soil that has high organic content or is extremely dry has a high sorption capacity of VOCs, which results in reduced removal rates.

- Exhaust air from the *in situ* SVE system may require treatment to meet discharge requirements.

- Off-gas treatment residuals (e.g., spent activated carbon) may require treatment/disposal.

- SVE is not effective in the saturated zone; however, groundwater pumping (dual-phase SVE) can expose more media to air flow.

Data requirements include the depth and areal extent of contamination, the concentration of the contaminants, depth to water table, and soil type and properties (e.g., structure, texture, permeability, and moisture content). Pilot studies should be performed to provide design information, including extraction well sizing, radius of influence, gas flow rates, optimal applied vacuum, and contaminant mass removal rates.

During full-scale operation, *in situ* SVE can be run intermittently (pulsed operation) after the mass removal rate has reached an asymptotic level. Pulsed operation can improve the cost-effectiveness of the system by facilitating extraction of higher concentrations of contaminants. After the contaminants are removed by *in situ* SVE, other remedial measures, such as biodegradation, can be investigated if remedial action objectives have not been met. *In situ* SVE projects typically are completed in 1 to 3 years (FRTR 2008).

This technology is potentially effective, technically implementable, and commercially available for treatment of VOCs in the UCRS. This technology is retained for further evaluation.

Air Sparging. Air sparging injects air into a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to volatilize the contaminants up into the unsaturated zone, where they typically are removed by an SVE system. This technology is designed to operate at high flow rates to maintain increased contact between groundwater and soil and strip more groundwater by sparging. Air sparging can act on aqueous, DNAPL and sorbed phase VOCs by promoting volatilization of VOCs into an air phase.

Oxygen added to contaminated groundwater and vadose zone soils also can enhance biodegradation of contaminants below and above the water table. Ozone may be generated on-site and added to air injection or sparging systems to oxidize contaminants *in situ*. This application of sparging was recommended for evaluation by Hightower *et al.* (2001) for remediation of TCE sources in the UCRS unsaturated zone at the PGDP.

The target contaminant groups for air sparging are VOCs and fuels. Methane can be used as an amendment to the sparged air to enhance cometabolism of chlorinated organics.

Factors that may limit the applicability and effectiveness of the process include the following:

- Soil heterogeneity may cause some zones to be relatively unaffected or may result in uncontrolled movement of vapors, and

- Sparging tends to create preferential flowpaths that may bypass contaminated areas.

Characteristics that should be determined include vadose zone gas permeability, depth to water, groundwater flow rate, radial influence of the sparging well, aquifer permeability and heterogeneities, presence of low permeability layers, presence of DNAPLs, depth of contamination, and contaminant volatility and solubility. Additionally, it is often useful to collect air-saturation data in the saturated zone during an air sparging test, using a neutron probe.

This technology is demonstrated at numerous sites, though only a few sites are well documented. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells. Air sparging has a medium to long duration that may last up to a few years (FRTR 2008). Air sparging using ozone to remediate VOCs in UCRS soils at PGDP was estimated to require approximately one year (MK Corporation 1999).

This technology is potentially effective, technically implementable and commercially available for treatment of VOCs in the saturated zones of the UCRS; however, pilot-testing would be required to select and design the technology.

Soil Flushing. *In situ* soil flushing is the extraction of contaminants from soil with water or other suitable aqueous solutions. Soil flushing is accomplished by passing the extraction fluid through in-place soils

using an injection or infiltration process. Extraction fluids must be recovered from the underlying aquifer and, when possible, they are recycled. Many soil flushing techniques are adapted from enhanced oil recovery methods used by the petroleum industry for many years. Soil flushing agents including cosolvents and surfactants are discussed here.

Cosolvent flushing involves injecting a solvent mixture (e.g., water plus a miscible organic solvent such as alcohol) into either vadose zone, saturated zone, or both to extract organic contaminants through solubilization into the cosolvent. Cosolvent flushing can be applied to soils to dissolve either the source of contamination or the contaminant plume emanating from it. The cosolvent mixture normally is injected upgradient of the contaminated area, and the solvent with dissolved contaminants is extracted downgradient and treated aboveground.

Surfactant flushing acts by reducing the interfacial tension between DNAPL and water or DNAPL and soil, thereby increasing the surface area for solubilization. Surfactant flushing can result in mobilization of DNAPL, and the process requires physical or hydraulic containment. Some soil flushing agents also can act on sorbed-phase VOCs.

Recovered contaminated groundwater and flushing fluids may need treatment to meet appropriate discharge standards prior to recycle or release to wastewater treatment works or receiving streams. Recovered fluids are reused in the flushing process to the extent practicable. The separation of surfactants from recovered flushing fluid, for reuse in the process, is a major factor in the cost of soil flushing. Treatment of the recovered fluids results in process sludges and residual solids, such as spent carbon and spent ion exchange resin, which must be appropriately treated before disposal. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated, as appropriate, to meet applicable regulatory standards. Residual flushing additives in the soil may be a concern and should be evaluated on a site-specific basis.

The duration of soil flushing process is generally short- to medium-term. Costs are high relative to most other *in situ* treatments. Flushing solutions may alter the physical/chemical properties of the soil system.

Factors that may limit the applicability and effectiveness of the process include the following:

- Low permeability or heterogeneous soils are difficult to treat. Effectiveness and technical implementability of soil flushing at the PGDP Southwest Plume sites are uncertain due to the heterogeneity and variable extent of saturation in the UCRS soils, resulting in difficult conditions for injecting and circulating liquid amendments.

- Surfactants can adhere to soil and reduce effective soil porosity.

- Reactions of flushing fluids with soil can reduce contaminant mobility.

- Control of mobilized fluids, in particular NAPLs, is critical to success. The technology should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.

- Aboveground separation and treatment costs for recovered fluids can drive the economics of the process.

Treatability tests are required to determine the feasibility of the specific soil-flushing process being considered. Physical and chemical soil characterization parameters that should be established include soil permeability, soil structure, soil texture, soil porosity, moisture content, total organic carbon, cation exchange capacity, pH, and buffering capacity.

Contaminant characteristics that should be established include concentration, solubility, partition coefficient, solubility products, reduction potential, and complex stability constants. Soil and contaminant characteristics will determine the flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with changes in contaminants.

Soil flushing is a developing technology that has had limited use in the United States. Typically, laboratory and field treatability studies must be performed under site-specific conditions before soil flushing is selected as the remedy of choice. To date, the technology has been selected as part of the source control remedy at 12 Superfund sites. There has been very little commercial success with this technology (FRTR 2008). This technology is retained for further evaluation.

Electrokinetics. The principle of electrokinetic remediation relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes. Metal ions, ammonium ions, and positively charged organic compounds move toward the cathode. Anions such as chloride, cyanide, fluoride, nitrate, and negatively charged organic compounds move toward the anode. The current creates an acid front at the anode and a base front at the cathode.

The two primary mechanisms, electromigration and electroosmosis, transport contaminants through the soil toward one or the other electrodes. In electromigration, charged particles are transported through the stationary soil moisture. In contrast, electroosmosis is the movement of the soil moisture containing ions relative to a stationary charged surface. The direction and rate of movement of an ionic species will depend on its charge, both in magnitude and polarity, as well as the magnitude of the electroosmosis-induced flow velocity. Non-ionic species, both inorganic and organic, also will be transported along with the electroosmosis induced water flow. Electrokinetics can act on aqueous, DNAPL, and sorbed phase VOCs. Electroosmosis has been used for years in the construction industry to dewater low-permeability soils.

Two approaches are taken during electrokinetic remediation: “Enhanced Removal” and “Treatment without Removal.” “Enhanced Removal” is achieved by electrokinetic transport of contaminants toward the polarized electrodes to concentrate the contaminants for subsequent removal and *ex situ* treatment. Removal of contaminants at the electrode may be accomplished by several means including electroplating at the electrode, precipitation or co-precipitation at the electrode, pumping of water near the electrode, or complexing with ion exchange resins. Enhanced removal is widely used in remediation of metals-contaminated soils.

“Treatment without Removal” is achieved by electro-osmotic transport of contaminants through treatment zones placed between electrodes. The polarity of the electrodes is reversed periodically, which reverses the direction of the contaminants back and forth through treatment zones. The frequency with which electrode polarity is reversed is determined by the rate of transport of contaminants through the soil. This approach can be used on *in situ* remediation of soils contaminated with organic species.

Targeted contaminants for electrokinetics are heavy metals, anions, and polar organics; in soil, mud, sludge, and sediments. Concentrations that can be treated range from a few ppm to tens of thousands ppm. Electrokinetics is applicable most in low permeability soils. Such soils are typically saturated and partially saturated clays and silt-clay mixtures that are not readily drained.

Factors that may limit the applicability and effectiveness of this process include the following:

- Effectiveness is sharply reduced for wastes with a moisture content of less than 10%. Maximum effectiveness occurs if the moisture content is between 14% and 18%.

- The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil, therefore, the natural geologic spatial variability should be delineated. Additionally, deposits that exhibit very high electrical conductivity, such as ore deposits, cause the technique to be inefficient.

- Inert electrodes, such as carbon, graphite, or platinum, must be used so that no residue will be introduced into the treated soil mass. Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil mass.

- Electrokinetics is most effective in clays because of the negative surface charge of clay particles; however, the surface charge of the clay is altered by both charges in the pH of the pore fluid and the adsorption of contaminants. Extreme pH at the electrodes and reduction-oxidation changes induced by the process electrode reactions may inhibit electrokinetics effectiveness.

- Oxidation/reduction reactions can form undesirable products (e.g., chlorine gas).

In addition to identifying soil contaminants and their concentrations, information necessary for engineering electrokinetic systems to specific applications includes soil moisture content and classification, soil pH, bulk density, soil pH, and cation-anion balance. Process-limiting characteristics such as pH or moisture content sometimes may be adjusted. In other cases, a treatment technology may be eliminated based upon the soil classification (e.g., particle-size distribution) or other soil characteristics.

The electrokinetic technology has been operated for test and demonstration purposes at the pilot scale and at full scale at a number of sites including the PGDP SWMU 91. The PGDP field test implemented the Lasagna™ process, a patented and trademarked "treatment without removal" electrokinetic soil treatment. The system uses a series of planar electrodes emplaced at the outer edge of a source zone, from 6.1 to 30.5 m (20 to 100 ft) apart. Treatment zones for TCE consist of iron filings and clay emplaced between and parallel to the electrode zones. When the power is on, the soil is heated and pore water travels from the anode toward the cathode. TCE is broken down into nonhazardous compounds as it comes in contact with the iron particles in the treatment zones.

In 1994, PGDP SWMU 91, the Cylinder Drop Test Area, was selected for the demonstration of the Lasagna™ technology. TCE was present in UCRS soils and groundwater at concentrations indicative of residual saturation to a depth of approximately 13.7 m (45 ft) bgs.

Phase I of the SWMU 91 Lasagna™ demonstration began in January 1995 and lasted for 120 days. The purpose of Phase I was to collect sufficient experience and information for site-specific design, installation, and operation of the Lasagna™ technology. Lasagna™ Phase IIa began in August 1996 and lasted 12 months. The purpose of Phase IIa was to perfect methods for installing treatment and electrode zones. During the technology demonstration, the average concentration of TCE in the target soil was reduced by approximately 95%.

Following the successful field-scale test DOE issued the *Record of Decision for Remedial Action at Solid Waste Management Unit 91 of Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1998b). The ROD designated Lasagna™ as the selected remedial alternative for reducing the concentration of TCE in SWMU 91. Following installation, the Lasagna™ system was operated for two years to reduce the concentration of TCE in SWMU 91 soils to the RGs established in the SWMU 91 ROD (DOE 2002b).

This technology has been demonstrated at the PGDP to be effective, technically implementable, and commercially available for remediation of VOCs in soil. This technology is retained for further evaluation.

Soil Mixing. Several types of deep soil mixing systems are commercially available, including single- and dual-auger systems. Dual-auger soil mixing involves the controlled injection and blending of reagents into soil through dual overlapping auger mixing assemblies, consisting of alternate sections of auger flights and mixing blades that rotate in opposite directions to pulverize the soil and blend in the appropriate volumes of treatment reagents. Each auger mixing assembly is connected to a separate, hollow shaft (Kelly-bar) that conveys the treatment reagents to the mixing area, where the reagents are injected through nozzles located adjacent to the auger cutting edge. The mix proportions, volume, and injection pressures of the reagents are continuously controlled and monitored by an electronic instrumentation system. This technology has been widely used for grout injection and ground improvement in the civil and geotechnical construction industry for many years. *In situ* soil mixing is most effective at depths to 40 ft bgs; however, depths to 100 ft may be treated using smaller diameter augers (DOE 1996).

During the mixing operation, the dual auger flights break the soil loose allowing the mixing blades to blend the reagents and the soil into a homogeneous mixture. As the augers advance to a greater depth, the soil and reagent(s) are re-mixed by an additional set of augers and mixing blades located above the preceding set on each shaft. When the desired depth is reached, the augers are reversed and withdrawn and the mixing process is repeated on the way to the surface, leaving a homogeneously treated block of soil. Each treated block of soil is composed of two overlapping columns. The pattern of columns is extended laterally in rows of treated blocks, in a repetitive manner to encompass the total area of the required remediation. The depth of the columns encompasses the vertical extent of the remediation. A hood and filter system can be added to the dual auger soil mixing system, therefore, eliminating the possibility of contaminants escaping into the atmosphere (ISF 2008).

Deep soil mixing can potentially reduce mass transfer limitations associated with UCRS soils, including low-permeability soils and partial saturation, by physically blending contaminated soils with amendments or heated air or water. Soil mixing can act on aqueous, DNAPL, and sorbed phase VOCs. Deep soil mixing has been demonstrated to remove up to 95% of VOCs in soil, through ZVI injection, hot air/steam stripping, and injection of bioremediation reagents (ISF 2008). This technology likely would require a pilot demonstration at the PGDP prior to full-scale implementation. This technology is potentially effective, technically implementable, and commercially available for remediation of VOCs in soil. This technology is retained for further evaluation.

Thermal Technologies

Electrical Resistance Heating. Electrical resistance heating (ERH) uses electrical resistance heaters or electromagnetic/fiber optic/radio frequency heating to increase the volatilization rate of semi-volatiles and facilitate vapor extraction. The vapor extraction component of ERH requires heat-resistant extraction wells, but is otherwise similar to SVE.

Contaminants in low-permeability soils such as clays and fine-grained sediments can be vaporized and recovered by vacuum extraction using this method. Electrodes are placed directly into the soil matrix and energized so that electrical current passes through the soil, creating a resistance which then heats the soil. The heat may dry out the soil causing it to fracture. These fractures make the soil more permeable allowing the use of SVE to remove the contaminants.

The heat created by ERH also forces trapped liquids, including DNAPLs, to vaporize and move to the steam zone for removal by SVE. ERH applies low-frequency electrical energy in circular arrays of three (three-phase) or six (six-phase) electrodes to heat soils. The temperature of the soil and contaminant is increased, thereby increasing the contaminant's vapor pressure and its removal rate. ERH also creates an *in situ* source of steam to strip contaminants from soil. Heating via ERH also can improve air flow in high moisture soils by evaporating water, thereby improving SVE performance. ERH can act on aqueous, DNAPL, and sorbed phase VOCs.

Six-phase heating (SPH) was evaluated and recommended by Hightower *et al.* (2001) for TCE DNAPL contamination in the saturated and unsaturated zones of the UCRS. A pilot study using SPH subsequently was conducted at PGDP between February and September of 2003. The heating array was 9.14 m (30 ft) in diameter and reached a depth of 30.2 m (99 ft) bgs. Baseline sampling results showed an average reduction in soil contamination of 98% and groundwater contamination of 99% (DOE 2003).

The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties;
- Low-permeability soils or soils with high moisture content have a reduced permeability to air, requiring more energy input to increase vacuum and temperature;
- Soils with a high organic content have a high VOC sorption capacity, which results in reduced removal rates;
- Air emissions may need to be regulated to eliminate possible harm to the public and the environment; and
- Residual liquids and spent activated carbon may require further treatment.

Data requirements include the depth and areal extent of contamination, the concentration of the contaminants, depth to the water table, and soil type and properties including structure, texture, permeability, organic carbon content, and moisture content.

Durations of thermally enhanced remediation projects are highly dependent upon the site-specific soil and chemical properties. The typical site consisting of 20,000 tons of contaminated media would require approximately nine months to remediate (FRTR 2008). This technology has been demonstrated at the PGDP for removal of DNAPL TCE and its degradation products. This technology is retained for further evaluation.

Steam Stripping. Hot air or steam is injected below the contaminated zone to heat contaminated soil and thereby enhance the release of VOCs and some SVOCs from the soil matrix. Desorbed or volatilized VOCs are removed through SVE (FRTR 2008). Steam injection has been used to enhance oil recovery for many years and was investigated for environmental remediation beginning in the 1980s. Approximately 10 applications of this technology for recovery of fuels, solvents and creosote are reported in EPA (2005), with varied results.

In situ steam stripping is commonly applied using soil mixing equipment to improve contact of steam with contaminated media. Steam stripping can act on aqueous, DNAPL, and sorbed phase VOCs. This technology is retained for further consideration.

Chemical Technologies

ISCO processes are *in situ* treatments whereby chemical compounds are injected to oxidize organic contaminants in the subsurface. Commercially available chemical oxidation technologies described in this section include the following:

- Permanganate
- Fenton's reagent
- ZVI
- Ozonation

- Persulfate
- Redox manipulation

ISCO has been used at many sites, and oxidants are available from a variety of vendors. Water-based oxidants can react only directly with the dissolved-phase of NAPL contaminants, since the two will not mix. This property limits their activity to the oxidant solution/DNAPL interface; however, significant mass reduction has been reported for application of ISCO at sites with dissolved-phase VOCs and DNAPL residual ganglia (EPA CLU-IN 2008). Off-gas control is often important during implementation of chemical oxidation technologies.

Data needs include heterogeneity of the site subsurface, soil oxidation demand, stability of the oxidant, and type and concentration of the contaminant. Effectiveness and technical implementability of ISCO at the PGDP Southwest Plume sites is uncertain due to the relatively low permeability, heterogeneity and variable extent of saturation in the UCRS soils, resulting in difficult conditions for injecting and circulating liquid amendments.

Permanganate. Permanganate typically is provided as liquid or solid potassium permanganate (KMnO4), but is also available in sodium, calcium, or magnesium salts. The following equation represents the chemical oxidation of TCE using potassium permanganate:

$$2KMnO_4 + C_2HCl_3 \rightarrow 2MnO_2 + 2CO_2 + 3Cl^- + H^+ + 2K^+$$

The use of permanganate to degrade TCE causes the generation of salts and hydrogen or hydroxyl ions (acids or bases) with no significant pH shifts. The direct application of permanganate has commonly been used for contaminant levels up to 100 ppm to avoid off-gassing. It has only recently been applied to contaminant levels exceeding 1,000 ppm. Permanganate can be delivered to the contaminated zone by injection probes, soil fracturing, soil mixing, and groundwater recirculation (EPA 2004b). Permanganate has an effective pH range of 3.5 to 12 (KRCEE 2005). This technology may potentially be effective and technically implementable in the UCRS, but has the same limitations as other aqueous-phase oxidants (i.e., it may not act directly on DNAPL). Secondary effects may include discoloration of water for some time after treatment.

Fenton's Reagent. Hydrogen peroxide (H_2O_2) was one of the first chemical oxidants to be used in industry and was commercialized in the early 1800s. Hydrogen peroxide works as a remedial chemical oxidant in two ways: (1) direct chemical oxidation as hydrogen peroxide and (2) in the presence of native or supplemental ferrous iron (Fe^{+2}), as Fenton's Reagent, which yields hydroxyl free radicals (OH^-). These strong, nonspecific oxidants can rapidly degrade a variety of organic compounds. Fenton's Reagent oxidation is most effective under very acidic pH and becomes ineffective under moderate to strongly alkaline conditions.

The most common field applications of chemical oxidation have been based on Fenton's Reagent. When peroxide is injected into the subsurface at concentrations of 10% to 35% in the presence of ferrous iron, the hydroxyl free radical oxidizes the VOCs to carbon dioxide (CO_2) and water. The residual hydrogen peroxide decomposes into oxygen and water, and the remaining iron precipitates (Jacobs and Testa 2003).

The oxidation reaction for TCE forms several unstable daughter products such as epoxides that break down to aldehydes and ketones, which then finally decompose to carbon dioxide, chloride ions, and water as shown in the following reaction (Jacobs and Testa 2003).

$$4OH\bullet + C_2HCl_3 \rightarrow 2CO2 + 3Cl- + 5H^+$$

The pH of the surrounding medium increases as the reaction process continues; therefore, it is necessary to lower the pH with acids. Organic acids should be avoided because they have a tendency to increase side reactions. The optimal pH range is from 3.5 to 5.0. The exothermic nature of the oxidation process causes a rise in subsurface temperature which may decomposes the peroxide. Field research has determined the optimal reaction temperature to be in the range of 35 to 41 °C (Jacobs and Testa 2003). This technology potentially may be effective and technically implementable in the UCRS, but has the same limitations as other aqueous-phase oxidants (i.e., it may not act directly on DNAPL).

Zero-Valent Iron. ZVI is more conventionally used in conjunction with a permeable reactive barrier to dechlorinate chlorinated hydrocarbons in the subsurface; however, the technology also may be applied as direct injection of particulate iron, mixing of iron with clay slurries or incorporating nanoscale ZVI into an oil emulsion prior to injection. A form of ZVI may be injected into the subsurface downgradient of the contaminant source to create a zone of treatment. This is an innovative/emerging technology that would require field demonstration prior to implementation. Technical implementability in the UCRS would be constrained by low-permeability soil layers and heterogeneity. This technology is potentially technically implementable and commercially available and is retained for further evaluation.

Ozonation. Ozone (O_3) is a strong oxidizer having an oxidation potential about 1.2 times that of hydrogen peroxide. Because of its instability, ozone typically is generated on-site and delivered to the contaminated zone through sparge wells. Air containing up to 5% ozone is injected through strategically placed sparge wells. Ozone dissolves in the groundwater and oxidizes the contaminant while decomposing to oxygen (O_2).

Ozone injection was evaluated and recommended by Hightower *et al.* (2001) for remediation of DNAPL TCE in the unsaturated zone of the UCRS at the PGDP. Pneumatic fracturing can be used to enhance ozone treatment effectiveness in low permeability soils (EPA 2004b). This technology potentially may be effective and technically implementable in the UCRS, but has the same limitations as other aqueous-phase oxidants (i.e., it may not act directly on DNAPL).

Sodium Persulfate. Persulfate is a strong oxidant with a higher oxidation potential than hydrogen peroxide and a potentially lower soil oxygen demand than permanganate or peroxide. Persulfate reaction is slow unless placed in the presence of a catalyst, such as ferrous iron, or heated to produce sulfate free radicals that are highly reactive and capable of degrading many organic compounds. The ferrous iron catalyst, when used, will degrade with time and precipitate. Persulfate becomes especially reactive at temperatures above 40 °C (104 °F), and can degrade most organics (EPA CLU-IN 2008).

This technology potentially may be effective and technically implementable in the UCRS, but has the same limitations as other aqueous-phase oxidants (i.e., it may not act directly on DNAPL).

Redox Manipulation. *In situ* redox manipulation (ISRM) manipulates natural processes to change the mobility or form of contaminants in the subsurface. ISRM creates a permeable treatment zone by injection of chemical reagents, such as sodium dithionite and/or microbial nutrients into the subsurface downgradient of the contaminant source. The chemical reagent then reacts with iron naturally present in the aquifer sediments in the form of various minerals present as clays, oxides, or other forms. Redox sensitive metals that migrate through the reduced zone in the aquifer may become immobilized and organic species may be destroyed (DOE 2000c). This technology is potentially technically implementable and commercially available and is retained for further evaluation.

***Ex Situ* Treatment.** *Ex situ* treatment technologies may be applicable to treatment of secondary wastes including recovered DNAPL TCE, excavated soils, extracted groundwater, or vapor. *Ex situ* treatment technologies potentially applicable to secondary wastes that may be generated during removal, treatment, or disposal at the Oil Landfarm and the C-720 Northeast and Southeast Sites are discussed here.

Physical/Chemical Technologies

Air Stripping. Air stripping removes volatile organics from extracted groundwater by greatly increasing the surface area of the contaminated water exposed to air. Air stripping is a presumptive technology for treatment of VOCs in extracted groundwater (EPA 1996). Air stripping may potentially be applicable to secondary waste treatment from groundwater extraction, light nonaqueous-phase liquid recovery processes, or *in situ* treatment processes. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process typically is conducted in a tray aerator, packed tower, or aeration tank. Tray aerators stack a number of perforated trays vertically in an enclosure. Air is blown upward through the perforations as water cascades downward through the trays. Tray aerators occupy relatively little space, are easy to clean, and are highly efficient. Currently the PGDP Northwest Plume Pump-and-Treat system includes low-profile tray air stripping for TCE removal.

Packed tower air strippers typically include a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes an air heater to improve removal efficiencies; automated control systems with sump level switches and safety features, such as differential pressure monitors, high sump level switches, and explosion-proof components; and air emission control and treatment systems, such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads or on a skid or a trailer.

Aeration tanks strip volatile compounds by bubbling air into a tank through which contaminated water flows. A forced air blower and a distribution manifold are designed to ensure air-water contact without the need for any packing materials. The baffles and multiple units ensure adequate residence time for stripping to occur. Aeration tanks typically are sold as continuously operated skid-mounted units. The advantages offered by aeration tanks are considerably lower profiles (less than 2 m or 6 ft high) than packed towers (5 to 12 m or 15 to 40 ft high) where height may be a problem, and the ability to modify performance or adapt to changing feed composition by adding or removing trays or chambers. The discharge air from aeration tanks can be treated using the same technology as for packed tower air discharge treatment.

Air strippers can be operated continuously or in a batch mode where the air stripper is intermittently fed from a collection tank. The batch mode ensures consistent air stripper performance and greater energy efficiency than continuously operated units because mixing in the storage tanks eliminates any inconsistencies in feed water composition.

Due to substantive permitting requirements, liquid and air effluents may require monitoring prior to release, but monitoring of the air effluent also may be necessary based on Commonwealth of Kentucky and EPA requirements. Data needs include influent flow rate, VOC concentrations, VOC chemical and physical properties, iron content, dissolved solids, total hardness, alkalinity, and pH. Air and water discharge limits also are required.

Air stripping is effective, technically implementable and commercially available for removal of VOCs from extracted groundwater. This technology is retained for further evaluation.

Ion Exchange. Ion exchange removes ions from the aqueous phase by exchanging cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are

attached. Resins also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for reuse. Wastewater is generated during the regeneration step, potentially requiring additional treatment and disposal.

These factors may affect the applicability and effectiveness of ion exchange (FRTR 2008):

- Oil and grease in the groundwater may clog the exchange resin;
- Suspended solids content greater than 10 ppm may cause resin blinding;
- The pH of the influent water may affect the ion exchange resin selection; and
- Oxidants in groundwater may damage the ion exchange resin.

VOCs are not removed by this method; however, removal of radionuclides including ^{99}Tc from extracted groundwater using ion exchange is effective, technically implementable, and commercially available. This technology is retained for further evaluation.

Granular-Activated Carbon (Vapor Phase). Vapor-phase carbon adsorption removes pollutants including VOCs removed from extracted air by physical adsorption onto activated carbon grains. Carbon is "activated" for this purpose by processing the carbon to create porous particles with a large internal surface area (300 to 2,500 m^2 or 3,200 to 27,000 ft^2 per gram of carbon) that attracts and adsorbs organic molecules as well as certain metal and inorganic molecules.

Commercial grades of activated carbon are available for specific use in vapor-phase applications. The granular form of activated carbon typically is used in packed beds through which the contaminated air flows until the concentration of contaminants in the effluent from the carbon bed exceeds an acceptable level. Granular-activated carbon (GAC) systems typically consist of one or more vessels filled with carbon connected in series and/or parallel operating under atmospheric, negative, or positive pressure. The carbon then can be regenerated in place, regenerated at an off-site regeneration facility, or disposed of, depending upon economic considerations.

Carbon can be used in conjunction with steam reforming. Steam reforming is a technology designed to destroy halogenated solvents (such as carbon tetrachloride and chloroform) adsorbed on activated carbon by reaction with superheated steam.

GAC is effective, technically implementable and commercially available for removal of VOCs from extracted air. This technology is retained for further evaluation.

Vapor Condensation. TCE and other VOCs in contaminated vapor streams can be cooled to condense the contaminants (EPA 2006). The contaminant-laden vapor stream is cooled below the dew point of the contaminants, e.g., below about 37.2 °C (99 °F) for TCE, and the condensate can be collected for recycling or disposal. Methods used to cool the vapor stream may include the use of liquid nitrogen, mechanical chilling, or a combination of the two.

Condensation systems are most often used when the vapor stream contains concentrations of contaminants greater than 5,000 ppm or when it is economically desirable to recover the organic contaminant contained in the vapor stream for reuse or recycling. Other configurations of vapor condensation include adsorbing or otherwise concentrating compounds from low-concentration vapors using another technology (e.g., GAC) and then performing condensation for recovery for disposal or recycling.

Vapor condensation of TCE and other VOCs present at the SW Plume source areas is potentially effective for removal of VOCs from extracted air; however, technical implementability and commercially availability are uncertain. This technology is retained for further evaluation.

Granular-Activated Carbon (Liquid Phase). GAC also is widely used for removal of VOCs including VOCs from aqueous streams, including pump-and treat systems. Liquid-phase carbon adsorption removes dissolved pollutants by physical adsorption onto activated carbon grains, similar to gas-phase absorption as described previously. Sizing of the GAC bed is done based on effluent flow rate, face velocity and residence time. Most GAC systems include a multiple bed configuration to optimize carbon utilization. To meet state and federal emission standards, it may be necessary to monitor the effluent prior to release to the environment. GAC currently is used as a polishing step after air stripping at the PGDP Northwest Plume Pump-and-Treat Facility.

GAC is effective, technically implementable, and commercially available for removal of VOCs from extracted groundwater. This technology is retained for further evaluation.

Thermal Technologies

Catalytic Oxidation. Oxidation equipment (thermal or catalytic) can be used for destroying contaminants in the exhaust gas from air strippers and SVE systems. Thermal oxidation units typically are single chamber, refractory-lined oxidizers equipped with a propane or natural gas burner and a stack. Lightweight ceramic blanket refractory is used because many of these units are mounted on skids or trailers. Flame arrestors are installed between the vapor source and the thermal oxidizer. Burner capacities in the combustion chamber range from 0.5 to 2 million BTUs per hour. Operating temperatures range from 760° to 870 °C (1,400 °F to 1,600 °F), and gas residence times typically are one second or less.

Catalytic oxidation includes a catalyst bed whish accelerates the rate of oxidation by adsorbing the oxygen and the contaminant on the catalyst surface where they react to form carbon dioxide, water, and hydrochloric gas. The catalyst enables the oxidation reaction to occur at much lower temperatures than required by a conventional thermal oxidation. VOCs are thermally destroyed at temperatures typically ranging from 320° to 540 °C (600° to 1,000 °F) by using a solid catalyst. First, the contaminated air is directly preheated (electrically or, more frequently, using natural gas or propane) to reach a temperature necessary to initiate the catalytic oxidation [310 °C to 370 °C (600 °F to 700 °F)] of the VOCs. Then the preheated VOC-laden air is passed through a bed of solid catalysts where the VOCs are rapidly oxidized. High chloride concentrations may require modification of the process to avoid corrosion.

Catalytic oxidation units are widely used for the destruction of VOCs and numerous vendors are available. As with the GAC absorption units, it may be necessary to monitor effluent concentrations to determine compliance with state and federal emission standards.

Catalytic oxidation is effective, technically implementable, and commercially available for removal of VOCs from extracted groundwater. This technology is retained for further evaluation.

Thermal Desorption. Thermal desorption heats wastes *ex situ* to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to a gas treatment system where they are collected or oxidized to CO_2 and water (FRTR 2008).

Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. Thermal screw units transport the medium through an enclosed trough using screw conveyors or hollow augers. Hot oil or steam circulates through the auger to indirectly heat the medium.

Thermal desorption systems typically require treatment of the off-gas to remove particulates and destroy contaminants. Particulates are removed by conventional particulate removal equipment such as wet scrubbers or fabric filters. Contaminants may be removed through condensation followed by carbon adsorption or destroyed in a secondary combustion chamber or a catalytic oxidizer.

Thermal desorption processes can be categorized into two groups based on operating temperatures, high temperature thermal desorption (HTTD), and low temperature thermal desorption (LTTD). HTTD heats wastes to 320° to 560 °C (600° to 1,000 °F) and is frequently used in combination with incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions. The technology can produce a final contaminant concentration level below 5 mg/kg for the target contaminants identified.

LTTD heats wastes to between 90° and 320 °C (200° to 600 °F). Contaminant destruction efficiencies in the afterburners of these units are greater than 95%. Decontaminated soil retains its physical properties. Unless heated to the higher end of the LTTD temperature range, soil organic matter remains available to support future biological activity. The target contaminant groups for LTTD systems are nonhalogenated VOCs and fuels. The technology can be used to treat SVOCs at reduced effectiveness.

The target contaminants for HTTD are SVOCs, PAHs, PCBs, and pesticides. VOCs and fuels also may be treated, but treatment may be less cost-effective. Volatile metals may be removed by HTTD systems. The presence of chlorine can affect the volatilization of some metals, such as lead.

The following factors may limit the applicability and effectiveness of the process:

- Particle size and materials handling requirements can affect applicability or cost at specific sites;
- Dewatering may be necessary to achieve acceptable soil moisture content levels;
- Highly abrasive feed potentially can damage the processor unit;
- Heavy metals in the feed may produce a treated solid residue that requires stabilization; and
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.

In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications include soil moisture content and classification, determination of boiling points for various compounds to be removed, and treatability tests to determine the efficiency of thermal desorption for removing various contaminants at various temperatures and residence times. A sieve analysis is needed to determine the dust loading in the system to properly design and size the air pollution control equipment.

Most of the hardware components for thermal desorption systems are readily available off the shelf. Most *ex situ* soil thermal treatment systems employ similar feed systems consisting of a screening device to separate and remove materials greater than five centimeters (2 inches), a belt conveyor to move the screened soil from the screen to the first thermal treatment chamber, and a weight belt to measure soil mass. Occasionally, augers are used rather than belt conveyors, but either type of system requires daily maintenance and is subject to failures that can shut down the system. Soil conveyors in large systems seem more prone to failure than those in smaller systems. Size reduction equipment can be incorporated into the feed system, but its installation is usually avoided to minimize shutdown as a result of equipment failure.

Many vendors offer LTTD units mounted on a single trailer. Soil throughput rates typically are 13 to 18 metric tons (15 to 20 tons) per hour for sandy soils and less than 6 metric tons (7 tons) per hour for clay soils when more than 10% of the material passes a 200-mesh screen. Units with capacities ranging from 23 to 46 metric tons (25 to 50 tons) per hour require four or five trailers for transport and two days for setup. The approximate time to complete cleanup of a 20,000-ton site using HTTD is just over four months.

Soil storage piles and feed equipment generally are covered as protection from rain to minimize soil moisture content and material handling problems. Soils and sediments with water contents greater than 20% to 25% may require the installation of a dryer in the feed system to increase the throughput of the desorber and to facilitate the conveying of the feed to the desorber. Some volatilization of contaminants occurs in the dryer, and the gases are routed to a thermal treatment chamber (FRTR 2008).

Thermal desorption is potentially effective, technically implementable, and commercially available for *ex situ* removal of VOCs from soil. This technology is retained for further evaluation.

2.4.1.7 Disposal technologies

Disposal technologies for recovered soil, groundwater, DNAPL, and secondary wastes produced during recovery and treatment are discussed below.

Land Disposal. Some of the treatment and removal technologies described previously would generate solid waste. RCRA hazardous wastes could be treated on-site to remove the hazardous characteristics or sent to Energy*Solutions* in Utah for treatment and disposal. Low-level radioactive waste or mixed low-level waste could be disposed of at sites such as Envirocare in Utah or the Nevada Test Site in Nevada. Nonhazardous soils or debris could be disposed of at the existing PGDP C-746-U Landfill if the waste acceptance criteria (WAC) were met, returned to the excavation, or otherwise used as fill.

Discharge to Groundwater or Surface Water. All water generated will be treated as needed and discharged via the KPDES permit requirements. Ion exchange resins from groundwater treatment could be sent to a land disposal facility. GAC beds could be returned to the manufacturer for thermal regeneration and reused.

2.4.2 Evaluation of Technologies and Selection of Representative Technologies

Technologies retained following the initial screening in Section 2.4.1 are evaluated with respect to effectiveness, implementability, and relative cost in Table A.2 (see Appendix A). The objective of this evaluation is to provide sufficient information for subsequent selection of RPOs in Section 2.4.3. No technologies are screened out at this stage.

Effectiveness is the most important criterion at this evaluation stage. The evaluation of effectiveness was based primarily on the following:

- The potential effectiveness of process options in handling the estimated areas or volumes of contaminated media and meeting the RAOs;
- The potential impacts to worker safety, human health, and the environment during construction and implementation; and
- The degree to which the processes are proven and reliable with respect to the contaminants and conditions at the site.

The evaluation of implementability includes consideration of the following:

- The availability of necessary resources, skilled workers, and equipment to implement the technology;
- The availability of treatment, storage, and disposal services, including capacity;
- Site accessibility and interfering infrastructure;

- Potential public concerns regarding implementation of the technology; and

- The time and cost-effectiveness of implementing the technology in the physical setting associated with the waste unit.

A relative cost evaluation is provided for comparison among technologies. Relative capital and O&M costs are described as high, medium, or low. These costs are based on references applicable to the particular process option given at the end of this section, prior estimates, previous experience, and engineering judgment. The costs are not intended for budgeting purposes.

2.4.3 Representative Process Options

RPOs selected are listed in Table 2.4, based on the evaluation of process options for VOCs in UCRS soils at the Oil Landfarm and the C-720 Northeast and Southeast Sites. The RPOs selected were determined to be the most potentially effective and implementable and have the lowest cost of the process options considered for each technology type. The RPOs selected were used to develop the alternatives presented in Section 3.

Technologies that are identified by EPA as presumptive remedies (i.e., SVE for removal of VOCs in soil) are favored. Technologies that have been demonstrated at the PGDP for treatment of DNAPL TCE in the UCRS, including ERH and electrokinetics using Lasagna™, have higher demonstrated effectiveness and implementability than other technologies within the same technology type and also are preferred.

The RPOs selected also were determined to most effectively meet the RAOs for all phases of VOCs potentially present at the Oil Landfarm and the C-720 Northeast and Southeast Sites, as discussed in Section 1. These may include DNAPL TCE and VOCs sorbed to soil solids, dissolved in pore water and present as vapor in pore space. RPO selection also was based on the potential effectiveness and technical implementability in variable saturation in the UCRS, as described in Section 1.

Existing conditions and operations in the SW Plume source areas also were considered in RPO selection. Considerations included the ability to allow for ongoing operations in and around the C-720 Building, ability to be implemented in areas with surface and subsurface infrastructure, and minimal effects on existing site uses. Use of existing infrastructure or programs (e.g., the C-746-U Landfill, existing DOE plant controls, and discharges to permitted outfalls) were also favored.

RPO selection also was based on consideration of the fate of co-contaminants including ^{99}Tc in groundwater; SVOCs including PCBs and dioxin; radionuclides including uranium and ^{99}Tc; and metals in the Oil Landfarm soil; during implementation of the technology. Considerations included the potential to increase the toxicity or mobility of co-contaminants, or to increase the volume of contaminated media. Selection of treatment and disposal RPOs also considered the technical and administrative feasibility of meeting discharge limits for effluents or disposal criteria for secondary wastes for these contaminants.

In some cases, more than one process option was selected for a technology type, for example, if two or more process options were considered to be sufficiently different in their performance that one would not adequately represent the other, or if the processes are complementary or part of a treatment train. Innovative technologies were selected as RPOs only if they were judged to provide better treatment, fewer or lower adverse effects, implementable within a reasonable time period, or lower costs than other established process options.

RPOs were not selected for every technology type (e.g., *in situ* chemical treatment of soils) based on lack of demonstrated effectiveness or implementability. These technologies were not screened out, but are available to be advanced to treatability studies or pilot demonstrations if the identified RPOs are

considered inadequate. The initial selection of RPOs may be revised in the ROD based on public comment on the Proposed Plan, a successful treatability study or pilot demonstration, or other considerations.

Table 2.4. Selection of Representative Process Options

General Response Actions	Technology Type	Representative Process Options	Basis for Selection
Land use controls	Institutional controls	Excavation/Penetration Permit program	Effective and implementable for worker protection; low cost.
Monitoring	Soil monitoring	Soil cores	Effective and implementable for confirmatory sampling; moderate cost.
		Soil vapor sampling	Effective and implementable for monitoring; low cost.
		Membrane interface probe	Effective and implementable for characterization; moderate cost.
	Groundwater monitoring	Sampling and analysis	Effective and implementable for monitoring; moderate to high cost.
		DNAPL interface probe	Effective and implementable for DNAPL detection in groundwater monitoring wells; low cost.
Removal	Excavators	Backhoes, trackhoes	Demonstrated effectiveness to depths of 13.7 m (45 ft) bgs; technically implementable; low costs.
		Vacuum excavation	Demonstrated effectiveness in alluvial soils to depths of 10.67+ m (35+ ft) bgs; technically implementable; moderate costs.
		Crane and clamshell	Effective in alluvial soils to depths greater than 30 m (100 ft) bgs; technically implementable; high cost.
Containment	Hydraulic containment	Recharge controls	Effective and implementable; moderate cost.
	Surface barriers	Conventional asphalt cover	Effective and implementable, trafficable surface, can be installed around infrastructure, trafficable surface; low cost.
		Flexible membrane	Effective and implementable; moderate cost.
	Subsurface barriers	Sheet pilings	Adjunct technology for removal technologies; effective and implementable; high cost.
Treatment	Physical/chemical	Dual-phase soil vapor extraction-*in situ*	Presumptive remedy for all VOC phases in UCRS; effective and implementable in variably saturated soils; moderate cost.

Table 2.4. Selection of Representative Process Option (Continued)

General Response Actions	Technology Type	Representative Process Options	Basis for Selection
		Air stripping-*ex situ*	Effective and implementable for *ex situ* removal of TCE from groundwater; low cost; currently implemented at Northwest Plume treatment plant.
		Ion exchange-*ex situ*	Effective and implementable for *ex situ* removal of Tc-99 from groundwater; moderate cost; currently implemented at Northwest Plume treatment plant.
	Biological	Anaerobic reductive dechlorination-*in situ*	Potentially effective and implementable for all VOC phases in UCRS; less effective in variably saturated soils; relatively low cost.
	Thermal	Electrical resistance heating-*in situ*	Demonstrated effectiveness and implementability for all VOC phases in UCRS at PGDP; effective and implementable in variably saturated soils; moderate cost.
		Thermal desorption-*ex situ*	Effective and implementable for all VOC phases as an adjunct technology for soil removal; high cost.
		Catalytic oxidation-*ex situ*	Effective and implementable treatment for thermal desorption, SVE or air stripper off-gas; high cost.
Disposal	Land Disposal	Off-site permitted commercial disposal facility	Effective and implementable as an adjunct technology for soil removal; high cost.
		C-746-U on-site landfill	Effective and implementable for non-hazardous non-radioactive wastes, currently available; low cost.
	Discharge to surface water	KPDES-permitted outfall	Effective and implementable for treated groundwater; low costs; currently implemented at Northwest Plume treatment plant.

DOE = U.S. Department of Energy
DNAPL = dense nonaqueous-phase liquid
KPDES = Kentucky Pollutant Discharge Elimination System
SVE = soil vapor extraction
Tc-99 = technetium-99
TCE = trichloroethene
UCRS = Upper Continental Recharge System
VOC = volatile organic compound

3. DEVELOPMENT AND SCREENING OF ALTERNATIVES

3.1 INTRODUCTION

The alternatives presented in the following sections were developed by combining the RPOs identified in Section 2.4 into a range of treatment strategies to meet the RAOs. The alternatives were formulated to create responses that vary in their extent of attainment of RAOs, effectiveness, implementabilty, and cost in order to meet EPA's expectation that the feasibility studies for source control actions provide "A range of alternatives in which treatment that reduces the toxicity, mobility, or volume of the hazardous substances, pollutants, or contaminants is a principal element" [40 *CFR* § 300.430(e)(1)(G)(3)(i)].

Also, the demonstrated effectiveness of combined technologies (e.g., capping and soil vapor extraction) was used to identify appropriate comprehensive alternatives. Media interactions including effects of source actions on RGA groundwater during implementation also were considered.

Alternatives are developed and discussed with the assumption that each would be applied to the Oil Landfarm and C-720 Northeast and Southeast Sites. Decision makers could apply different alternatives to individual sites, depending on regulator preferences or public response to the Proposed Plan. Sufficient information is provided to allow for this type of alternative selection in the Proposed Plan and ROD.

3.2 CRITERIA FOR THE DEVELOPMENT OF REMEDIAL ALTERNATIVES

The purpose of the FFS and the overall remedy selection process is to identify remedial actions that eliminate, reduce, or control risks to human health and the environment and meet ARARs. The national program goal of the FS process, as defined in the NCP, is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste. The NCP defines certain expectations for developing remedial action alternatives to achieve these goals, stated in 40 *CFR* § 300.430. These expectations were used to guide the development of alternatives, discussed below.

3.3 ARARS

Section 121(d) of CERCLA and Section 300.430(f)(1)(ii)(B) of the NCP require that remedial actions at CERCLA sites at least attain legally "applicable" or "relevant and appropriate" federal and state environmental requirements, standards, criteria, and limitations, unless such ARARs are waived under CERCLA Section 121(d)(4).

Chemical-specific ARARs provide health- or risk-based concentration limits or discharge limitations in various environmental media (i.e., surface water, groundwater, soil, or air) for specific hazardous substances, pollutants, or contaminants. There are no chemical-specific ARARs for remediation of the contaminated subsurface soils at the source areas; however, Kentucky drinking water standard MCLs at 401 *KAR* 8:420 for VOCs were used for calculation of soil RGs to meet RAO #3.

Location-specific ARARs establish restrictions on permissible concentrations of hazardous substances or establish requirements for how activities will be conducted because they are in special locations (e.g., floodplains or historic districts). Action-specific ARARs include operation, performance, and design of the preferred alternative based on waste types and/or media to be addressed and removal/remedial

activities to be implemented. Location- and action-specific ARARs have been identified and evaluated for each alternative in Section 4.

3.4 DEVELOPMENT OF ALTERNATIVES

The RPOs selected in Section 2.4.3 were combined to formulate a range of comprehensive remedial alternatives to satisfy the NCP expectations and the RAOs for the Oil Landfarm and the C-720 Northeast and Southeast Sites. Alternatives are summarized in Table 3.1. Effectiveness, implementability, and cost are criteria used to guide the development and screening of remedial alternatives.

Conceptual designs are developed for each alternative with sufficient detail to allow for detailed and comparative analysis, and cost estimating with a -30% to +50% range of accuracy, per CERCLA guidance (EPA 1988). Implementation procedures and operations, monitoring, and maintenance requirements are discussed. Supporting calculations and cost estimates for the conceptual designs are provided in Appendix B.

3.4.1 Alternative 1—No Action

Formulation of a No Action Alternative is required by the NCP [40 *CFR* § 300.430(e)(6)] and CERCLA FS guidance (EPA 1988). The No Action Alternative serves as a baseline for evaluation of other remedial action alternatives and is generally retained throughout the FS process. As defined in CERCLA guidance (EPA 1988), a No Action Alternative may include environmental monitoring; however, other actions taken to reduce exposure, such as site fencing are not included as a component of the No Action Alternative. Alternative 1, therefore, includes no actions and no costs.

3.4.2 Alternative 2—*In Situ* Bioremediation

Alternative 2 consists of the following:

- Remedial design (RD) investigation to refine the extent of VOC contamination and determine ISB parameters
- Injection of electron donor into the UCRS saturated zones of the source areas
- Soil and groundwater monitoring
- Secondary waste management
- Confirmatory sampling of treated soils for VOCs
- Site restoration
- E/PP program
- Five-year reviews

Table 3.1. Alternative Formulation for the Oil Landfarm and the C-720 Northeast and Southeast Sites

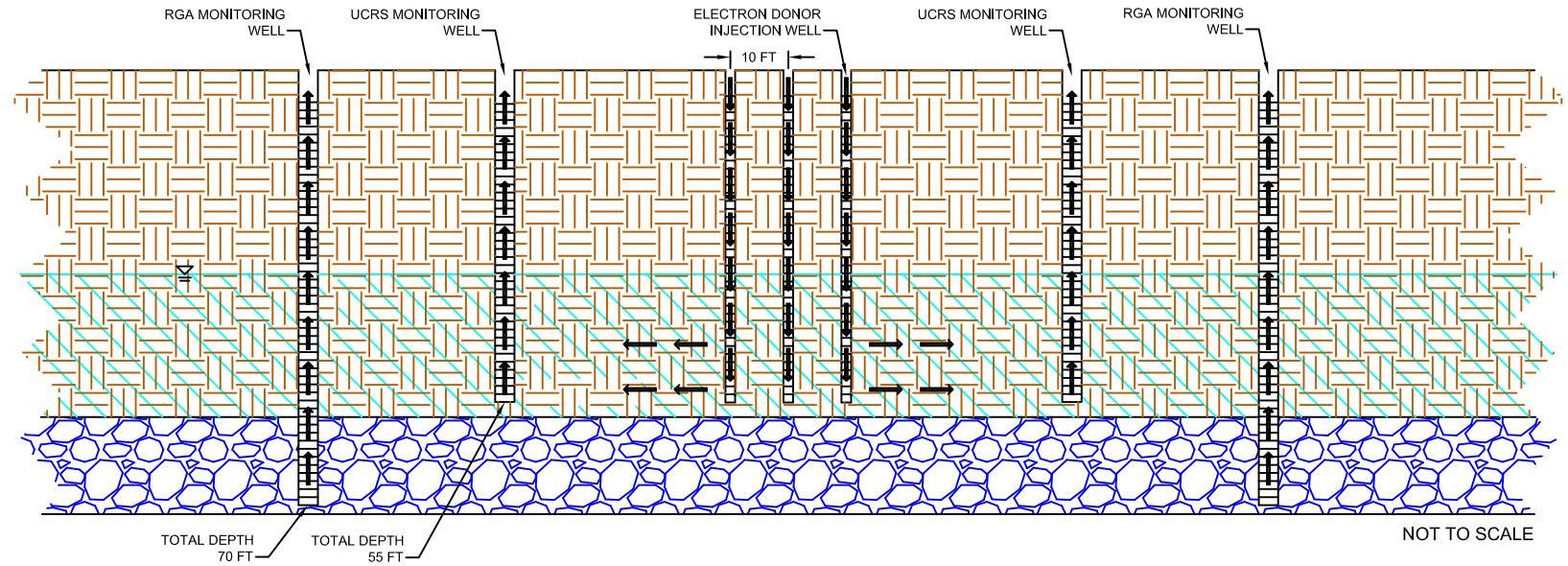
Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
No Action	***In Situ* Bioremediation**	**Source Removal and *Ex Situ* Thermal Treatment**	**SVE Source Treatment and Containment**	***In Situ* Thermal Source Treatment**
	RD investigation	RD investigation	RD investigation	RD investigation
	Electron donor injection	Excavate VOC-contaminated source area soils	Containment and recharge controls	Treatment using electrical resistance heating with soil vapor extraction
	Soil and groundwater monitoring	Thermal treatment of excavated soils	Dual-phase soil vapor extraction	Off-gas treatment
	Confirmation sampling of treated soils	Confirmation sampling of treated soils	Off-gas treatment	Process monitoring
	E/PP program	Backfill with treated soil or other clean fill	Co-produced groundwater treatment	Confirmation sampling of treated soils
			Sampling and monitoring	Groundwater monitoring
			Confirmation sampling of treated soils	E/PP program
			E/PP program	

E/PP program = excavation/penetration permit program
RD = Remedial Design

This alternative would reduce the mass of VOCs present in the source areas and eliminate risks to receptors by eliminating the exposure pathways shown in Figure 2.1. Requirements and conceptual designs for each element of Alternative 2 are discussed below in detail. A schematic view of the conceptual design is provided in Figure 3.1, and plan views of areas that would be treated at the Oil Landfarm and the C-720 Northeast and Southeast Sites are shown in Figures 3.2 and 3.3, respectively.

3.4.2.1 RD investigation

RD investigation would be performed at the Oil Landfarm and the C-720 Northeast and Southeast Sites to better determine the extent and distribution of VOCs, including DNAPL TCE, and to determine UCRS soil and groundwater parameters specific to the ISB technology. Based on the calculated RGs for VOC concentrations in source area soil presented in Section 2.2, supplemental investigations to bound the lateral and vertical extent of VOC contamination at the C-720 Northeast and Southeast Sites and the Oil Landfarm are described below.



U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

PADUCAH Remediation Services
A Portage Shaw Joint Venture Company

Figure 3.1. Schematic View of ISB for Alternative 2

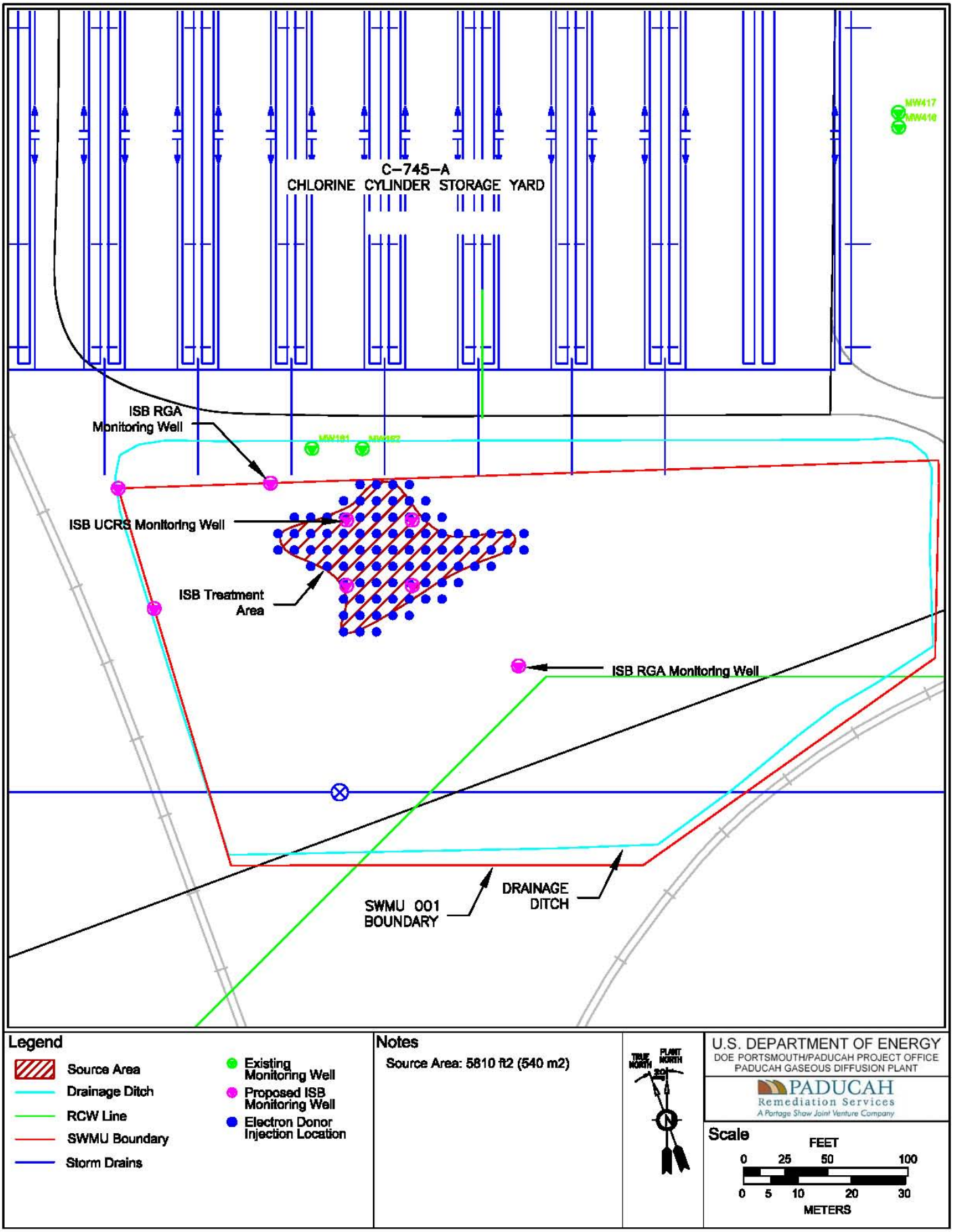


Figure 3.2. Plan View of Alternative 2 at the Oil Landfarm

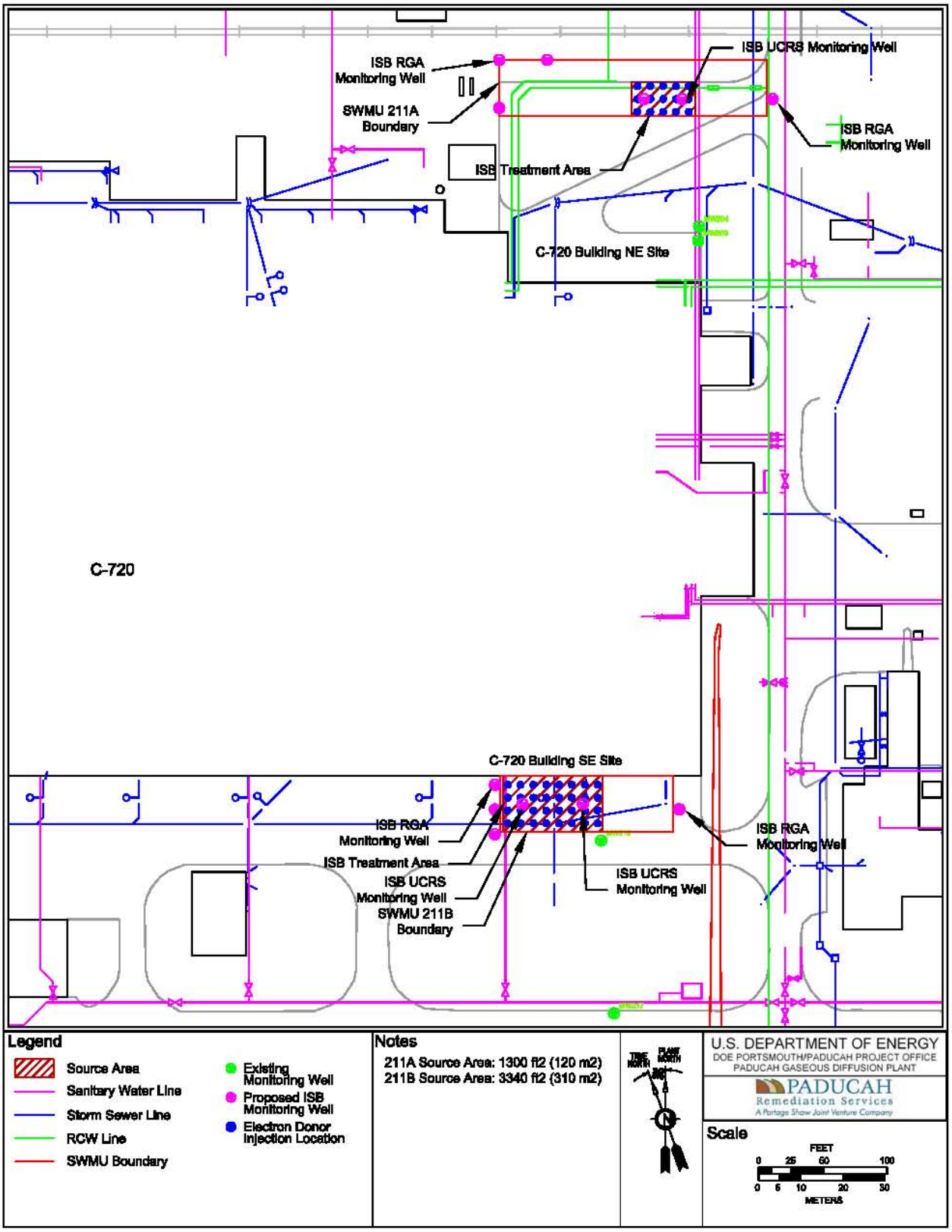


Figure 3.3. Plan View of Alternative 2 at C-720 Northeast and Southeast Sites

Figure 1.15 shows the WAG 27 and Southwest Plume SI sampling locations and results for the C-720 Building Area. The Southwest Plume investigation of the C-720 Northeast site consisted of six MIP/DPT borings (720-101 through 720-106) pushed between the north edge of the parking lot and a storm sewer that collects all surface runoff for the parking lot. The extent of TCE present at concentrations above the RG of 75 µg/kg is not bounded on the south, as evidenced by concentrations greater than the RG detected in borings 720-104 and 720-105. The extent was not bounded on the east, as evidenced by concentrations above the RG detected in borings 720-106 and 720-105. The extent was not bounded on the north, as evidenced by concentrations above the RG detected in 720-027 (WAG 27). The extent was not bounded vertically, as evidenced by concentrations above the RGs at the maximum depths of boreholes 720-104, 720-105, and 720-106. Given that the extent is not bounded on the north or south, contamination above the RG may extend farther west than borings 720-101 and 720-102, which show concentrations below the RG.

The SI for the southeast corner of C-720, also as described in DOE 2007, consisted of two MIP/DPT borings (720-107 and 720-108) pushed through the parking lot adjacent to the C-720 Building loading dock. The extent of TCE present at concentrations greater than the calculated RG of 75 µg/kg is bounded on the south as evidenced by nondetect in 720-022, a WAG 27 boring. The extent is not bounded on the west, as evidenced by concentrations above the RG in 720-107. The extent is bounded on the east as evidenced by concentrations below the RG in 720-108. The extent is not bounded on the north, unless it is to be assumed that VOCs have not migrated beneath the building. The extent is not bounded vertically, due to refusal encountered at 26 ft bgs in 720-002, where TCE concentrations of 32,000 ug/kg were determined.

Figures 1.11 and 1.12, respectively, show the WAG 27 and Southwest Plume SI sampling locations and results for the Oil Landfarm. The extent of TCE present at concentrations greater than the calculated RG is not bounded on the north, as evidenced by concentrations above the RG in WAG 27 boring 001-069. The vertical extent of TCE is not bounded, as evidenced by concentrations above the RG detected at the maximum depths of borings in both investigations. SI boring 001-202 encountered TCE at 3,400 µg/kg at the maximum depth of 59.5 ft bgs. SI boring 001-204 encountered TCE at 290 µg/kg at the maximum depth of 58.5 ft bgs. Boring 001-201 encountered TCE at 1,800 µg/kg at 56.0 ft bgs.

The uppermost unit of the RGA, the HU4, occurs at approximately 53 ft bgs at the Oil Landfarm and at 58.4 ft bgs at C-720, as discussed in Section 1. The presence of TCE concentrations above RGs at depths greater than 53 ft bgs at the Oil Landfarm indicates that VOC contamination potentially including DNAPL has migrated to the upper RGA. The presence of TCE above RGs at maximum borehole depths of 56.5 ft bgs at the C-720 Northeast Site also indicates that VOC contamination potentially including DNAPL has migrated to the RGA. The significance of the possibility of DNAPL migration to the RGA at the Southwest Plume source areas is that the scope of the source control actions, currently limited to the UCRS, may have to be extended to the RGA.

The RD investigation would be based on a systematically planned approach developed in the Remedial Action Work Plan (RAWP). Principal study questions to be resolved by the investigation would include the following:

(1) What are the areal and vertical extents of VOC contamination above RGs at the C-720 Northeast and Southeast Sites?

(2) What is the vertical extent of VOC contamination above RGs at the Oil Landfarm?

(3) Has DNAPL migrated to the RGA at the C-720 Northeast Site, C-720 Southeast Site, or at the Oil Landfarm?

The conceptual design for RD investigation at the Oil Landfarm and the C-720 Northeast and Southeast Sites includes the following:

- Preliminary soil gas sampling using the MIP and on-site analysis for VOCs at the C-720 Area Northeast and Southeast Sites to estimate the areal and vertical extent of contamination including DNAPL; and at the Oil Landfarm to determine vertical extent of contamination including DNAPL.

- Soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent, at locations determined using the MIP results, at the C-720 Area Northeast and Southeast Sites and at the Oil Landfarm, to determine the extent of VOC contamination present at concentrations above RGs. Soil cores also would be evaluated to determine the presence or absence of DNAPL.

- Sampling of existing UCRS wells in the vicinity of the source areas and analysis for ISB parameters including VOCs, pH, ORP, dissolved oxygen, total and dissolved iron, total and dissolved manganese, sulfate, nitrate, methane, ethene, ethane, alkalinity, total organic carbon (TOC).

- Geodetic survey of all sampling and well locations.

3.4.2.2 Electron donor injection

Regenesis Hydrogen Release Compound (HRC®) or an approved equal would be injected in adjacent rows on 3.05-m (10-ft) centers as shown in Figures 3.2 and 3.3. The HRC would serve to establish anaerobic conditions in the UCRS saturated zone. Only one injection is assumed to be required. Electron donor would be injected using DPT at each location, continuously from 16.76 m (55 ft) bgs to 1.52 m (5 ft) bgs, as the drill rods were withdrawn.

Regenesis products are cited only because they are readily available commercially and are specifically designed for ISB-ARD. Other products (e.g., sodium lactate, vegetable oil, and others) have been used successfully, but may be more difficult to purchase and implement.

3.4.2.3 Secondary waste management

Secondary wastes produced under this alternative would include drill cuttings and decontamination fluids from the RD investigation and purge water from groundwater monitoring. All wastes are assumed to be managed as mixed waste pending sampling and dispositioning. PCBs potentially present at the Oil Landfarm would be expected to occur at concentrations below 50 ppm and would not require management as Toxic Substances Control Act (TSCA) waste. Groundwater monitoring purge water would be containerized and treated on-site prior to discharge. Actual dispositioning requirements would be determined during remedial design and by sampling of containerized soils, decontamination fluids and purge water. All secondary wastes would be managed in accordance with all ARARs.

3.4.2.4 Site restoration

Site restoration activities would include demobilizing and removing all equipment; sealing all MIP, soil coring and electron donor injection locations with bentonite; reseeding disturbed vegetated areas at the Oil Landfarm and the C-720 Northeast Site; and repairing penetrations of asphalt and concrete at the C-720 Northeast and Southeast Sites. Monitoring wells would be left in place.

3.4.2.5 Excavation/Penetration Permit Program

The existing E/P permit program would be maintained at the source areas to control exposures to contaminants in soils, pending remedy completion. This interim LUC would be implemented through the ROD.

3.4.2.6 Soil and Groundwater Monitoring

Soil and groundwater monitoring would be used to determine the effectiveness of the remedy. One upgradient and four downgradient wells screened in the shallow RGA would be constructed at each source area. Wells would monitor for VOCs, oxygen, nitrate, sulfate, iron, manganese, chloride, organic acids, pH, ORP, alkalinity, water levels, and other parameters, at least quarterly for one year following electron donor injection to determine the treatment effectiveness and to ensure that DNAPL TCE was not mobilized by the injections. Wells would be monitored thereafter for VOCs to determine progress toward attainment of RAO #3 and also for pH, conductivity, presence of DNAPL using the interface probe, and water levels twice annually. Results would be reported in the five-year reviews and provided to the sitewide environmental monitoring program and to the Dissolved-Phase Plumes RA Project under the Groundwater OU.

Wells would be installed in the UCRS at four locations at the Oil Landfarm and two locations each at the C-720 Northeast and Southeast Sites. UCRS groundwater samples would be collected at least quarterly for the duration of implementation to determine the treatment effectiveness and to ensure that DNAPL TCE was not mobilized by the injections. Locations would be monitored for VOCs, oxygen, nitrate, sulfate, iron, manganese, chloride, organic acids, pH, ORP, alkalinity, water levels, and other parameters. Wells would be checked for the presence of DNAPL using the interface probe at each sampling event.

3.4.2.7 Five-year reviews

Five-year reviews would be required under the PGDP FFA as long as soil contaminant concentrations remained above RGs. A review would be submitted to EPA and Kentucky Energy and Environment Cabinet no less often than once every five years after the initiation of the remedial action for as long as the PGDP remained on the NPL to assure that human health and the environment are protected by the RA being implemented. Groundwater monitoring results would be included in the report.

3.4.3 Alternative 3—Source Removal and *Ex Situ* Thermal Treatment

Alternative 3 consists of all the following:

- RD investigation
- Excavating source area soils contaminated with VOCs above RGs
- Treating excavated soils
- Confirmatory sampling of treated soils for VOCs
- Backfilling with treated soil or other approved fill
- Site restoration
- Secondary waste management

This alternative combines process options from the GRAs of Removal, Treatment (*ex situ*), and Disposal. Alternative 3 would eliminate all VOCs present in all phases from the excavated area in a relatively short time. Requirements and conceptual designs for each element of Alternative 3 are discussed below. No LUCs would be required assuming all VOCs and non-VOCs were excavated and removed from the

source areas. A schematic view of the excavation and treatment process is provided in Figure 3.4, and plan views of the overall layout for the Oil Landfarm and C-720 Northeast and Southeast Sites, including soil stockpile areas and treatment system areas are shown in Figures 3.5 and 3.6, respectively.

3.4.3.1 RD investigation

RD investigation would be performed at the Oil Landfarm and the C-720 Northeast and Southeast Sites to supplement delineation of the extent of VOCs and DNAPL TCE and to close any data gaps concerning the areal and vertical extent of contamination. RD investigation would be based on a systematically planned approach. The conceptual design for RD investigation includes these elements:

- Preliminary soil gas sampling using the MIP and on-site analysis for VOCs at the C-720 Area Northeast and Southeast Sites to estimate the areal and vertical extent of contamination, including DNAPL, and at the Oil Landfarm to determine vertical extent of contamination, including DNAPL.

- Soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent at locations determined using the MIP results. Soil cores also would be evaluated to determine the presence or absence of DNAPL.

- Geodetic survey of all sampling locations.

3.4.3.2 Excavation

Excavation would include the following processes.

- Reroute all subsurface infrastructure and cut all process lines, storm sewers, and utilities at the excavation area perimeter.

- Enclose the extent of VOC source zones by installing sheet pilings to the top of the RGA.

- Excavate all soils inside the enclosure, to the top of the RGA, using tracked excavators, vacuum excavation and a crane and clamshell at the C-720 Northeast and Southeast Sites and a crane and dragline at the Oil Landfarm. Estimated bank and loose volumes, assuming a swell factor of 1.25 for excavated soils, based on Figures 3.5 and 3.6 include these:

  — Oil Landfarm: 12,707 m^3 (16,620 yd^3) (bank), 15,887 m^3 (20,780 yd^3) (loose)
  — C-720 Northeast Site: 2,210 m^3 (2,890 yd^3) (bank), 2,760 m^3 (3,610 yd^3) (loose)
  — C-720 Southeast Site: 5,682 m^3 (7,432 yd^3) (bank), 7,102 m^3 (9,290 yd^3) (loose)

- Weld structural steel crossbeams, also called walers, to support the sheet piles as the excavation proceeds.

- Pumping to remove groundwater entering the excavation.

- Stockpile excavated soils on-site within an area of contamination (AOC) consistent with to be considered (TBC) guidance and ARARs.

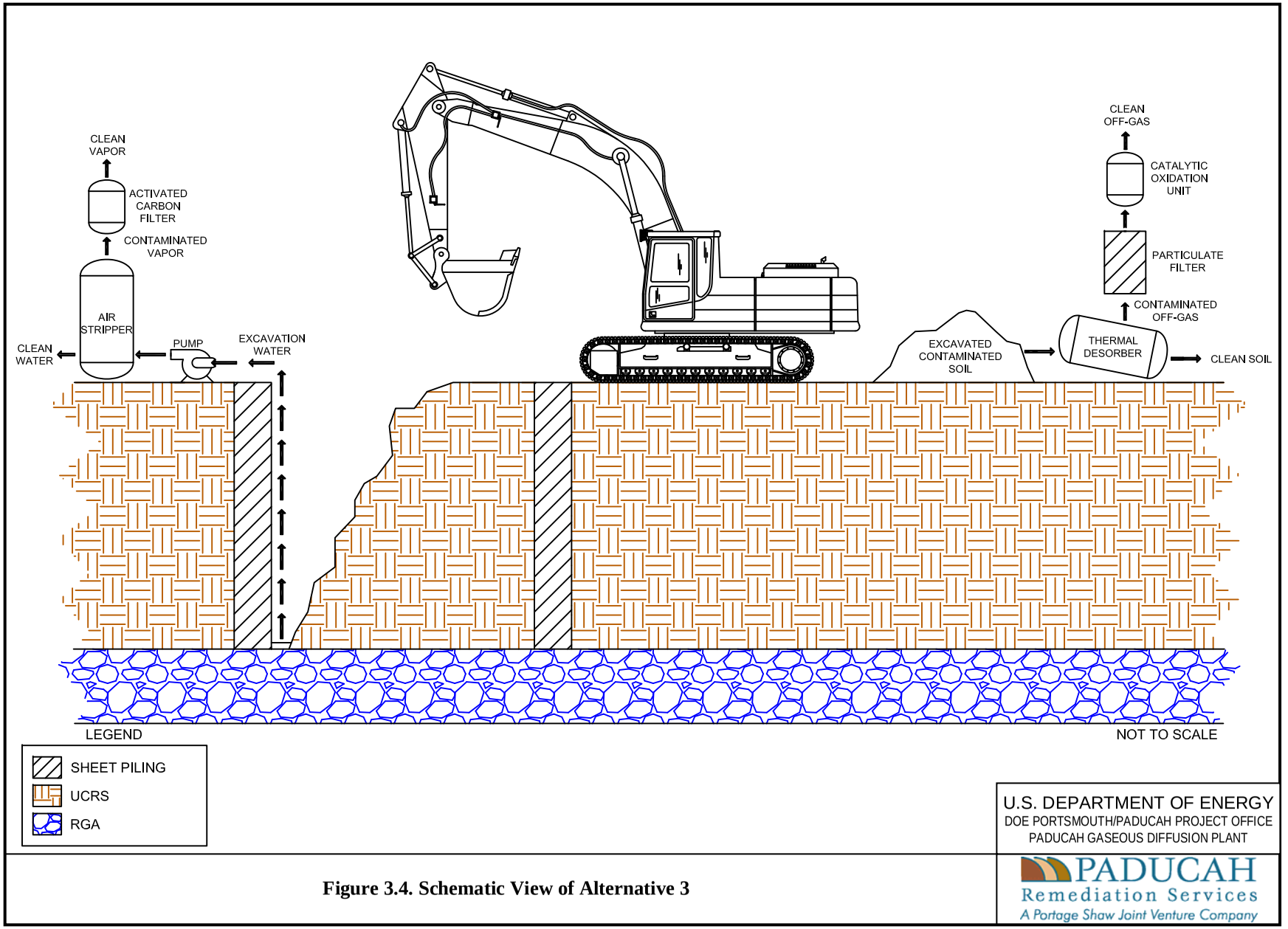


Figure 3.4. Schematic View of Alternative 3

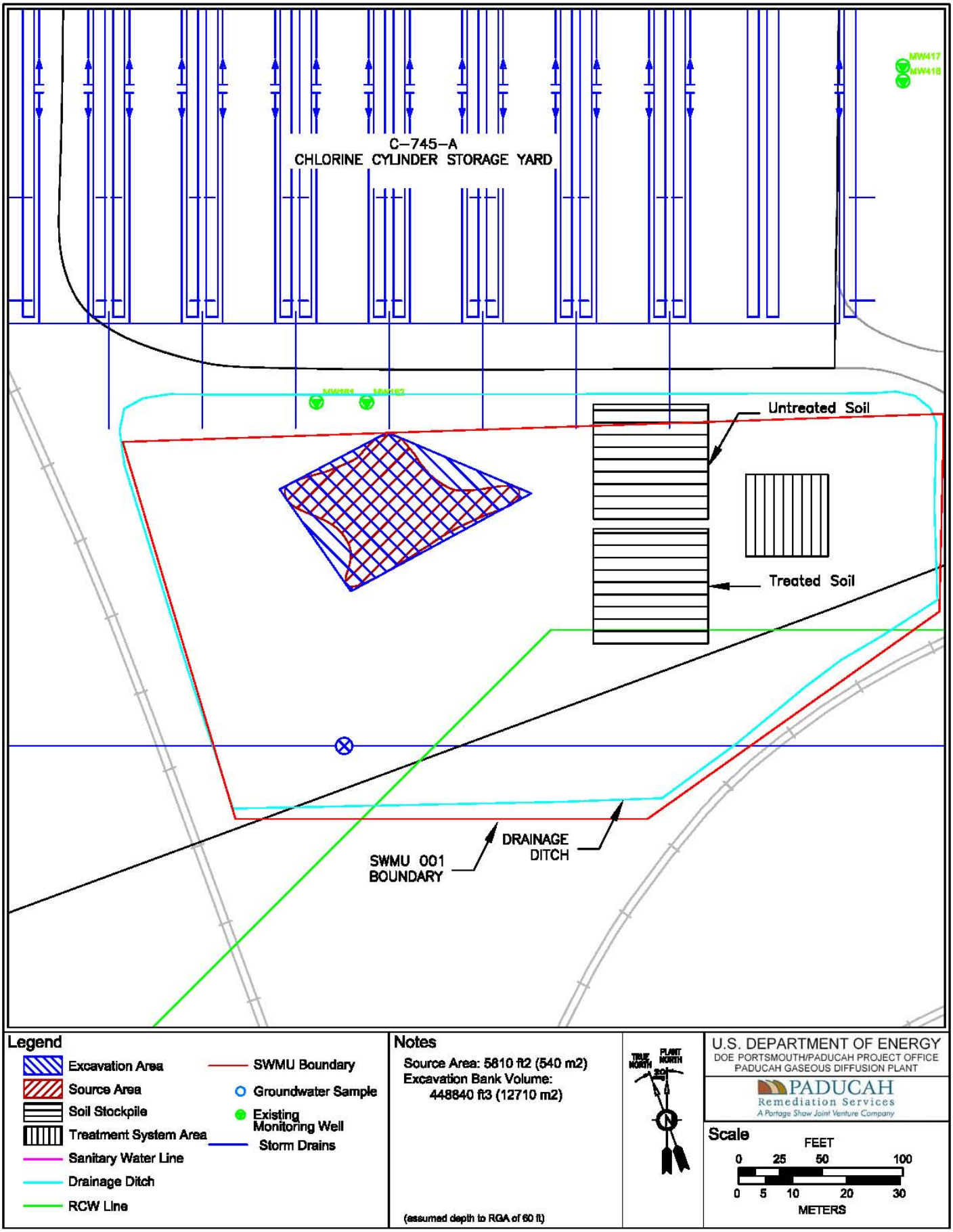


Figure 3.5. Plan View of Alternative 3 at the Oil Landfarm

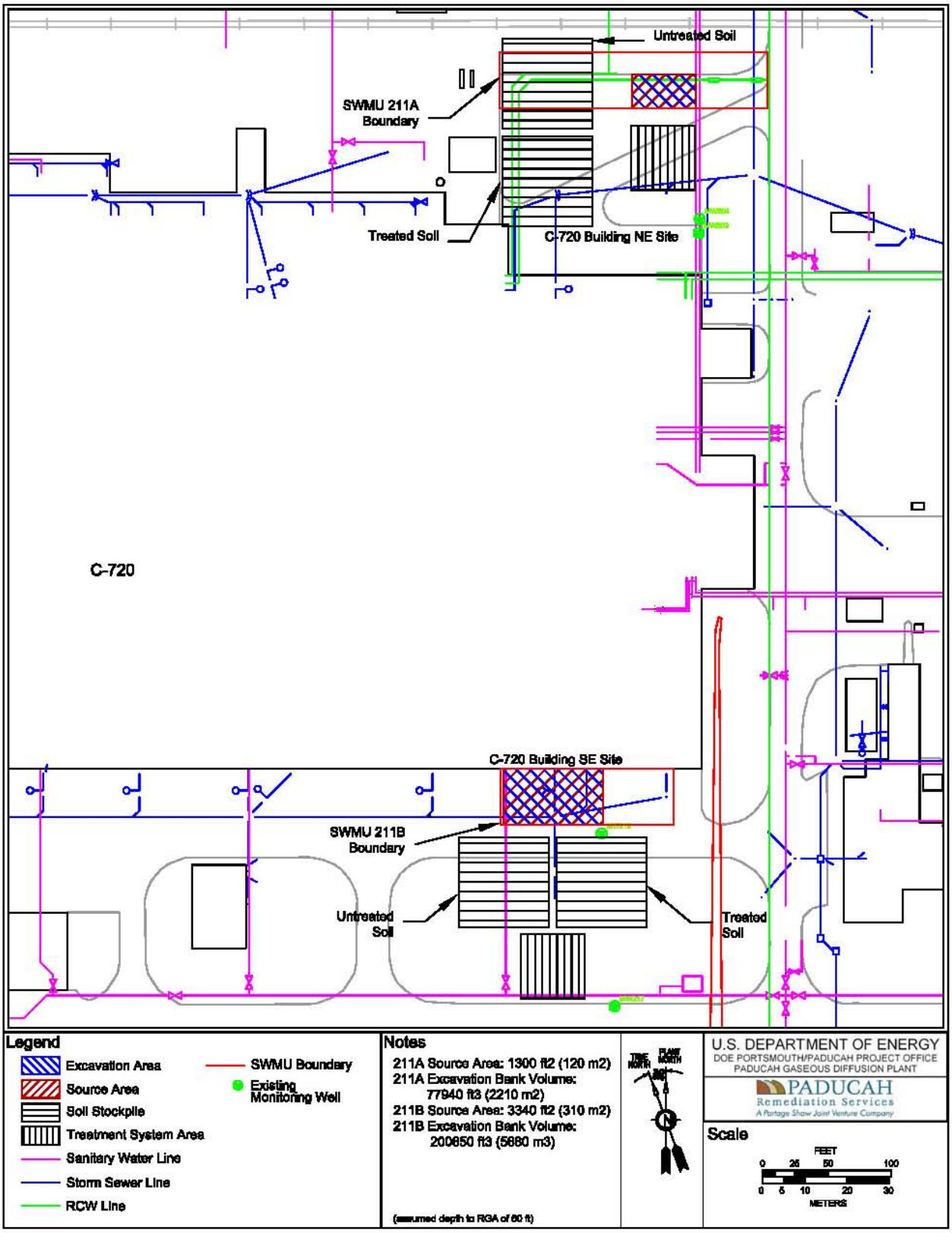


Figure 3.6. Plan View of Alternative 3 at C-720 Northeast and Southeast Sites

Construction would begin by rerouting and cutting subsurface water lines, storm sewers, and utilities within the area to be excavated. Sheet pilings would be installed to approximately 18.3 m (60 ft) bgs using a crane and vibrating head. The upper 6.1 to 9.14 m (20 to 30 ft) bgs would be excavated using a trackhoe with a 13.7-m (45-ft) boom and a vacuum excavator. The lower 9.14 to 18.3 (30 to 60) ft would be excavated using a crane with a clamshell at the C-720 Northeast and Southeast Sites and a crane and dragline at the Oil Landfarm, due to the longer reach required across the excavation.

An alternative method would involve installing sheet pilings on three sides of the contaminated area, then excavating at a stable slope angle, or with benches and terraces, so that trackhoes and other equipment could operate inside. The preferred excavation method would be determined during RD and would require safety analysis prior to implementation.

Soils would be stockpiled on-site within the AOC, assumed to be within the SWMU boundary, pending treatment. The stockpiles shown on Figures 3.5 and 3.6 are 3.05 m (10 ft) in height. Stockpiles likely would require VOC and dust emission controls, as well as storm water runoff controls. Use of tarps, foams, or other measures for air emission controls and storm water best management practices (BMPs) for the stockpiles would be evaluated in the RD/RAWP. A management plan for the stockpiles including segregation of soils as untreated, treated, sampled, and approved for disposal also would be required in the RD/RAWP.

3.4.3.3 Treatment

Treatment of excavated soil and groundwater pumped from the excavation would include the following:

- Thermal desorption of VOCs from excavated soils to meet the disposal facility WAC. A separate dewatering or drying process unit might be required prior to VOC treatment, depending on the soil moisture content and the particular thermal desorption unit selected. Treatment would be performed within the AOC, assumed to be the SWMU boundary. Radionuclides, metals, and SVOCs potentially present at SWMU 1 would not be removed by this method. Conversion of dioxins or furans at these temperatures would not be expected.

- Filtration of off-gas from thermal desorption to remove particulates.

- Catalytic oxidation of thermal desorption off-gas for destruction of VOCs to meet air emission ARARs. PCBs and other SVOCs potentially present at SWMU 1 would not be removed in thermal desorption off-gas and, therefore, would not be converted to dioxins or furans during catalytic oxidation.

- Pumping and on-site storage and treatment of groundwater pumped from the excavation on-site using air stripping/GAC/ion exchange to meet liquid effluent ARARs.

- Stockpiling treated soils on-site within the AOC.

3.4.3.4 Confirmatory sampling

Confirmatory sampling and analysis of treated soils for VOCs would be required prior to backfilling. A confirmatory sampling plan would be prepared for the RAWP. The conceptual design for confirmatory sampling includes one grab sample per 76.5 m^3 (100 yd^3) of treated soils, one sample per 9.3 m^2 (100 ft^2) of excavation, and analysis for VOCs using EPA SW-846 Method 8260B or equivalent.

3.4.3.5 Backfill

Treated soil or other approved fill would be used to backfill the excavation. Compaction of the backfill would be specified in the RD/RAWP.

Wales would be cut with torches as backfilling proceeded to allow for removal of the sheet pilings. Pilings would be removed when the backfill was at or near ground surface.

3.4.3.6 Secondary waste management

Secondary wastes produced under this alternative would include treated excavated soils, excavation water, and spent GAC. All wastes are assumed to be managed as mixed waste pending sampling and dispositioning. PCBs potentially present at the Oil Landfarm would be expected to occur at concentrations below 50 ppm and would not require management as TSCA waste. Excavation water would be containerized and treated on-site prior to discharge. Spent GAC would be shipped off-site for regeneration. Actual dispositioning requirements would be determined during remedial design and by sampling of secondary wastes. All secondary wastes would be managed in accordance with all ARARs.

3.4.3.7 Site restoration

Surface completion of the excavation would be topsoil and vegetation at the Oil Landfarm and asphalt or concrete at the C-720 Northeast and Southeast Sites. Sites would be graded to promote runoff and surveyed for final as-built drawings.

3.4.4 Alternative 4—SVE Source Treatment, and Containment

Alternative 4 consists of all of the following:

- RD investigation
- Hydrofracturing in the UCRS to increase vapor recovery rates
- Containment and recharge controls
- Dual-phase soil vapor extraction
- Off-gas treatment
- Co-produced groundwater treatment
- Treated groundwater discharge to a permitted outfall
- Sampling and monitoring
- Confirmatory sampling for VOCs
- Secondary waste management
- Site restoration
- E/PP program as described for Alternative 2

- Five-year reviews as described for Alternative 2.

Alternative 4 combines process options from the GRAs of Treatment (*in situ* and *ex situ*), Containment, and Disposal. This alternative would reduce the VOC sources in the UCRS, including PTW, reduce recharge through the UCRS and thereby mitigate the secondary release mechanism, and eliminate risks to receptors by eliminating the exposure pathways, as described in the CSM presented in Section 1. Security, warning signs, and boundary markers would be maintained as long as soil concentrations remained above RGs. Requirements and conceptual designs for each element of Alternative 4 are discussed below in detail.

A schematic view of the dual-phase SVE process is provided in Figure 3.7 and plan views of the overall layout at the Oil Landfarm and C-720 Northeast and Southeast Sites are shown in Figures 3.8 and 3.9. Supporting calculations for the Alternative 4 conceptual design are provided in Appendix B.

3.4.4.1 RD investigation

RD investigation would be performed at the Oil Landfarm and the C-720 Northeast and Southeast Sites to better delineate the extent of VOCs and DNAPL TCE and to close any data gaps concerning the areal and vertical extent of contamination. RD investigation would be based on a systematically planned approach. The conceptual design for RD investigation includes these elements:

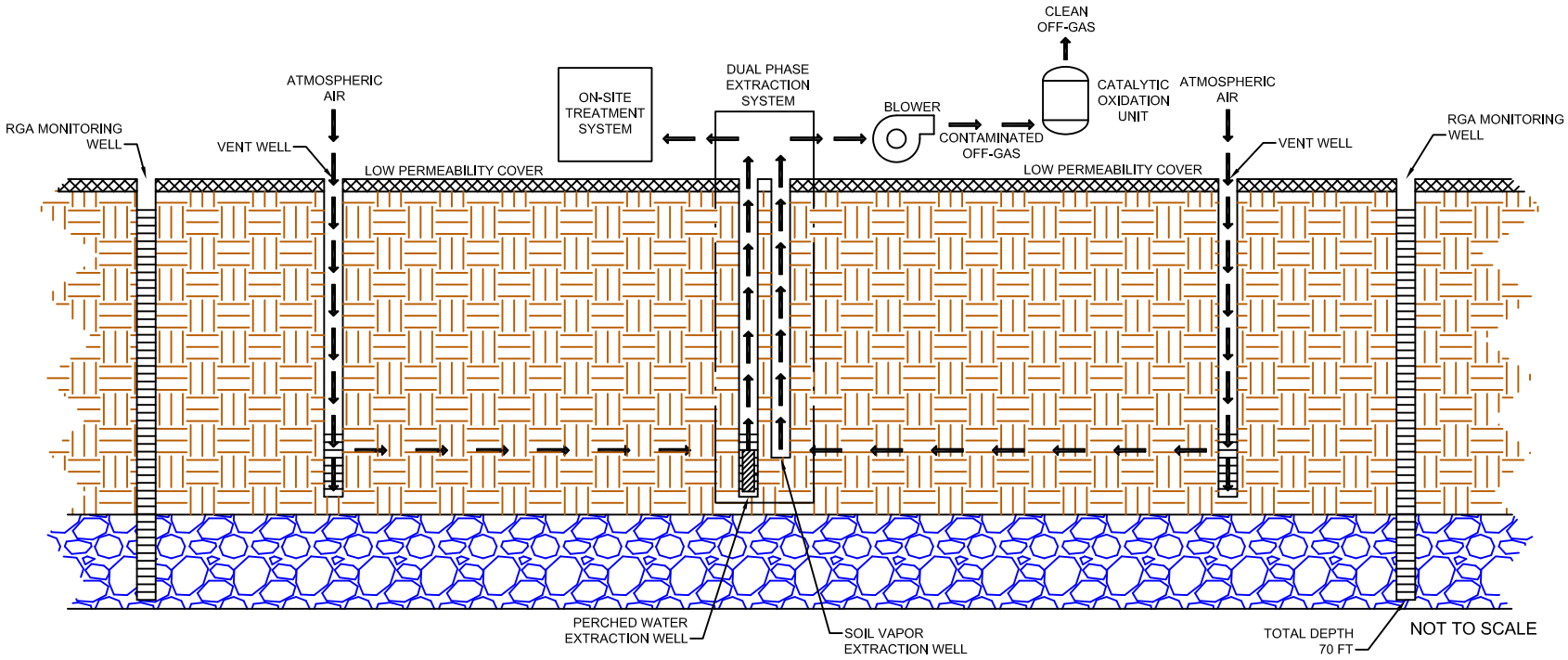
- Preliminary soil gas sampling using the MIP and on-site analysis for VOCs at the C-720 Area Northeast and Southeast Sites to estimate the areal and vertical extent of contamination including DNAPL and at the Oil Landfarm to determine vertical extent of contamination including DNAPL.

- Soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent at locations determined using the MIP results. Soil cores also would be evaluated to determine the presence or absence of DNAPL.

- Installation of dedicated soil gas monitoring points using DPT and sampling and analysis for VOCs. Dedicated soil gas monitoring points would be used to monitor air pressure and vapor concentrations during soil vapor extraction.

- Geodetic survey of all sampling locations.

- Air permeability testing for each site. Air permeability testing would consist of installing at least one 4-inch vapor extraction well and applying vacuum using a skid-mounted blower and off-gas treatment system. Air pressure would be monitored using transducers or pressure gauges installed on the dedicated soil gas monitoring points or additional 10.16-cm (4-inch) wells. The radial pressure distribution observed in the air permeability test would be used to determine the required venting well spacing.



U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

PADUCAH
Remediation Services
A Portage Shaw Joint Venture Company

Figure 3.7. Schematic View of Alternative 4

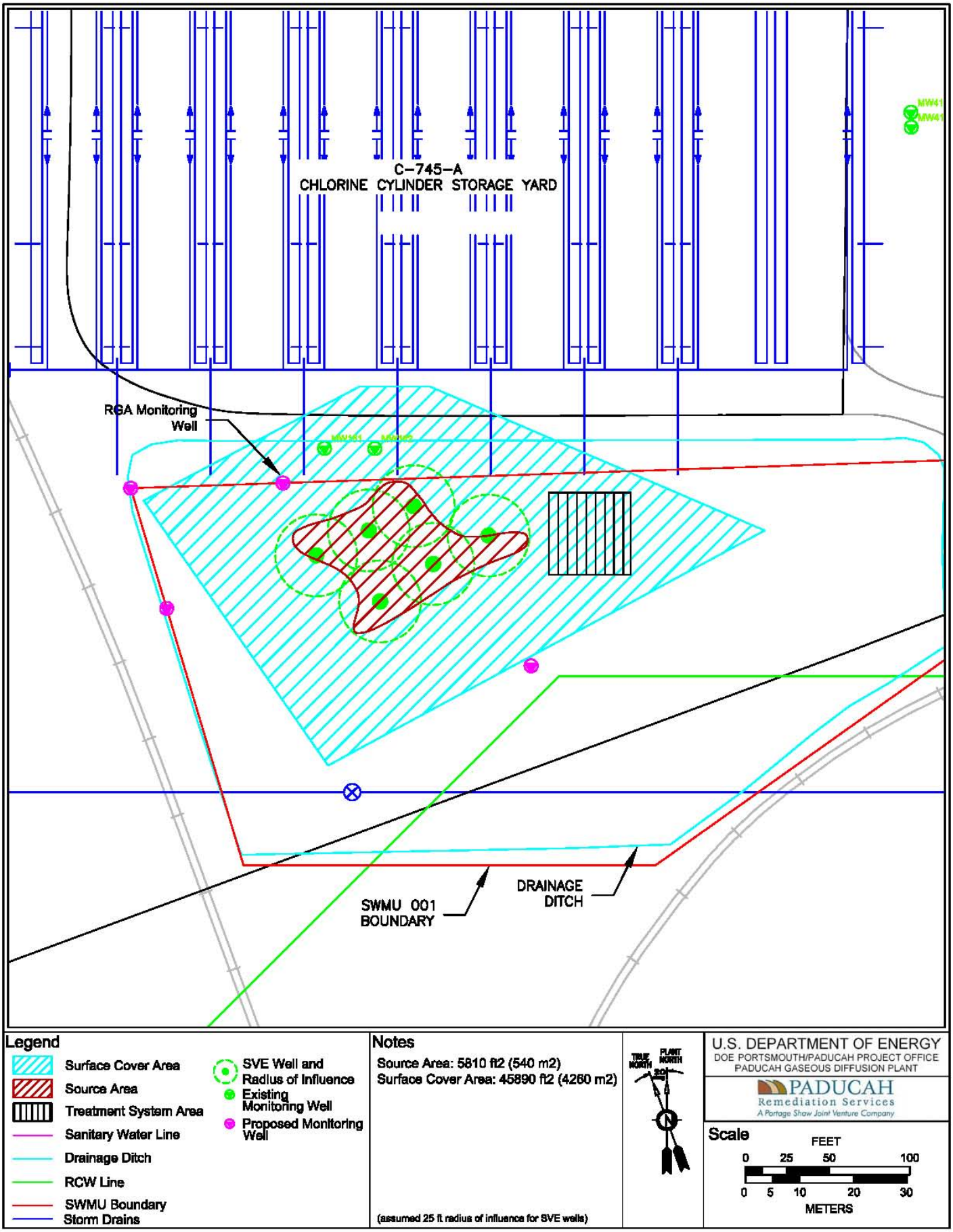


Figure 3.8. Plan View of Alternative 4 at the Oil Landfarm

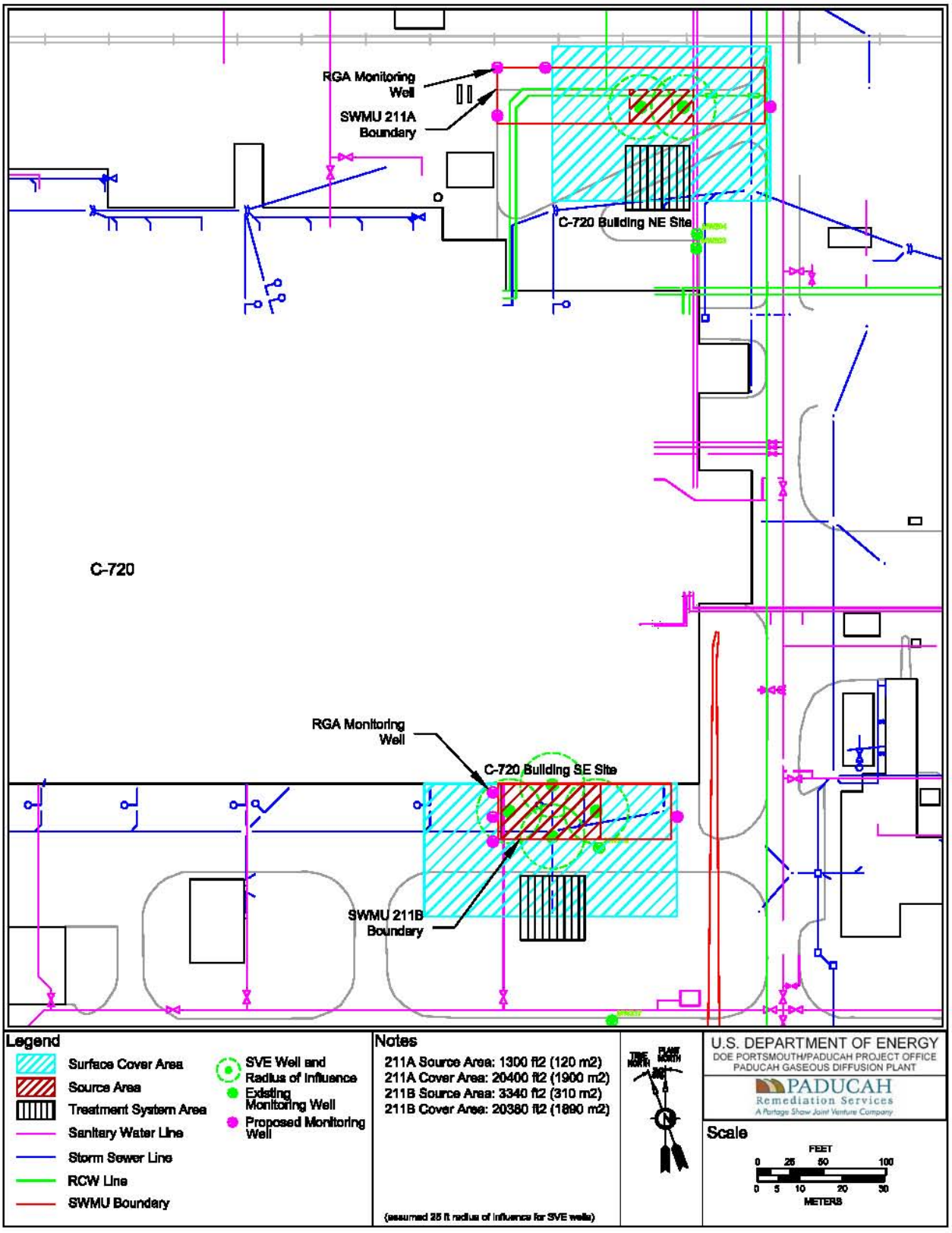


Figure 3.9. Plan View of Alternative 4 at C-720 Northeast and Southeast Sites

3.4.4.2 Recharge Controls

Recharge controls would include the following:

- Installing rain gutters on the east end of the C-720 Building and directing rainfall outfall away from the capped areas;
- Diverting surface runoff away from the capped areas;
- Lining ditches in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites with FMLs (e.g., Oil Landfarm perimeter drainage ditches);
- Routing runoff from roofs, roads, and asphalt parking areas to lined ditches or storm drains;
- Inspecting, clearing, and repairing discharge pipes, culverts, and storm drains in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites, as needed;
- Inspecting and metering water lines in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites. Lines determined to leak would be repaired by sliplining or replaced; and
- Eliminating French drains, condensate discharge, or other sources of water to the subsurface in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites.

3.4.4.3 Containment

Surface covers would be installed at the Oil Landfarm and the C-720 Northeast and Southeast Sites source areas. Surface cover design and implementation must meet the constraints of PGDP operations. Specifically, surface covers at the C-720 Northeast and Southeast site corners must have a trafficable surface and accommodate ongoing facility operations. Figures 3.1 and 3.2 show schematic cross-sectional views and site plans of the surface covers, respectively. The estimated capped surface areas are as follows:

- Oil Landfarm capped area: 4,263 m^2 (45,890 ft^2)
- C-720 Southeast capped area: 1,893 m^2 (20,380 ft^2)
- C-720 Northeast Site capped area: 1,895 m^2 (20,400 ft^2)

Other dimensions and quantities are provided in Appendix B. From the top down, the surface covers would consist of the following:

- 10.16 cm (4 inches) of asphalt with a 1% slope
- 20.32 cm (8 inches) of aggregate placed in two 10.16-cm (4-inch) lifts and compacted
- Geosynthetic drainage layer
- 40-mil HDPE FML
- Compacted subgrade

The cover would extend approximately 18.3 m (60 ft) beyond the source area on all sides, to ensure control of recharge through the area. Given the depth to the RGA of 18.3 m (60 ft) and the predominantly downward hydraulic gradients in the UCRS, this overlap is expected to control recharge through the VOC source areas. The actual overlap needed would be determined in the RD.

Construction would begin with mobilizing subcontractors and equipment to a staging area. Mobilization would include obtaining required equipment and personnel, setting up temporary field trailers, taking delivery of initial materials, and locating and marking underground utilities. Pre-construction meetings and training would be conducted with site workers and subcontractors. Equipment would access the work area by prescribed routes only.

Surface infrastructure in the source areas would be cleared and grubbed of surface vegetation. The surface would be graded to approximately a 1% overall slope and compacted. The FML panels would be placed and welded and anchored in perimeter trenches. The geocomposite drainage net would be placed over the FML and also anchored. A single 15.24-cm (6-inch) lift of gravel would be carefully placed on the drainage net to avoid tearing or damage. Polyvinyl chloride (PVC) drainage pipe would be installed to drain any water that collected on the liner to the cover perimeter. A single 10.16-cm (4-inch) lift of asphalt would be placed on the gravel lift and rolled. After cooling, a surface sealant would be applied. Groundwater and soil moisture MWs would be installed with subsurface completions. Active or passive venting wells also could be installed if TCE vapor concentrations were observed to increase at site perimeter or with depth.

3.4.4.4 Dual-phase soil vapor extraction

Preliminary air permeability testing would be required to optimize design, including well spacing, optimal vacuum, and extraction rate. Screen placement would be determined by lithology, water saturation, and TCE concentrations. Preliminary conceptual design of the SVE system includes the following:

- Dual-phase extraction wells spaced assuming a 0.64 m (25 ft) radius of venting well influence. This estimate would be refined based on preliminary air permeability testing results.

- Approximately 10 standard cubic ft per minute per extraction well, manifolded to one blower per site. This estimate would be refined based on preliminary air permeability testing results.

- 4-inch schedule 40 PVC well casings, screened in most contaminated intervals, 0.13 m (5 ft) bgs to top of RGA capillary fringe [assume 1.4 m (55 ft) bgs. Thirty ft of screen per well was assumed for conceptual design; however, this value would be revised based on preliminary air permeability testing results. Larger diameter well casings could be used, if determined during the RD, to improve performance.

- Submersible pump with float switch per each water extraction well.

The SVE system initially would be operated continuously. Soil gas concentrations in dedicated drive points and off-gas concentrations in individual wells would be monitored to optimize operations. Air flow from individual wells could be increased, reduced, or shut off depending on monitoring results. Additional performance enhancements including passive recharge wells could be implemented depending on results.

As concentrations of VOCs in off-gas decreased over time, the system could be operated in a pulsed pumping mode, to allow concentrations in soil gas to approach equilibrium levels before removal. When concentrations of VOCs in off-gas became asymptotic and showed little or no rebound during pulsed pumping, shut-down of the system could be proposed to regulators.

Potential ancillary technologies for SVE at the Southwest Plume sites include air sparging and/or passive air injection wells. Pilot-scale testing would be required to determine effectiveness and implementability of these technologies.

3.4.4.5 Off-gas treatment

Off-gas treatment would be required to meet air emission ARARs. Equilibrium partitioning of DNAPL TCE and soil air was assumed for conceptual design calculations of TCE concentrations, provided in Appendix B. PCBs and other SVOCs, metals, and radionuclides potentially present at the Oil Landfarm would be expected to remain in the soils and would not be removed in the off-gas.

Electrical supply and natural gas requirements also are provided. The preliminary conceptual design of the SVE off-gas treatment system for each site includes these:

- Dehumidification of influent air and
- Catalytic oxidation of SVE off-gas for destruction of VOCs to meet air emission ARARs.

3.4.4.6 Co-produced groundwater treatment

Co-produced groundwater will be treated to meet liquid effluent ARARs and discharged. Estimates for groundwater production rates based on UCRS well recovery rates are provided in Appendix B. Initial recovery rates would be expected to decrease over time as the formation drained and the surface cover and recharge controls limited recharge.

The preliminary conceptual design for co-produced groundwater treatment includes the following:

- One 5,000-gal tank per site for storage of co-produced groundwater. The tank would be placed within the AOC.

- Treatment on-site including these:
  - Filtration for solids removal;
  - Air stripping for VOC removal including TCE;
  - Ion exchange for ^{99}Tc removal;
  - GAC for air stripper off-gas treatment.

- Discharge at the treatment plant outfall.

3.4.4.7 Soil Fracturing

Soil fracturing would be implemented at the source areas to improve vapor recovery, contingent upon the results of air permeability testing during RD investigation. Soil fracturing would be implemented after installation and startup of dual-phase recovery wells in an effort to provide containment and recovery of any DNAPL TCE mobilized during fracturing. The selection of pneumatic vs. hydraulic fracturing, proppants, well spacing, and fracturing depths would be determined during RD.

3.4.4.8 Sampling and Monitoring

Soil moisture content, water levels, and concentrations of VOCs in soil gas in the UCRS would be monitored. Piezometers and neutron probe access tubes would be installed in the UCRS to the top of the RGA outside the influence of the capped areas and recharge controls, for background measurements and inside the capped areas for monitoring the effectiveness of the alternative. If the alternative was effective, water levels in piezometers and soil moisture contents, as measured by neutron probes would decrease, relative to measurements outside the capped areas. Water levels and soil moisture contents would be monitored at least quarterly for the first year.

Sampling of SVE off-gas and dedicated soil gas points would be required for process optimization (e.g., to determine when to shut off individual extraction wells, when to switch to pulsed pumping, when to turn off the system, etc.). An operational sampling and monitoring plan would be prepared during the RD/RAWP. The preliminary conceptual design for soil vapor sampling and soil vapor monitoring includes the following:

- Weekly SVE off-gas sampling and analysis for VOCs;
- Monthly soil gas dedicated drive point sampling and analysis for VOCs; and
- Quarterly soil moisture monitoring to assess effectiveness of remedy, for the duration of operations.

In addition, one upgradient and four downgradient wells screened in the shallow RGA would be constructed at each source area. Wells would be monitored for VOCs, to determine progress toward attainment of RAO #3, and also pH, conductivity, presence of DNAPL using the interface probe, and water levels, twice annually. Results would be reported in the five-year reviews and provided to the sitewide environmental monitoring program and to the Dissolved-Phase Plumes RA Project under the Groundwater OU.

3.4.4.9 Operation and Maintenance

O&M for Alternative 4 would consist of the following:

- Inspecting, resealing and repairing the asphalt surface covers as needed;
- Inspecting, clearing, and repairing storm water discharge pipes, culverts, lined ditches, and storm drains as needed;
- Inspecting, metering, and repairing water lines in the vicinity of the Oil Landfarm and the C-720 Northeast and Southeast Sites, as needed;
- Maintaining and replacing soil moisture monitoring equipment, as needed;
- Inspecting and maintaining SVE blowers;
- Inspecting and maintaining the catalytic oxidation units;
- Inspecting and maintaining air strippers;
- Carbon replacement; and
- Periodic removal and disposal of filter solids.

3.4.4.10 Confirmatory sampling

Confirmatory sampling in the treatment area would be required to determine post-treatment TCE soil concentrations. A confirmatory sampling plan would be prepared during RAWP development. The conceptual design for confirmatory sampling includes soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent. Depths and locations of coring would be determined based on the results of RD investigation.

3.4.4.11 Secondary waste management

Secondary wastes would include co-produced groundwater, spent GAC, drill cuttings produced during dual-phase well installation, personal protective equipment (PPE), and decontamination fluids. For cost-estimating purposes, drill cuttings, PPE, and decontamination fluids were assumed to require containerization, dewatering, and testing prior to off-site disposal. Actual dispositioning requirements would be determined during remedial design and by sampling of containerized soils. Spent GAC would be shipped off-site for regeneration. Coproduced groundwater would be treated and discharged as described previously. All secondary wastes would be managed in accordance with all ARARs.

3.4.4.12 Site restoration

Site restoration activities prior to remedy completion would include demobilizing and removing all RDSI equipment, sealing all MIP and soil coring locations with bentonite, reseeding disturbed vegetated areas at the Oil Landfarm and the C-720 Northeast Site, and repairing penetrations of asphalt and concrete at the C-720 Northeast and Southeast Sites.

If wetlands are identified, actions will be taken in accordance with the identified ARARs. Surface covers, monitoring wells and SVE wells would remain in place through the O&M period until soil RGs were attained. Surface covers would be removed and wells abandoned if desired at the end of the O&M period. If removed, surface cover materials including the HDPE liner, gravel and asphalt would be characterized and dispositioned as secondary waste prior to disposal.

3.4.4.13 Land use controls

The E/PP program as described for Alternative 2 would be implemented through the ROD.

3.4.4.14 Five-year reviews

Five-year reviews as for Alternative 2 would be implemented as long as soil contaminant concentrations remained above RGs.

3.4.5 Alternative 5—*In Situ* Thermal Source Treatment

Alternative 5 consists of the following:

- RD investigation
- Treatment using electrical resistance heating with vapor extraction
- Treatment of recovered vapor
- Process monitoring
- Confirmatory sampling for VOCs
- Groundwater monitoring
- Secondary waste management
- Land use controls as described for Alternative 2
- Monitoring as described for Alternative 2
- Five-year reviews as described for Alternative 2

This alternative would reduce the VOC sources in the UCRS, including PTW; reduce recharge through the UCRS and thereby mitigate the secondary release mechanism; and eliminate risks to receptors by eliminating the exposure pathways, as described in the CSM presented in Section 1. Requirements and

conceptual designs for each element of Alternative 5 are discussed below in detail. This alternative would reduce the VOC secondary source and eliminate risks to receptors by eliminating the exposure pathways. The ERH system design would include measures to reduce the potential for mobilization of DNAPL TCE during treatment. Five-year reviews would be required until RGs were met.

Conceptual design and a cost estimate for the ERH treatment component of Alternative 5 was provided by the McMillan-McGee Corp. The McMillan-McGee Corp., is cited because they currently are contracted to implement ERH at the PGDP C-400 area. Other vendors and proprietary ERH technologies are available. Specific citation of the McMillan-McGee Corp., and their proprietary technology would not constrain selection of an alternative ERH technology or vendor.

The ERH treatment system design would include measures to ensure that DNAPL TCE was not mobilized during treatment. Details for each element of Alternative 5 are discussed below. A schematic view of the ERH treatment process is provided in Figure 3.10, and a plan view of the overall layout for the Oil Landfarm and the C-720 Northeast and Southeast Sites are shown in Figures 3.11 and 3.12, respectively.

3.4.5.1 RD investigation

RD investigation would be performed at the Oil Landfarm and the C-720 Northeast and Southeast Sites to better delineate the extent of VOCs and DNAPL TCE and to close any data gaps concerning the areal and vertical extent of contamination. RD investigation would be based on a systematically planned approach. The conceptual design for RD investigation includes these elements:

- Preliminary soil gas sampling using the MIP and on-site analysis for VOCs at the C-720 Area Northeast and Southeast Sites to estimate the areal and vertical extent of contamination including DNAPL and at the Oil Landfarm to determine vertical extent of contamination including DNAPL;

- Soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent at locations determined using the MIP results. Soil cores also would be evaluated to determine the presence or absence of DNAPL; and

- Geodetic survey of all sampling locations.

3.4.5.2 Treatment

McMillan-McGee Corp. implements a proprietary ERH approach trademarked as the Electro Thermal Dynamic Stripping Process (ET-DSP™). Using this approach, electrodes are strategically placed into the contaminated zone in a pattern such that conventional three-phase power can be used to heat the soil. The distance between electrodes and their location is determined from the heat transfer mechanisms associated with vapor extraction, electrical heating, and fluid movement in the contaminated zone. To determine the ideal pattern of electrode and extraction wells, a multi-phase, multi-component, 3-D thermal model is used to simulate the process. Numerical modeling is also used to design the power delivery system, the power requirements from the utility, and the project capital requirements (McMillan-McGee 2009).

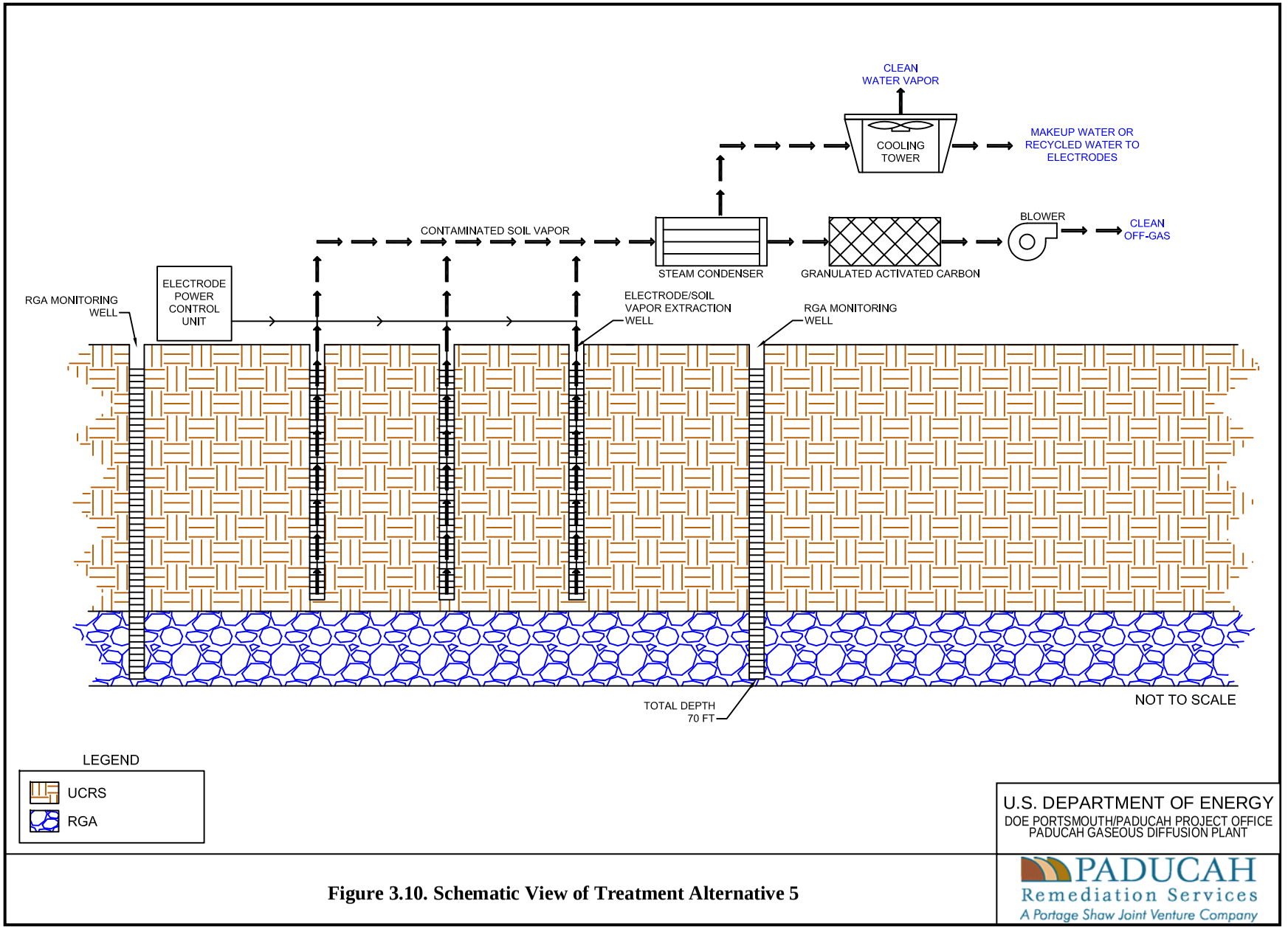


Figure 3.10. Schematic View of Treatment Alternative 5

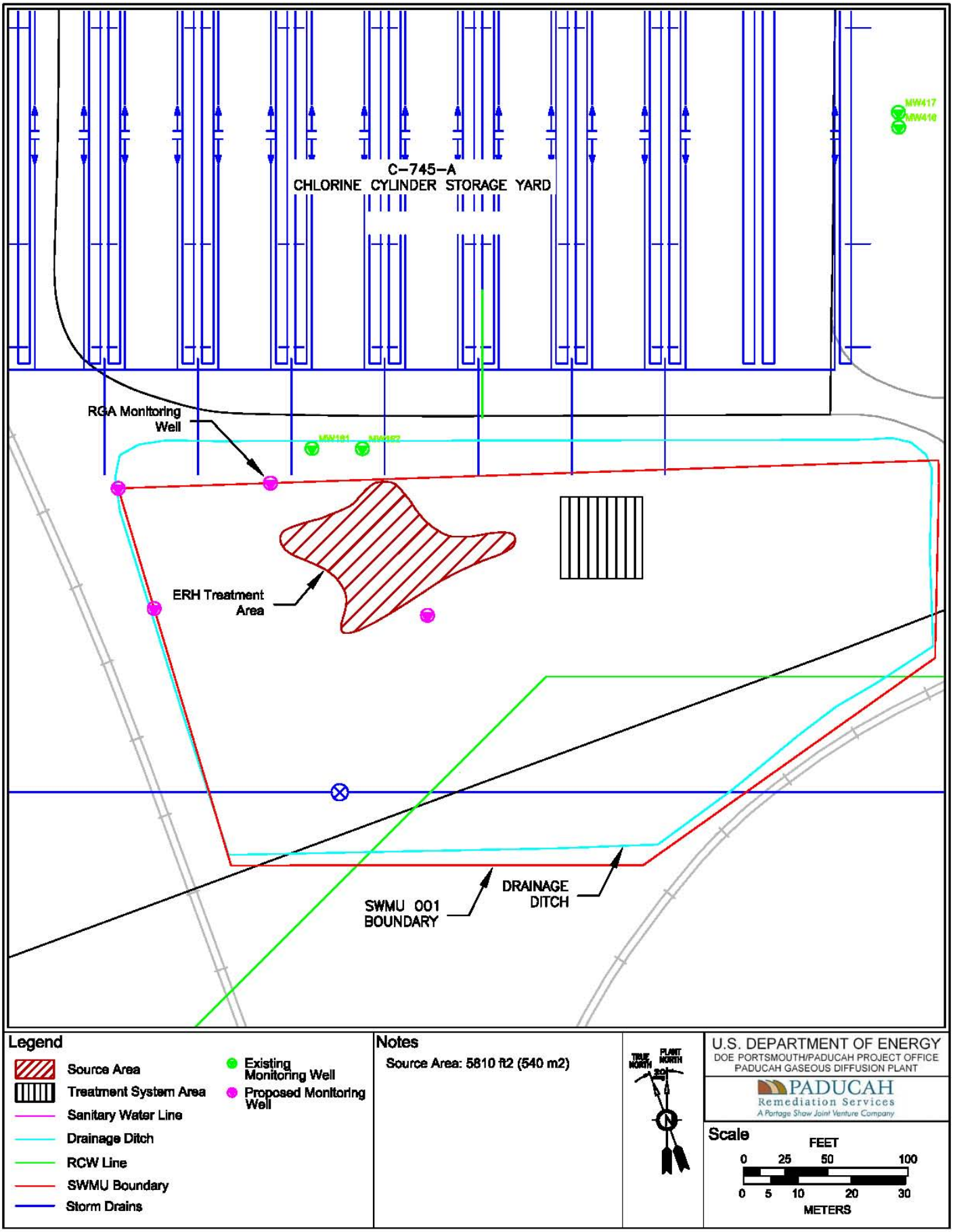


Figure 3.11. Plan View of Alternative 5 at the Oil Landfarm

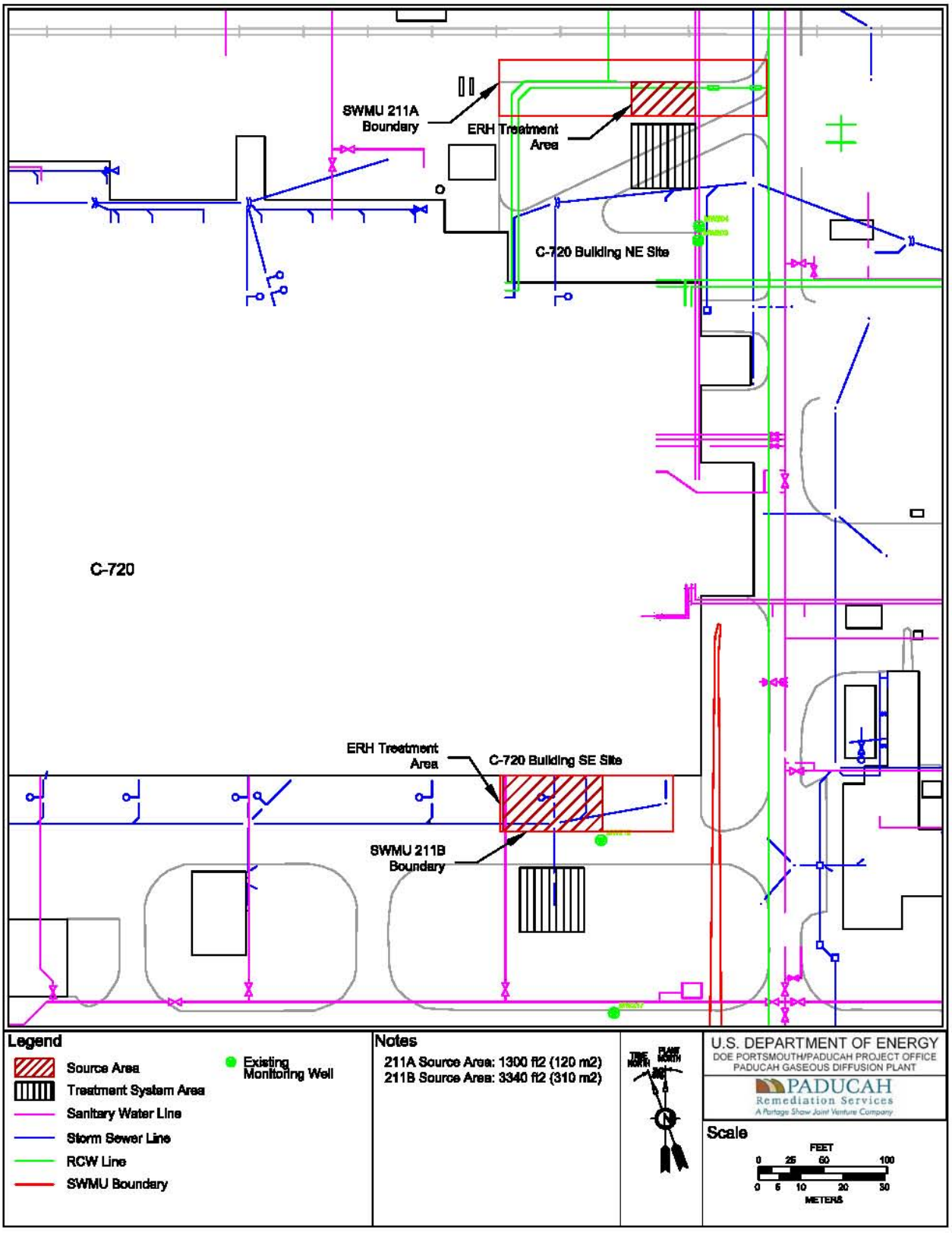


Figure 3.12. Plan View of Alternative 5 at C-720 Northeast and Southeast Sites

Overall the ERH treatment system conceptual design for the three Southwest Plume source areas includes:

- 272 total electrodes
- 68 electrode wells
- 12 UCRS wells
- 4 contingency wells
- 2 digital thermocouple temperature MWs
- 9 vacuum monitoring/digital thermocouple temperature MWs
- Well field piping
- Recovery of TCE from vapor using GAC and off-site regeneration

In addition to characterization of the site for contaminant concentration levels as described above, electrical conductivity of the soil and its distribution would be measured. This involves measurements of the electrical properties of the soil as a function of temperature and water saturation. The data are used to design the power delivery system, estimate the time required to heat the soil, determine power requirements, and numerically simulate the heating process. All existing PVC wells within the source areas would be abandoned in place prior to starting thermal treatment.

The electrodes are arranged so that the contaminated volume of soil is contained inside the periphery of the electrodes. The vapor extraction wells are located within the contaminated soil. The position of the extraction wells relative to the electrodes is determined so that heat transfer by convection within the porous soil is maximized, thus minimizing heat losses and increasing the uniformity of the temperature distribution.

A conventional water handling and vapor recovery system is installed as part of the process. The water circulation system provides water to the electrode wells to prevent overheating. The electrode wells are designed with fluid injection capability; therefore, some of the injected water flows from the electrode wells towards the vapor extraction wells. The heat transported by fluid movement tends to heat the soil rapidly and more uniformly and is an integral stage of ET-DSP™. The produced fluids increase with temperature over time. These fluids are reinjected and the overall thermal efficiency is improved. The current path is shared between the electrodes passing through the connate water in the porous soil. The temperature is controlled to minimize drying out of the soil until the latter stages of the heating process.

As the soil changes in temperature, the resistivity of the connate water typically will decrease. Also, as the soil dries out, the resistivity will increase. A computer control system is installed to ensure that the maximum current is applied to the subsurface via the electrodes at all times. The electrodes are connected to a three-phase power delivery system. The power delivery system is equipped with computer controls so that the power from the three phases can be alternated among the electrodes.

McMillan-McGee Corp. utilizes a system of Time-Distributed Control and Inter-Phase Synchronization to control the power to the electrodes. This process effectively controls the amount and timing of power sent to individual electrodes. For example, should it become apparent that certain electrodes are in electrically resistive zones resulting in cold spots, the power to the electrodes can be increased in these areas to ensure a uniform heating process. Using readily available three-phase power eliminates the need for expensive specialty transformers and higher capital costs. This system is fully programmable and can be accessed over the Internet for remote monitoring and control.

PCBs and other SVOCs, metals, and radionuclides potentially present at the Oil Landfarm would be expected to remain in the soils and would not be removed in the recovered vapor.

The installation and treatment period was estimated at approximately one year. System shutdown criteria would be established in the RD and would incorporate lessons learned from the C-400 Interim Action.

3.4.5.3 Process monitoring

TCE vapor waste stream concentrations would be measured daily at the influent of the primary GAC vessel using a photo acoustic analyzer. The vapor waste stream velocity also would be measured daily using a handheld flow meter. The resulting measurements would be used to calculate the approximate TCE loading for each GAC vessel and mass removal rate.

Air samples would be collected weekly from the influent of the primary GAC using summa canisters. The summa canisters would be configured to collect a 24-hour integrated sample. The air samples would be sent off-site for laboratory analysis using analytical method TO-14A.

Subsurface temperatures and electrical usage would be monitored by the vendor.

3.4.5.4 Confirmatory sampling

Confirmatory sampling in the treatment area would be required to determine post-treatment TCE soil concentrations. A confirmatory sampling plan would be prepared during RAWP development. The conceptual design for confirmatory sampling includes soil coring using DPT and analysis for VOCs using EPA SW-846 Method 8260B or equivalent. Depths and locations of coring would be determined based on the results of RD investigation.

3.4.5.5 Secondary waste management

Secondary wastes would include vapor, spent GAC, drill cuttings produced during installation of electrodes and vapor recovery wells, PPE, and decontamination fluids. TCE would be recovered from vapor on GAC and shipped for off-site regeneration. Condensate would be recirculated to the electrode wells to reduce drying of the soil.

For cost-estimating purposes, drill cuttings, PPE, and decontamination fluids were assumed to require containerization, dewatering, and testing prior to off-site disposal. Actual dispositioning requirements would be determined during remedial design and by sampling of containerized soils. Spent GAC would be shipped off-site for regeneration. All secondary wastes would be managed in accordance with all ARARs.

3.4.5.6 Site Restoration

Site restoration activities would include demobilizing and removing all RDSI equipment; sealing all MIP and soil coring locations with bentonite; reseeding disturbed vegetated areas at the Oil Landfarm and the C-720 Northeast Site; and repairing penetrations of asphalt and concrete at the C-720 Northeast and Southeast Sites. If wetlands are identified, actions will be taken in accordance with the identified ARARs.

3.4.5.7 Sampling and Monitoring

Soil and groundwater monitoring would be used to determine the effectiveness of the remedy. One upgradient and four downgradient wells screened in the shallow RGA would be constructed at each source area. Wells would be monitored for VOCs, pH, conductivity and water levels and potentially other analytes determined in the RAWP through a DQO process twice annually. Wells also would be checked for the presence of DNAPL using the interface probe at each sampling event. Results would be reported

in the five-year reviews and provided to the sitewide environmental monitoring program and to the Dissolved-Phase Plumes RA Project under the Groundwater OU.

Monitoring wells would remain in place until soil RGs were attained. ERH equipment would be removed from vapor recovery wells to the extent feasible and the wells abandoned in place.

3.4.5.8 Land use controls

The E/PP program as described for Alternative 2 would be implemented through the ROD.

3.4.5.9 Five-year reviews

Five-year reviews as for Alternative 2 would be implemented as long as soil contaminant concentrations remained above RGs.

3.5 SCREENING OF ALTERNATIVES

Alternatives are screened in this section, using the process described in EPA 1988 and the NCP, to reduce the number of alternatives carried forward to detailed analysis. Alternatives are screened with respect to effectiveness, implementability, and cost. Table 3.2 summarizes the results of screening, with gray shading showing the alternatives that were screened out at this step. The evaluation of effectiveness considers reductions in toxicity, mobility, and volume of VOCs. The evaluation of implementability considers technical feasibility criteria including the ability to construct, operate, and maintain the remedy and administrative feasibility criteria including the ability to obtain required regulatory approvals. Evaluation of cost for the alternatives is based on the relative capital and O&M costs for the primary technologies utilized, as identified in Table A.2.

Alternatives with the best combinations of effectiveness and implementability and the lowest costs are retained for detailed analysis in Section 4 and comparative analysis in Section 5. Given the focused nature of this FFS (i.e., VOCs in UCRS soils at the Oil Landfarm and the C-720 Building Areas), three alternatives, including No Action, were determined by DOE, EPA, and KDEP to be sufficient. The results of the screening are provided in Table 3.2, with shading indicating that Alternatives 2 and 3 are screened from further consideration.

Alternative 2, *In Situ* Bioremediation is screened from further consideration because VOC reduction is less certain than for Alternatives 4 or 5, with roughly similar cost and implementability. ISB-ARD would reduce the mass of TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, VC, and 1,1-DCE present in source areas, but the extent of reduction and time to attainment of RAO #3 is uncertain. VOC concentrations in the unsaturated zone above the UCRS water level, which averages 4.3 m (14 ft) bgs at the Oil Landfarm and 8.8 m (29 ft) bgs at the C-720 Building Area, would not be significantly reduced by this alternative. The unsaturated interval accounts for a significant fraction of the total mass of VOCs.

Table 3.2. Summary of Screening of Alternatives

Screening Criteria	Alternative 1 No Action	Alternative 2 *In Situ* Bioremediation	Alternative 3 Source Removal and *Ex Situ* Thermal Treatment	Alternative 4 SVE Source Treatment and Containment	Alternative 5 *In Situ* Thermal Source Treatment
Overall Effectiveness	NA	Moderate	Low	Moderate to High	High
Short-term	NA	High	Low	Moderate	Moderate
Long-term	NA	Low-uncertain	High	Moderate	High
Overall Implementability	NA	Moderate	Low	High	Moderate
Technical	NA	High	Low	Moderate to High	Moderate
Administrative	NA	Moderate	Low	High	High
Overall Cost	NA	Low	High	Moderate	Moderate
Capital	NA	Low	High	Moderate	Moderate
O&M	NA	Moderate	None	High	None

O&M = operation and maintenance
SVE = soil vapor extraction

The presence of DNAPL TCE also would limit the effectiveness of Alternative 2. DNAPL TCE is only slowly degraded by ISB-ARD, as discussed in Section 2. Dissolved- and sorbed-phases are much more readily degraded. Establishing conditions favorable for ARD may inhibit existing aerobic biodegradation processes in the RGA. Alternative 2 is screened from further consideration for the reasons cited above.

Alternative 3, Source Removal and *Ex Situ* Thermal Treatment, is screened from further consideration because it is much less technically implementable and much more expensive than any other alternative, while providing VOC removal roughly equivalent to Alternative 5, *In Situ* Thermal Source Treatment. Installing sheet piles and excavating to 18.3 m (60 ft) bgs would present technical and administrative challenges. The excavation likely would have to be pumped continuously as soil removal proceeded below the water table and the water treated and discharged to a permitted outfall.

The volume to be excavated at the Oil Landfarm was estimated in Section 3 to be approximately 13,000 m^3 (17,000 yd^3). The volume of excavated soil would increase to approximately 15,300 m^3 (20,000 yd^3) accounting for swell. Stockpiling and treating this amount of soil on-site would present technical and administrative challenges in controlling storm water runoff, fugitive dust, and spatial logistics.

The presence of subsurface water lines and storm sewers, overhead power lines, active roads and sidewalks, and proximity to the C-720 Building potentially could prohibit implementation of Alternative 3 at the C-720 Northeast and Southeast Sites until after the building is inactive. Existing concrete or paved surfaces would be removed, and subsurface water lines and storm sewers would be rerouted and cut prior to installing sheet pilings. A vibrating head suspended from a crane would drive the sheet pilings to the required depth. This equipment would produce significant noise and vibration that potentially could interfere with operations in the C-720 Building. The sheet piling installation and the excavation potentially would affect the C-720 Building foundation, which would have to be evaluated by a structural engineer prior to implementation.

Installation of sheet pilings and operation of excavators would produce ground vibration that potentially could induce downward movement of DNAPL from the UCRS to the RGA. Removal of soil overburden could result in localized upwelling of the RGA. Monitoring for mobilization of DNAPL likely could only be done in the RGA and would be detectable only after mobilization had occurred (i.e., too late to prevent).

Health and safety would be the primary administrative concerns at all sites. The excavation could be performed from ground surface; however, construction personnel would have to enter the excavation periodically to weld steel structural crossbeams in place as the excavation progressed to prevent the sheet piling from collapsing inward. These would have to be removed with cutting torches as the excavation was backfilled and compacted; assuming that the sheet piles would be pulled out, this would require additionally entry by personnel. Health and safety issues, including fall protection, confined space entry, structural stability of the enclosure, air quality, and exposure to VOCs, could preclude implementation of Alternative 3. Alternative 3 is screened from further consideration for the reasons cited here.

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4. DETAILED ANALYSIS OF ALTERNATIVES

Remedial alternatives developed in Section 3 and retained after screening are analyzed in detail in this section. Results of this analysis will form the basis for comparing alternatives and for preparing the Proposed Plan.

4.1 INTRODUCTION

4.1.1 Purpose of the Detailed Analysis

The remedial action alternatives developed in Section 3 are analyzed in detail against the seven CERCLA threshold and balancing criteria to form the basis for selecting a final remedial action. The intent of this analysis is to present sufficient information to allow the EPA, KDEP, and DOE to select an appropriate remedy.

Alternatives are evaluated with respect to the seven CERCLA threshold and balancing criteria outlined in 40 *CFR* § 300.430(e)(9)(iii) and as discussed in Section 4.1.2. This evaluation is the basis for determining the ability of a remedial action alternative to satisfy CERCLA remedy selection requirements.

4.1.2 Overview of the CERCLA Evaluation Criteria

The CERCLA evaluation criteria include technical, administrative, and cost considerations; compliance with specific statutory requirements; and state and community acceptance. Overall protection of human health and the environment and compliance with ARARs are categorized as threshold criteria that any viable alternative must meet. Long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost are considered balancing criteria upon which the detailed analysis is primarily based. State and community acceptance is evaluated following comment on the RI/FS report and the Proposed Plan and is addressed as a final decision is made and the ROD is prepared. Each criterion is described below.

4.1.2.1 Overall protection of human health and the environment

Alternatives will be assessed to determine whether they can adequately protect human health and the environment in both the short- and long-term from unacceptable risks posed by contaminants present at the Oil Landfarm and the C-720 Northeast and Southeast Sites by eliminating, reducing, or controlling exposures as established during the development of RAOs consistent with 40 *CFR* § 300.430(e)(2)(I). Overall protection of human health and the environment draws on the assessments of the other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

4.1.2.2 Compliance with ARARs

Section 121(d) of CERCLA and NCP Section 300.430(f)(1)(ii)(B) require that remedial actions at CERCLA sites at least attain legally "applicable" or "relevant and appropriate" federal and state environmental requirements, standards, criteria, and limitations, which are collectively referred to as "ARARs," unless such ARARs are waived under CERCLA Section 121(d)(4). ARARs include federal or more stringent state substantive environmental or facility siting laws/regulations; they do not include occupational safety protection requirements. Additionally, per 40 *CFR* § 300.405(g)(3), other advisories, criteria, or guidance may be considered in determining remedies (TBC category). CERCLA 121(d)(4)

provides several ARAR waiver options that may be invoked, provided that human health and the environment are protected. Activities conducted on-site must comply with the substantive but not administrative requirements. Administrative requirements include applying for permits, recordkeeping, consultation, and reporting. Activities conducted off-site must comply with both the substantive and administrative requirements of applicable laws. Measures required to meet ARARs will be incorporated into the design phase and implemented during the construction and operation phases of the remedial action.

ARARs typically are divided into three categories: (1) chemical-specific, (2) location-specific, and (3) action-specific. Chemical-specific ARARs provide health- or risk-based concentration limits or discharge limitations in various environmental media (i.e., surface water, groundwater, soil, or air) for specific hazardous substances, pollutants, or contaminants. Location-specific ARARs establish restrictions on permissible concentrations of hazardous substances or establish requirements for how activities will be conducted because they are in special locations (e.g., floodplains or historic districts). Action-specific ARARs include operation, performance, and design of the preferred alternative based on waste types and/or media to be addressed and removal/remedial activities to be implemented.

There are no chemical-specific ARARs for remediation of the contaminated soils at the source areas; however, Kentucky drinking water standard MCLs at 401 *KAR* 8:420 for VOCs were used for calculation of soil RGs. Action and location-specific ARARs are further identified in each alternative.

Alternatives are assessed to determine whether they meet ARARs identified for each alternative. If ARARs will not be met at the end of an action, an evaluation will occur to determine when a basis exists for invoking one of the ARAR waivers cited in 40 *CFR* § 300.430(f)(l)(ii)(c), that are listed here:

- The alternative is an interim measure and will become part of a total remedial action that will attain the applicable or relevant and appropriate federal or state requirement.

- Compliance with the requirement will result in greater risk to human health and the environment than other alternatives.

- Compliance with the requirement is technically impracticable from an engineering perspective.

- The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach.

- With respect to a state requirement, the state has not consistently applied, or demonstrated the intention to consistently apply, the promulgated requirement in similar circumstances at other remedial actions within the state.

In addition to ARARs, policies such as *Management of Contaminated Media*, EPA Region 4, September 7, 1999 allow use of an area of contamination may be TBC. Use of an AOC does not constitute "placement" and, therefore, does not trigger land disposal restriction (LDR) and other RCRA requirements.

4.1.2.3 Long-term effectiveness and permanence

Long-term effectiveness and permanence is the anticipated ability of the alternatives to maintain reliable protection of human health and the environment for the duration of risk above RGs, once the RAOs are met. Alternatives will be assessed for the long-term effectiveness and permanence they afford, along with

the degree of certainty that the alternative will prove successful. These are factors that may be considered in this assessment.

- The magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the remedial activities, including their volume, toxicity, and mobility.

- The adequacy and reliability of controls such as containment systems necessary to manage treatment residuals and untreated waste. For example, this factor addresses uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative, such as a cover or treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.

4.1.2.4 Reduction of toxicity, mobility, or volume through treatment

The degree to which the alternatives employ treatment or recycling that reduces toxicity, mobility, or volume will be assessed, including how the treatment is used to address the principal threats posed by the release sites. Factors that will be considered, as appropriate, include these:

- Treatment or recycling processes that the alternatives employ and the materials that they will treat;

- The amount of hazardous substances, pollutants, or contaminants that will be destroyed or recycled;

- The degree of expected reduction in toxicity, mobility, or volume of the waste because of the treatment or recycling and the specification of which reductions are occurring;

- The degree to which the treatment is irreversible;

- The type and quantity of residuals that will remain following treatment, taking into consideration the persistence, toxicity, mobility, and propensity to bioaccumulate such hazardous substances and their constituents; and

- The degree to which treatment reduces the inherent hazards posed by the principal threats at the release sites.

Reduction of the volume or mass of VOCs present in the UCRS for alternatives implementing treatment was estimated using removal efficiencies for the primary technologies, as reported in previous field-scale treatability studies or remedial actions and from analytical solutions to the governing equations for the treatment processes. Reduction of the mobility of VOCs for alternatives implementing surface covers and recharge controls was estimated based on performance of similar cover systems in field studies and numerical modeling as described in Appendix C.

4.1.2.5 Short-term effectiveness

Short-term effects during implementation of the remedial action will be assessed, including the following:

- Short-term risks that might be posed to the community
- Potential risks or hazards to workers, and the effectiveness and reliability of protective measures
- Potential environmental effects, and the effectiveness and reliability of mitigative measures
- Time until protection is achieved

4.1.2.6 Implementability

The ease or difficulty of implementing the alternatives will be assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including the technical difficulties and unknowns associated with constructing and operating the technology, reliability of the technology, ease of undertaking additional remedial actions, and ability to monitor the effectiveness of the remedy.

- Administrative feasibility, including activities required to coordinate with other offices and agencies and the ability and time needed to obtain any necessary approvals and permits for off-site actions from other agencies.

- Availability of required materials and services.

4.1.2.7 Cost

Supporting calculations for conceptual designs including cost estimates are provided in Appendix B. These are the types of costs assessed:

- RD and construction documentation costs, including remedial design, construction management and oversight, remedial design and remedial action document preparation, project/program management and oversight, and reporting costs;

- Construction costs, including capital equipment, general and administrative costs, and construction subcontract fees;

- Operating and maintenance costs;

- Equipment replacement costs; and

- Surveillance and monitoring costs.

Life-cycle costs are presented as constant value fiscal year (FY) 2009 dollars; escalated value FY 2009 dollars; and present worth for capital, O&M, and periodic costs for each alternative. Escalation was applied as directed by DOE Order 430.1A, "Life Cycle Asset Management." Escalation rates were obtained at "Escalation Rate Assumptions for DOE Projects (January 2009)" accessed at http://www.cfo.doe.gov/cf70/escalation.pdf. Long-term costs of maintenance and monitoring were estimated for 30 years as applicable, as recommended by CERCLA guidance (EPA 1988). A contingency of 25% was applied to the escalated life-cycle cost of each alternative.

Present worth costs were calculated as described in EPA (2000b) guidance. The discount rate was obtained from OMB Circular A-94 Appendix C (OMB 2008).

Detailed total costs for implementing each alternative at the Oil Landfarm and the C-720 Northeast and Southeast Sites are presented in Appendix B. Summary costs for implementing each alternative at each individual source area are presented in this section and in Section 5 and were developed parametrically by dividing the detailed total costs for each alternative by the fractional area of each site.

The alternative cost estimates are for comparison purposes only and are not intended for budgetary, planning, or funding purposes. Estimates were prepared to meet the -30% to +50% range of accuracy

recommended in EPA (1988) CERCLA guidance. Detailed cost estimate backup is provided in Appendix B.

4.1.2.8 State acceptance

This assessment evaluates the technical and administrative issues and concerns the Commonwealth of Kentucky may have regarding each of the alternatives. This criterion will be addressed in the Proposed Plan and ROD after Commonwealth of Kentucky comments on the FFS are received.

4.1.2.9 Community acceptance

This assessment evaluates the issues and concerns the public may have regarding each of the alternatives. As for state acceptance, this criterion will be addressed in the ROD after public comments on the FFS and Proposed Plan are received.

4.1.3 Federal Facility Agreement and NEPA Requirements

Specific requirements of the FFA and NEPA consistent with the DOE's Secretarial Policy Statement on NEPA in June of 1994 are considered in the FFS.

4.1.3.1 Otherwise required permits under the FFA

When DOE proposes a response action, Section XXI of the FFA further requires that DOE identify each state and federal permit that otherwise would have been required in the absence of CERCLA Section 121(e)(1) and the NCP. DOE must identify the permits that otherwise would be required, the standards, requirements, criteria, or limitations necessary to obtain such permits and provide an explanation of how the proposed action will meet the standards, requirements, criteria, or limitations identified.

An evaluation of alternatives evaluated in the FFS determined that the otherwise required permits may include KPDES; RCRA Treatment, Storage, and Disposal Facility; and Solid Waste Landfill permits. Jurisdictional wetlands have been identified on PGDP and will be delineated, as necessary, prior to the remedial action.

PGDP currently operates under KPDES Permit No. KY0004049, Hazardous Waste Facility Operating Permit No. KY8-890-008-982,and Solid Waste Permit No. 07300045, which define the applicable standards, requirements, criteria, or limitations. In the absence of the existing permits, the substantive requirements of the otherwise required permits are identified in the ARARs provided for each alternative.

4.1.3.2 NEPA values

The following NEPA values, not normally addressed by CERCLA documentation, also are considered in this FFS to the extent practicable, consistent with DOE policy:

- Land use
- Air quality and noise
- Geologic resources and soils
- Water resources
- Wetlands and floodplains
- Ecological resources
- T&E species
- Migratory birds

- Cultural and archeological resources
- Socioeconomics, including environmental justice and transportation

Alternatives 4 and 5 would have no identified short-term or long-term impacts on geological resources, cultural resources, or socioeconomics. Upon final selection of the alternative, the absence of any short- and long-term impacts to these values will be verified.

No long-term impacts to air quality or noise would result from implementation of the remedial action alternatives evaluated. Process engineering controls and remedial actions should not result in generation of air pollutants above regulatory limits, and noise levels should be similar to current background levels.

None of the remedial alternatives would have any impacts on geologic resources, and construction activities would have only short-term impacts on soils. Site clearing, excavation, grading, and contouring would alter the topography of the construction area, but the geologic formations underlying those sites should not be affected. Construction would disturb existing soils, and some topsoil might be removed in the process. Soil erosion impacts during construction would be mitigated through the use of BMP control measures (e.g., covers and silt fences). No conversion of prime farmland soils is expected to occur. Any alternative that would create disturbances also would include restoration of the affected areas.

None of the activities associated with the remedial alternatives would be conducted within a floodplain. Wetlands were identified during the 1994 COE environmental investigation for the area surrounding the PGDP. This investigation identified five acres of potential wetlands inside the fence at the PGDP (COE 1994) including wetlands along the southern and eastern boundaries of the Oil Landfarm. The COE made the determination that these areas are jurisdictional wetlands (COE 1995).

Construction activities must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values (Executive Order 11990 and 10 *CFR* § 1022). These applicable requirements include avoiding construction in wetlands, avoiding (to the extent practicable) long- and short-term adverse impacts to floodplains and wetlands, avoiding degradation or destruction of wetlands, and avoiding discharge of dredge and fill material into wetlands. In addition, the protection of wetlands shall be incorporated into all planning documents and decision making, as required by 10 *CFR* § 1022.3.

No long- or short-term impacts have been identified to archeological or cultural resources. DOE developed the CRMP (BJC 2006) to define the preservation strategy for PGDP, and direct efficient compliance with the NHPA and federal archaeological protection legislation at PGDP. No archaeological or historical resources have been identified within the vicinity of the Oil Landfarm or the C-720 Northeast and Southeast Sites; however, should portions of the project remove soils that previously have been undisturbed, an archaeological survey will be conducted in accordance with the CRMP. If archaeological properties are located that will be affected adversely, then appropriate mitigation measures will be employed.

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations*, requires agencies to identify and address disproportionately high and adverse human health or environmental effects their activities may have on minority and low-income populations. There is a disproportionately high percentage of minority and low-income populations within 50 miles of the PGDP site (DOE 2004), but because there are no potential impacts from these alternatives, there would be no disproportionate or adverse environmental justice impacts to these populations associated with this alternative.

No long- or short-term adverse transportation impacts are expected to result from implementation of remedial alternatives. During construction activities there would be a slight increase in the volume of truck traffic in the vicinity of the Oil Landfarm or the C-720 Northeast and Southeast Sites, but the affected roads are capable of handling the additional truck traffic. Any wastes transferred off-site or transported in commerce along public rights-of-ways will meet the ARAR both substantive and administrative the requirements. These include the permitting, packaging, labeling, marking, manifesting, and placarding requirements for hazardous materials at 49 *CFR* Parts 107, 171–174, and 178; however, transport of wastes along roads within the PGDP site that are not accessible to the public would not be considered "in commerce" and would, therefore, only need to meet the substantive requirements of the regulations.

In addition, CERCLA 121(d)(3) provides that the off-site transfer of any hazardous substance, pollutant, or contaminant generated during CERCLA response actions be sent to a treatment, storage, or disposal facility that complies with applicable federal and state laws and has been approved by the EPA for acceptance of CERCLA waste. Accordingly, DOE will verify with the appropriate EPA regional contact that any needed off-site facility is acceptable for receipt of CERCLA wastes before transfer.

4.2 MODELING RESULTS

Because the remediation technologies under consideration for implementation for the Southwest Plume sources likely will not reduce subsurface soil VOC levels to the remedial goal concentration within the anticipated period of active treatment (5 years of SVE operations for Alternative 4 and 12 months of active ERH operation for Alternative 5), the time required for residual VOC mass to attenuate advectively over time and demonstrate remedy compliance with RAO #3 was assessed. This assessment focuses on the contribution of VOC mass leaching to the RGA from the individual Southwest Plume sources, irrespective of ambient VOC contamination in the RGA. Contributions of leached residual VOC mass from these sources was deterministically assessed in terms of time required to achieve sub-MCL concentrations in the RGA in the area of attainment. The modeling methodology and results, including discussion of uncertainty, are provided in Appendix C and are summarized in Table 4.1. The time required for leached residual VOC mass to diminish to levels that are less than the MCL in the RGA below the source areas was estimated for each alternative and each site using TCE half-lives in UCRS soils ranging from 5 years to 50 years to assess the potential effects of degradation on remedy time frames (50 years essentially representing no observable degradation). Other VOCs were assumed not to be degraded. The shorter time frames observed in Table 4.1 for the SVE alternative are due to the continued presence of a surface cap that serves to inhibit recharge. Any contamination from upgradient sources was not accounted for. An uncertainty analysis was conducted using probabilistic analyses.

The time to attainment of MCLs for TCE, assuming a half-life of 50 years in the UCRS, is discussed as the bounding case for the detailed and comparative analysis of alternatives. The actual degradation rate of TCE in the UCRS has not been determined; however, the 50 year half-life is considered conservative based on literature values discussed in Claussen *et al*. (1997), the KRCEE (2008) evaluation of biodegradation in the RGA, and values used in TCE transport model development. Additionally, the time to attainment assuming a 50-year TCE half-life is longer than for any other VOC assuming no degradation, as shown in Table 4.1. TCE attainment time, assuming a 50 year half-life, therefore, is conservative and bounding and is the basis for discussion in the evaluation of effectiveness of alternatives.

Table 4.1. Time to Attainment of MCLs for VOCs in the RGA from Oil Landfarm and C-720 Area Sources

C-720 Southeast Sites Time to Attainment of MCL				
Analyte	**TCE Half-Life in UCRS (yr)** [a]	**Time (years)**		
		Alternative 1:No Action	**Alternative 4: SVE Source Treatment and Containment**[b]	**Alternative 5: *In Situ* Thermal Source Treatment**
TCE	5	35	2	1
TCE	25	97	3	22
TCE	50	>100	3	29
1,1-DCE	infinite	0	0	0
cis-1,2-DCE	infinite	36	0	0
trans-1,2-DCE	infinite	0	0	0
Vinyl Chloride	infinite	34	0	0
Oil Landfarm Time to Attainment of MCL				
Analyte	**TCE Half-Life in UCRS (yr)** [a]	**Time (years)**		
		Alternative 1: No Action	**Alternative 4: SVE Source Treatment and Containment**[b]	**Alternative 5: *In Situ* Thermal Source Treatment**
TCE	5	41	5	15
TCE	25	>100	5	41
TCE	50	>100	5	52
cis-1,2-DCE	infinite	26	0	0
trans-1,2-DCE	infinite	32	0	0
Vinyl Chloride	infinite	0	0	0
1,1-DCE	infinite	0	0	0

[a]TCE degradation rate in the RGA based on a half-life of 7.25 yr–all other analytes were infinite half-lives.
[b]SVE assumes the presence of a surface cap that inhibits recharge during all times.
SVE = soil vapor extraction
UCRS = Upper Continental Recharge System

4.3 DETAILED ANALYSIS OF ALTERNATIVES

4.3.1 Alternative 1—No Action

4.3.1.1 Overall protection of human health and the environment

Alternative 1 would not meet this threshold criterion. Risks to excavation workers and groundwater receptors would be reduced only by natural processes, which would require over 100 years at the C-720 Northeast and Southeast Sites and at the Oil Landfarm, based on a conservative modeling assumption of a TCE half-life in the UCRS of 50 years. RAOs would not be met because no action would be implemented to reliably reduce exposures and attain RGs.

4.3.1.2 Compliance with ARARs

Alternative 1 would not meet this threshold criterion. Alternative 1 is estimated to require over 100 years to meet the RGs based on modeling results summarized in Table 4.1 and conservatively assuming a TCE half-life of 50 years in the UCRS.

4.3.1.3 Long-term effectiveness and permanence

Alternative 1 does not provide long-term controls to reduce flux of VOCs to the RGA from PTW. Potential excavation worker and RGA groundwater exposure risks identified in Section 1 would remain unchanged for this alternative.

4.3.1.4 Reduction of toxicity, mobility, or volume through treatment

Treatment would not be implemented with Alternative 1. Reduction in contaminant mass and concentration would be achieved only through natural attenuation processes, such as dilution, dispersion, and biodegradation of VOCs in UCRS soils and groundwater.

4.3.1.5 Short-term effectiveness

No actions would be implemented under Alternative 1; therefore, no additional risks to workers, the public, or the environment would be incurred. Alternative 1 is estimated to require over 100 years to meet Commonwealth of Kentucky drinking water standards stated in 401 *KAR* 8:420 for VOCs, based on a conservative modeling assumption of a TCE half-life in the UCRS of 50 years.

4.3.1.6 Implementability

Alternative 1 would involve no actions and is therefore technically implementable.

4.3.1.7 Cost

No costs are associated with Alternative 1.

4.3.2 Alternative 4—SVE Source Treatment and Containment

4.3.2.1 Overall protection of human health and the environment

Alternative 4 would meet this threshold criterion. Monitoring, the E/PP program, and SVE process controls during implementation would assure that risks to workers, off-site residents, and the environment were reduced to allowable levels. Existing DOE plant controls, which are administered and maintained

outside of CERCLA, provide additional protection of human health by restricting access. Recharge controls and surface covers would reduce the flux of VOCs from the source areas to the RGA by reducing infiltration, thereby reducing the driving force for contaminant migration. Infiltration reduction would continue as long as the recharge controls and surface covers remained intact.

SVE would further reduce VOC source mass by removal of vapor. SVE also would increase the rate of drainage of water of the formation by applying a pressure gradient in addition to the elevation head gradient created by groundwater pumping. SVE also would remove water vapor and thereby reduce the soil moisture content. This would further reduce the unsaturated hydraulic conductivity in the unsaturated portions of the treatment areas, resulting in reduced seepage of infiltration to the RGA. SVE would increase volatilization rates from DNAPL, sorbed, and aqueous phase VOCs.

RAO #1 would be met by removal of PTW as vapor and destroying the vapor *ex situ*. RAO #2a would be met by removing VOCs to levels within EPA's generally acceptable risk range for site-related exposures of 1E-04 to 1E-06. RAO #2b would be met by the E/PP program until final disposition through the Soils OU.

RAO #3 would be met by the combination of infiltration reduction and VOC removal. Up to 90% of the VOCs present likely would be removed in two to five years using SVE, based on results of previous implementation elsewhere (FRTR 2008; Hightower *et al.* 2001). Surface covering and recharge controls would reduce infiltration sufficiently to meet RAO #3 during the SVE operation period, as shown in Table 4.1.

Modeling results presented in Appendix C show that, through a combination of mass removal due to active remediation, containment, and advective attenuation, MCLs for VOCs leached from the Oil Landfarm and C-720 source areas would be attained in the RGA within about five years and three years, respectively. Mass removal due to volatilization would continue after the SVE system was shut off, if the wells were left in place and allowed to vent passively. Five-year reviews, cover maintenance, and monitoring would be required until VOC concentrations in soils reached RGs. The time required to reach TCE groundwater protection RGs at the Oil Landfarm and the C-720 sites was estimated at 77 years and 73 years, respectively, assuming a 50 year half-life for TCE, as reported in Appendix C.

The actual rate and extent of TCE removal would depend, in part, on the rate of drainage of pore water from the capped areas and the effectiveness of reducing surface recharge by capping and recharge controls. Assuming no recharge from the surface, drainage from a 9.14-m (30-ft) saturated zone would take about a year, at the pore water velocity of 0.1 ft/day estimated for the UCRS in Section 1. Actual soil moisture reduction would be expected to occur more rapidly, under the additional influence of intermittent groundwater pumping and SVE. Drainage and drying of the soil would allow for more volatilization and removal of TCE. Some TCE would remain in dead-end pores, zones that remain saturated, and/or low-permeability zones, after vapor concentrations reached asymptotic levels.

4.3.2.2 Compliance with ARARs

Alternative 4 would meet this threshold criterion. Table 4.2 summarizes compliance with ARARs for Alternative 4.

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS

Location-specific ARARs					
Location	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Cultural resources					
Presence of wetlands as defined in 10 *CFR* § 1022.4	Avoid, to the extent possible, the long- and short-term adverse effects associated with destruction, occupancy, and modification of wetlands.	DOE actions that involve potential impacts to, or take place within, wetlands—**applicable**.	10 *CFR* § 1022.3(a)	✓	✓
	Take action, to extent practicable, to minimize destruction, loss, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands.		10 *CFR* § 1022.3(a)(7) and (8)	✓	✓
	Undertake a careful evaluation of the potential effects of any new construction in wetlands. Identify, evaluate, and, as appropriate, implement alternative actions that may avoid or mitigate adverse impacts on wetlands.		10 *CFR* § 1022.3(b) and (d)	✓	✓
	Measures that mitigate the adverse effects of actions in a wetland including, but not limited to, minimum grading requirements, runoff controls, design and construction constraints, and protection of ecologically-sensitive areas.		10 *CFR* § 1022.13(a)(3)	✓	✓
	If no practicable alternative to locating or conducting the action in the wetland is available, then before taking action design or modify the action in order to minimize potential harm to or within the wetland, consistent with the policies set forth in E.O. 11990.		10 *CFR* § 1022.14(a)	✓	✓
Location encompassing aquatic ecosystem as defined in 40 *CFR* § 230.3(c)	Except as provided under section 404(b)(2), no discharge of dredged or fill material is permitted if there is a practicable alternative that would have less adverse impact on the aquatic ecosystem or if it will cause or contribute to significant degradation of the waters of the United States.	Action that involves the discharge of dredged or fill material into waters of the United States, including jurisdictional wetlands—**relevant and appropriate**.	40 *CFR* § 230.10(a) and (c)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Location-specific ARARs					
Location	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Except as provided under section 404(b)(2), no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken that will minimize potential adverse impacts of the discharge on the aquatic ecosystem. 40 *CFR* § 230.70 *et seq*. identifies such possible steps.		40 *CFR* § 230.10(d)	✓	✓
Nationwide Permit Program	Must comply with the substantive requirements of the NWP 38, General Conditions, as appropriate.	Discharge of dredged or fill material into waters of the United States, including jurisdictional wetlands—**relevant and appropriate**.	Nation Wide Permit (38) Cleanup of Hazardous and Toxic Waste 33 *CFR* § 323.3(b)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Site preparation, construction, and excavation activities					
Activities causing fugitive dust emissions	No person shall cause, suffer, or allow any material to be handled, processed, transported, or stored, a building or its appurtenances to be constructed, altered, repaired, or demolished, or a road to be used without taking reasonable precaution to prevent particulate matter from becoming airborne. Such reasonable precautions shall include, when applicable, but not be limited to, the following: • Use, where possible, of water or chemicals for control of dust in the demolition of existing buildings or structures, construction operations, the grading of roads or the clearing of land; • Application and maintenance of asphalt, oil, water, or suitable chemicals on roads, materials stockpiles, and other surfaces which can create airborne dusts; • Covering, at all times when in motion, open bodied trucks transporting materials likely to become airborne; • The maintenance of paved roadways in a clean condition; and The prompt removal of earth or other material from a paved street which earth or other material has been transported thereto by trucking or earth moving equipment or erosion by water.	Fugitive emissions from land-disturbing activities (e.g., handling, processing, transporting or storing of any material, demolition of structures, construction operations, grading of roads, or the clearing of land, etc.)—**applicable**.	401 *KAR* 63:010 § 3(1) and (1)(a), (b), (d), (e) and (f)	✓	✓
	No person shall cause or permit the discharge of visible fugitive dust emissions beyond the lot line of the property on which the emissions originate.		401 *KAR* 63:010 § 3(2)	✓	✓
Activities causing radionuclide emissions	Emissions of radionuclides to the ambient air from DOE facilities shall not exceed those amounts that would cause any member of the public to receive in any year an EDE of 10 mrem/yr.	Radionuclide emissions from point sources at a DOE facility—**applicable**.	40 *CFR* § 61.92 401 *KAR* 57:002	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Activities causing toxic substances or potentially hazardous matter emissions	Persons responsible for a source from which hazardous matter or toxic substances may be emitted shall provide the utmost care and consideration in the handling of these materials to the potentially harmful effects of the emissions resulting from such activities. No owner or operator shall allow any affected facility to emit potentially hazardous matter or toxic substances in such quantities or duration as to be harmful to the health and welfare of humans, animals and plants.	Emissions of potentially hazardous matter or toxic substances as defined in 401 *KAR* 63:020 § 2 (2) —**applicable**.	401 *KAR* 63:020 § 3	✓	✓
Radiation dose limits for individual members of the public	Exposure to individual members of the public from radiation shall not exceed a total EDE of 0.1 rem/year (100 mrem/year), exclusive of the dose contributions from background radiation, any medical administration the individual has received, or voluntary participation in medical/research programs.	Dose received from operations —**relevant and appropriate**.	10 *CFR* § 20.1301(a)(1) 902 *KAR* 100:019 § 10 (1)	✓	✓
	Shall use, to the extent practicable, procedures and engineering controls based on sound radiation protection principles to achieve doses to members of the public that are ALARA.		10 *CFR* § 20.1101(b) 902 *KAR* 100:019 § 2(2)	✓	✓
Radiation protection of the public and the environment	Except as provided in 5400.1(II)(1)(a)(4), the exposure of members of the public to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an EDE greater than 100 mrem per year. The ALARA process shall be implemented for all DOE activities and facilities that cause public doses.	Dose received from all exposure modes from all DOE activities (including remedial actions) at a DOE facility—**TBC**.	DOE O 5400.5(II)(1)(a) and (2)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Activities causing storm water runoff (e.g., clearing, grading, excavation)	Implement good construction techniques to control pollutants in storm water discharges during and after construction in accordance with substantive requirements provided by permits issued pursuant to 40 *CFR* § 122.26(c).	Storm water discharges associated with small construction activities as defined in 40 *CFR* § 122.26(b)(15) and 401 *KAR* 5:002 § 1 (157)—**applicable**.	40 *CFR* § 122.26(c)(1)(ii)(C) and (D) 401 *KAR* 5:060 § 8	✓	✓
	Storm water runoff associated with construction activities taking place at a facility with an existing Best Management Practices (BMP) Plan shall be addressed under the facility BMP and not under a storm water general permit.	Storm water discharges associated with small construction activities as defined in 40 *CFR* § 122.26(b)(15) and 401 *KAR* 5:002 § 1 (157)—**TBC**.	Fact Sheet for the KPDES General Permit For Storm water Discharges Associated with Construction Activities, June 2009	✓	✓
	Best management storm water controls will be implemented and may include, as appropriate, erosion and sedimentation control measures, structural practices (e.g., silt fences, straw bale barriers) and vegetative practices (e.g., seeding); storm water management (e.g., diversion); and maintenance of control measures in order to ensure compliance with the standards in Section C.5. Storm Water Discharge Quality.	Storm water runoff associated with construction activities taking place at a facility [PGDP] with an existing BMP Plan—**TBC**.	Appendix C of the PGDP Best Management Practices Plan (2007) — Examples of Storm water Controls	✓	✓
Monitoring, Extraction, and Injection Well Installation and Abandonment					
Monitoring well installation	Permanent monitoring wells shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §1(2)	✓	✓
	All permanent (including boreholes) shall be constructed to comply with the substantive requirements provided in the following Sections of 401 *KAR* 6:350: • Section 2. Design Factors; • Section 3. Monitoring Well Construction; • Section 7. Materials for Monitoring Wells; and • Section 8. Surface Completion.		401 *KAR* 6:350 § 2, 3, 7, and 8	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4
(SVE Source Treatment and Containment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	If conditions exist or are believed to exist that preclude compliance with the requirements of 401 *KAR* 6:350, may request a variance prior to well construction or well abandonment. *NOTE: Variance shall be made as part of the FFA CERCLA document review and approval process and shall include:* • A justification for the variance; and • Proposed construction, modification, or abandonment procedures to be used in lieu of compliance with 401 *KAR* 6:350 and an explanation as to how the alternate well construction procedures ensure the protection of the quality of the groundwater and the protection of public health and safety.		401 *KAR* 6:350 § 6 (a)(6) and (7)	✓	✓
Development of monitoring well	Newly installed wells shall be developed until the column of water in the well is free of visible sediment. This well-development protocol shall not be used as a method for purging prior to water quality sampling.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §9	✓	✓
Direct Push monitoring well installation	Wells installed using direct push technology shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of direct push monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §5 (1)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Shall also comply with the following additional standards: (a) The outside diameter of the borehole shall be a minimum of 1 inch greater than the outside diameter of the well casing; (b) Premixed bentonite slurry or bentonite chips with a minimum of one-eighth (1/8) diameter shall be used in the sealed interval below the static water level; an (c) 1. Direct push wells shall not be constructed through more than one water-bearing formation unless the upper water bearing zone is isolated by temporary or permanent casing. 2. The direct push tool string may serve as the temporary casing.		401 *KAR* 6:350 §5 (3)	✓	✓
Monitoring well abandonment	A monitoring well that has been damaged or is otherwise unsuitable for use as a monitoring well, shall be abandoned within 30 days from the last sampling date or 30 days from the date it is determined that the well is no longer suitable for its intended use.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §11 (1)	✓	✓
	Wells shall be abandoned in such a manner as to prevent the migration of surface water or contaminants to the subsurface and to prevent migration of contaminants among water bearing zones.		401 *KAR* 6:350 §11 (1)(a)	✓	✓
	Abandonment methods and sealing materials for all types of monitoring wells provided in subparagraphs (a)-(b) and (d)-(e) shall be followed.		401 *KAR* 6:350 §11 (2)	✓	✓
Extraction well installation	Wells shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of monitoring well for remedial action—**relevant and appropriate**.	401 *KAR* 6:350 §1 (2)	✓	✓
Reinjection of treated contaminated groundwater	No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 *CFR* Part 142 or may otherwise adversely affect the health of persons.	Underground injection into an underground source of drinking water—**relevant and appropriate**.	40 *CFR* § 144.12(a)		✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4
(SVE Source Treatment and Containment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Wells are not prohibited if injection is approved by EPA or a State pursuant to provisions for cleanup of releases under CERCLA or RCRA *as provided in the FFA CERCLA document*.	Class IV wells [as defined in 40 *CFR* § 144.6(d)] used to reinject treated contaminated groundwater into the same formation from which it was drawn—**relevant and appropriate**.	40 *CFR* § 144.13(c) RCRA § 3020(b)		✓
	Prior to abandonment any Class IV well, the owner or operator shall plug or otherwise close the well in a manner *as provided in the FFA CERCLA document*.	Class IV wells [as defined in 40 *CFR* § 144.6(d)] used to reinject of treated contaminated groundwater into the same formation from which it was drawn—**relevant and appropriate**.	40 *CFR* § 144.23(b)(1)		✓
Plugging and abandonment of Class IV injection wells	Prior to abandoning the well, the owner or operator shall close the well in accordance with 40 *CFR* § 144.23(b).	Operation of a Class IV injection well [as defined in 40 *CFR* § 144.6(d)] —**relevant and appropriate**.	40 *CFR* § 146.10(b)		✓
General Waste Management					
Management of PCB waste	Any person storing or disposing of PCB waste must do so in accordance with 40 *CFR* § 761, Subpart D.	Storage or disposal of waste containing PCBs at concentrations ≥ 50 ppm—**applicable**.	40 *CFR* § 761.50(a)	✓	✓
	Any person cleaning up and disposing of PCBs shall do so based on the concentration at which the PCBs are found.	Cleanup and disposal of PCB remediation waste as defined in 40 *CFR* § 761.3—**applicable**.	40 *CFR* § 761.61	✓	✓
Management of PCB/Radioactive waste	Any person storing such waste ≥ 50 ppm PCBs must do so taking into account both its PCB concentration and radioactive properties, except as provided in 40 *CFR* § 761.65(a)(1), (b)(1)(ii) and (c)(6)(i).	Storage of PCB/Radioactive waste for a disposal—**applicable**.	40 *CFR* § 761.50(b)(7)(i)	✓	✓
	Any person disposing of such waste must do so taking into account both its PCB concentration and its radioactive properties. If, taking into account only the properties of the PCBs in the waste, the waste meets the requirements for disposal in a nonhazardous waste landfill, then the PCB/radioactive waste may be disposed without regard to the PCB component of the waste.		40 *CFR* § 761.50(b)(7)(ii)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Waste Characterization					
Characterization of solid waste	Must determine if solid waste is excluded from regulation under 40 *CFR* § 261.4.	Generation of solid waste as defined in 40 *CFR* § 261.2—**applicable**.	40 *CFR* § 262.11(a) 401 *KAR* 32:010 §2	✓	✓
	Must determine if waste is listed as a hazardous waste in subpart D of 40 *CFR* Part 261.	Generation of solid waste which is not excluded under 40 *CFR* § 261.4—**applicable**.	40 *CFR* § 262.11(b) 401 *KAR* 32:010 §2	✓	✓
	Must determine whether the waste is characteristic waste (identified in subpart C of 40 *CFR* Part 261) by using prescribed testing methods or applying generator knowledge based on information regarding material or processes used.	Generation of solid waste that is not listed in subpart D of 40 *CFR* Part 261 and not excluded under 40 *CFR* § 261.4—**applicable**.	40 *CFR* § 262.11(c) 401 *KAR* 32:010 §2	✓	✓
	Must refer to Parts 261, 262, 264, 265, 266, 268, and 273 of Chapter 40 for possible exclusions or restrictions pertaining to management of the specific waste.	Generation of solid waste which is determined to be hazardous waste—**applicable**.	40 *CFR* § 262.11(d) 401 *KAR* 32:010 §2	✓	✓
Characterization of hazardous waste	Must obtain a detailed chemical and physical analysis on a representative sample of the waste(s), which at a minimum contains all the information that must be known to treat, store, or dispose of the waste in accordance with pertinent sections of 40 *CFR* §§ 264 and 268.	Generation of RCRA-hazardous waste for storage, treatment or disposal—**applicable**.	40 *CFR* § 264.13(a)(1) 401 *KAR* 34:020 § 4	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Characterization of industrial wastewater	Industrial wastewater discharges that are point source discharges subject to regulation under section 402 of the Clean Water Act, as amended, are not solid wastes for the purpose of hazardous waste management. [Comment: This exclusion applies only to the actual point source discharge. It does not exclude industrial wastewaters while they are being collected, stored or treated before discharge, nor does it exclude sludges that are generated by industrial wastewater treatment.] NOTE: For purpose of this exclusion, the CERCLA on-site treatment system for extracted VOCs and groundwater will be considered equivalent to a wastewater treatment unit and the point source discharges subject to regulation under CWA Section 402, provided the effluent meets all identified CWA ARARs.	Generation of industrial wastewater for treatment and discharge into surface water—**applicable**.	40 *CFR* § 261.4(a)(2) 401 *KAR* 31:010 § 4	✓	✓
Determinations for management of hazardous waste	Must determine each EPA Hazardous Waste Number (Waste Code) to determine the applicable treatment standards under 40 *CFR* § 268.40 *et. seq*. *Note:* This determination may be made concurrently with the hazardous waste determination required in 40 *CFR* § 262.11.	Generation of hazardous waste—**applicable**.	40 *CFR* § 268.9(a) 401 *KAR* 37:010 §8	✓	✓
	Must determine the underlying hazardous constituents [as defined in 40 *CFR* § 268.2(i)] in the characteristic waste.	Generation of RCRA characteristic hazardous waste (and is not D001 non-wastewaters treated by CMBST, RORGS, or POLYM of Section 268.42 Table 1) for storage, treatment or disposal—**applicable**.	40 *CFR* § 268.9(a) 401 *KAR* 37:010 §8	✓	✓
	Must determine if the hazardous waste meets the treatment standards in 40 *CFR* §§ 268.40, 268.45, or 268.49 by testing in accordance with prescribed methods or use of generator knowledge of waste. *Note:* This determination can be made concurrently with the hazardous waste determination required in 40 *CFR* § 262.11.	Generation of hazardous waste—**applicable**.	40 *CFR* § 268.7(a) 401 *KAR* 37:010 §7	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Characterization of LLW	Shall be characterized using direct or indirect methods and the characterization documented in sufficient detail to ensure safe management and compliance with the WAC of the receiving facility.	Generation of LLW for storage and disposal at a DOE facility—**TBC**.	DOE M 435.1-1(IV)(I)	✓	✓
	Characterization data shall, at a minimum, include the following information relevant to the management of the waste:		DOE M 435.1-1(IV)(I)(2)	✓	✓
	• physical and chemical characteristics;		DOE M 435.1-1(IV)(I)(2)(a)	✓	✓
	• volume, including the waste and any stabilization or absorbent media;		DOE M 435.1-1(IV)(I)(2)(b)	✓	✓
	• weight of the container and contents;		DOE M 435.1-1(IV)(I)(2)(c)	✓	✓
	• identities, activities, and concentration of major radionuclides;		DOE M 435.1-1(IV)(I)(2)(d)	✓	✓
	• characterization date;		DOE M 435.1-1(IV)(I)(2)(e)	✓	✓
	• generating source; and		DOE M 435.1-1(IV)(I)(2)(f)	✓	✓
	• any other information that may be needed to prepare and maintain the disposal facility performance assessment, or demonstrate compliance with performance objectives.		DOE M 435.1-1(IV)(I)(2)(g)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Waste Accumulation, Storage and Staging					
Temporary on-site storage of hazardous waste in containers	A generator may accumulate hazardous waste at the facility provided that	Accumulation of RCRA hazardous waste on-site as defined in 40 *CFR* § 260.10—**applicable**.	40 *CFR* § 262.34(a) 401 *KAR* 32:030 §5	✓	✓
	• waste is placed in containers that comply with 40 *CFR* § 265.171-173;		40 *CFR* § 262.34(a)(1)(i) 401 *KAR* 32:030 §5	✓	✓
	• the date upon which accumulation begins is clearly marked and visible for inspection on each container;		40 *CFR* § 262.34(a)(2) 401 *KAR* 32:030 §5	✓	✓
	• container is marked with the words "hazardous waste."		40 *CFR* § 262.34(a)(3) 401 *KAR* 32:030 § 5	✓	✓
	Container may be marked with other words that identify the contents.	Accumulation of 55 gal or less of RCRA hazardous waste or one quart of acutely hazardous waste listed in 261.33(e) at or near any point of generation—**applicable**.	40 *CFR* § 262.34(c)(1) 401 *KAR* 32:030 §5	✓	✓
Use and management of containers holding hazardous waste	If container is not in good condition or if it begins to leak, must transfer waste into container in good condition.	Storage of RCRA hazardous waste in containers—**applicable**.	40 *CFR* § 265.171 401 *KAR* 35:180 §2	✓	✓
	Use container made or lined with materials compatible with waste to be stored so that the ability of the container is not impaired.		40 *CFR* § 265.172 401 *KAR* 35:180 §3	✓	✓
	Keep containers closed during storage, except to add/remove waste.		40 *CFR* § 265.173(a) 401 *KAR* 35:180 §4	✓	✓
	Open, handle and store containers in a manner that will not cause containers to rupture or leak.		40 *CFR* § 265.173(b) 401 *KAR* 35:180 §4	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Must not pile remediation waste on same base where incompatible wastes or materials were previously piled unless you have sufficiently decontaminated the base to comply with 40 *CFR* § 264.17(b).		40 *CFR* § 264.554(f)(3)	✓	✓
Storage of hazardous waste in container area	Area must have a containment system designed and operated in accordance with 40 *CFR* § 264.175(b).	Storage of RCRA hazardous waste in containers with free liquids—**applicable**.	40 *CFR* § 264.175(a)	✓	✓
	Area must be sloped or otherwise designed and operated to drain liquid from precipitation, or Containers must be elevated or otherwise protected from contact with accumulated liquid.	Storage of RCRA-hazardous waste in containers that do not contain free liquids (other than F020, F021, F022, F023,F026 and F027)—**applicable**.	40 *CFR* § 264.175(c)	✓	✓
Storage of PCB waste and/or PCB/radioactive waste in a RCRA-regulated container storage area	Does not have to meet storage unit requirements in 40 *CFR* § 761.65(b)(1) provided unit	Storage of PCBs and PCB Items at concentrations ≥ 50ppm designated for disposal— **applicable**.	40 *CFR* § 761.65(b)(2)	✓	✓
	• is permitted by EPA under RCRA § 3004 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761; or		40 *CFR* § 761.65(b)(2)(i)	✓	✓
	• qualifies for interim status under RCRA § 3005 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761; or		40 *CFR* § 761.65(b)(2)(ii)	✓	✓
	• is permitted by an authorized state under RCRA § 3006 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761.		40 *CFR* § 761.65(b)(2)(iii)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	NOTE: For purpose of this exclusion, CERCLA remediation waste, which is also considered PCB waste, can be stored on-site provided the area meets all of the identified RCRA container storage ARARs and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761.				
Storage of PCB waste and/or PCB/radioactive waste in non-RCRA regulated unit	Except as provided in 40 *CFR* § 761.65 (b)(2), (c)(1), (c)(7), (c)(9), and (c)(10), after July 1, 1978, owners or operators of any facilities used for the storage of PCBs and PCB Items designated for disposal shall comply with the storage unit requirements in 40 *CFR* § 761.65(b)(1).	Storage of PCBs and PCB Items at concentrations ≥ 50ppm designated for disposal —**applicable**.	40 *CFR* § 761.65(b)	✓	✓
	Storage facility shall meet the following criteria: • Adequate roof and walls to prevent rainwater from reaching stored PCBs and PCB items;		40 *CFR* § 761.65(b)(1) 40 *CFR* § 761.65(b)(1)(i)	✓	✓
	• Adequate floor that has continuous curbing with a minimum 6-inch high curb. Floor and curb must provide a containment volume equal to at least two times the internal volume of the largest PCB article or container or 25% of the internal volume of all articles or containers stored there, whichever is greater. *Note*: 6 inch minimum curbing not required for area storing PCB/radioactive waste;		40 *CFR* § 761.65(b)(1)(ii)	✓	✓
	• No drain valves, floor drains, expansion joints, sewer lines, or other openings that would permit liquids to flow from curbed area;		40 *CFR* § 761.65(b)(1)(iii)	✓	✓
	• Floors and curbing constructed of Portland cement, concrete, or a continuous, smooth, non-porous surface that prevents or minimizes penetration of PCBs; and		40 *CFR* § 761.65(b)(1)(iv)	✓	✓
	• Not located at a site that is below the 100-year flood water elevation.		40 *CFR* § 761.65(b)(1)(v)	✓	✓
	Storage area must be properly marked as required by 40 *CFR* § 761.40(a)(10).		40 *CFR* § 761.65(c)(3)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Risk-based storage of PCB remediation waste	May store PCB remediation waste in a manner other than prescribed in 40 *CFR* § 761.65(b) if approved in writing from EPA provided the method will not pose an unreasonable risk of injury to human health or the environment. *NOTE:* EPA approval of alternative storage method will be obtained by approval of the FFA CERCLA document.	Storage of waste containing PCBs in a manner other than prescribed in 40 *CFR* § 761.65(b) (see above) —**applicable**.	40 *CFR* § 761.61(c)	✓	✓
Temporary storage of PCB waste (e.g., PPE, rags) in a container(s)	Container(s) shall be marked as illustrated in 40 *CFR* § 761.45(a).	Storage of PCBs and PCB items at concentrations ≥ 50ppm in containers for disposal—**applicable**.	40 *CFR* § 761.40(a)(1)	✓	✓
	Storage area must be properly marked as required by 40 *CFR* § 761.40(a)(10).		40 *CFR* § 761.65(c)(3)	✓	✓
	Any leaking PCB Items and their contents shall be transferred immediately to a properly marked nonleaking container(s).		40 *CFR* § 761.65(c)(5)	✓	✓
	Container(s) shall be in accordance with requirements set forth in DOT HMR at 49 *CFR* §§ 171-180.		40 *CFR* § 761.65(c)(6)	✓	✓
Staging of LLW	Shall be for the purpose of the accumulation of such quantities of wastes necessary to facilitate transportation, treatment, and disposal.	Staging of LLW at a DOE facility—**TBC**.	DOE M 435.1-1 (IV)(N)(7)	✓	✓
Temporary storage of LLW	Shall not be readily capable of detonation, explosive decomposition, reaction at anticipated pressures and temperatures, or explosive reaction with water.	Temporary storage of LLW at a DOE facility—**TBC**.	DOE M 435.1-1 (IV)(N)(1)	✓	✓
	Shall be stored in a location and manner that protects the integrity of waste for the expected time of storage.		DOE M 435.1-1 (IV)(N)(3)	✓	✓
	Shall be managed to identify and segregate LLW from mixed waste.		DOE M 435.1-1 (IV)(N)(6)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Packaging of LLW for storage	Shall be packaged in a manner that provides containment and protection for the duration of the anticipated storage period and until disposal is achieved or until the waste has been removed from the container.	Storage of LLW in containers at a DOE facility —**TBC**.	DOE M 435.1-1(IV)(L)(1)(a)	✓	✓
	Vents or other measures shall be provided if the potential exists for pressurizing or generating flammable or explosive concentrations of gases within the waste container.		DOE M 435.1-1(IV)(L)(1)(b)	✓	✓
	Containers shall be marked such that their contents can be identified.		DOE M 435.1-1(IV)(L)(1)(c)	✓	✓
Packaging of LLW for off-site disposal	Waste shall not be packaged for disposal in a cardboard or fiberboard box.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(b)	✓	✓
	Liquid waste shall be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid.	Preparation of liquid LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(c)	✓	✓
	Solid waste containing liquid shall contain as little freestanding and noncorrosive liquid as is reasonably achievable. The liquid shall not exceed one (1) percent of the volume.	Preparation of solid LLW containing liquid for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(d)	✓	✓
	Waste shall not be readily capable of • Detonation; • Explosive decomposition or reaction at normal pressures and temperatures; or • Explosive reaction with water.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility —**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(e)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Waste shall not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to a person transporting, handling, or disposing of the waste.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility —**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(f)	✓	✓
	Waste shall not be pyrophoric.	Packaging of pyrophoric LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(g)	✓	✓
Labeling of LLW packages	Each package of waste shall be clearly labeled to identify if it is Class A, Class B, or Class C waste, in accordance with 10 *CFR* § 61.55 or Agreement State waste classification requirements.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.57 902 *KAR* 100:021 § 8	✓	✓
Waste treatment and disposal/discharge					
Treatment, storage, transportation, or conveyance of collected RCRA wastewater using a WWTU that receives and treats or stores hazardous waste located on the facility	Any dedicated tank systems, conveyance systems, and ancillary equipment used to treat, store or convey wastewater to an on-site KPDES-permitted wastewater treatment facility subject to regulation under the CWA are exempt from the requirements of RCRA Subtitle C standards. *NOTE:* For purposes of this exclusion, any dedicated tank systems, conveyance systems, and ancillary equipment used to treat, store or convey CERCLA remediation wastewater to a CERCLA on-site wastewater treatment unit that meets all of the identified CWA ARARs for point source discharges from such a facility, are exempt from the requirements of RCRA Subtitle C standards.	On-site wastewater treatment units (as defined in 40 *CFR* § 260.10) subject to regulation under § 402 or § 307(b) of the CWA (i.e., KPDES-permitted) that manages hazardous wastewaters —**applicable**.	40 *CFR* § 264.1(g)(6) 401 *KAR* 34:010 § 1	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Discharge of contaminated groundwater or wastewater	Properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used to achieve compliance with the effluent standards. Proper operation and maintenance also includes adequate laboratory controls and appropriate quality assurance procedures. This provision requires the operation of back-up or auxiliary facilities or similar systems which are installed only when the operation is necessary to achieve compliance with the effluent standards.	Discharge of pollutants to surface waters— **relevant and appropriate**.	401 *KAR* 5:065 Section 2(1) and 40 *CFR* § 122.41(e)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Discharge of contaminated groundwater or wastewater	Surface waters shall not be aesthetically or otherwise degraded by substances that: • Settle to form objectionable deposits; • Float as debris, scum, oil, or other matter to form a nuisance; • Produce objectionable color, odor, taste, or turbidity; • Injure, are chronically or acutely toxic to or produce adverse physiological or behavioral responses in humans, animals, fish, and other aquatic life; • Produce undesirable aquatic life or result in the dominance of nuisance species; 1. Cause fish flesh tainting. 2. The concentration of phenol shall not exceed 300 mg/l as an in stream value.	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 2(1)(a-f)	✓	✓
Kentucky Surface Water Standards	Warm water aquatic habitat. The following parameters and associated criteria shall apply: • Natural alkalinity as CaCO3 shall not be reduced by more than 25 percent; • pH shall not be less than 6.0 nor more than 9.0 and shall not fluctuate more than 1.0 pH units over a period of 24 hours; • Flow shall not be altered to a degree that will adversely affect the aquatic community; • Temperature shall not exceed 31.7°C (89°F); • Dissolved oxygen shall be maintained at a minimum concentration of 5.0 mg/l as a 24 hour average; instantaneous minimum shall not be less than 4.0 mg/l; • Total dissolved solids or specific conductance shall not be changed to the extent that the indigenous aquatic community is adversely affected; • Total suspended solids shall not be changed to the extent that the indigenous aquatic community is adversely affected; • Addition of settleable solids that may alter the stream bottom so as to adversely affect productive aquatic communities shall be prohibited;	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 4(1) excluding § 4(1)(k)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	• Concentration of the un-ionized ammonia shall not be greater than 0.05 mg/l at any time instream after mixing; • Allowable instream concentration of toxic substances, or whole effluents containing toxic substances, which are noncumulative or nonpersistent with a half-life of less than 96 hours, shall not exceed: 1. 0.1 of the 96 hour median LC50 of representative indigenous or indicator aquatic organisms; or 2. A chronic toxicity unit of 1.00 utilizing the 25 percent inhibition concentration, or LC25. • Allowable instream concentration of toxic substances, or whole effluents containing toxic substances, which are bioaccumulative or persistent, including pesticides, if not otherwise regulated, shall not exceed: 1. 0.01 of the 96 hour median LC50 of representative indigenous or indicator aquatic organisms; or 2. A chronic toxicity unit of 1.00 utilizing the LC25. • In the absence of acute criteria for pollutants listed in 401 *KAR* 10:031 Section 6, for other substances known to be toxic but not listed in this administrative regulation, or for whole effluents that are acutely toxic, the allowable instream concentration shall not exceed the LC1 or 1/3 LC50 concentration derived from toxicity tests on representative indigenous or indicator aquatic organisms or exceed 0.3 acute toxicity units. • If specific application factors have been determined for a toxic substance or whole effluent such as an acute to chronic ratio or water effect ratio, they may be used instead of the 0.1 and 0.01 factors; • Allowable instream concentrations for specific pollutants for the protection of warm water aquatic habitat are listed in 401 *KAR* 10:031 Section 6 shall not be exceeded; and Instream concentrations for total residual chlorine shall not exceed an acute criteria value of 19 µg/l or a chronic criteria value of 11 µg/l.				

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Kentucky Surface Water Standards	Provides chemical-specific numeric standards for pollutants discharged or found in surface waters.	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 6(1)	✓	✓
	Monitoring location and frequency will be conducted in accordance with the substantive provisions of the KPDES Permit	Discharge of pollutants to surface waters—**TBC**.	KPDES Permit KY0004049	✓	✓
	Absorbed dose to native animal aquatic organisms must not exceed 1 rad/day	Discharge of radioactive materials in liquid waste to surface water at a DOE facility—**TBC**.	DOE O 5400.5(II)(3)(a)(1)(1)	✓	✓
Discharge of radionuclides into surface water	For liquid wastes containing radionuclides from DOE activities which are discharged to surface water, the best available technology (BAT) is the prescribed level of treatment if the surface waters otherwise would contain, at the point of discharge and prior to dilution, radioactive material at annual average concentrations greater than the DCG values in liquids given in Chapter III of DOE Order 5400.5. The BAT selection process shall be implemented in accordance with II.3a(1)(a) and (b) of the Order 5400.5.	Discharge of radioactive materials in liquid waste to surface water at a DOE facility—**TBC**.	DOE O 5400.5 II 3.a(1)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Selection of the best available technology for a specific application will be made from among candidate alternative treatment technologies which are identified by an evaluation process that includes factors related to technology, economics, and public policy considerations. Factors that are to be considered in selecting BAT, at a minimum, shall include: • the age of equipment and facilities involved; • the process employed; • the engineering aspects of the application of various types of control techniques; • process changes; • the cost of achieving such effluent reduction; • non-water quality environmental impact (including energy requirements); • safety considerations; and public policy considerations.		DOE O 5400.5 II 3.a(1)(a)	✓	✓
	Implementation of the BAT process for liquid radioactive wastes is not required where radionuclides are already at a low level, i.e., the annual average concentration is less than DCG level. Additional treatment will not be required for waste streams that contain radionuclide concentrations of not more than the DCG values in Chapter III of DOE Order 5400.5 at the point of discharge to a surface waterway. However, the ALARA provisions are applicable.		DOE O 5400.5 II 3.a(2)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	To prevent the buildup of radionuclide concentrations in sediments, liquid process waste streams containing radioactive material in the form of settleable solids may be released to natural waterways if the concentration of radioactive material in the solids present in the waste stream does not exceed 5 pCi (O.2 Bq) per gram above background level, of settleable solids for alpha-emitting radionuclides or 50 pCi (2 Bq) per gram above background level, of settleable solids for beta gamma- emitting radionuclides.	Discharge of radioactive concentrations in sediments to surface water from a DOE facility—**TBC**.	DOE O 5400.5 II.3.a(4)	✓	✓
	To protect native animal aquatic organisms, the absorbed dose to these organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways.		DOE O 5400.5 II.3.a(5)	✓	✓
General standards for process vents (including closed vent systems with control devices) used in site remediation treatment units	Select and meet the requirements under one of the options specified below: • Control HAP emissions from the affected process vents according to the applicable standards specified in § 63.7890. • Determine for the remediation material treated or managed by the process vented through the affected process vents that the average total volatile organic hazardous air pollutant (VOHAP) concentration, as defined in § 63.7957, of this material is less than 10 (ppmw). Determination of VOHAP concentration will be made using procedures specified in § 63.7943. • Control process vents subject to another subpart under 40 *CFR* part 61 or 40 *CFR* part 63 in compliance with the standards specified in the applicable subpart.	Process vent stream $\geq$ 0.005 m^3/min at standard conditions or process vent stream flow rate $\geq$ 6.0 m^3/min at standard condition and total HAP $\geq$ than 20 ppmv—**relevant and appropriate**.	40 *CFR* § 63:7885(b) 401 *KAR* 63:002, Sections 1 and 2, except for 40 *CFR* § 63.72 as incorporated in Section 2(3)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Select and meet the requirements under one of the options specified below: • Reduce from all affected process vents the total emissions of the HAP to a level less than 1.4 kilograms per hour (kg/hr) and 2.8 Mg/yr (3.0 pounds per hour (lb/hr) and 3.1 tpy); or • Reduce from all affected process vents the emissions of total organic compounds (TOC) (minus methane and ethane) to a level below 1.4 kg/hr and 2.8 Mg/yr (3.0 lb/hr and 3.1 tpy); or • Reduce from all affected process vents the total emissions of the HAP by 95 percent by weight or more; or • Reduce from all affected process vents the emissions of TOC (minus methane and ethane) by 95 percent by weight or more. For each closed vent system and control device you use to comply with the requirements above, you must meet the operating limit requirements and work practice standards in Sec. 63.7925(c) through (j) that apply to your closed vent system and control device. These emission limits are for the remediation activities conducted at the PGDP by the DOE.		40 *CFR* § 63.7890 401 *KAR* 63:002, Sections 1 and 2, except for 40 *CFR* § 63.72 as incorporated in Section 2(3)	✓	✓
Treatment of LLW	Treatment to provide more stable waste forms and to improve the long-term performance of a LLW disposal facility shall be implemented as necessary to meet the performance objectives of the disposal facility.	Treatment of LLW for disposal at a LLW disposal facility—**TBC**.	DOE M 435.1-1(IV)(O)	✓	✓
Disposal of prohibited RCRA hazardous waste in a land-based unit	May be land disposed if it meets the requirements in the table "Treatment Standards for Hazardous Waste" at 40 *CFR* § 268.40 before land disposal.	Land disposal, as defined in 40 *CFR* § 268.2, of prohibited RCRA waste—**applicable**.	40 *CFR* § 268.40(a) 401 *KAR* 37:040 §2	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	All underlying hazardous constituents [as defined in 40 *CFR* § 268.2(i)] must meet the Universal Treatment Standards, found in 40 *CFR* § 268.48 Table UTS prior to land disposal.	Land disposal of restricted RCRA characteristic wastes (D001-D043) that are not managed in a wastewater treatment system that is regulated under the CWA, that is CWA equivalent, or that is injected into a Class I nonhazardous injection well—**applicable**.	40 *CFR* § 268.40(e) 401 *KAR* 37:040 § 2	✓	✓
	Must be treated according to the alternative treatment standards of 40 *CFR* § 268.49(c) or according to the UTSs specified in 40 *CFR* § 268.48 applicable to the listed and/or characteristic waste contaminating the soil prior to land disposal.	Land disposal, as defined in 40 *CFR* § 268.2, of restricted hazardous soils—**applicable**.	40 *CFR* § 268.49(b) 401 *KAR* 37:040 §10	✓	✓
Disposal of RCRA hazardous debris in a land-based unit	Must be treated prior to land disposal as provided in 40 *CFR* § 268.45(a)(1)-(5) unless EPA determines under 40 *CFR* § 261.3(f)(2) that the debris no longer contaminated with hazardous waste or the debris is treated to the waste-specific treatment standard provided in 40 *CFR* § 268.40 for the waste contaminating the debris.	Land disposal, as defined in 40 *CFR* § 268.2, of RCRA-hazardous debris—**applicable**.	40 *CFR* § 268.45(a) 401 *KAR* 37:040 §7	✓	✓
Disposal of RCRA characteristic wastewaters	Are not prohibited, if the wastes are managed in a treatment system which subsequently discharges to waters of the U.S. pursuant to a permit issued under 402 of the CWA (i.e., NPDES permitted) unless the wastes are subject to a specified method of treatment other than DEACT in 40 *CFR* § 268.40, or are D003 reactive cyanide. NOTE: For purposes of this exclusion, a CERCLA on-site wastewater treatment unit that meets all of the identified CWA ARARs for point source discharges from such a system, is considered a wastewater treatment system that is NPDES permitted.	Land disposal of hazardous wastewaters that are hazardous only because they exhibit a hazardous characteristic and are not otherwise prohibited under 40 *CFR* Part 268—**applicable**.	40 *CFR* § 268.1(c)(4)(i) 401 *KAR* 37:010 §2	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Disposal of bulk PCB remediation waste off-site (self-implementing)	May be sent off-site for decontamination or disposal provided the waste either is dewatered on-site or transported off-site in containers meeting the requirements of DOT HMR at 49 *CFR* parts 171-180.	Generation of bulk PCB remediation waste (as defined in 40 *CFR* § 761.3) for off-site disposal—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)	✓	✓
	Must provide written notice including the quantity to be shipped and highest concentration of PCBs [using extraction EPA Method 3500B/3540C or Method 3500B/3550B followed by chemical analysis using Method 8082 in SW-846 or methods validated under 40 *CFR* § 761.320-26 (Subpart Q)] before the first shipment of waste to each off-site facility where the waste is destined for an area not subject to a TSCA PCB Disposal Approval.	Bulk PCB remediation waste (as defined in 40 *CFR* § 761.3) destined for an off-site facility not subject to a TSCA PCB Disposal Approval—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(iv)*	✓	✓
	Shall be disposed of in accordance with the provisions for cleanup wastes at 40 *CFR* § 761.61(a)(5)(v)(A).	Off-site disposal of dewatered bulk PCB remediation waste with a PCB concentration < 50 ppm—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(ii)*	✓	✓
	Shall be disposed of • in a hazardous waste landfill permitted by EPA under §3004 of RCRA;	Off-site disposal of dewatered bulk PCB remediation waste with a PCB concentration ≥ 50 ppm—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(iii)*	✓	✓
	• in a hazardous waste landfill permitted by a State authorized under §3006 of RCRA; or			✓	✓
	• in a PCB disposal facility approved under 40 *CFR* § 761.60.			✓	✓
Disposal of liquid PCB remediation waste (self-implementing)	Shall either • decontaminate the waste to the levels specified in 40 *CFR* § 761.79(b)(1) or (2); or	Liquid PCB remediation waste (as defined in 40 *CFR* § 761.3)—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(iv) 40 *CFR* § 761.61(a)(5)(iv)(A)	✓	✓
	• dispose of the waste in accordance with the performance-based requirements of 40 *CFR* § 761.61(b) or in accordance with a risk-based approval under 40 *CFR* § 761.61(c).		40 *CFR* § 761.61(a)(5)(iv)(B)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Performance-based disposal of PCB remediation waste	May dispose by one of the following methods • in a high-temperature incinerator under 40 *CFR* § 761.70(b);	Disposal of non-liquid PCB remediation waste (as defined in 40 *CFR* § 761.3)—**applicable**.	40 *CFR* § 761.61(b)(2) 40 *CFR* § 761.61(b)(2)(i)	✓	✓
	• by an alternate disposal method under 40 *CFR* § 761.60(e);			✓	✓
	• in a chemical waste landfill under 40 *CFR* § 761.75;			✓	✓
	• in a facility under 40 *CFR* § 761.77; or			✓	✓
	• through decontamination in accordance with 40 *CFR* § 761.79.		40 *CFR* § 761.61(b)(2)(ii)	✓	✓
	Shall be disposed according to 40 *CFR* § 761.60(a) or (e), or decontaminate in accordance with 40 *CFR* § 761.79.	Disposal of liquid PCB remediation waste—**applicable**.	40 *CFR* § 761.61(b)(1)	✓	✓
Risk-based disposal of PCB remediation waste	May dispose of in a manner other than prescribed in 40 *CFR* § 761.61(a) or (b) if approved in writing from EPA and method will not pose an unreasonable risk of injury to [sic] human health or the environment. *NOTE:* EPA approval of alternative disposal method will be obtained by approval of the FFA CERCLA document.	Disposal of PCB remediation waste—**applicable**.	40 *CFR* § 761.61(c)	✓	✓
Disposal of PCB cleanup wastes (e.g., PPE, rags, non-liquid cleaning materials) (self-implementing option)	Shall be disposed of • in a municipal solid waste facility under 40 *CFR* § 258 or non-municipal, nonhazardous waste subject to 40 *CFR* § 257.5 thru 257.30; or • in a RCRA Subtitle C landfill; or • in a PCB disposal facility; or • through decontamination under 40 *CFR* § 761.79(b) or (c).	Generation of non-liquid PCBs during and from the cleanup of PCB remediation waste—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(v)(A)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Disposal of PCB cleaning solvents, abrasives, and equipment (self-implementing option)	May be reused after decontamination in accordance with 40 *CFR* § 761.79; or For liquids, disposed in accordance with 40 *CFR* § 761.60(a).	Generation of PCB wastes from the cleanup of PCB remediation waste—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(v)(B) 40 *CFR* § 761.60(b)(1)(i)(B)	✓	✓
Disposal of PCB decontamination waste and residues	Shall be disposed of at their existing PCB concentration unless otherwise specified in 40 *CFR* § 761.79(g)(1) through (6).	PCB decontamination waste and residues for disposal—**applicable**.	40 *CFR* § 761.79(g)	✓	✓
Disposal of LLW	LLW shall be certified as meeting waste acceptance requirements before it is transferred to the receiving facility.	Disposal of LLW at a LLW disposal facility—**TBC**.	DOE M 435.1-1(IV)(J)(2)	✓	✓
Waste Treatment & Disposition					
Release of property with residual radioactive material	Property with residual radioactive material will be released from DOE control under survey methods and criteria of DOE Order 5400.5.	Release of soil, equipment and material with residual radioactive material from DOE control — **TBC**.	DOE O 5400.5	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Decontamination/Cleanup					
Decontamination of movable equipment contaminated by PCBs (self-implementing option)	May decontaminate by • swabbing surfaces that have contacted PCBs with a solvent; • a double wash/rinse as defined in 40 *CFR* § 761.360-378; or • another applicable decontamination procedure under 40 *CFR* § 761.79.	Movable equipment contaminated by PCB and tools and sampling equipment—**applicable**.	40 *CFR* § 761.79(c)(2)	✓	✓
Decontamination of PCB containers (self-implementing option)	Must flush the internal surfaces of the container three times with a solvent containing < 50 ppm PCBs. Each rinse shall use a volume of the flushing solvent equal to approximately 10% of the PCB container capacity.	PCB Container as defined in 40 *CFR* § 761.3—**applicable**.	40 *CFR* § 761.79(c)(1)	✓	✓
Decontamination of PCB contaminated water	For discharge to a treatment works as defined in 40 *CFR* § 503.9 (aa), or discharge to navigable waters, meet standard of < 3 ppb PCBs; or	Water containing PCBs regulated for disposal—**applicable**.	40 *CFR* § 761.79(b)(1)(ii)	✓	✓
	The decontamination standard for water containing PCBs is less than or equal to 0.5 µg/L (i.e., approximately ≤0.5 ppb PCBs) for unrestricted use.		40 *CFR* § 761.79(b)(1)(iii)	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Unit Closure					
Waste transportation					
Transportation of RCRA hazardous waste on-site	The generator manifesting requirements of 40 *CFR* §§ 262.20–262.32(b) do not apply. Generator or transporter must comply with the requirements set forth in 40 *CFR* § 263.30 and 263.31 in the event of a discharge of hazardous waste on a private or public right-of-way.	Transportation of hazardous wastes on a public or private right-of-way within or along the border of contiguous property under the control of the same person, even if such contiguous property is divided by a public or private right-of-way—**applicable**.	40 *CFR* § 262.20(f) 401 *KAR* 32:020 § 1	✓	✓
Transportation of RCRA hazardous waste off-site	Must comply with the generator requirements of 40 *CFR* § 262.20–23 for manifesting, § 262.30 for packaging, § 262.31 for labeling, § 262.32 for marking, § 262.33 for placarding, § 262.40, 262.41(a) for record keeping requirements, and § 262.12 to obtain EPA ID number.	Preparation and initiation of shipment of hazardous waste off-site—**applicable**.	40 *CFR* § 262.10(h) 401 *KAR* 32:010 § 1	✓	✓
Transportation of PCB wastes off-site	Must comply with the manifesting provisions at 40 *CFR* § 761.207 through 218.	Relinquishment of control over PCB wastes by transporting, or offering for transport—**applicable**.	40 *CFR* § 761.207(a)	✓	✓
Determination of radionuclide concentration	The concentration of a radionuclide may be determined by an indirect method, such as use of a scaling factor which relates the inferred concentration of one (1) radionuclide to another that is measured or radionuclide material accountability if there is reasonable assurance that an indirect method may be correlated with an actual measurement. The concentration of a radionuclide may be averaged over the volume or weight of the waste if the units are expressed as nanocuries per gram.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.55 (a)(8) 902 *KAR* 100:021 § 6(8)(a) and (b)	✓	✓
Labeling of LLW packages	Each package of waste shall be clearly labeled to identify if it is Class A, Class B, or Class C waste, in accordance with 10 *CFR* § 61.55 or Agreement State waste classification requirements.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.57 902 *KAR* 100:021 § 8	✓	✓

Table 4.2. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 4 (SVE Source Treatment and Containment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Transportation of radioactive waste	Shall be packaged and transported in accordance with DOE Order 460.1B and DOE Order 460.2.	Preparation of shipments of radioactive waste—**TBC**.	DOE M 435.1-(I)(1)(E)(11)	✓	✓
Transportation of LLW	To the extent practicable, the volume of the waste and the number of the shipments shall be minimized.	Preparation of shipments of LLW—**TBC**.	DOE M 435.1-1(IV)(L)(2)	✓	✓
Transportation of hazardous materials	Shall be subject to and must comply with all applicable provisions of the HMR at 49 *CFR* §§ 171–180 related to marking, labeling, placarding, packaging, emergency response, etc.	Any person who, under contract with a department or agency of the federal government, transports "in commerce," or causes to be transported or shipped, a hazardous material—**applicable**.	49 *CFR* § 171.1(c)	✓	✓
Transportation of hazardous materials on-site	Shall comply with 49 *CFR* Parts 171-174, 177, and 178 or the site- or facility-specific Operations of Field Office approved Transportation Safety Document that describes the methodology and compliance process to meet equivalent safety for any deviation from the Hazardous material Regulations [i.e., *Transportation Safety Document for On-Site Transport within the Paducah Gaseous Diffusion Plant*, PRS-WSD-0661, (PRS 2007)].	Any person who, under contract with the DOE, transports a hazardous material on the DOE facility—**TBC**.	DOE O 460.1B(4)(b)	✓	✓
Transportation of hazardous materials off-site	Off-site hazardous materials packaging and transfers shall comply with 49 *CFR* Parts 171-174, 177, and 178 and applicable tribal, State, and local regulations not otherwise preempted by DOT and special requirements for Radioactive Material Packaging.	Preparation of off-site transfers of LLW—**TBC**.	DOE O 460.1B(4)(a)	✓	✓

ARAR = as low as reasonably achievable; AOC = area of contamination; *CFR* = *Code of Federal Regulations*; CWA = Clean Water Act; DOE = U.S. Department of Energy; EDE = effective dose equivalent; EPA = U.S. Environmental Protection Agency; HMR = hazardous material regulations; *KAR* = *Kentucky Administrative Rules*; LDR = land disposal restriction; LLW = low-level waste; NRC = Nuclear Regulatory Commission; NWP = Nationwide Permit; PCB = polychlorinated biphenyl; PPE = personal protective equipment; RAWP = Remedial Action Work Plan; RCRA = Resource Conservation and Recovery Act; ROD = Record of Decision; TBC = to be considered; T&E = threatened and endangered; *USC* = *United States Code*; UTS = Universal Treatment Standards; WAC = waste acceptance criteria

4.3.2.3 Long-term effectiveness and permanence

The long-term effectiveness and permanence of Alternative 4 is moderate, because most of the VOCs in the UCRS at the Oil Landfarm source area and the C-720 Northeast and Southeast Sites would be removed by SVE and destroyed through catalytic oxidation. Overall removal efficiency is estimated at up to 90% over approximately two to five years, based on reports for previous applications (FRTR 2008; Hightower *et al.* 2001). It is expected that after active treatment, the average residual TCE concentration in the upper 10 ft of the SWMU 1 source area will range from 0.15–0.76 mg/kg and will be approximately 2.96 mg/kg at C-720, depending on the alternative selected. These values are similar to or below the TCE soil action levels for direct contact contained in the PGDP Risk Methods Document (DOE 2009).

The E/PP program, five-year reviews, non-CERCLA DOE plant controls, cover maintenance, and monitoring would be required as long as soil contaminant concentrations remained above RGs. The time required to reach the groundwater protection RGs at the Oil Landfarm and the C-720 sites was estimated at 77 years and 73 years, respectively, assuming a 50 year half-life for TCE, as reported in Appendix C. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access. Non-VOC concentrations would not be reduced; however, the E/PP program will limit exposures pending remedy selection as part of the Soils OU.

4.3.2.4 Reduction of toxicity, mobility, or volume through treatment

This alternative would oxidize most of the VOCs to innocuous byproducts. Overall removal efficiency is estimated at up to 90% over approximately two to five years, based on reports for previous applications (FRTR 2008; Hightower *et al.* 2001). PCBs and other SVOCs, metals and radionuclides potentially present at the Oil Landfarm would be expected to remain in the soils and would not be removed in the off-gas. Secondary wastes would include co-produced groundwater, drill cuttings produced during dual-phase well installation, PPE, and decontamination fluids. For cost-estimating purposes, drill cuttings, PPE, and decontamination fluids were assumed to require containerization, dewatering, and testing prior to off-site disposal. Actual dispositioning requirements would be determined during remedial design and by sampling of containerized soils. Coproduced groundwater was assumed to require on-site treatment prior to disposal. Actual treatment requirements would be determined during remedial design and by sampling and analyzing coproduced groundwater.

4.3.2.5 Short-term effectiveness

Short-term effectiveness of Alternative 4 is relatively moderate. Surface cover construction would not result in significant worker risks, because contaminated soils would not be disturbed. Installation of dual-phase wells and groundwater monitoring wells, subsurface piping at C-720 Northeast and Southeast Sites, piezometers and neutron probe access tubes would encounter contaminated soils. Direct-push equipment would be used to the extent feasible to minimize returns of contaminated soils to the surface and thereby minimize risks to workers. Soil returns produced during installation of dual-phase SVE wells would be managed in accordance with the health and safety plans (HASPs), waste characterization plan (WCP), and waste management plan (WMP) prepared during the RD/RAWP. Work would be conducted by trained personnel in accordance with standard radiological engineering operational procedures including as low as reasonably achievable (ALARA) review, HASP, and safe work practices to minimize injury or exposure risks. The E/PP program will protect workers pending remedy selection as part of the Soils OU. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

Implementation of site preparation, recharge controls, surface covers and SVE wells, and operation of the SVE system until off-gas concentrations remained asymptotic during pulsed operation was estimated to require two to five years. Five-year reviews, maintenance of the asphalt soil covers, and groundwater monitoring would be required as long as concentrations of contaminants in soil remained above RGs. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access. The time required to reach TCE soil RGs at the Oil Landfarm and the C-720 sites was estimated at 77 years and 73 years, respectively, assuming a 50 year half-life for TCE, as reported in Appendix C. The E/PP program will limit non-VOC exposures, pending remedy selection as part of the Soils OU.

Monitoring, the E/PP program, and SVE process controls will be protective of the public throughout construction and implementation of the remedy. Existing DOE plant controls, which are administered outside of CERCLA, provide additional protection of human health by restricting access to areas. The Southwest Plume sites are located more than one mile from any residential population, and effects on outlying communities would be negligible because of the continued access restrictions and groundwater use restrictions in the area from the PGDP Water Policy would eliminate the exposure risks.

No ecological impacts are anticipated under this alternative. The Southwest Plume sites are located at an active operational facility already disturbed by construction and operational activities and do not support any unique or significant ecological resources. No archaeological or historical sites or critical habitat exist at the Southwest Plume sites. A wetlands assessment would be performed prior to remedy implementation at the Oil Landfarm and, if present, the effects of remediation would be assessed and mitigated as required by ARARs.

4.3.2.6 Implementability

Overall implementability of Alternative 4 is relatively moderate; however, ongoing operations and subsurface infrastructure at the C-720 Building would constrain implementation at the C-720 Northeast and Southeast Sites. Removal of the concrete surfaces and cover construction would impede access and remove the Southeast loading dock from service for the duration of construction. Lining, repair, or replacement of water lines and installation of water meters would remove the lines from service for the duration of construction. Installation of dual-phase wells and soil moisture monitoring equipment would require utility location and clearance.

The surface covers would require relatively minimal maintenance and repairs. Fog sealing of the asphalt covers with an asphalt emulsion would likely be required annually to maintain the low-permeability function. Inspection of the drainage ditch liners and repair would be required at least annually. Water meters would be checked periodically and a water balance determined to locate leaking lines.

Dual-phase extraction wells and groundwater monitoring wells would require periodic submersible pump replacement and potentially redevelopment if the well filter packs became plugged with fines or if screens became iron fouled. The off-gas treatment system would require maintenance depending on the specific unit selected, including replacement of the catalytic bed, heat exchanger, and other components. Electricity and natural gas would be ongoing utility requirements for the duration of operation.

Equipment, personnel, and services required to implement this alternative are readily commercially available. No additional development of these technologies, beyond initial air permeability testing, would be required. In general, standard construction practices would be used to implement this alternative, and a sufficient number of contractors possessing the required skills and experience are available.

Administrative feasibility for Alternative 4 is relatively high. Surface barriers and recharge controls do not represent any unique or unusual requirements for regulatory approval, concurrence, or variance actions. Dual-phase wells, groundwater monitoring wells, soil gas drive points, piezometers, and neutron probe access tubes would be constructed according to Commonwealth of Kentucky rules and abandoned after completion of the project.

4.3.2.7 Cost

Estimated capital and operation, maintenance, and monitoring (O&M&M) costs for Alternative 4 are summarized in Table 4.3.

Table 4.3. Summary of Estimated Costs for Alternative 4

Cost element[1]	Oil Landfarm	C-720 NE Site	C-720 SE Site	Total
Unescalated cost				
Capital cost	$4.7M	$1.0M	$2.7M	$8.4M
O&M&M	$6.0M	$1.3M	$3.5M	$10.8M
Subtotal	**$10.7M**	**$2.4M**	**$6.1M**	**$19.2M**
Escalated cost				
Capital cost	$5.2M	$1.2M	$3.0M	$9.4M
O&M&M	$8.4M	$1.9M	$4.8M	$15.1M
Subtotal	**$13.6M**	**$3.0M**	**$7.8M**	**$24.5M**
Present Worth[2]				
Capital cost	$4.7M	$1.0M	$2.7M	$8.4M
O&M&M	$5.1M	$1.1M	$3.0M	$9.2M
Subtotal	**$9.8M**	**$2.2M**	**$5.6M**	**$17.6M**

[1]Includes general and administrative fee and contingency
[2]Present worth costs are based on an assumption that outyear costs will be financed by investments made in year 0 and are provided for purposes of comparison only. Escalated costs are used by DOE for planning and budgeting.

4.3.3 Alternative 5—*In Situ* Thermal Source Treatment

4.3.3.1 Overall protection of human health and the environment

Alternative 5 would meet this threshold criterion. Monitoring, the E/PP program, and ERH process controls during implementation would assure that risks to workers, off-site residents, and the environment were reduced to allowable levels. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

RAO #1 would be met by removal of PTW as vapor and destroying it *ex situ*. RAO #2a would be met by removing VOCs to levels within EPA's generally acceptable risk range for site-related exposures of 1E-04 to 1E-06. RAO #2b would be met by the E/PP program until final disposition through the Soils OU. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

RAO #3 would be met by reducing VOC soil concentrations to groundwater protection RGs through a combination of active remediation and advective attenuation. Modeling results presented in Appendix C show that after approximately one year of active treatment, residual VOC mass will leach to groundwater in the RGA and attain sub-MCL levels within 29 years at the C-720 Northeast and Southeast Sites and

within 52 years at the Oil Landfarm. Key assumptions that contribute to the remedy time frame assessment for attainment of RAO #3 include 98% removal efficiency of TCE from UCRS subsurface soil resulting from active treatment as demonstrated in the C-400 Treatability Study and a conservative TCE half-life in the UCRS of 50 years.

4.3.3.2 Compliance with ARARs

Alternative 5 would meet this threshold criterion. Table 4.4 summarizes compliance with ARARs for Alternative 5.

4.3.3.3 Long-term effectiveness and permanence

The long-term effectiveness and permanence of Alternative 5 is high, because nearly all of the VOCs in the UCRS at the Oil Landfarm source area and the C-720 Northeast and Southeast Sites would be removed by ERH and destroyed off-site. Overall removal efficiency is estimated at up to 98% over approximately six months, based on results of the C-400 ERH Treatability Study. It is expected that after active treatment, the average residual TCE concentration in the upper 10 ft of the SWMU 1 source area will range from 0.15–0.76 mg/kg and will be approximately 2.96 mg/kg at C-720, depending on the alternative selected. These values are similar to or below the TCE soil action levels for direct contact contained in the PGDP Risk Methods Document (DOE 2009).

Five-year reviews and monitoring would be required as long as VOC soil concentrations remained above groundwater protection RGs, estimated at 52 years for the Oil Landfarm and 29 years for the C-720 Northeast and Southeast sites, based on a conservative assumption of a TCE half-life in the UCRS of 50 years.

Non-VOC concentrations would not be reduced, however the E/PP program and non-CERCLA DOE plant controls would limit exposures pending remedy selection as part of the Soils OU.

4.3.3.4 Reduction of toxicity, mobility, or volume through treatment

This alternative would remove and oxidize most of the VOCs to innocuous byproducts. Overall removal efficiency is estimated at up to 98% over approximately six months, based on results for the C-400 ERH Treatability Study. The ERH system design would include measures to reduce the potential for mobilization of DNAPL TCE during treatment. PCBs and other SVOCs, metals, and radionuclides potentially present at the Oil Landfarm would be expected to remain in the soils and would not be removed in ERH off-gas. Secondary wastes would include approximately 8,165 kg (18,000 pounds) of GAC, drill cuttings produced during electrode/vapor recovery well installation, PPE, and decontamination fluids. For cost-estimating purposes, drill cuttings, PPE, and decontamination fluids were assumed to require containerization, dewatering, and testing prior to off-site disposal as mixed waste. Actual dispositioning requirements would be determined during remedial design and by sampling of containerized soils. Spent GAC would be shipped off-site for regeneration. Condensate would be treated to meet ARARs prior to discharge.

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5
(*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS

Location-specific ARARs					
Location	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Cultural resources					
Presence of wetlands as defined in 10 *CFR* § 1022.4	Avoid, to the extent possible, the long- and short-term adverse effects associated with destruction, occupancy, and modification of wetlands.	DOE actions that involve potential impacts to, or take place within, wetlands—**applicable**.	10 *CFR* § 1022.3(a)	✓	✓
	Take action, to extent practicable, to minimize destruction, loss, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands.		10 *CFR* § 1022.3(a)(7) and (8)	✓	✓
	Undertake a careful evaluation of the potential effects of any new construction in wetlands. Identify, evaluate, and, as appropriate, implement alternative actions that may avoid or mitigate adverse impacts on wetlands.		10 *CFR* § 1022.3(b) and (d)	✓	✓
	Measures that mitigate the adverse effects of actions in a wetland including, but not limited to, minimum grading requirements, runoff controls, design and construction constraints, and protection of ecologically-sensitive areas.		10 *CFR* § 1022.13(a)(3)	✓	✓
	If no practicable alternative to locating or conducting the action in the wetland is available, then before taking action design or modify the action in order to minimize potential harm to or within the wetland, consistent with the policies set forth in E.O. 11990.		10 *CFR* § 1022.14(a)	✓	✓
Location encompassing aquatic ecosystem as defined in 40 *CFR* § 230.3(c)	Except as provided under section 404(b)(2), no discharge of dredged or fill material is permitted if there is a practicable alternative that would have less adverse impact on the aquatic ecosystem or if it will cause or contribute to significant degradation of the waters of the United States.	Action that involves the discharge of dredged or fill material into waters of the United States, including jurisdictional wetlands—**relevant and appropriate**.	40 *CFR* § 230.10(a) and (c)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Except as provided under section 404(b)(2), no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken that will minimize potential adverse impacts of the discharge on the aquatic ecosystem. 40 *CFR* § 230.70 *et seq*. identifies such possible steps.		40 *CFR* § 230.10(d)	✓	✓
Nationwide Permit Program	Must comply with the substantive requirements of the NWP 38, General Conditions, as appropriate.	Discharge of dredged or fill material into waters of the United States, including jurisdictional wetlands—**relevant and appropriate**.	Nation Wide Permit (38) Cleanup of Hazardous and Toxic Waste 33 *CFR* § 323.3(b)	✓	✓
Site preparation, construction, and excavation activities					
Activities causing fugitive dust emissions	No person shall cause, suffer, or allow any material to be handled, processed, transported, or stored, a building or its appurtenances to be constructed, altered, repaired, or demolished, or a road to be used without taking reasonable precaution to prevent particulate matter from becoming airborne. Such reasonable precautions shall include, when applicable, but not be limited to, the following: • Use, where possible, of water or chemicals for control of dust in the demolition of existing buildings or structures, construction operations, the grading of roads or the clearing of land; • Application and maintenance of asphalt, oil, water, or suitable chemicals on roads, materials stockpiles, and other surfaces which can create airborne dusts; • Covering, at all times when in motion, open bodied trucks transporting materials likely to become airborne; • The maintenance of paved roadways in a clean condition; and The prompt removal of earth or other material from a paved street which earth or other material has been transported thereto by trucking or earth moving equipment or erosion by water.	Fugitive emissions from land-disturbing activities (e.g., handling, processing, transporting or storing of any material, demolition of structures, construction operations, grading of roads, or the clearing of land, etc.)—**applicable**.	401 *KAR* 63:010 § 3(1) and (1)(a), (b), (d), (e) and (f)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	No person shall cause or permit the discharge of visible fugitive dust emissions beyond the lot line of the property on which the emissions originate.		401 *KAR* 63:010 § 3(2)	✓	✓
Activities causing radionuclide emissions	Emissions of radionuclides to the ambient air from DOE facilities shall not exceed those amounts that would cause any member of the public to receive in any year an EDE of 10 mrem/yr.	Radionuclide emissions from point sources at a DOE facility—**applicable**.	40 *CFR* § 61.92 401 *KAR* 57:002	✓	✓
Activities causing toxic substances or potentially hazardous matter emissions	Persons responsible for a source from which hazardous matter or toxic substances may be emitted shall provide the utmost care and consideration in the handling of these materials to the potentially harmful effects of the emissions resulting from such activities. No owner or operator shall allow any affected facility to emit potentially hazardous matter or toxic substances in such quantities or duration as to be harmful to the health and welfare of humans, animals and plants.	Emissions of potentially hazardous matter or toxic substances as defined in 401 *KAR* 63:020 § 2 (2) —**applicable**.	401 *KAR* 63:020 § 3	✓	✓
Radiation dose limits for individual members of the public	Exposure to individual members of the public from radiation shall not exceed a total EDE of 0.1 rem/year (100 mrem/year), exclusive of the dose contributions from background radiation, any medical administration the individual has received, or voluntary participation in medical/research programs.	Dose received from operations —**relevant and appropriate**.	10 *CFR* § 20.1301(a)(1) 902 *KAR* 100:019 § 10 (1)	✓	✓
	Shall use, to the extent practicable, procedures and engineering controls based on sound radiation protection principles to achieve doses to members of the public that are ALARA.		10 *CFR* § 20.1101(b) 902 *KAR* 100:019 § 2(2)	✓	✓
Radiation protection of the public and the environment	Except as provided in 5400.1(II)(1)(a)(4), the exposure of members of the public to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an EDE greater than 100 mrem per year. The ALARA process shall be implemented for all DOE activities and facilities that cause public doses.	Dose received from all exposure modes from all DOE activities (including remedial actions) at a DOE facility—**TBC**.	DOE O 5400.5(II)(1)(a) and (2)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Activities causing storm water runoff (e.g., clearing, grading, excavation)	Implement good construction techniques to control pollutants in storm water discharges during and after construction in accordance with substantive requirements provided by permits issued pursuant to 40 *CFR* § 122.26(c).	Storm water discharges associated with small construction activities as defined in 40 *CFR* § 122.26(b)(15) and 401 *KAR* 5:002 § 1 (157)**—applicable**.	40 *CFR* § 122.26(c)(1)(ii) (C) and (D) 401 *KAR* 5:060 § 8	✓	✓
	Storm water runoff associated with construction activities taking place at a facility with an existing Best Management Practices (BMP) Plan shall be addressed under the facility BMP and not under a storm water general permit.	Storm water discharges associated with small construction activities as defined in 40 *CFR* § 122.26(b)(15) and 401 *KAR* 5:002 § 1 (157)**—TBC**.	Fact Sheet for the KPDES General Permit For Storm water Discharges Associated with Construction Activities, June 2009	✓	✓
	Best management storm water controls will be implemented and may include, as appropriate, erosion and sedimentation control measures, structural practices (e.g., silt fences, straw bale barriers) and vegetative practices (e.g., seeding); storm water management (e.g., diversion); and maintenance of control measures in order to ensure compliance with the standards in Section C.5. Storm Water Discharge Quality.	Storm water runoff associated with construction activities taking place at a facility [PGDP] with an existing BMP Plan**—TBC**.	Appendix C of the PGDP Best Management Practices Plan (2007) — Examples of Storm water Controls	✓	✓
Monitoring, Extraction, and Injection Well Installation and Abandonment					
Monitoring well installation	Permanent monitoring wells shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §1(2)	✓	✓
	All permanent (including boreholes) shall be constructed to comply with the substantive requirements provided in the following Sections of 401 *KAR* 6:350: • Section 2. Design Factors; • Section 3. Monitoring Well Construction; • Section 7. Materials for Monitoring Wells; and • Section 8. Surface Completion.		401 *KAR* 6:350 § 2, 3, 7, and 8	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	If conditions exist or are believed to exist that preclude compliance with the requirements of 401 *KAR* 6:350, may request a variance prior to well construction or well abandonment. *NOTE: Variance shall be made as part of the FFA CERCLA document review and approval process and shall include:* • A justification for the variance; and • Proposed construction, modification, or abandonment procedures to be used in lieu of compliance with 401 *KAR* 6:350 and an explanation as to how the alternate well construction procedures ensure the protection of the quality of the groundwater and the protection of public health and safety.		401 *KAR* 6:350 § 6 (a)(6) and (7)	✓	✓
Development of monitoring well	Newly installed wells shall be developed until the column of water in the well is free of visible sediment. This well-development protocol shall not be used as a method for purging prior to water quality sampling.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §9	✓	✓
Direct Push monitoring well installation	Wells installed using direct push technology shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of direct push monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §5 (1)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Shall also comply with the following additional standards: (a) The outside diameter of the borehole shall be a minimum of 1 inch greater than the outside diameter of the well casing; (b) Premixed bentonite slurry or bentonite chips with a minimum of one-eighth (1/8) diameter shall be used in the sealed interval below the static water level; an (c) 1. Direct push wells shall not be constructed through more than one water-bearing formation unless the upper water bearing zone is isolated by temporary or permanent casing. 2. The direct push tool string may serve as the temporary casing.		401 *KAR* 6:350 §5 (3)	✓	✓
Monitoring well abandonment	A monitoring well that has been damaged or is otherwise unsuitable for use as a monitoring well, shall be abandoned within 30 days from the last sampling date or 30 days from the date it is determined that the well is no longer suitable for its intended use.	Construction of monitoring well as defined in 401 *KAR* 6:001 §1(18) for remedial action—**applicable**.	401 *KAR* 6:350 §11 (1)	✓	✓
	Wells shall be abandoned in such a manner as to prevent the migration of surface water or contaminants to the subsurface and to prevent migration of contaminants among water bearing zones.		401 *KAR* 6:350 §11 (1)(a)	✓	✓
	Abandonment methods and sealing materials for all types of monitoring wells provided in subparagraphs (a) -(b) and (d)-(e) shall be followed.		401 *KAR* 6:350 §11 (2)	✓	✓
Extraction well installation	Wells shall be constructed, modified, and abandoned in such a manner as to prevent the introduction or migration of contamination to a water-bearing zone or aquifer through the casing, drill hole, or annular materials.	Construction of monitoring well for remedial action—**relevant and appropriate**.	401 *KAR* 6:350 §1 (2)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Reinjection of treated contaminated groundwater	No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 *CFR* Part 142 or may otherwise adversely affect the health of persons.	Underground injection into an underground source of drinking water—**relevant and appropriate**.	40 *CFR* § 144.12(a)		✓
	Wells are not prohibited if injection is approved by EPA or a State pursuant to provisions for cleanup of releases under CERCLA or RCRA *as provided in the FFA CERCLA document*.	Class IV wells [as defined in 40 *CFR* § 144.6(d)] used to reinject treated contaminated groundwater into the same formation from which it was drawn—**relevant and appropriate**.	40 *CFR* § 144.13(c) RCRA § 3020(b)		✓
	Prior to abandonment any Class IV well, the owner or operator shall plug or otherwise close the well in a manner *as provided in the FFA CERCLA document*.	Class IV wells [as defined in 40 *CFR* § 144.6(d)] used to reinject of treated contaminated groundwater into the same formation from which it was drawn—**relevant and appropriate**.	40 *CFR* § 144.23(b)(1)		✓
Plugging and abandonment of Class IV injection wells	Prior to abandoning the well, the owner or operator shall close the well in accordance with 40 *CFR* § 144.23(b).	Operation of a Class IV injection well [as defined in 40 *CFR* § 144.6(d)] —**relevant and appropriate**.	40 *CFR* § 146.10(b)		✓
General Waste Management					
Management of PCB waste	Any person storing or disposing of PCB waste must do so in accordance with 40 *CFR* § 761, Subpart D.	Storage or disposal of waste containing PCBs at concentrations ≥ 50 ppm—**applicable**.	40 *CFR* § 761.50(a)	✓	✓
	Any person cleaning up and disposing of PCBs shall do so based on the concentration at which the PCBs are found.	Cleanup and disposal of PCB remediation waste as defined in 40 *CFR* § 761.3—**applicable**.	40 *CFR* § 761.61	✓	✓
Management of PCB/Radioactive waste	Any person storing such waste ≥ 50 ppm PCBs must do so taking into account both its PCB concentration and radioactive properties, except as provided in 40 *CFR* § 761.65(a)(1), (b)(1)(ii) and (c)(6)(i).	Storage of PCB/Radioactive waste for a disposal—**applicable**.	40 *CFR* § 761.50(b)(7)(i)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Any person disposing of such waste must do so taking into account both its PCB concentration and its radioactive properties. If, taking into account only the properties of the PCBs in the waste, the waste meets the requirements for disposal in a nonhazardous waste landfill, then the PCB/radioactive waste may be disposed without regard to the PCB component of the waste.		40 *CFR* § 761.50(b)(7)(ii)	✓	✓
Waste Characterization					
Characterization of solid waste	Must determine if solid waste is excluded from regulation under 40 *CFR* § 261.4.	Generation of solid waste as defined in 40 *CFR* § 261.2—**applicable**.	40 *CFR* § 262.11(a) 401 *KAR* 32:010 §2	✓	✓
	Must determine if waste is listed as a hazardous waste in subpart D of 40 *CFR* Part 261.	Generation of solid waste which is not excluded under 40 *CFR* § 261.4—**applicable**.	40 *CFR* § 262.11(b) 401 *KAR* 32:010 §2	✓	✓
	Must determine whether the waste is characteristic waste (identified in subpart C of 40 *CFR* Part 261) by using prescribed testing methods or applying generator knowledge based on information regarding material or processes used.	Generation of solid waste that is not listed in subpart D of 40 *CFR* Part 261 and not excluded under 40 *CFR* § 261.4—**applicable**.	40 *CFR* § 262.11(c) 401 *KAR* 32:010 §2	✓	✓
	Must refer to Parts 261, 262, 264, 265, 266, 268, and 273 of Chapter 40 for possible exclusions or restrictions pertaining to management of the specific waste.	Generation of solid waste which is determined to be hazardous waste—**applicable**.	40 *CFR* § 262.11(d) 401 *KAR* 32:010 §2	✓	✓
Characterization of hazardous waste	Must obtain a detailed chemical and physical analysis on a representative sample of the waste(s), which at a minimum contains all the information that must be known to treat, store, or dispose of the waste in accordance with pertinent sections of 40 *CFR* §§ 264 and 268.	Generation of RCRA-hazardous waste for storage, treatment or disposal—**applicable**.	40 *CFR* § 264.13(a)(1) 401 *KAR* 34:020 § 4	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Characterization of industrial wastewater	Industrial wastewater discharges that are point source discharges subject to regulation under section 402 of the Clean Water Act, as amended, are not solid wastes for the purpose of hazardous waste management. [Comment: This exclusion applies only to the actual point source discharge. It does not exclude industrial wastewaters while they are being collected, stored or treated before discharge, nor does it exclude sludges that are generated by industrial wastewater treatment.] NOTE: For purpose of this exclusion, the CERCLA on-site treatment system for extracted VOCs and groundwater will be considered equivalent to a wastewater treatment unit and the point source discharges subject to regulation under CWA Section 402, provided the effluent meets all identified CWA ARARs.	Generation of industrial wastewater for treatment and discharge into surface water—**applicable**.	40 *CFR* § 261.4(a)(2) 401 *KAR* 31:010 § 4	✓	✓
Determinations for management of hazardous waste	Must determine each EPA Hazardous Waste Number (Waste Code) to determine the applicable treatment standards under 40 *CFR* § 268.40 *et. seq*. *Note:* This determination may be made concurrently with the hazardous waste determination required in 40 *CFR* § 262.11.	Generation of hazardous waste—**applicable**.	40 *CFR* § 268.9(a) 401 *KAR* 37:010 §8	✓	✓
	Must determine the underlying hazardous constituents [as defined in 40 *CFR* § 268.2(i)] in the characteristic waste.	Generation of RCRA characteristic hazardous waste (and is not D001 non-wastewaters treated by CMBST, RORGS, or POLYM of Section 268.42 Table 1) for storage, treatment or disposal—**applicable**.	40 *CFR* § 268.9(a) 401 *KAR* 37:010 §8	✓	✓
	Must determine if the hazardous waste meets the treatment standards in 40 *CFR* §§ 268.40, 268.45, or 268.49 by testing in accordance with prescribed methods or use of generator knowledge of waste. *Note:* This determination can be made concurrently with the hazardous waste determination required in 40 *CFR* § 262.11.	Generation of hazardous waste—**applicable**.	40 *CFR* § 268.7(a) 401 *KAR* 37:010 §7	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Characterization of LLW	Shall be characterized using direct or indirect methods and the characterization documented in sufficient detail to ensure safe management and compliance with the WAC of the receiving facility.	Generation of LLW for storage and disposal at a DOE facility—**TBC**.	DOE M 435.1-1(IV)(I)	✓	✓
	Characterization data shall, at a minimum, include the following information relevant to the management of the waste:		DOE M 435.1-1(IV)(I)(2)	✓	✓
	• physical and chemical characteristics;		DOE M 435.1-1(IV)(I)(2)(a)	✓	✓
	• volume, including the waste and any stabilization or absorbent media;		DOE M 435.1-1(IV)(I)(2)(b)	✓	✓
	• weight of the container and contents;		DOE M 435.1-1(IV)(I)(2)(c)	✓	✓
	• identities, activities, and concentration of major radionuclides;		DOE M 435.1-1(IV)(I)(2)(d)	✓	✓
	• characterization date;		DOE M 435.1-1(IV)(I)(2)(e)	✓	✓
	• generating source; and		DOE M 435.1-1(IV)(I)(2)(f)	✓	✓
	• any other information that may be needed to prepare and maintain the disposal facility performance assessment, or demonstrate compliance with performance objectives.		DOE M 435.1-1(IV)(I)(2)(g)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Waste Accumulation, Storage and Staging					
Temporary on-site storage of hazardous waste in containers	A generator may accumulate hazardous waste at the facility provided that	Accumulation of RCRA hazardous waste on-site as defined in 40 *CFR* § 260.10—**applicable**.	40 *CFR* § 262.34(a) 401 *KAR* 32:030 §5	✓	✓
	• waste is placed in containers that comply with 40 *CFR* § 265.171-173;		40 *CFR* § 262.34(a)(1)(i) 401 *KAR* 32:030 §5	✓	✓
	• the date upon which accumulation begins is clearly marked and visible for inspection on each container;		40 *CFR* § 262.34(a)(2) 401 *KAR* 32:030 §5	✓	✓
	• container is marked with the words "hazardous waste."		40 *CFR* § 262.34(a)(3) 401 *KAR* 32:030 § 5	✓	✓
	Container may be marked with other words that identify the contents.	Accumulation of 55 gal or less of RCRA hazardous waste or one quart of acutely hazardous waste listed in 261.33(e) at or near any point of generation—**applicable**.	40 *CFR* § 262.34(c)(1) 401 *KAR* 32:030 §5	✓	✓
Use and management of containers holding hazardous waste	If container is not in good condition or if it begins to leak, must transfer waste into container in good condition.	Storage of RCRA hazardous waste in containers—**applicable**.	40 *CFR* § 265.171 401 *KAR* 35:180 §2	✓	✓
	Use container made or lined with materials compatible with waste to be stored so that the ability of the container is not impaired.		40 *CFR* § 265.172 401 *KAR* 35:180 §3	✓	✓
	Keep containers closed during storage, except to add/remove waste.		40 *CFR* § 265.173(a) 401 *KAR* 35:180 §4	✓	✓
	Open, handle and store containers in a manner that will not cause containers to rupture or leak.		40 *CFR* § 265.173(b) 401 *KAR* 35:180 §4	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Must not pile remediation waste on same base where incompatible wastes or materials were previously piled unless you have sufficiently decontaminated the base to comply with 40 *CFR* § 264.17(b).		40 *CFR* § 264.554(f)(3)	✓	✓
Storage of hazardous waste in container area	Area must have a containment system designed and operated in accordance with 40 *CFR* § 264.175(b).	Storage of RCRA hazardous waste in containers with free liquids—**applicable**.	40 *CFR* § 264.175(a)	✓	✓
	Area must be sloped or otherwise designed and operated to drain liquid from precipitation, or containers must be elevated or otherwise protected from contact with accumulated liquid.	Storage of RCRA-hazardous waste in containers that do not contain free liquids (other than F020, F021, F022, F023,F026 and F027)—**applicable**.	40 *CFR* § 264.175(c)	✓	✓
Storage of PCB waste and/or PCB/radioactive waste in a RCRA-regulated container storage area	Does not have to meet storage unit requirements in 40 *CFR* § 761.65(b)(1) provided unit	Storage of PCBs and PCB Items at concentrations ≥ 50ppm designated for disposal— **applicable**.	40 *CFR* § 761.65(b)(2)	✓	✓
	• is permitted by EPA under RCRA § 3004 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761; or		40 *CFR* § 761.65(b)(2)(i)	✓	✓
	• qualifies for interim status under RCRA § 3005 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761; or		40 *CFR* § 761.65(b)(2)(ii)	✓	✓
	• is permitted by an authorized state under RCRA § 3006 to manage hazardous waste in containers and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761.		40 *CFR* § 761.65(b)(2)(iii)	✓	✓
	NOTE: For purpose of this exclusion, CERCLA remediation waste, which is also considered PCB waste, can be stored on-site provided the area meets all of the identified RCRA container storage ARARs and spills of PCBs cleaned up in accordance with Subpart G of 40 *CFR* § 761.				

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Storage of PCB waste and/or PCB/radioactive waste in non-RCRA regulated unit	Except as provided in 40 *CFR* § 761.65 (b)(2), (c)(1), (c)(7), (c)(9), and (c)(10), after July 1, 1978, owners or operators of any facilities used for the storage of PCBs and PCB Items designated for disposal shall comply with the storage unit requirements in 40 *CFR* § 761.65(b)(1).	Storage of PCBs and PCB Items at concentrations ≥ 50ppm designated for disposal —**applicable**.	40 *CFR* § 761.65(b)	✓	✓
	Storage facility shall meet the following criteria: • Adequate roof and walls to prevent rainwater from reaching stored PCBs and PCB items;		40 *CFR* § 761.65(b)(1) 40 *CFR* § 761.65(b)(1)(i)	✓	✓
	• Adequate floor that has continuous curbing with a minimum 6-inch high curb. Floor and curb must provide a containment volume equal to at least two times the internal volume of the largest PCB article or container or 25% of the internal volume of all articles or containers stored there, whichever is greater. *Note*: 6 inch minimum curbing not required for area storing PCB/radioactive waste;		40 *CFR* § 761.65(b)(1)(ii)	✓	✓
	• No drain valves, floor drains, expansion joints, sewer lines, or other openings that would permit liquids to flow from curbed area;		40 *CFR* § 761.65(b)(1)(iii)	✓	✓
	• Floors and curbing constructed of Portland cement, concrete, or a continuous, smooth, non-porous surface that prevents or minimizes penetration of PCBs; and		40 *CFR* § 761.65(b)(1)(iv)	✓	✓
	• Not located at a site that is below the 100-year flood water elevation.		40 *CFR* § 761.65(b)(1)(v)	✓	✓
	Storage area must be properly marked as required by 40 *CFR* § 761.40(a)(10).		40 *CFR* § 761.65(c)(3)	✓	✓
Risk-based storage of PCB remediation waste	May store PCB remediation waste in a manner other than prescribed in 40 *CFR* § 761.65(b) if approved in writing from EPA provided the method will not pose an unreasonable risk of injury to human health or the environment. *NOTE:* EPA approval of alternative storage method will be obtained by approval of the FFA CERCLA document.	Storage of waste containing PCBs in a manner other than prescribed in 40 *CFR* § 761.65(b) (see above) —**applicable**.	40 *CFR* § 761.61(c)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Temporary storage of PCB waste (e.g., PPE, rags) in a container(s)	Container(s) shall be marked as illustrated in 40 *CFR* § 761.45(a).	Storage of PCBs and PCB items at concentrations ≥ 50 ppm in containers for disposal—**applicable**.	40 *CFR* § 761.40(a)(1)	✓	✓
	Storage area must be properly marked as required by 40 *CFR* § 761.40(a)(10).		40 *CFR* § 761.65(c)(3)	✓	✓
	Any leaking PCB Items and their contents shall be transferred immediately to a properly marked nonleaking container(s).		40 *CFR* § 761.65(c)(5)	✓	✓
	Container(s) shall be in accordance with requirements set forth in DOT HMR at 49 *CFR* §§ 171-180.		40 *CFR* § 761.65(c)(6)	✓	✓
Staging of LLW	Shall be for the purpose of the accumulation of such quantities of wastes necessary to facilitate transportation, treatment, and disposal.	Staging of LLW at a DOE facility—**TBC**.	DOE M 435.1-1 (IV)(N)(7)	✓	✓
Temporary storage of LLW	Shall not be readily capable of detonation, explosive decomposition, reaction at anticipated pressures and temperatures, or explosive reaction with water.	Temporary storage of LLW at a DOE facility—**TBC**.	DOE M 435.1-1 (IV)(N)(1)	✓	✓
	Shall be stored in a location and manner that protects the integrity of waste for the expected time of storage.		DOE M 435.1-1 (IV)(N)(3)	✓	✓
	Shall be managed to identify and segregate LLW from mixed waste.		DOE M 435.1-1 (IV)(N)(6)	✓	✓
Packaging of LLW for storage	Shall be packaged in a manner that provides containment and protection for the duration of the anticipated storage period and until disposal is achieved or until the waste has been removed from the container.	Storage of LLW in containers at a DOE facility —**TBC**.	DOE M 435.1-1(IV)(L)(1)(a)	✓	✓
	Vents or other measures shall be provided if the potential exists for pressurizing or generating flammable or explosive concentrations of gases within the waste container.		DOE M 435.1-1(IV)(L)(1)(b)	✓	✓
	Containers shall be marked such that their contents can be identified.		DOE M 435.1-1(IV)(L)(1)(c)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Packaging of LLW for off-site disposal	Waste shall not be packaged for disposal in a cardboard or fiberboard box.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(b)	✓	✓
	Liquid waste shall be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid.	Preparation of liquid LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(c)	✓	✓
	Solid waste containing liquid shall contain as little freestanding and noncorrosive liquid as is reasonably achievable. The liquid shall not exceed one (1) percent of the volume.	Preparation of solid LLW containing liquid for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(d)	✓	✓
	Waste shall not be readily capable of • Detonation; • Explosive decomposition or reaction at normal pressures and temperatures; or • Explosive reaction with water.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility —**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(e)	✓	✓
	Waste shall not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to a person transporting, handling, or disposing of the waste.	Packaging of LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility —**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(f)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Waste shall not be pyrophoric.	Packaging of pyrophoric LLW for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.56 902 *KAR* 100:021 § 7 (1)(g)	✓	✓
Labeling of LLW packages	Each package of waste shall be clearly labeled to identify if it is Class A, Class B, or Class C waste, in accordance with 10 *CFR* § 61.55 or Agreement State waste classification requirements.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.57 902 *KAR* 100:021 § 8	✓	✓
Waste treatment and disposal/discharge					
Treatment, storage, transportation, or conveyance of collected RCRA wastewater using a WWTU that receives and treats or stores hazardous waste located on the facility	Any dedicated tank systems, conveyance systems, and ancillary equipment used to treat, store or convey wastewater to an on-site KPDES-permitted wastewater treatment facility subject to regulation under the CWA are exempt from the requirements of RCRA Subtitle C standards. *NOTE:* For purposes of this exclusion, any dedicated tank systems, conveyance systems, and ancillary equipment used to treat, store or convey CERCLA remediation wastewater to a CERCLA on-site wastewater treatment unit that meets all of the identified CWA ARARs for point source discharges from such a facility, are exempt from the requirements of RCRA Subtitle C standards.	On-site wastewater treatment units (as defined in 40 *CFR* § 260.10) subject to regulation under § 402 or § 307(b) of the CWA (i.e., KPDES-permitted) that manages hazardous wastewaters —**applicable**.	40 *CFR* § 264.1(g)(6) 401 *KAR* 34:010 § 1	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Discharge of contaminated groundwater or wastewater	Properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used to achieve compliance with the effluent standards. Proper operation and maintenance also includes adequate laboratory controls and appropriate quality assurance procedures.	Discharge of pollutants to surface waters—**relevant and appropriate**	401 *KAR* 5:065 Section 2(1) and 40 *CFR* § 122.41(e)	✓	✓
	Surface waters shall not be aesthetically or otherwise degraded by substances that: • Settle to form objectionable deposits; • Float as debris, scum, oil, or other matter to form a nuisance; • Produce objectionable color, odor, taste, or turbidity; • Injure, are chronically or acutely toxic to or produce adverse physiological or behavioral responses in humans, animals, fish, and other aquatic life; • Produce undesirable aquatic life or result in the dominance of nuisance species; 1. Cause fish flesh tainting. 2. The concentration of phenol shall not exceed 300 mg/l as an in stream value.	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 2(1)(a-f)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Kentucky Surface Water Standards	Warm water aquatic habitat. The following parameters and associated criteria shall apply: • Natural alkalinity as CaCO3 shall not be reduced by more than 25 percent; • pH shall not be less than 6.0 nor more than 9.0 and shall not fluctuate more than 1.0 pH units over a period of 24 hours; • Flow shall not be altered to a degree that will adversely affect the aquatic community; • Temperature shall not exceed 31.7°C (89°F); • Dissolved oxygen shall be maintained at a minimum concentration of 5.0 mg/l as a 24 hour average; instantaneous minimum shall not be less than 4.0 mg/l; • Total dissolved solids or specific conductance shall not be changed to the extent that the indigenous aquatic community is adversely affected; • Total suspended solids shall not be changed to the extent that the indigenous aquatic community is adversely affected; • Addition of settleable solids that may alter the stream bottom so as to adversely affect productive aquatic communities shall be prohibited; • Concentration of the un-ionized ammonia shall not be greater than 0.05 mg/l at any time instream after mixing; • Allowable instream concentration of toxic substances, or whole effluents containing toxic substances, which are noncumulative or nonpersistent with a half-life of less than 96 hours, shall not exceed: 1. 0.1 of the 96 hour median LC50 of representative indigenous or indicator aquatic organisms; or 2. A chronic toxicity unit of 1.00 utilizing the 25 percent inhibition concentration, or LC25. Allowable instream concentration of toxic substances, or whole effluents containing toxic substances, which are bioaccumulative or persistent, including pesticides, if not otherwise regulated, shall not exceed: 1. 0.01 of the 96 hour median LC50 of representative indigenous or indicator aquatic organisms; or 2. A chronic toxicity unit of 1.00 utilizing the LC25.	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 4(1) excluding § 4(1)(k)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	• In the absence of acute criteria for pollutants listed in 401 *KAR* 10:031 Section 6, for other substances known to be toxic but not listed in this administrative regulation, or for whole effluents that are acutely toxic, the allowable instream concentration shall not exceed the LC1 or 1/3 LC50 concentration derived from toxicity tests on representative indigenous or indicator aquatic organisms or exceed 0.3 acute toxicity units. • If specific application factors have been determined for a toxic substance or whole effluent such as an acute to chronic ratio or water effect ratio, they may be used instead of the 0.1 and 0.01 factors; • Allowable instream concentrations for specific pollutants for the protection of warm water aquatic habitat are listed in 401 *KAR* 10:031 Section 6 shall not be exceeded; and Instream concentrations for total residual chlorine shall not exceed an acute criteria value of 19 µg/l or a chronic criteria value of 11 µg/l.				
Kentucky Surface Water Standards	Provides chemical-specific numeric standards for pollutants discharged or found in surface waters.	Discharge of pollutants to surface waters—**applicable**.	401 *KAR* 10:031 Section 6(1)	✓	✓
	Monitoring location and frequency will be conducted in accordance with the substantive provisions of the KPDES Permit	Discharge of pollutants to surface waters—**TBC**.	KPDES Permit KY0004049	✓	✓
	Absorbed dose to native animal aquatic organisms must not exceed 1 rad/day	Discharge of radioactive materials in liquid waste to surface water at a DOE facility—**TBC**.	DOE O 5400.5(II)(3)(a)(1)(1)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Discharge of radionuclides into surface water	For liquid wastes containing radionuclides from DOE activities which are discharged to surface water, the best available technology (BAT) is the prescribed level of treatment if the surface waters otherwise would contain, at the point of discharge and prior to dilution, radioactive material at annual average concentrations greater than the DCG values in liquids given in Chapter III of DOE Order 5400.5. The BAT selection process shall be implemented in accordance with II.3a(1)(a) and (b) of the Order 5400.5.	Discharge of radioactive materials in liquid waste to surface water at a DOE facility—**TBC**.	DOE O 5400.5 II 3.a(1)	✓	✓
	Selection of the best available technology for a specific application will be made from among candidate alternative treatment technologies which are identified by an evaluation process that includes factors related to technology, economics, and public policy considerations. Factors that are to be considered in selecting BAT, at a minimum, shall include: • the age of equipment and facilities involved; • the process employed; • the engineering aspects of the application of various types of control techniques; • process changes; • the cost of achieving such effluent reduction; • non-water quality environmental impact (including energy requirements); • safety considerations; and public policy considerations.		DOE O 5400.5 II 3.a(1)(a)	✓	✓
	Implementation of the BAT process for liquid radioactive wastes is not required where radionuclides are already at a low level, i.e., the annual average concentration is less than DCG level. Additional treatment will not be required for waste streams that contain radionuclide concentrations of not more than the DCG values in Chapter III of DOE Order 5400.5 at the point of discharge to a surface waterway. However, the ALARA provisions are applicable.		DOE O 5400.5 II 3.a(2)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	To prevent the buildup of radionuclide concentrations in sediments, liquid process waste streams containing radioactive material in the form of settleable solids may be released to natural waterways if the concentration of radioactive material in the solids present in the waste stream does not exceed 5 pCi (O.2 Bq) per gram above background level, of settleable solids for alpha-emitting radionuclides or 50 pCi (2 Bq) per gram above background level, of settleable solids for beta gamma- emitting radionuclides.	Discharge of radioactive concentrations in sediments to surface water from a DOE facility—**TBC**.	DOE O 5400.5 II.3.a(4)	✓	✓
	To protect native animal aquatic organisms, the absorbed dose to these organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways.		DOE O 5400.5 II.3.a(5)	✓	✓
General standards for process vents (including closed vent systems with control devices) used in site remediation treatment units	Select and meet the requirements under one of the options specified below: • Control HAP emissions from the affected process vents according to the applicable standards specified in § 63.7890. • Determine for the remediation material treated or managed by the process vented through the affected process vents that the average total volatile organic hazardous air pollutant (VOHAP) concentration, as defined in § 63.7957, of this material is less than 10 (ppmw). Determination of VOHAP concentration will be made using procedures specified in § 63.7943. • Control process vents subject to another subpart under 40 *CFR* part 61 or 40 *CFR* part 63 in compliance with the standards specified in the applicable subpart.	Process vent stream $\geq$ 0.005 m^3/min at standard conditions or process vent stream flow rate $\geq$ 6.0 m^3/min at standard condition and total HAP $\geq$ than 20 ppmv**—relevant and appropriate**.	40 *CFR* § 63:7885(b) 401 *KAR* 63:002, Sections 1 and 2, except for 40 *CFR* § 63.72 as incorporated in Section 2(3)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	Select and meet the requirements under one of the options specified below: • Reduce from all affected process vents the total emissions of the HAP to a level less than 1.4 kilograms per hour (kg/hr) and 2.8 Mg/yr (3.0 pounds per hour (lb/hr) and 3.1 tpy); or • Reduce from all affected process vents the emissions of total organic compounds (TOC) (minus methane and ethane) to a level below 1.4 kg/hr and 2.8 Mg/yr (3.0 lb/hr and 3.1 tpy); or • Reduce from all affected process vents the total emissions of the HAP by 95 percent by weight or more; or • Reduce from all affected process vents the emissions of TOC (minus methane and ethane) by 95 percent by weight or more. For each closed vent system and control device you use to comply with the requirements above, you must meet the operating limit requirements and work practice standards in Sec. 63.7925(c) through (j) that apply to your closed vent system and control device. NOTE: These emission limits are for the remediation activities conducted at the PGDP by the DOE.		40 *CFR* § 63.7890 401 *KAR* 63:002, Sections 1 and 2, except for 40 *CFR* § 63.72 as incorporated in Section 2(3)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Treatment of LLW	Treatment to provide more stable waste forms and to improve the long-term performance of a LLW disposal facility shall be implemented as necessary to meet the performance objectives of the disposal facility	Treatment of LLW for disposal at a LLW disposal facility—**TBC**.	DOE M 435.1-1(IV)(O)	✓	✓
Disposal of prohibited RCRA hazardous waste in a land-based unit	May be land disposed if it meets the requirements in the table "Treatment Standards for Hazardous Waste" at 40 *CFR* § 268.40 before land disposal.	Land disposal, as defined in 40 *CFR* § 268.2, of prohibited RCRA waste—**applicable**.	40 *CFR* § 268.40(a) 401 *KAR* 37:040 §2	✓	✓
	All underlying hazardous constituents [as defined in 40 *CFR* § 268.2(i)] must meet the Universal Treatment Standards, found in 40 *CFR* § 268.48 Table UTS prior to land disposal.	Land disposal of restricted RCRA characteristic wastes (D001-D043) that are not managed in a wastewater treatment system that is regulated under the CWA, that is CWA equivalent, or that is injected into a Class I nonhazardous injection well—**applicable**.	40 *CFR* § 268.40(e) 401 *KAR* 37:040 § 2	✓	✓
	Must be treated according to the alternative treatment standards of 40 *CFR* § 268.49(c) or according to the UTSs specified in 40 *CFR* § 268.48 applicable to the listed and/or characteristic waste contaminating the soil prior to land disposal.	Land disposal, as defined in 40 *CFR* § 268.2, of restricted hazardous soils—**applicable**.	40 *CFR* § 268.49(b) 401 *KAR* 37:040 §10	✓	✓
Disposal of RCRA hazardous debris in a land-based unit	Must be treated prior to land disposal as provided in 40 *CFR* § 268.45(a)(1)-(5) unless EPA determines under 40 *CFR* § 261.3(f)(2) that the debris no longer contaminated with hazardous waste or the debris is treated to the waste-specific treatment standard provided in 40 *CFR* § 268.40 for the waste contaminating the debris.	Land disposal, as defined in 40 *CFR* § 268.2, of RCRA-hazardous debris—**applicable**.	40 *CFR* § 268.45(a) 401 *KAR* 37:040 §7	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Disposal of RCRA characteristic wastewaters	Are not prohibited, if the wastes are managed in a treatment system which subsequently discharges to waters of the U.S. pursuant to a permit issued under 402 of the CWA (i.e., NPDES permitted) unless the wastes are subject to a specified method of treatment other than DEACT in 40 *CFR* § 268.40, or are D003 reactive cyanide. NOTE: For purposes of this exclusion, a CERCLA on-site wastewater treatment unit that meets all of the identified CWA ARARs for point source discharges from such a system, is considered a wastewater treatment system that is NPDES permitted.	Land disposal of hazardous wastewaters that are hazardous only because they exhibit a hazardous characteristic and are not otherwise prohibited under 40 *CFR* Part 268—**applicable**.	40 *CFR* § 268.1(c)(4)(i) 401 *KAR* 37:010 §2	✓	✓
Disposal of bulk PCB remediation waste off-site (self-implementing)	May be sent off-site for decontamination or disposal provided the waste either is dewatered on-site or transported off-site in containers meeting the requirements of DOT HMR at 49 *CFR* parts 171-180.	Generation of bulk PCB remediation waste (as defined in 40 *CFR* § 761.3) for off-site disposal—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)	✓	✓
	Must provide written notice including the quantity to be shipped and highest concentration of PCBs [using extraction EPA Method 3500B/3540C or Method 3500B/3550B followed by chemical analysis using Method 8082 in SW-846 or methods validated under 40 *CFR* § 761.320-26 (Subpart Q)] before the first shipment of waste to each off-site facility where the waste is destined for an area not subject to a TSCA PCB Disposal Approval.	Bulk PCB remediation waste (as defined in 40 *CFR* § 761.3) destined for an off-site facility not subject to a TSCA PCB Disposal Approval—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(iv)*	✓	✓
	Shall be disposed of in accordance with the provisions for cleanup wastes at 40 *CFR* § 761.61(a)(5)(v)(A).	Off-site disposal of dewatered bulk PCB remediation waste with a PCB concentration < 50 ppm—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(ii)*	✓	✓
	Shall be disposed of • in a hazardous waste landfill permitted by EPA under §3004 of RCRA;	Off-site disposal of dewatered bulk PCB remediation waste with a PCB concentration ≥ 50 ppm—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(i)(B)(2)*(iii)*	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
	• in a hazardous waste landfill permitted by a State authorized under §3006 of RCRA; or			✓	✓
	• in a PCB disposal facility approved under 40 *CFR* § 761.60.			✓	✓
Disposal of liquid PCB remediation waste (self-implementing)	Shall either • decontaminate the waste to the levels specified in 40 *CFR* § 761.79(b)(1) or (2); or	Liquid PCB remediation waste (as defined in 40 *CFR* § 761.3)—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(iv) 40 *CFR* § 761.61(a)(5)(iv)(A)	✓	✓
	• dispose of the waste in accordance with the performance-based requirements of 40 *CFR* § 761.61(b) or in accordance with a risk-based approval under 40 *CFR* § 761.61(c).		40 *CFR* § 761.61(a)(5)(iv)(B)	✓	✓
Performance-based disposal of PCB remediation waste	May dispose by one of the following methods • in a high-temperature incinerator under 40 *CFR* § 761.70(b);	Disposal of non-liquid PCB remediation waste (as defined in 40 *CFR* § 761.3)—**applicable**.	40 *CFR* § 761.61(b)(2) 40 *CFR* § 761.61(b)(2)(i)	✓	✓
	• by an alternate disposal method under 40 *CFR* § 761.60(e);			✓	✓
	• in a chemical waste landfill under 40 *CFR* § 761.75;			✓	✓
	• in a facility under 40 *CFR* § 761.77; or			✓	✓
	• through decontamination in accordance with 40 *CFR* § 761.79.		40 *CFR* § 761.61(b)(2)(ii)	✓	✓
	Shall be disposed according to 40 *CFR* § 761.60(a) or (e), or decontaminate in accordance with 40 *CFR* § 761.79.	Disposal of liquid PCB remediation waste—**applicable**.	40 *CFR* § 761.61(b)(1)	✓	✓
Risk-based disposal of PCB remediation waste	May dispose of in a manner other than prescribed in 40 *CFR* § 761.61(a) or (b) if approved in writing from EPA and method will not pose an unreasonable risk of injury to [sic] human health or the environment. *NOTE:* EPA approval of alternative disposal method will be obtained by approval of the FFA CERCLA document.	Disposal of PCB remediation waste—**applicable**.	40 *CFR* § 761.61(c)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Disposal of PCB cleanup wastes (e.g., PPE, rags, non-liquid cleaning materials) (self-implementing option)	Shall be disposed of • in a municipal solid waste facility under 40 *CFR* § 258 or non-municipal, nonhazardous waste subject to 40 *CFR* § 257.5 thru 257.30; or • in a RCRA Subtitle C landfill; or • in a PCB disposal facility; or • through decontamination under 40 *CFR* § 761.79(b) or (c).	Generation of non-liquid PCBs during and from the cleanup of PCB remediation waste—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(v)(A)	✓	✓
Disposal of PCB cleaning solvents, abrasives, and equipment (self-implementing option)	May be reused after decontamination in accordance with 40 *CFR* § 761.79; or For liquids, disposed in accordance with 40 *CFR* § 761.60(a).	Generation of PCB wastes from the cleanup of PCB remediation waste—**relevant and appropriate**.	40 *CFR* § 761.61(a)(5)(v)(B) 40 *CFR* § 761.60(b)(1)(i)(B)	✓	✓
Disposal of PCB decontamination waste and residues	Shall be disposed of at their existing PCB concentration unless otherwise specified in 40 *CFR* § 761.79(g)(1) through (6).	PCB decontamination waste and residues for disposal—**applicable**.	40 *CFR* § 761.79(g)	✓	✓
Disposal of LLW	LLW shall be certified as meeting waste acceptance requirements before it is transferred to the receiving facility.	Disposal of LLW at a LLW disposal facility—**TBC**.	DOE M 435.1-1(IV)(J)(2)	✓	✓
Waste Treatment & Disposition					
Release of property with residual radioactive material	Property with residual radioactive material will be released from DOE control under survey methods and criteria of DOE Order 5400.5.	Release of soil, equipment and material with residual radioactive material from DOE control —**TBC**.	DOE O 5400.5	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Decontamination/Cleanup					
Decontamination of movable equipment contaminated by PCBs (self-implementing option)	May decontaminate by • swabbing surfaces that have contacted PCBs with a solvent; • a double wash/rinse as defined in 40 *CFR* § 761.360-378; or • another applicable decontamination procedure under 40 *CFR* § 761.79.	Movable equipment contaminated by PCB and tools and sampling equipment—**applicable**.	40 *CFR* § 761.79(c)(2)	✓	✓
Decontamination of PCB containers (self-implementing option)	Must flush the internal surfaces of the container three times with a solvent containing < 50 ppm PCBs. Each rinse shall use a volume of the flushing solvent equal to approximately 10% of the PCB container capacity.	PCB Container as defined in 40 *CFR* § 761.3—**applicable**.	40 *CFR* § 761.79(c)(1)	✓	✓
Decontamination of PCB contaminated water	For discharge to a treatment works as defined in 40 *CFR* § 503.9 (aa), or discharge to navigable waters, meet standard of < 3 ppb PCBs; or	Water containing PCBs regulated for disposal—**applicable**.	40 *CFR* § 761.79(b)(1)(ii)	✓	✓
	The decontamination standard for water containing PCBs is less than or equal to 0.5 µg/L (i.e., approximately ≤0.5 ppb PCBs) for unrestricted use.		40 *CFR* § 761.79(b)(1)(iii)	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment) Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Unit Closure					
Waste transportation					
Transportation of RCRA hazardous waste on-site	The generator manifesting requirements of 40 *CFR* §§ 262.20–262.32(b) do not apply. Generator or transporter must comply with the requirements set forth in 40 *CFR* §§ 263.30 and 263.31 in the event of a discharge of hazardous waste on a private or public right-of-way.	Transportation of hazardous wastes on a public or private right-of-way within or along the border of contiguous property under the control of the same person, even if such contiguous property is divided by a public or private right-of-way—**applicable**.	40 *CFR* § 262.20(f) 401 *KAR* 32:020 § 1	✓	✓
Transportation of RCRA hazardous waste off-site	Must comply with the generator requirements of 40 *CFR* § 262.20–23 for manifesting, § 262.30 for packaging, § 262.31 for labeling, § 262.32 for marking, § 262.33 for placarding, § 262.40, 262.41(a) for record keeping requirements, and § 262.12 to obtain EPA ID number.	Preparation and initiation of shipment of hazardous waste off-site—**applicable**.	40 *CFR* § 262.10(h) 401 *KAR* 32:010 § 1	✓	✓
Transportation of PCB wastes off-site	Must comply with the manifesting provisions at 40 *CFR* § 761.207 through 218.	Relinquishment of control over PCB wastes by transporting, or offering for transport—**applicable**.	40 *CFR* § 761.207(a)	✓	✓
Determination of radionuclide concentration	The concentration of a radionuclide may be determined by an indirect method, such as use of a scaling factor which relates the inferred concentration of one (1) radionuclide to another that is measured or radionuclide material accountability if there is reasonable assurance that an indirect method may be correlated with an actual measurement. The concentration of a radionuclide may be averaged over the volume or weight of the waste if the units are expressed as nanocuries per gram.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.55 (a)(8) 902 *KAR* 100:021 § 6(8)(a) and (b)	✓	✓
Labeling of LLW packages	Each package of waste shall be clearly labeled to identify if it is Class A, Class B, or Class C waste, in accordance with 10 *CFR* § 61.55 or Agreement State waste classification requirements.	Preparation for off-site shipment of LLW to a commercial NRC or Agreement State licensed disposal facility—**relevant and appropriate**.	10 *CFR* § 61.57 902 *KAR* 100:021 § 8	✓	✓

Table 4.4. ARARs for the Oil Landfarm and the C-720 Northeast and Southeast Sites Alternative 5 (*In Situ* Thermal Source Treatment)
Combined ARARs Table for SW Plume FFS (Continued)

Action-specific ARARs					
Action	**Requirement**	**Prerequisite**	**Citation**	**Alt 4**	**Alt 5**
Transportation of radioactive waste	Shall be packaged and transported in accordance with DOE Order 460.1B and DOE Order 460.2.	Preparation of shipments of radioactive waste—**TBC**.	DOE M 435.1-(I)(1)(E)(11)	✓	✓
Transportation of LLW	To the extent practicable, the volume of the waste and the number of the shipments shall be minimized.	Preparation of shipments of LLW—**TBC**.	DOE M 435.1-1(IV)(L)(2)	✓	✓
Transportation of hazardous materials	Shall be subject to and must comply with all applicable provisions of the HMR at 49 *CFR* §§ 171–180 related to marking, labeling, placarding, packaging, emergency response, etc.	Any person who, under contract with a department or agency of the federal government, transports "in commerce," or causes to be transported or shipped, a hazardous material—**applicable**.	49 *CFR* § 171.1(c)	✓	✓
Transportation of hazardous materials on-site	Shall comply with 49 *CFR* Parts 171-174, 177, and 178 or the site- or facility-specific Operations of Field Office approved Transportation Safety Document that describes the methodology and compliance process to meet equivalent safety for any deviation from the Hazardous material Regulations [i.e., *Transportation Safety Document for On-Site Transport within the Paducah Gaseous Diffusion Plant*, PRS-WSD-0661, (PRS 2007)].	Any person who, under contract with the DOE, transports a hazardous material on the DOE facility—**TBC**.	DOE O 460.1B(4)(b)	✓	✓
Transportation of hazardous materials off-site	Off-site hazardous materials packaging and transfers shall comply with 49 *CFR* Parts 171-174, 177, and 178 and applicable tribal, State, and local regulations not otherwise preempted by DOT and special requirements for Radioactive Material Packaging.	Preparation of off-site transfers of LLW—**TBC**.	DOE O 460.1B(4)(a)	✓	✓

ARAR = as low as reasonably achievable; AOC = area of contamination; *CFR* = *Code of Federal Regulations*; CWA = Clean Water Act; DOE = U.S. Department of Energy; EDE = effective dose equivalent; EPA = U.S. Environmental Protection Agency; HMR = hazardous material regulations; *KAR* = *Kentucky Administrative Rules*; LDR = land disposal restriction; LLW = low-level waste; NRC = Nuclear Regulatory Commission; NWP = Nationwide Permit; PCB = polychlorinated biphenyl; PPE = personal protective equipment; RAWP = Remedial Action Work Plan; RCRA = Resource Conservation and Recovery Act; ROD = Record of Decision; TBC = to be considered; T&E = threatened and endangered; *USC* = *United States Code*; UTS = Universal Treatment Standards; WAC = waste acceptance criteria

4.3.3.5 Short-term effectiveness

Short-term effectiveness of Alternative 5 is high. Installation of electrode/vapor recovery wells and monitoring equipment and groundwater monitoring wells would encounter contaminated soils. Soil returns produced during installation of electrode/vapor recovery wells and groundwater monitoring wells would be managed in accordance with the HASPs, WCP, and WMP prepared during the RD/RAWP. Installation and operation of the ERH system would be conducted by trained personnel in accordance with procedures including ALARA review, the HASP, and safe work practices to minimize injury or exposure risks. Site preparation and ERH system operation is expected to require approximately one year. Five-year reviews and monitoring would be required as long as VOC soil concentrations remained above groundwater protection RGs, estimated at 52 years for the Oil Landfarm and 29 years for the C-720 Northeast and Southeast sites, based on a conservative assumption of a TCE half-life in the UCRS of 50 years. The E/PP program will protect workers pending remedy selection as part of the Soils OU. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

Monitoring and ERH process controls would be protective of the public throughout construction and implementation of the remedy. The Southwest Plume sites are not located near any residential population, and effects on outlying communities would be negligible because of the continued access restrictions which would eliminate the exposure risks.

No ecological impacts are anticipated under this alternative. The Southwest Plume sites are located at an active operational facility already disturbed by construction and operational activities and do not support any unique or significant ecological resources.

4.3.3.6 Implementability

Overall implementability of Alternative 5 is relatively high. Existing surfaces and infrastructure would be largely unaffected. Rerouting of utilities would not be required. Equipment, personnel, and services required to implement this alternative are readily commercially available. No additional development of these technologies would be required. Contractors possessing the required skills and experience are available.

Administrative feasibility for Alternative 5 is high. The electrode/vapor extraction wells and groundwater monitoring wells would be constructed according to Commonwealth of Kentucky substantive rules and abandoned after completion of the project. Recovered vapor would be treated to meet allowable emission levels prior to discharge.

4.3.3.7 Cost

Estimated capital and O&M&M costs for Alternative 5 are summarized in Table 4.5. Long-term Monitoring for the Oil Landfarm were estimated for 30 years, as recommended by CERCLA guidance (EPA 1988).

Table 4.5. Summary of Estimated Costs for Alternative 5

Cost element[1]	Oil Landfarm	C-720 NE Site	C-720 SE Site	Total
Unescalated cost				
Capital cost	$8.5M	$1.9M	$4.9M	$15.3M
O&M&M	$1.3M	$0.3M	$0.7M	$2.3M
Subtotal	**$9.8M**	**$2.2M**	**$5.6M**	**$17.6M**
Escalated cost				
Capital cost	$9.5M	$2.1M	$5.5M	$17.1M
O&M&M	$2.4M	$0.5M	$1.4M	$4.4M
Subtotal	**$12.0M**	**$2.7M**	**$6.9M**	**$21.5M**
Present Worth[2]				
Capital cost	$8.5M	$1.9M	$4.9M	$15.3M
O&M&M	$0.9M	$0.2M	$0.5M	$1.5M
Subtotal	**$9.4M**	**$2.1M**	**$5.4M**	**$16.8M**

[1]Includes general and administrative fee and contingency.

[2]Present worth costs are based on an assumption that outyear costs will be financed by investments made in year 0 and are provided for purposes of comparison only. Escalated costs are used by DOE for planning and budgeting.

5. COMPARATIVE ANALYSIS

The PGDP Southwest Plume source area remedial action alternatives, which were developed in Section 3 and analyzed in detail in Section 4, are compared in this section. The comparative analysis identifies the relative advantages and disadvantages of each alternative, so that the key tradeoffs that risk managers must balance can be identified. The comparative analysis provides a measure of the relative performance of the alternatives against each evaluation criterion.

Alternatives are compared based on two of the three CERCLA categories including threshold criteria and primary balancing criteria. The third category, modifying criteria, including state and community acceptance, will not be addressed until the Proposed Plan has been issued for public review. These modifying criteria will be addressed in the responsiveness summary and the ROD, which will be prepared following the public comment period.

Sections 0 and 5.2 present the remedial alternative comparisons relative to each evaluation criterion. Table 5.1 summarizes the relative performance of each alternative for each evaluation criterion.

5.1 THRESHOLD CRITERIA

Threshold criteria are of greatest importance in the comparative analysis because they reflect the key statutory mandates of CERCLA, as amended. The threshold criteria that any viable alternative must meet are as follows:

- Overall protection of human health and the environment and
- Compliance with ARARs.

Southwest Plume source area remedial alternatives are evaluated with respect to the threshold criteria in this section. A summary discussion is provided in Table 5.1.

5.1.1 Overall Protection of Human Health and the Environment

This threshold criterion evaluates the ability of an alternative to provide adequate protection of human health and the environment. The overall evaluation primarily draws from assessments of long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Alternatives 4 and 5 would meet the threshold criterion through treatment of VOCs in soil including PTW. The E/PP program and existing DOE plant controls would protect workers and the public. It is expected that after active treatment, the average residual TCE concentration in the upper 10 ft of the SWMU 1 source area will range from 0.15–0.76 mg/kg and will be approximately 2.96 mg/kg at C-720, depending on the alternative selected. These values are similar to or below the TCE soil action levels for direct contact contained in the PGDP Risk Methods Document (DOE 2009b). Non-VOC concentrations would not be reduced; however, the E/PP program will limit exposures pending remedy selection as part of the Soils OU. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

Table 5.1. Summary of Comparative Analysis of Southwest Plume Source Area Alternatives

	Threshold Criteria		Primary Balancing Criteria				
Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Total Project Cost (Escalated value)
Alternative 1: No Action	Does not meet the threshold criterion because no action would be implemented. Risks resulting from flux of VOCs would not be reduced.	No actions implemented; therefore, does not meet ARARs.	No long-term effectiveness or permanence.	No direct treatment-natural attenuation only.	Low. Time to attainment of RGs estimated at over 100 years, assuming 50 year TCE half-life.	High technical and administrative implementability.	$0

Table 5.1. Summary of Comparative Analysis of Southwest Plume Source Area Alternatives (Continued)

	Threshold Criteria		Primary Balancing Criteria				
Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Total Project Cost (Escalated value)
Alternative 4: SVE Source Treatment and Containment	Meets the threshold criterion. VOC concentrations in soil would be reduced by SVE over a period of 2 to 5 years; VOC flux to the RGA would continue to decline as long as the cover remained in place. MCLs attained in RGA at all sites within 2-5 years. Workers protected from non-VOCs through E/PP program pending initiation of Soils OU.	Meets the threshold criterion. Complies with ARARs.	High. Up to 90% of VOCs would be removed and destroyed. Long-term cover maintenance and monitoring required.	Up to 90% of VOCs removed and destroyed in 2 to 5 years.	Moderate. Over 70 years of cover maintenance and groundwater monitoring required. Worker protections required during implementation.	Moderate technical and administrative implementability.	Oil Landfarm: $13.6M C-720 Northeast: $3.0M C-720 Southeast : $7.8M Total = $24.5M

Table 5.1. Summary of Comparative Analysis of Southwest Plume Source Area Alternatives (Continued)

	Threshold Criteria		Primary Balancing Criteria				
Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Total Project Cost (Escalated value)
Alternative 5: *In Situ* Thermal Source Treatment	Meets the threshold criterion. Up to 98% of VOCs would be removed from source areas and destroyed *ex situ* in approximately 1 year. MCLs attained within 29 year at C-720 sites and within 52 years at the Oil Landfarm. Workers protected from non-VOCs Through E/PP program pending initiation of Soils OU.	Meets the threshold criterion. Compliance with ARARs anticipated.	High. Up to 98% of VOCs would be removed and destroyed. Groundwater monitoring required for up to 29 years at C-720 Northeast and Southeast Sites and up to 52 years at Oil Landfarm.	Up to 98% of VOCs would be treated and destroyed in approximately 1 year.	High. ERH completed in one year. Groundwater monitoring required for up to 29 years at C-720 Northeast and Southeast Sites and up to 52 years at Oil Landfarm. Worker protections required during implementation	High. Technically complex, but previously demonstrated in C-400 ERH treatability study.	Oil Landfarm: $12.0M C-720 Northeast: $2.7M C-720 Southeast: $6.9M Total = $21.5M

The combination of removal of VOCs as vapor, containment by surface covers, and recharge controls for Alternative 4 would reduce source area mass and residual mass migration sufficiently to be protective of groundwater by attaining MCLs in the area of attainment within two to five years at the C-720 Northeast and Southeast sites and at the Oil Landfarm. All ARARs defined for Alternative 4 also would be met.

Long-term cover maintenance, and groundwater monitoring would be required for over 70 years for Alternative 4 after SVE treatment, until groundwater protection RGs were met. Excavation worker exposure risks to VOCs would be within EPA's generally acceptable risk range for site-related exposures of 1E-04 to 1E-06 after completion of active treatment. Monitoring and SVE process controls would be protective of the public throughout construction and implementation of the remedy.

Sufficient removal of VOCs is achieved by Alternative 5 through active treatment and subsequent reductions in residual mass migration to reach MCLs in the area of attainment in about 29 years at the C-720 Northeast and Southeast Sites and within about 52 years at the Oil Landfarm. All ARARs defined for Alternative 5 would be met. Risks to excavation workers would be within EPA's generally acceptable risk range for site-related exposures of 1E-04 to 1E-06 after completion of active treatment. Long-term groundwater monitoring would be required for Alternative 5 after ERH treatment until groundwater protection RGs were met.

Alternative 1 would not meet the threshold criterion of overall protection of human health and the environment or compliance with ARARs. Alternative 1 would provide no treatment or removal of PTW other than by natural processes, no protection for excavation workers, and no reduction in migration of VOCs to the RGA. Over 100 years would be required to attain MCLs and groundwater protection RGs at the C-720 Northeast and Southeast Sites and at the Oil Landfarm, based on a conservative modeling assumption of a TCE half-life in the UCRS of 50 years.

Alternative 1 would not meet this threshold criterion. Risks to groundwater receptors would be reduced only by natural processes, which have not been sufficiently quantified to accurately predict time to attainment of RGs. RAOs would not be met because no action would be implemented to reliably treat or remove PTW, protect excavation workers or to reduce VOC migration to groundwater.

5.1.2 Compliance with ARARs

A summary discussion of compliance with ARARs is provided in Table 5.1. Alternative 1 does not meet ARARs while Alternatives 4 and 5 meet the threshold criterion. Alternatives 4 and 5 also would meet location- and action-specific ARARs through design and planning during preparation of the RD/RAWP.

Alternative 1 would not meet the threshold criterion, because action- and location-specific ARARs are not relevant because no action would be taken. No chemical-specific ARARs were identified.

5.2 BALANCING CRITERIA

The Southwest Plume source area alternatives are compared with respect to the balancing criteria in the following discussion. The primary balancing criteria to which relative advantages and disadvantages of the alternatives are compared include the following:

- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility, and volume through treatment;
- Short-term effectiveness;
- Implementability; and

- Cost.

The first and second balancing criteria address the statutory preference for treatment as a principal element of the remedy and the bias against off-site land disposal of untreated material. Together with the third and fourth criteria, they form the basis for determining the general feasibility of each potential remedy. The final criterion addresses whether the costs associated with a potential remedy are proportional to its overall effectiveness, considering both the cleanup period and O&M requirements during and following cleanup, relative to other alternatives. Key tradeoffs among alternatives will most frequently relate to one or more of the balancing criteria.

5.2.1 Long-Term Effectiveness and Permanence

Alternative 5 would provide the best long-term effectiveness and permanence, because groundwater protection RGs could be attained and RAOs met at the C-720 Northeast and Southeast Sites in about 29 years, while up to 52 years could be required at the Oil Landfarm. Expected risks to excavation workers after ERH treatment would be within EPA's generally acceptable risk range for site-related exposures of 1E-04 to 1E-06 at the Oil Landfarm, and less than 1E-06 at the C-720 Northeast and Southeast sites. Alternative 4 would rank behind Alternative 5 because long-term cover maintenance, and monitoring would be required at all sites after completion of SVE, for about 70 years. Non-VOC concentrations would not be reduced; however, the E/PP program will limit exposures pending remedy selection as part of the Soils OU. Existing DOE plant controls, which are administered and maintained outside of CERCLA, provide additional protection of human health by restricting access.

Alternative 1 would provide no long-term effectiveness or permanence. Attainment of RGs would take over 100 years. The overall ranking of alternatives with respect to long-term effectiveness and permanence, highest to lowest, is 5, 4, 1.

5.2.2 Reduction of Toxicity, Mobility, and Volume through Treatment

Alternative 5 would accomplish the greatest reduction of toxicity, mobility, and volume using the *in situ* ERH process. Alternative 4 would accomplish less reduction of VOC mass; however, the reduction in VOC mobility, through capping and recharge controls, during and after completion of SVE operations would be significant.

Alternative 1 would not implement treatment and would reduce VOC concentrations only through natural processes. The overall ranking of alternatives with respect to reduction of toxicity, mobility and volume through treatment, highest to lowest, is 5, 4, 1.

5.2.3 Short-Term Effectiveness

No added risks to the public or the environment would result from implementing any of the alternatives; therefore, only worker risks during remedy implementation are discussed. All worker risks and hazards could be mitigated by worker protection programs, which would increase the cost and complexity of the alternatives. The E/PP program would protect workers until final disposition through the Soils OU.

Alternative 5 has the highest short-term effectiveness, because it would attain VOC RGs in the least time. Alternative 5 also would result in worker exposure risks while drilling and installing electrode/vapor recovery wells in contaminated soil areas, and also would result in thermal and electrical hazards. The concomitant increase in requirements for safety analysis, hazard identification and control would result in increased complexity and cost for implementation; however, all of these issues were successfully resolved

for the C-400 ERH Treatability Study. Alternative 5 would attain groundwater protection RGs and RAOs in about 29 years at the C-720 Northeast and Southeast Sites, but would require up to 52 years at the Oil Landfarm.

Alternative 4 would result in worker chemical exposure risks during dual-phase and groundwater monitoring well installation, requiring on-site industrial hygienist coverage during drilling, in addition to appropriate monitoring, PPE, and procedures. RAOs would be met in two to five years; however, long-term cover maintenance, and monitoring would be required for about 70 years at all sites, until RGs in soil were attained.

Alternative 1 has the lowest short-term effectiveness, because it would require the longest time for attainment of RGs.

The overall ranking of alternatives with respect to short-term effectiveness, highest to lowest, is 5, 4, 1.

5.2.4 Implementability

Alternative 1 would be the most readily implementable alternative, because no action would be taken. Implementability constraints for Alternative 5 would include the technical complexity of the alternative, relatively few vendors offering the technology, and the worker protection issues discussed previously under short-term effectiveness; however, these constraints were resolved for the C-400 ERH Treatability Study. No O&M would be required after completion of the ERH treatment; however, long-term groundwater monitoring and five-year reviews would be required as long as VOC concentrations in soil remained above RGs.

Alternative 4 could be implemented using readily available industry equipment and services; however, the longer period of O&M relative to Alternative 5 reduces the overall implementability. Treatment of off-gas and co-produced groundwater, maintenance of the surface covers, and soil vapor and soil moisture monitoring would be required for the estimated 2- to 5-year duration of operation. Long-term cover maintenance, and groundwater monitoring would be required as long as VOC concentrations in soil remained above RGs.

The overall ranking of alternatives with respect to implementability, highest to lowest, is 1, 5, 4.

5.2.5 Cost

Total project costs for each alternative are listed in Table 5.1. The overall ranking of alternatives with respect to escalated value, lowest to highest, is 1, 5, 4.

5.3 SUMMARY OF THE COMPARATIVE ANALYSIS OF ALTERNATIVES

Alternatives 4 and 5 would meet the threshold criterion of overall protection of human health and the environment by removing and treating PTW, preventing VOC and non-VOC exposures and reducing VOC migration from the source areas to the RGA groundwater. Alternative 1 does not meet the threshold criterion of overall protection of human health and the environment.

Overall Alternative 5 offers the highest effectiveness and implementability at relatively moderate cost. Implementation concerns including infrastructure constraints, worker risks, and regulator acceptance were successfully resolved in the C-400 Treatability Study and would be expected to be manageable for the Oil Landfarm and the C-720 Northeast and Southeast Sites. Recovered VOCs would not be destroyed on-site,

but off-site destruction would be certified by the vendor. Remedial action would begin within 15 months of signing the ROD and likely would be completed in less than one year. Five-year reviews would be required at the C-720 Northeast and Southeast sites and at the Oil Landfarm until soil RGs were attained, estimated at up to 29 years and 52 years, respectively.

Non-VOC concentrations would not be reduced by either alternative; however, the E/PP program and non-CERCLA plant controls would limit exposures pending remedy selection as part of the Soils OU.

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APPENDIX A

EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS

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Table A.1. Oil Landfarm and the C-720 Northeast and Southeast Sites Technology Screening

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
Land use controls	Institutional controls	E/PP program	Requires review and approval of any proposed intrusive activities to protect workers and remedy integrity.	Available	Technically implementable
Monitoring	Soil monitoring and/or characterization	Soil cores	Collection of soil cores and laboratory analysis for VOCs may be used to identify areas of TCE NAPL residual saturation. Continuous soil cores may be obtained using DPT, hollow-stem auger, or other drilling methods and analyzed. DNAPL TCE may be detected using field "shake tests," UV fluorescence, or dyes.	Commercially available	Technically implementable
		Membrane interface probe	The MIP is used for real-time VOC profiling and sampling. MIP sampling uses a heating element and gas permeable membrane. The element heats the material surrounding the probe, causing the VOCs contained in the material to vaporize. Vapors enter the probe through a gas permeable membrane and are transported through tubing to the surface by an inert carrier gas. The sample then is analyzed in the field with equipment appropriate to the needs of the investigation.	Commercially available	Technically implementable
		Soil vapor sampling	Soil vapor sampling may be used to determine concentrations of VOCs in soil pore space and thereby indirectly determine the presence and extent of NAPL TCE. Drive points connected to plastic or stainless steel tubing are driven or pushed to the desired depth and soil vapor extracted and analyzed.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		Soil moisture sampling	Soil moisture sampling using suction lysimeters may be used to determine pore water concentrations of VOCs. Porous cups attached to plastic tubing are installed in silica flour in drilled or driven boreholes. Vacuum is applied to tubing causing water to flow into the porous cup. The collected water is then analyzed on- or off-site.	Commercially available	Technically implementable
		Gore-sorbers	Passive soil gas samplers are used to characterize saturated and unsaturated zone VOC contamination.	Commercially available	Technically implementable
		Raman spectroscopy	Implemented using CPT. Raman spectroscopy relies on the detection of light wavelength shifts from compounds of interest and is capable of direct identification of several chlorinated DNAPL.	Commercially available	Technically implementable
	Groundwater monitoring	Sampling and analysis	Groundwater samples can be obtained from wells completed in saturated zone using pumps, bailers or passive samplers. Analysis can be performed on-site using field instrumentation or off-site at fixed-base laboratories.	Commercially available	Technically implementable
		Partitioning interwell tracer test (PITT)	The PITT uses surfactant techniques to measure the volume and describe the spatial distribution of subsurface DNAPL contamination zones.	Commercially available	Low technical implementability
		Diffusion bags	Diffusion bags are passive groundwater sampling devices that can be hung in wells to collect VOCs or other soluble contaminants. Semipermeable diffusion bags containing deionized water are allowed to equilibrate with surrounding groundwater and eventually reach the same concentrations of soluble constituents. The bags are sent to the vendor for analysis.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		Borehole fluxmeter	Groundwater flows through the PFM deployed in a well under natural gradient conditions. The interior composition of the PFM is a matrix of hydrophobic and hydrophilic permeable sorbents that retain dissolved organic and/or inorganic contaminants present in fluid intercepted by the unit. The sorbent matrix is also impregnated with known amounts of one or more fluid soluble resident tracers, which are leached from the sorbent at rates proportional to fluid flux.	Innovative/emerging	Technically implementable
		Ribbon NAPL Sampler	Direct sampling device that provides detailed depth discrete mapping of NAPLs in a borehole. The RNS has been deployed in the vadose and saturated zones.	Innovative/Emerging	Technically implementable in UCRS only
		DNAPL interface probe	Direct sampling device that detects DNAPL-water interface in groundwater monitoring wells.	Commercially available	Technically implementable.
Monitored Natural Attenuation	Monitoring and natural processes	Soil and groundwater monitoring; abiotic and biological processes	Natural processes including dilution, diffusion, dispersion, sorption, biodegradation, combined with monitoring.	Commercially available	Technically implementable
Removal	Excavators	Backhoes, trackhoes	Tracked excavators with 13.7-m (45-ft) arms limited to approximately 9.14 m (30 ft) bgs.	Commercially available	Technically implementable
		Vacuum excavation, remote excavator	Commercial vacuum excavators used for potholing, radioactive waste cleanup.	Commercially available	Technically implementable
		Crane and clamshell	Excavation at depths greater than 100 ft bgs possible.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
Containment	Hydraulic containment	Recharge controls	Recharge controls can reduce facility discharges to the UCRS, promote surface water run-off, and reduce recharge of the UCRS in the Southwest Plume TCE source areas, thereby limiting leaching of TCE from NAPL source areas and migration to the RGA.	Implements best management practices and equipment/materials.	Technically implementable
		Groundwater extraction	Groundwater pumping wells create a cone of depression in the piezometric surface, causing flow to the well and thereby a capture zone.	Commercially available	Yields of wells in the UCRS are too low to be technically implementable-retained only as a secondary technology for other treatments
	Surface barriers	RCRA Subtitle C cover	Multi-layer cover incorporating compacted clay and geosynthetics, used for RCRA hazardous waste landfill closures.	Commercially available	Technically implementable
		Concrete-based cover	Concrete cover systems may consist of a single layer of concrete pavement over a prepared subgrade to isolate contaminated soils, reduce infiltration, and provide a trafficable surface.	Commercially available	Technically implementable
		Conventional asphalt cover	Asphalt cover systems may consist of a single layer of bituminous pavement over a prepared subgrade to isolate contaminated soils, reduce infiltration, and provide a trafficable surface. Must be sealed and/or combined with a low-permeability membrane to effectively reduce permeability.	Commercially available	Technically implementable
		MatCon asphalt	MatCon™ asphalt has been used for RCRA Subtitle C-equivalent closures of landfills and soil contamination sites. MatCon™ is produced using a mixture of a proprietary binder and a specified aggregate in a conventional hot-mix asphalt plant.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		Flexible membrane	Single layers of relatively impermeable polymeric plastic (high-density polyethylene [HDPE] and others) laid out in rolls or panels and welded together. The resulting membrane cover is essentially impermeable to transmission of water unless breached. Flexible membranes can be sealed around surface infrastructure using waterproof sealants.	Commercially available	Technically implementable
	Subsurface horizontal barriers	Freeze walls	Constructed by artificially freezing the soil pore water, resulting in decreased permeability and formation of a low-permeability barrier. The frozen soil remains relatively impermeable and migration of contaminants is thereby reduced.	Commercially available	Technically implementable
		Jet grouting	Grouts are injected through drill rods to reduce infiltration of water. The jetted grout mixes with the soil form a column or panel.	Commercially available	No demonstrated technical implementability
		Permeation grouting	Low-viscosity grout is injected vertically or directionally at multiple locations into soil. Establishing and verifying a continuous, effective subsurface barrier is difficult or impossible in heterogeneous and/or low-permeability soils or in the presence of subsurface infrastructure.	Commercially available	Not technically implementable
	Subsurface vertical barriers	Slurry walls	Vertically excavated trenches that are kept open backfilled with a slurry, generally bentonite and water. Soil (often excavated material) is then mixed with bentonite and water to create a low-permeability soil-bentonite backfill.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		Sheet pilings	Long [e.g., 18.3 m (60 ft)] structural steel sections with a vertical interlocking system that are driven into the ground to create a continuous subsurface wall. After the sheet piles have been driven to the required depth, they are cut off at the surface. The subsurface soils must be relatively homogenous (i.e., no boulders) to allow for a uniform installation.	Commercially available	Technically implementable
		Permeable reactive barrier	Permeable reactive barriers (PRBs) are designed and constructed to permit the passage of water while immobilizing or destroying contaminants through the use of various reactive agents.	Commercially available	Technically implementable
Treatment	Biological	Anaerobic reductive dechlorination	ARD occurs when microbes utilize chloroethenes as terminal electron acceptors in metabolic processes. Saturated conditions are required.	Commercially available	Technically implementable
		Aerobic cooxidation	Aerobic cooxidation of TCE occurs when a microbe using a different organic compound as a carbon and energy source produces enzymes that fortuitously degrade a second compound without deriving energy or carbon for growth from that compound. Saturated conditions are required.	Commercially available	Technically implementable
		Phytoremediation	Phytoremediation exploits plant processes including transpiration and rhizosphere enzymatic activity to uptake water and dissolved-phase contaminants or to transform contaminants.	Commercially available	Not technically implementable due to depth of NAPL
	Physical/chemical	Soil vapor extraction	Removal of unsaturated zone air and vapor by applying vacuum. Can be implemented as dual-phase extraction where co-produced groundwater is also removed.	Commercially available	Technically implementable
		Air sparging	Promotes volatilization of VOCs in saturated zone by injecting air. Can be combined with SVE.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		Soil flushing	Promotes dissolution or desorption of VOCs in soil, may mobilize NAPLs by reducing interfacial tension. Can be applied *in situ* or *ex situ*.	Commercially available	Technically implementable
		Electrokinetics	Applied *in situ* as LASAGNA process.	Commercially available	Technically implementable
		Air stripping	Applied *ex situ* for secondary waste treatment.	Commercially available	Technically implementable
		Ion exchange	Applied *ex situ* for removal of cations or anions from aqueous secondary wastes.	Commercially available	Technically implementable
		Granular activated carbon	Applied *ex situ* for secondary aqueous waste or off-gas treatment.	Commercially available	Technically implementable
		Vapor condensation	Applied *ex situ* for secondary waste off-gas treatment.	Commercial availability uncertain	Technical implementability uncertain
		Soil fracturing	Potential adjunct technology for some *in situ* treatment, containment or removal technologies.	Commercially available	Technically implementable
		Soil mixing	Potential adjunct technology for some *in situ* treatment, containment or removal technologies.	Commercially available	Technically implementable
	Thermal	Catalytic oxidation	Applied *ex situ* for secondary vapor treatment.	Commercially available	Technically implementable
		Electrical resistance heating	Saturated or unsaturated soils are heated by applying current in subsurface, resulting in *in situ* steam stripping. VOCs and steam are recovered by SVE wells and treated. Can be implemented as 3-phase or 6-phase heating.	Commercially available	Technically implementable
		Thermal desorption	Soils are heated to volatilize VOCs, which are then treated. Applied *ex situ* for excavated waste treatment.	Commercially available	Technically implementable
		Steam stripping	*In situ* injection of steam.	Commercially available	Technically implementable
	Chemical	Permanganate	Injection of permanganate species in subsurface to oxidize VOCs. Does not act directly on NAPLs.	Commercially available	Technically implementable
		Fenton's reagent	Injection of hydrogen peroxide and ferrous iron in subsurface to oxidize VOCs. Does not act directly on NAPLs.	Commercially available	Technically implementable

Table A.1. Southwest Plume Source Areas Technology Screening (Continued)

General Response Action	Technology Type	Process Options	Description	Technology Status	Screening Comments
		ZVI	Dechlorination of chloroethenes by elemental iron. Applied *in situ* as permeable reactive treatment zone or barrier.	Commercially available	Technically implementable
		Ozonation	Injection of ozone gas in saturated zone to oxidize VOCs. Does not act directly on NAPLs.	Commercially available	Technically implementable
		Persulfate	Injection of sodium persulfate in soils to oxidize VOCs. Most effective when ferrous iron is added as a catalyst or when heated.	Commercially available	Technically implementable
		Redox manipulation	Dithionite injection, others to promote oxidation or reduction in saturated zone. Does not act directly on NAPLs.	Commercially available	Technically implementable
Disposal	Land disposal	Off-site permitted commercial disposal facility	Shallow land burial site for LLW, MLLW, and HW disposal option.	Commercially available	Technically implementable
		NTS	Shallow land burial site for LLW, MLLW, disposal option.	Commercially available	Technically implementable
		PGDP C-746-U Landfill	Existing on-site nonhazardous nonradioactive waste landfill.	Available	Technically implementable if WAC are met
	Discharge to groundwater	Within AOC after treatment	Allowed under CERCLA after treatment.	Available on-site; injection wells required	Technically implementable
	Discharge to surface water	Permitted outfall after treatment	Existing permitted outfalls for treated liquid effluents.	Available on-site	Technically implementable

Table A.2. Evaluation of Southwest Plume Source Area Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability		Relative Cost	
			Long-term effectiveness	Short-term effectiveness	Demon-strated effectiveness and reliability	Technical	Administra-tive	Capital	O&M
Land use controls	Institutional controls	E/PP program	Low-Only effective for duration of plant operations	High-effective at preventing worker exposures	High	High	High	Low	Low
Monitoring	Soil monitoring and/or characterization	Soil cores	High-effective at determining total TCE concentrations for compliance monitoring	Moderate-less effective for determining DNAPL distribution	Moderate for locating DNAPL	High	High	High-off-site analysis required	NA
		Membrane interface probe	Low-not useful for compliance monitoring	High-effective for determining NAPL distribution	Moderate	High	High	Low	NA
		Soil vapor sampling	High-effective in determining progress of remedy	High-effective for determining NAPL distribution	Moderate	High	High	Moderate	NA
		Soil moisture sampling	High-can measure actual TCE pore water concentrations	High-effective for determining NAPL distribution	Moderate	High	High	Low	Low

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability		Relative Cost	
			Long-term effectiveness	**Short-term effectiveness**	**Demon-strated effectiveness and reliability**	**Technical**	**Administra-tive**	**Capital**	**O&M**
		Gore-sorbers	Low-not useful for compliance monitoring	High-effective for determining NAPL distribution	Moderate	High	High	Low	NA
		Raman spectroscopy	Low-not useful for compliance monitoring	High-effective for determining NAPL distribution	High for locating NAPL	Moderate	High	High	NA
	Groundwater monitoring	Sampling and analysis	High-commonly used for compliance monitoring	High-effective for determining NAPL distribution	High	High	High	High	High
		Diffusion bags	High-may be useful for compliance monitoring	High-effective for determining NAPL distribution	Moderate	High	High	Moderate	NA
		Borehole fluxmeter	Low-not useful for compliance monitoring	High-effective for determining NAPL distribution	Low	High	High	Moderate	NA
		Ribbon NAPL Sampler	Low-not useful for compliance monitoring	High-effective for determining NAPL distribution	Low	High	High	High-FLUTe liner installation required	NA

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability		Relative Cost	
			Long-term effectiveness	Short-term effectiveness	Demon-strated effectiveness and reliability	Technical	Administra-tive	Capital	O&M
		DNAPL interface probe	High-may be useful for compliance monitoring	High-useful for determining effects of treatment on DNAPL mobilization	High	High	High	Low	Low
Monitored Natural Attenuation	Monitoring and natural processes	Soil and groundwater monitoring; abiotic and biological processes	Potentially high for dissolved-phase VOCs	High	Potentially high for dissolved-phase VOCs	High	High	Low	Moderate
Removal	Excavators	Backhoes, trackhoes	High-remove source to 9.14 to 12.2 m (30-40 ft) bgs	Moderate-risks to workers in excavation	High	High	High	Low	Low
		Vacuum excavation, remote excavator	High-remove source to 9.14 to 12.2 m (30-40 ft) bgs	High-lower worker risks	High	High	High	Moderate	Moderate
		Crane and clamshell	High-remove source to > 30 m (100 ft) bgs	Moderate-more technically complex; hoisting and rigging concerns	High	Moderate	Moderate	High	High
	Groundwater extraction	Pumping wells	Low for DNAPL	High for groundwater control during implement-tation	Low for DNAPL	Low in UCRS	Moderate-discharge or reinjection required	High-well installation costs	High-continuous operating costs
Containment	Hydraulic containment	Recharge controls	Potentially high	High	Potentially high	High	High	Low	Low

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implement ability	Relative Cost		
			Long-term effectiveness	**Short-term effectiveness**	**Demon-strated effectiveness and reliability**	**Technical**	**Administra-tive**	**Capital**	**O&M**
		Groundwater extraction	Low in UCRS	Moderate	Low in UCRS	Low in UCRS	Moderate-discharge or reinjection required	High-well installation costs	High-continuous operating costs
	Surface barriers	RCRA Subtitle C cover	Potentially high	High	Moderate	Low	High	High-complex construction	Moderate-ongoing maintenance and monitoring required
		Concrete-based cover	Low-prone to cracking	High	Low-prone to cracking	Moderate	High	High	High
		Conventional asphalt cover	Low-relatively permeable	High	Low-relatively permeable	High	High	Low	Moderate
		Low-permeability asphalt	High	High	High	Moderate	High	Moderate	Moderate
		Flexible membrane	Potentially high	High	Moderate-must be protected from damage	High	High	Moderate	Low
	Subsurface horizontal barriers	Freeze walls	Low-effectiveness can't be readily monitored	Low-installation of pipes brings contaminated materials to surface	Low-few applications	Low	Moderate	High	High-energy and refrigerant costs
Treatment	Biological	Anaerobic reductive dechlorination	Uncertain for DNAPL; potentially high for dissolved-phase VOCs	Moderate	Moderate	Low	Moderate-discharge or reinjection required	Low	Low

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implement ability	Relative Cost		
			Long-term effectiveness	**Short-term effectiveness**	**Demon-strated effectiveness and reliability**	**Technical**	**Administra-tive**	**Capital**	**O&M**
		Aerobic cooxidation	Uncertain for DNAPL; potentially high for dissolved-phase VOCs	Moderate	Moderate	Low	Moderate-discharge or reinjection required	Moderate	Moderate
	Physical/chemical	Soil vapor extraction-*in situ*	Moderate-High Presumptive remedy for VOCs in soil; treats all phases	High	Moderate	High	High	Moderate-extraction well installation	Moderate-ongoing energy costs, long duration
		Air sparging-*in situ*	Moderate to high for dissolved-phase; must be combined with SVE	High	Moderate	High	High	High-extraction well installation	High-ongoing energy costs, long duration
		Soil flushing-*in situ*	Uncertain	Moderate	Low	Low	Low-amendment injection required	High-formulation and injection of surfactants or other amendments	None
		Electrokinetics-*in situ*	High-demonstrated at PGDP	Low	High	Moderate	High	High	High, short duration
		Hydrofracturing-*in situ*	Uncertain; potentially high	Moderate	Low	Low	Moderate	Moderate	None
		Soil mixing- *in situ*	Potentially high; can treat all VOC phases	Moderate	Low	Moderate	Moderate	High	Varies depending on application
		Air stripping-*ex situ*	High	High	High	High	Moderate-air emissions	Moderate	Moderate-ongoing energy costs

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implement ability	Relative Cost		
			Long-term effectiveness	Short-term effectiveness	Demon-strated effectiveness and reliability	Technical	Administra-tive	Capital	O&M
		Ion exchange-*ex situ*	High	High	High	High	High	Low	Moderate-ongoing secondary waste treatment and disposal
		Granular activated carbon-*ex situ*	High	High	High	High	High	Low	High-ongoing carbon replacement costs
		Vapor condensation	Uncertain; potentially high	Low-few vendors available	Low	Uncertain	Uncertain	High	High
	Thermal	Catalytic oxidation-*ex situ*	High	High	High	Moderate	High	High	Moderate-ongoing energy costs
		Electrical resistance heating-*in situ*	High-demonstrated at PGDP	High; *in situ* process	High	High	Moderate-air emissions	Moderate	High energy costs during implement-ation; none after completion
		Thermal desorption-*ex situ*	High	Moderate; soil must be excavated	High	High	Moderate-air emissions	High	High energy costs during implement-ation; none after completion
		Steam stripping-*in situ*	High	Moderate; soil must be removed	Moderate	Moderate	Moderate-air emissions	High	High energy costs during implement-ation; none after completion

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability	Relative Cost		
			Long-term effectiveness	**Short-term effectiveness**	**Demonstrated effectiveness and reliability**	**Technical**	**Administrative**	**Capital**	**O&M**
	Chemical	Permanganate-*in situ*	Uncertain for DNAPLs	Uncertain; treatability study needed	Uncertain for DNAPLs	Low in UCRS	Low-amendment injection required	Moderate	Low; primarily monitoring
		Fenton's reagent-*in situ*	Uncertain for DNAPLs	Uncertain; treatability study needed	Uncertain for DNAPLs	Low in UCRS	Low-amendment injection required	Moderate	Low; primarily monitoring
		ZVI-*in situ*	Uncertain for DNAPLs	Moderate	Uncertain for DNAPLs	Low in UCRS	Low-amendment injection required	High	Low; primarily monitoring
		Ozonation-*in situ*	Uncertain for DNAPLs	Uncertain; treatability study needed	Uncertain for DNAPLs	Low in UCRS	Low-amendment injection required	Low	Moderate; continuing operation of sparge system and monitoring required
		Sodium persulfate- *in situ*	Uncertain for DNAPLs	Uncertain; treatability study needed	Uncertain for DNAPLs	Low in UCRS	Low-amendment injection required	Moderate	Low; primarily monitoring
		Redox manipulation-*in situ*	Uncertain for DNAPLs	Uncertain; treatability study needed	Uncertain for DNAPLs	Unknown	Low-amendment injection required	High	High; longer term O&M
	Monitored Natural Attenuation	Monitoring and natural processes	Low for NAPL	High	Low for NAPL	High	Low-inadequate for DNAPL	Low	Moderate

Table A.2. Evaluation of Southwest Plume Source Area Process Options (Continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability	Relative Cost		
			Long-term effectiveness	Short-term effectiveness	Demonstrated effectiveness and reliability	Technical	Administrative	Capital	O&M
Disposal	Land disposal	Off-site permitted commercial disposal facility	High	Moderate-long-distance transportation required	High	High	High	High	None
		On-site C-746-U Landfill	High	High	High	High	High	Low	None-long-term monitoring and maintenance not paid by program
	Discharge to groundwater	Within AOC after treatment	High	Moderate	Moderate	High	Low-groundwater injection required	Low	None
	Discharge to surface water	Permitted outfall after treatment	High	High	High	High	Moderate	Moderate	None

APPENDIX B

CONCEPTUAL DESIGN CALCULATIONS AND COST ESTIMATES

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Form WCE-F-0036
CALCULATION COVER SHEET

Project Title Southwest Plume Focused Feasibility Study **Job No.** PRS-BA-061

Area SW Plume

Discipline Environmental Restoration ***Calc. No.** CAV-0000ES-P010

Subject Alternative #4 Calculation for the SW Plume Feasibility Study

Computer Program Microsoft Office Excel 2007 **Program No.**

Committed Calculation **Preliminary** x **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
0	1	J. Keck	G. McManus	J. Keck	J. Keck	09/24/08
0	2-4	H. Guerrero	G. McManus	J. Keck	J. Keck	09/24/08
0	5-6	J. Keck	G. McManus	J. Keck	J. Keck	09/24/08
0	7-14	J. Towers	G. McManus	J. Keck	J. Keck	09/24/08
1	1-6	J. Keck	G. McManus	J. Keck	J. Keck	11/06/08
1	7-14	J. Towers	G. McManus	J. Keck	J. Keck	11/06/08
2	1-6	J. Keck	G. McManus	J. Keck	J. Keck	03/27/09
2	7-19	J. Towers	G. McManus	J. Keck	J. Keck	03/27/09
3	1-19	J. Towers	J. Keck	J. Keck	J. Keck	06/29/09
4	1-18	J. Towers	T. Poat	T. Poat	T. Poat	07/01/09
5	1-20	J. Towers	A. Montgomery	A. Montgomery	A. Montgomery 12/10/09	12/03/09

SUMMARY OF REVISION

Rev. 1 Incorporates resolutions to comments on D-1 FS. Primary changes are revised source area dimensions.

Rev. 2 Incorporated resolutions to additional comments by DOE on D0 FFS regarding remediation goals and monitoring.

Rev 3 Incorporates revisions to G&A, fee, escalation, scope details pursuant to DOE review .

Rev 4 Incorporates revisions to G&A, fee, escalation, and schedule pursuant to DOE review.

Rev 5 Incorporates resolutions to comments by EPA and KY on D1 including present worth analysis

Microfilmed	Rev.	Date	Reel No.	Rev.	Date	Reel No.

*Obtain Calculation Number from Engineering Manager
WCE-F-0036 (8-06) PRS-WCE-1026 Rev. 0

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Form WCE-F-0034
CALCULATION LOG

Discipline Environmental Restoration Page No. 1

Project Southwest Plume Focused Feasibility Study Job No. **NA**

Calculation Number	Subject	Originator and Date	Type*		
			C	P	S
CAV-0000ES-P010	Alternative #4 Calculation for the SW Plume Feasibility Study	J. Towers 11/23/09		x	

*C = Committed P = Preliminary S = Superseded

WCE-F-0034 (8-06) PRS-WCE-1026 Rev. 0

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Form WCE-F-0035
CALCULATION SHEET

Originator Jeff Towers Date 11/23/09 Calc. No. CAV-0000ES-P010
Rev. No. 5

Project SW Plume Focused Feasibility Study Job No. Checked [signature] Date 12/10/09

Subject Alternative # 4 for SW Plume Focused Feasibility Study Sheet No. _____

Cost Summary Sheet in 2009 Dollars

Alternative 4 Cost Summary			
	Cost in unescalated $	Cost in escalated $	Present Value $
RAWP Documents	239,944	254,557	239,944
Engineering & Design	355,372	388,325	355,372
Characterization	1,475,109	1,564,943	1,475,109
System Construction	3,553,720	3,999,712	3,553,720
Confirmation Sampling	439,625	573,622	439,625
Total Construction	**6,063,770**	**6,781,159**	**6,063,770**
O&M costs for 5 yrs	**6,199,373**	**7,694,654**	**6,299,280**
O&M costs for 30 yrs	7,790,915	10,891,015	6,667,583
Total Cost	13,854,685	17,672,174	12,731,353
Total Cost with 25%	**19,188,254**	**24,475,342**	**17,632,478**

Acronyms used in Alternative 4

bcy	bank cubic yards
BGOU	Burial Grounds Operable Unit
cy	cubic yards
DPP	Dissolved Phase Plume
DPT	direct push technology
FRTR	Federal Remediation Technology Roundtable
ft	foot
ID	inside diameter
lf	linear foot
RI	remedial investigation
RI/FS	remedail investigation/feasibility study
sy	square yard
TCE	trichloroethylene
Tc-99	technetium 99
ug/l	micrograms per liter
VOC	volatile organic compound

12/10/09

SW PLUME CONCEPTUAL DESIGN CALCULATIONS						
Alternative 4-Soil Vapor Extraction, Containment and Institutional Controls						
8/13/2008						
Conversions						
cf per cy	27					
sf per acre	43560					
Parameter	**Units**	**SWMU 1**	**C-720 NE**	**C-720 SE**	**Total**	**Basis**
Recharge Controls						
Rain gutters on C-720	lf	0			1110	Quantity take-off from Drawing 3-3; perimeter of C-720 east end inside study area
Lining ditches						
40-mil FML	lf	1340	0	0	1340	- Quantity take-off from Drawing 3-3. - Assumes Polyflex HDPE smooth geomembrane or equivalent, http://www.poly-flex.com
40-mil FML	sf	11720	0	0	11720	Assumes 5-ft wide ditches, 1.5 ft deep, triangular cross-section. Includes 1.5x overage for anchor trenches. No ditches identifed in SWOU SI BRA for C-720 area.
Channel protection	cy	145	0	0	145	Assumes single lift of NSA R-3 riprap (nominal 4-in thickness)
Inspection, metering and repair of water lines						
Slip lining (or replacement)						Quantity take-offs from Drawing 3-3
Sanitary water	lf	0	273	157	430	Assume 16-in
Storm sewer	lf	0	309	370	679	Assume 16-in
RCW	lf	0	341	0	341	Assume 10-in
Trenching	bcy				1346	Assumes 341-ft ditch 3-ft deep, 3-ft wide (10-in lines) plus 1109-ft ditch 5-ft deep, 6-ft wide (16-in lines)
Surface covers						
Concrete demo	cy				755	Assumes capped area for C-720 (50,830 sf) and concrete thickness of 6-in
Capped area	sf	45890	20400	20380	86670	Quantity take-offs from Figure 3-2 and 3-3.
Asphalt thickness	ft	0.33	0.33	0.33	NA	Quantity take-off from Figure 3-1.
Asphalt volume	cy	567	252	252	1070	
Aggregate thickness	ft	0.67	0.67	0.67	NA	Quantity take-off from Figure 3-1.
Aggregate volume	cy	1133	504	503	2140	
FML thickness	mil	40	40	40	NA	- Quantity take-off from Figure 3-1. - Polyflex HDPE smooth geomembrane or equivalent, http://www.poly-flex.com
Cap Perimeter	ft	900	580	600	2080	Quantity take-offs from Figure 3-2 and 3-3.
FML area	sf	49490	22720	22780	94990	
Geosynthetic drainage layer thickness	mil	250	250	250	NA	- Quantity take-off from Figure 3-1. - Polyflex GN-200 or equivalent
GDL area	sf	49490	22720	22780	94990	
Grading fill	cy	1700	756	755	3210	Assumes 1-ft average thickness over capped area; assume silt or sand loam soil
Soil and Groundwater Monitoring						
Neutron probe access tubes	ea	13	8	8	29	- Assumes 8/acre inside + 4 outside per area; would be defined in RD/RAWP. - 2 in aluminum tubes
	lf	780	480	480	1740	
Neutron probe	ea				1	- Assumes Troxler Model 4300 Soil Moisture Gauge - http://www.troxlerlabs.com/PRODUCTS/4300.shtml
Piezometers	ea	13	8	8	29	- Assumes 8/acre inside + four outside per area; would be defined in RD/RAWP. - 2 in PVC w/stainless screens. - Assumes e-line is available and purchase not required.
	lf	780	480	480	1740	
Operations and Maintenance						
Quarterly neutron probe logging						Assume 2 people 1 day
Quarterly piezometer water level measurements						Assume 2 people 1 day
Biannual asphalt surface fog seal	sf	45890	20400	20380	86670	Every other year

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SW PLUME CONCEPTUAL DESIGN CALCULATIONS
Alternative 4-Dual-Phase Soil Vapor Extraction
8/11/2008

Conversions	
cm^3 per ft^3	28316.8
mg per g	1000
Pa per atm	101325
psi per atm	14.69
gal per ft^3	7.48

Equations

$$Q = \frac{\pi H k P_w}{\mu} \frac{\left[1 - (P_a/P_w)^2\right]}{\ln(R_w/R_i)}$$ Eq 1) Source: EPA/5040/2-91/003, pp 205

$$C = \frac{x P_v MW}{RT}$$ Eq 2) Source: EPA/5040/2-91/003, pp 201

$$D = D^o \frac{\varepsilon_a^{3.33}}{\varepsilon^2}$$ Eq 3) Source: EPA/5040/2-91/003, pp 209

$$\eta = \frac{(6D\mu/k)^{1/2}}{3H}\left[\frac{\ln(R_i/R_w)}{P_a - P_w}\right]^{1/2}\left(R_2^2 - R_1^2\right)^{1/2}$$ Eq 4) Source: EPA/5040/2-91/003, pp 207

$$C_{eff} = \eta C$$ Eq 5)

$$HP = \frac{Q\Delta P}{229n}$$ Eq 6) Source: Engineers Edge

$$A = 2\pi r h$$ Eq 7)

$$\frac{Q_1}{A_1} = \frac{Q_2}{A_2}$$ Eq 8) Source: Freeze and Cherry (1979), *Groundwater*, Eq. 2.1, for specific discharge, where $v_1 = v_2$; used to scale pump test flow rates (Q) to larger diameter wells based on relative screen areas (A).

$$HP = \frac{h_a Q S}{3960n}$$ Eq 9) Source: Engineers Edge

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SW PLUME CONCEPTUAL DESIGN CALCULATIONS
Alternative 4-Dual-Phase Soil Vapor Extraction
8/11/2008

Variables	Symbol	Value	Units	Basis
Screened well interval	H	914.4	cm	Assumed screened well interval of 30 ft
Permeability	k	9.87E-09	cm^2	Assumed permeability of 1 darcy
Absolute pressure at SVE well	P_w	9.35E+05	$g/cm\text{-}s^2$	Average value EPA/5040/2-91/003, pp 205
Absolute ambient pressure	P_a	1.01E+06	$g/cm\text{-}s^2$	EPA/5040/2-91/003, pp 205
Dynamic viscosity of air	μ	1.80E-04	g/cm-s	EPA/5040/2-91/003, pp 205
Radius of SVE well	R_w	5.08	cm	Design parameter of 4-in schedule 40 PVC piping
Radius of influence	R_i	762	cm	Assumed 25-ft radius of influence
Mole fraction of TCE	x	1		Assumed TCE only
Vapor pressure of TCE	P_v	0.026	atm	EPA/5040/2-91/003, pp 202
Molecular weight of TCE	MW	131.5	g/mole	EPA/5040/2-91/003, pp 202
Universal gas constant	R	0.0821	L-atm/mole-K	
Operating Temperature	T	293.15	K	Assumed standard temperature of 20 C
Molecular diffusion coefficient	D^o	0.079	cm^2/sec	Chemical and Physical Properties Database, 08/05/08
Effective porosity	ε_a	0.3		SI Appendix F, Table F.15
Porosity	ε	0.45		SI Appendix F, Table F.14
Upper region of contamination	R_1	0	cm	Assumed region of contamination of 30 ft
Lower region of contamination	R_2	914.4	cm	Assumed region of contamination of 30 ft
Pressure drop over blower	ΔP	1.1	psi	
Blower efficiency	n	75%		
Test well radius	r_1	0.17	ft	(Bruce Philips, personal communication, 7/18/08)
SVE well radius	r_2	0.33	ft	Design parameter of 4-in schedule 40 PVC piping
Test well filter pack height	h_1	10	ft	(Bruce Philips, personal communication, 7/18/08)
SVE well filter pack height	h_2	40	ft	Design parameter of 40-ft filter pack
Test well flow rate	Q_1	0.19	gal/min	(Bruce Philips, personal communication, 7/18/08)
Hydraulic head	h_a	60	ft	Assumed depth to RGA
Specific gravity of water	S	1		

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SW PLUME CONCEPTUAL DESIGN CALCULATIONS
Alternative 4-Dual-Phase Soil Vapor Extraction
8/11/2008

Parameter	Units	SWMU 1	C-720 NE	C-720 SE	Total	Basis
Characterization of DNAPL Source Area						
Area of contaminated soil	acre	0.1	0.3	0.2	0.6	Quantity taken from Figure 3.2
Soil gas analysis	ea	0	10	10	20	Assume 10 samples per acre of contaminated soil
Soil core analysis	ea	0	40	40	80	Assume 10 locations per acre of contaminated soil and 4 samples per location
Geodetic Survey	ea	1	1	1	3	
Air permeability test	ea	1	1	1	3	
Soil Vapor Extraction						
Air flow rate per well (Q)	cm^3/s	4904	4904	4904	NA	Eq 1
Air flow rate per well	ft^3/min	10	10	10	NA	
Theoretical TCE vapor concentration (C)	mg/L	142	142	142	NA	Eq 2
Soil vapor diffusion coefficient (D)	cm^2/sec	0.0071	0.0071	0.0071	NA	Eq 3
Soil venting efficiency (η)	%	7.6	7.6	7.6	NA	Eq 4
Effective TCE vapor concentration (C_{eff})	mg/L	11	11	11	NA	Eq 5
Rqd no. wells	ea	6	2	4	12	Quanitity taken from Figure 3.8 and 3.9
Rqd. no. well vaults	ea	0	2	4	6	Required for subsurface well completion at C-720 sites
Rqd total flow	ft^3/min	62	21	42	NA	
Blower Power	HP	0.4	0.1	0.3	NA	Eq 6
Test well area (A_1)	ft^2	11	11	11	NA	Eq 7
SVE well area (A_2)	ft^2	84	84	84	NA	Eq 7
Water flow rate per well	gpm	1.5	1.5	1.5	NA	Eq 8
Rqd. No. submersible pumps	ea	6	2	4	12	
Submersible pump Power	HP	0.03	0.03	0.03	NA	Eq 9
3-Day water storage	gal	6494	6494	6494	19482	
Groundwater storage tank capacity	gal	7500	7500	7500	22500	
Groundwater transfer truck	ea			1		Will service all three sites
Off-Gas Treatment						
Catalytic Oxidation Unit	ea	1	1	1	3	

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Site Dimensions		
Site	Attainment area, sf	Capped area for Alt 4, sf
SWMU 1	5810	45890
C-720 SE	3340	20380
C-720 NE	1300	20400

Characterization frequency and depth			
Characterization method	Frequency		Units
MIP/soil core sampling location (xy) frequency	1 location per	200	sf
MIP/soil core depth interval	1 sample per	5	ft
Soil gas location (xy) frequency	1 location per	2000	sf
MIP max depth	TD	100	ft
Soil coring max depth	TD	60	ft
RGA well max depth	TD	70	ft

Numbers of measurements or locations per alternative			
Characterization method	Alternative		
	1	4	5
Dedicated SGS			
SWMU 1 (xy)	0	23	0
SWMU 1 (depths per xy location)		4	
C-720 SE (xy)	0	10	0
C-720 SE (depths per xy location)	0	4	0
C-720 NE (xy)	0	10	0
C-720 NE (depths per xy location)	0	4	0
MIP			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
Preliminary Soil Cores			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
Confirmatory Soil Cores			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
RGA wells			
SWMU 1	0	4	4
C-720 SE	0	4	4
C-720 NE	0	4	4

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Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Project Plans												
Remedial Action Work Plan												
	Labor - D-1						560	67.4	37,744	37,744		Labor rate is an average rate based on seven recent plans (total cost for the plans/total hours) including work plans, RI/FS, etc. with costs through 2008 (Paducah Cost Documents)
	Labor - D0						420	67.4	28,308	28,308		
	Labor - D1						210	67.4	14,154	14,154		
	Labor - D2						210	67.4	14,154	14,154		
Health and Safety Plan												
	Labor - D-1						100	67.4	6,740	6,740		
	Labor - D0						40	67.4	2,696	2,696		
	Labor - D1						40	67.4	2,696	2,696		
	Labor - D2						40	67.4	2,696	2,696		
Security Plan												
	Labor - Draft						80	67.4	5,392	5,392		
	Labor - D0						40	67.4	2,696	2,696		
QA Plan												
	Labor - D-1						240	67.4	16,176	16,176		
	Labor - D0						180	67.4	12,132	12,132		
	Labor - D1						80	67.4	5,392	5,392		
	Labor - D2						80	67.4	5,392	5,392		
Sampling and Analysis Plan												
	Labor - D-1						210	67.4	14,154	14,154		
	Labor - D0						160	67.4	10,784	10,784		
	Labor - D1						80	67.4	5,392	5,392		
	Labor - D2						80	67.4	5,392	5,392		
Waste Management Plan												
	Labor - D-1						120	67.4	8,088	8,088		
	Labor - D0						60	67.4	4,044	4,044		
	Labor - D1						60	67.4	4,044	4,044		
	Labor - D2						60	67.4	4,044	4,044		
LUCIP	Labor - D0						210	67.4	14,154	14,154		
	Labor - D1						100	67.4	6,740	6,740		
	Labor - D2						100	67.4	6,740	6,740		
									Plan Costs	239,944		
									Escalated	254,557		2011 dollars

Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Engineering and Design												10% of total construction cost
30% design			1	lump sum	98,000.00	98,000.00				142,149		40% of the 10%
60% design			1	lump sum	61,250.00	61,250.00				88,843		25% of the 10%
90% design			1	lump sum	61,250.00	61,250.00				88,843		25% of the 10%
Final Design			1	lump sum	24,500.00	24,500.00				35,537		10% of the 10%
									Design Costs	355,372		
									Escalated	388,325		2012 dollars
Soil Characterization and Monitoring												
MIP Sampling	equipment		13	day	7,000.00	91,000.00				91,000		MIP rig and onsite lab,from Cluin.org
	labor						80	75	6,000	6,000		MIP report
	excavation permits		53	each	360.00	19,080				19,080		Paducah Cost Documents
	civil survey		53	each	282.00	14,946				14,946		Elevations and coordinates, Paducah Cost Documents
	H&S		1				140	67	9,387	9,387		
	Radcon		1				140	38	5,278	5,278		
	escort		1				140	31	4,350	4,350		For subcontractor personnel
Excavation permits - preparation and finalization			1	115	350	41,400				41,400		44 soil gas locations, 53 preliminary soil cores, 12 dual-phase wells, 3 capping excavations (Paducah Cost Documents)
Civil survey			2	115	282	32,430				32,430		elevations and coordinates for above permits (Paducah Cost Documents)

Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Soil cores												
	analysis		1060	each	235	249,100				249,100		VOCs and Tc-99, USEC lab (Paducah Cost Documents DPP)
	labor						212	57.4	12,169	12,169		2 samplers, 4 cores/day, 13.25 days (53 cores) (Paducah Cost Documents DPP)
	equipment		20	each	565	11,300				11,300		split samplers, Forestry Suppliers
	DPT		3180	lf	40	127,200				127,200		53 cores to 60', (Paducah Cost Documents BGOU RI)
Soil gas												
	excavation permits		43	each	360	15,480				15,480		Paducah Cost Documents
	civil survey		43	each	282	12,126				12,126		Paducah Cost Documents
	DPT		2580	lf	40	103,200				103,200		Direct push technology labor and equipment to install 43 soil gas positions to 60' (2700 lf), 4 positions a day (Paducah Cost Documents BGOU RI)
	monitoring points		172	each	16.9	2,907				2,907		Forestry Suppliers, 43 positions, 4 depths
			7095	lf	2.28	16,177				16,177		McMaster-Carr teflon tubing 3/8" ID (43 points, 165'/point)
	labor - sampling			each			192	41.2	7,910	7,910		assume 4 positions (16 samples)/day, 12 days of sampling, 2 samplers
	analysis		172	each	450	77,400				77,400		evacuated cannisters provided by lab
	sample shipping		58	each	60	3,480				3,480		assume 3 Summa cannisters/shipment
Soil moisture monitoring												
	equipment		1	each	10000	10,000				10,000		Troxler 4300
	excavation permits		58	each	360	20,880				20,880		Paducah Cost Documents
	civil surveys		58	each	282	16,356				16,356		Paducah Cost Documents
			1740	lf	1.34	2,332				2,332		2" PVC soil moisture monitoring points, 29 positions, 60' deep
			1740	lf	24.33	42,334				42,334		2' Schd 40 aluminum pipe for neutron measurements, 29 positions, 60' deep (McMaster Carr)
	DPT		3480	lf	40	139,200				139,200		2" PVC pushed to 60' and 2" aluminum pipe pushed to 60', 4 monitoring points per day
Install RGA wells												Well costs are actuals from SWOU RI
	drilling		840	lf	94	78,960				78,960		
	well installation		12	each	17974	215,688				215,688		Costs include installation, surveying, permit, waste
	gw sampling		24	each	1250	30,000				30,000		2 samples/yr for 12 wells, analysis and labor included
	Data management		1	Lump sum	57040	57,040				57,040		Data management costs of 16% of analysis costs (Paducah Cost Documents)
									Total	1,475,109		Characterization costs
									Escalated	1,564,943		2011 dollars

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Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
System Construction												
Temporary decon pad and tear down			1	lump sum	100000	100,000				100,000		For construction equip. and drill rig, demolition waste disposal on-site (U-landfill), includes labor, materials, and waste certification documentation for disposal
Mob/demob of drill rig			1	lump sum	44335	44,335				44,335		Includes cost of standard per diem for 3 man drill crew for 15 wks and drill rig travel to and from Paducah (Paducah Cost Documents) based on 1 wk drilling and well development time per well
Contstruction trailer			6	month	1000	6,000				6,000		Includes cost of delivery, setup, furniture rental, and return (44'x12')(Williams Scotsman, Inc., Hamilton, Ohio)
Change Trailer			6	month	1200	7,200				7,200		Includes cost of delivery, setup, and return (Williams Scotsman, Inc., Hamilton, Ohio)
Recharge Controls												
Install rain gutters and downspouts on C720			1110	ft	13164.76	13,165				13,165		R.S. Means
Line ditches			11720	sf	1.1	12,892				12,892		R.S. Means
Place riprap			145	cy	648	93,960				93,960		R.S. Means - placement & material

Altemative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Water Line Removal and Reroute												
Remove lines in C-720 NE & SE Areas												For estimating purposes it is assumed all water and storm drains in the areas will be replaced.
RCW lines - 10"			341	lf								
Sanitary - 16"			430	lf								
Storm drain - 16" (?)			679	lf								
Trenching			1346	bcy	7.23	9,732				9,732		R.S. Means
Removal of piping												
	laborers		2				160	29.41	4,706	4,706		KY prevailing wage
	fitters		2				160	41.53	6,645	6,645		KY prevailing wage
	operator and excavator		1				80	185	14,800	14,800		GE equip.rental + operator prevailing wage
Replacement of piping												
	laborers		2				320	29.41	9,411	9,411		
	fitters		2				320	41.53	13,290	13,290		
	operator and excavator		1				160	185	29,600	29,600		
	pipe - 16"		44	sections	4167	183,348				183,348		FastFab Pipe, Louisville, KY
	flange - 16"		46	each	647	29,762				29,762		FastFab Pipe
	pipe - 10"		20	sections	1724	34,480				34,480		FastFab Pipe
	flange - 10"		22	each	224	4,928				4,928		FastFab Pipe
	pipe - 8"		6	sections	1638	9,828				9,828		FastFab Pipe
	flange - 8"		8	each	159	1,272				1,272		FastFab Pipe
Install Surface Covers												
Concrete demo			755	cy	125.35	94,639				94,639		R.S. Means
Grade and level surface			86670	sf	2.1	182,007				182,007		R.S. Means
Place fill			3210	cy						0		1' thickness over cap, price included in grade and level surface
Place geosynthetic liner			94990	sf	1.1	104,489				104,489		scaled from current Colstrip work
Place aggregate			2140	cy	18	38,520				38,520		8" layer, R.S. Means
Place asphalt			1070	cy	107	114,490				114,490		quote from Eddy @ Central Paving, Paducah
Asphalt sealing			86670	sf	0.17	14,734				14,734		Asphalt Maintenance, Inc. - today's price for GSB-78

Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Soil Vapor Extraction												
	installation of 12 dual-phase wells		720	ft	300	216,000				216,000		Current well installation including waste costs and abandoment, 12 wells to 60' (Paducah Cost Documents (C-400))
	well vaults		6	each	2000	12,000				12,000		Install vaults for well in Bldg. 720 area
	connection to Cat-Ox unit with PVC - 6"		2500	ft	7.76	19,400				19,400		McMaster-Carr
	2" PVC for water from wells and knockout pot		2500	ft	1.24	3,100				3,100		McMaster-Carr
	PVC fittings		1	lump sum	3375	3,375				3,375		15% of piping cost for fittings
	labor						192	41.53	7,974	7,974		Fitter for PVC, includes connections at well heads, piping, and treatment skids (16 hrs per well (12 wells))
	labor						192	27.25	5,232	5,232		Fitter's helper
	labor						120	40.32	4,838	4,838		Electrician to connect pumps and controllers at each well head (12 wells) and connect the treatment skids at each area (SWMU-1, 720 NE, 720 SE) 8 hrs for each well and treatment unit (8 x 15 = 120 hrs)
	labor						120	27.25	3,270	3,270		Electrician's helper
	conduit		2500	ft	4.33	10,825				10,825		3/4" waterproof flexible conduit and fittings (10% allowance for fittings), McMaster-Carr
	wire		2500	ft	2.43	6,075				6,075		No.10, 3-conductor power cable and N0.18 2-conducto alarm cable, McMaster-Carr
	water tanks		3	each	6500	19,500				19,500		10,000-gal storage tanks at each treatment area (SWMU-1, 720 NE, 720 SE) (WaterTanks.com - price includes shipping), for storage of well and knockout pot water for treatment at site with treated water discharge to storm sewer
	co-produced groundwater treatment equipment		3	each	47,000	141,000				141,000		50 gpm, tray-type, air stripper for removal of TCE; ion exchange column to remove any Tc-99, granular activated carbon for off-gas treatment (FRTR)
	Catalytic-oxidation unit, 250 scfm, propane-fired		3	each	112500	337,500				337,500		Treatment of vapor-phase from soil vapor extraction, Enviro-Equipment, Inc. - Global Remdicat unit
Groundwater pumps & controller			12	each	5486.5	65,838				65,838		Grundfos Redi-Flo2 and Variable Frequency Drive
	labor						120	42.25	5,070	5,070		Fitter and electrician for pump installation
Professional labor												
	labor						2080	98.17	204,194	204,194		PM Level IV

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Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
							2080	83.93	174,574	174,574		Geologist Level III
							2080	67.05	139,464	139,464		Health & Safety Level II
							2080	67.05	139,464	139,464		Site Superintendent Level II
							2080	37.7	78,416	78,416		2 Radcon techs for 6 months
							4160	31.07	129,251	129,251		4 escorts for 6 months
Construction and 1st year operating report												
	labor - D-1						320	67.4	21,568	21,568		
	labor - D0						200	67.4	13,480	13,480		
	labor - D1						100	67.4	6,740	6,740		
	labor - D2						100	67.4	6,740	6,740		
Fracturing - a possible option to increase SVE efficiency would be the pneumatic fracturing of the contaiminated soil to allow for more area of influence for vapor extraction			50050	ton	12	600,600				600,600		Based on 26,943 bank cubic yds of contaminated soil, 3400 lb/yd, and 2000 lb/ton and $12/ton fracturing costs in the UCRS soils (www.frtr.gov)
									Total	3,553,720		2009 dollars
									Escalated	3,999,712		2013 dollars (since construction ends in 2013)
O&M Costs for the 1st year												
	O&M of groundwater treatment system		1	lump sum	55,966	55,966				55,966		operating cost of air stripper (labor, electricity, repairs) (FRTR)
	O&M of Cat-Ox system		1	lump sum	67,014	67,014				67,014		operating cost of cat-ox unit based on $.17/1000 scfm per year (FRTR)
	treatment costs		9.46E+06	gallon	0	1.89E+04				18,920		cost of treatment for VOCs per gallon (FRTR)
	treatment costs		9.46E+06	gallon	0	7.57E+03				7,568		cost of treatment for ion exchange for Tc-99 oer gallon (FRTR)
	treatment costs		1.02E+04	lb	3	3.07E+04				30,684		cost of carbon for off-gas treatment based on TCE concentration of 210 ug/l (FRTR)
	propane		43098	gallon	2.31	99,556				99,556		Based on current cost of heating propane in Paducah (01-2009)
	water treatment		1	each	58000	58,000				58,000		Includes labor, carbon ,electricity, est. equip. repairs
	labor						2080	37.7	78,416	78,416		1 operator handles all 3 units
	water samples		156	each	235	36,660				36,660		1 sample per week per unit (3 units x 52 weeks)
	off-gas monitoring		156	each	450	70,200				70,200		1 sample per week per unit (3 units x 52 weeks)
	shipping		52	each	60	3,120				3,120		1 cooler per week

Initials _____ Date 12/8/09

Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
	labor						832	57.4	47,757	47,757		2 samplers 1 day per week for 52 weeks (take water and off-gas samples at the same time)
	Data Management		156	each	685	17,098				17,098		16% of analyses costs, unit price cost combines water and off-gas prices (Paducah Cost Documents)
	Quarterly water level and moisture monitoring						256	57.4	440,832	440,832		2 samplers, 32 hrs per qtr, 4 qtrs/yr
	RGA water samples		24	each	1250	30,000				30,000		
									O&M Costs/yr	1,061,791		
Out-year costs for years 2,3,4,& 5												
	year				O&M	bi-annual seal coating	five-year review	well abandonment and gw well maintenance	Remedial Action Completion Report			
	2				1061791	14,734				1,076,525		
	3				1061791					1,061,791		
	4				1061791	14,734				1,076,525		
	5				1061791		70000	288181	103,000	1,522,972		5-year review cost is based on Burial Grounds 5-year review cost. Well abandonment costs were based on 93 DPT-installed soil gas and soil moisture wells closed using the block-squeeze method , gw well maintenance $5k/well/12 wells(Paducah Cost Documents)
									Total	4,737,813		Years 2 through 5
Confirmation Sampling												At the end of active SVE (end of Year 5)
	analysis		1060	each	235	249,100				249,100		VOCs and Tc-99, USEC lab (Paducah Cost Documents DPP)

Initials _____ Date 12/10/09

Alternative 4 - Source Treatment and Containment												
				Material				Labor				
Task			Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
	labor						212	57.4	12,169	12,169		2 samplers, 4 cores/day, 13.25 days (53 cores) (Paducah Cost Documents DPP)
	equipment		20	each	565	11,300				11,300		split samplers, Forestry Suppliers
	DPT		3180	lf	40	127,200				127,200		53 cores to 60', (Paducah Cost Documents BGOU RI)
	data management		1	lump sum	39856	39,856				39,856		16% of analysis cost (Paducah Cost Documents)
									Total	439,625		2009 dollars
									Escalated	573,622		
Long-Term O&M Costs									Total	7,790,915		2009 dollars
									Escalated	10,891,015		
Total Cost w/o G&A or Fee										**13,854,685**		2009 dollars
									Escalated	**17,672,174**		
G&A										358,836		G&A of 2.59%
									Escalated	457,709		
Fee										1,137,082		Fee of 8%
									Escalated	1,450,391		
Total Cost with G&A and Fee										**15,350,603**		
									Escalated	**19,580,274**		
Total Cost with 25% Contingency										**19,188,254**		2009 dollars
									Escalated	**24,475,342**		

Initials RJM Date 12/16/09

Cost Breakdown by Site in 2009 Dollars					
Non-Escalated Costs					
		Oil Landfarm (SWMU-1)	C-720NE	C-720SE	Total
Area (ft^2)		5810	1300	3340	10450
% of total area		55.60%	12.40%	32%	
Alt 4 - Capital Costs ($)		3,371,456	751,907	1,940,406	6,063,770
Alt 4 - O&M ($)		4,331,749	966,073	2,493,093	7,790,915
Alt 4 - Total ($)		**7,703,205**	**1,717,981**	**4,433,499**	**13,854,685**
Total with 2.59% G&A and 8% Fee					15,350,603
Total w/25% contingency					19,188,254
Escalated Costs					
		Oil Landfarm (SWMU-1)	C-720NE	C-720SE	Total
Area (ft^2)		5810	1300	3340	10450
% of total area		55.60%	12.40%	32%	
Alt 4 - Capital Costs ($)		3,770,324	840,864	2,169,971	6,781,159
Alt 4 - O&M ($)		6,055,404	1,350,486	3,485,125	10,891,015
Alt 4 - Total ($)		**9,825,729**	**2,191,350**	**5,655,096**	**17,672,174**
Total with 2.59% G&A and 8% Fee					19,580,274
Total w/25% contingency					24,475,342
Present Value					
Alt 4 Capital Costs ($)		3,371,456	751,907	1,940,406	6,063,770
Alt 4 O&M Costs ($)		3,707,176	826,780	2,133,627	6,667,583
Total					12,731,353
Total w/G&A and 25% fee ($)					**17,632,478**

Initials _____ Date 12/10/09

Alternative 4 Out-Year O&M Costs
Present Value

Year	O&M Costs	Asphalt Sealing	5-Yr Review	Confirmation Sampling	GW Well Maintenance	Well Abandonment and RACR	Multiplier	Present Value Cost
1	1,061,791						0.97371	1,033,876
2	1,061,791	14,734					0.948111	1,020,665
3	1,061,791						0.923185	980,229
4	1,061,791	14,734					0.898914	967,704
5	1,061,791		70,000	399,769	60,000	331,181	0.875282	1,682,940
6	30,000	14,734					0.85227	38,125
7	30,000						0.829864	24,896
8	30,000	14,734					0.808047	36,147
9	30,000						0.786803	23,604
10	30,000	14,734	70,000		60,000		0.766118	133,867
11	30,000						0.745976	22,379
12	30,000	14,734					0.726365	32,493
13	30,000						0.707268	21,218
14	30,000	14,734					0.688674	30,807
15	30,000		70,000		60,000		0.670569	107,291
16	30,000	14,734					0.652939	29,209
17	30,000						0.635774	19,073
18	30,000	14,734					0.619059	27,693
19	30,000						0.602784	18,084
20	30,000	14,734	70,000		60,000		0.586937	102,558
21	30,000						0.571506	17,145
22	30,000	14,734					0.556481	24,894
23	30,000						0.541851	16,256
24	30,000	14,734					0.527606	23,602
25	30,000		70,000		60,000		0.513735	82,198
26	30,000	14,734					0.500229	22,377
27	30,000						0.487077	14,612
28	30,000	14,734					0.474272	21,216
29	30,000						0.461803	13,854
30	30,000	14,734	70,000		60,000		0.449663	78,571
	6,058,955	221,010	420,000	399,769	360,000	331,181		6,667,583

Alternative 4 Out-Year O&M Costs

Year	O&M Costs	Asphalt Sealing	5-Yr Review	Confirmation Sampling	GW Well Maintenance	Well Abandonment and RACR	Multiplier	Escalated Costs
1	1,061,791						1.159274	1,230,907
2	1,061,791	14,734					1.194052	1,285,427
3	1,061,791						1.229874	1,305,869
4	1,061,791	14,734					1.26677	1,363,710
5	1,061,791		70,000	399,769	60,000	331,181	1.304773	2,508,741
6	30,000	14,734					1.343916	60,119
7	30,000						1.384234	41,527
8	30,000	14,734					1.425761	63,780
9	30,000						1.468534	44,056
10	30,000	14,734	70,000		60,000		1.51259	264,301
11	30,000						1.557967	46,739
12	30,000	14,734					1.604706	71,785
13	30,000						1.652848	49,585
14	30,000	14,734					1.702433	76,157
15	30,000		70,000		60,000		1.753506	280,561
16	30,000	14,734					1.806111	80,795
17	30,000						1.860295	55,809
18	30,000	14,734					1.916103	85,715
19	30,000						1.973587	59,208
20	30,000	14,734	70,000		60,000		2.032794	355,198
21	30,000						2.093778	62,813
22	30,000	14,734					2.156591	96,473
23	30,000						2.221289	66,639
24	30,000	14,734					2.287928	102,348
25	30,000		70,000		60,000		2.356566	377,050
26	30,000	14,734					2.427262	108,581
27	30,000						2.50008	75,002
28	30,000	14,734					2.575083	115,194
29	30,000						2.652335	79,570
30	30,000	14,734	70,000		60,000		2.731905	477,357
	6,058,955	221,010	420,000	399,769	360,000	331,181		10,891,015

Total unescalated cost **7,790,915**

Total escalated cost **10,891,015**

Note: Year 1 of O&M is assumed to be 2014

Cost element	Oil Landfarm	C-720 NE Site	C-720 SE Site	Total
Non-escalated cost[1]				
Capital cost	4,669,349	1,041,365	2,687,394	8,398,108
O&M&M	5,999,321	1,337,977	3,452,847	10,790,145
Subtotal	10,668,669	2,379,342	6,140,241	19,188,252
Escalated cost[1]				
Capital cost	5,221,767	1,164,567	3,005,334	9,391,668
O&M&M	8,386,523	1,870,376	4,826,776	15,083,675
Subtotal	13,608,289	3,034,943	7,832,110	24,475,342
Present Worth[1, 2]				
Capital cost	4,669,349	1,041,365	2,687,394	8,398,108
O&M&M	5,134,309	1,145,062	2,954,998	9,234,369
Subtotal	9,803,658	2,186,427	5,642,393	17,632,477

1: Includes G&A, fee and contingency

2: Present worth costs are based on an assumption that outyear costs will be financed by investments made in year 0, and are provided for purposes of comparison only. Escalated costs are used by the DOE for planning and budgeting.

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Remediation Services
A Portage Shaw Joint Venture Company

Form WCE-F-0036
CALCULATION COVER SHEET

Project Title Southwest Plume Focused Feasibility Study **Job No.** PRS-BA-061

Area SW Plume

Discipline Environmental Restoration ***Calc. No.** CAV-0000ES-P011

Subject Alternative #5 Calculation for the SW Plume Feasibility Study

Computer Program Microsoft Office Excel 2007 **Program No.**

Committed Calculation **Preliminary** x **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
0	1-3	J. Keck	G. McManus	J. Keck	J. Keck	09/24/08
0	4-5	J. Towers	G. McManus	J. Keck	J. Keck	09/24/08
1	1-3	J. Keck	G. McManus	J. Keck	J. Keck	11/06/08
1	4-8	J. Towers	G. McManus	J. Keck	J. Keck	11/06/08
2	1-3	J. Keck	G. McManus	J. Keck	J. Keck	03/27/09
2	4-9	J. Towers	G. McManus	J. Keck	J. Keck	03/27/09
3	1-9	J. Towers	J. Keck	J. Keck	J. Keck	06/29/09
4	1-11	J. Keck	T. Poat	T. Poat	T. Poat	07/01/09
5	1-13	J. Towers	A. Montgomery	A. Montgomery	A. Montgomery 12/10/09	12/09/09

SUMMARY OF REVISION

Rev. 1 Incorporates resolutions to comments from D-1 review. Primary changes are revised source area dimensions.

Rev. 2 Incorporated resolutions to additional comments by DOE on D0 FFS regarding remediation goals and monitoring.

Rev. 3 Incorporates revisions to G&A, fee, escalation, scope details pursuant to DOE review

Rev. 4 Incorporates revisions to G&A, fee, escalation, and scope details pursuant to DOE review.

Rev. 5 Incorporates resolutions to comments by EPA and KY on D1 including present worth analysis

	Rev.	Date	Reel No.	Rev.	Date	Reel No.
Microfilmed						

*Obtain Calculation Number from Engineering Manager
WCE-F-0036 (8-06) PRS-WCE-1026 Rev. 0

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Form WCE-F-0034
CALCULATION LOG

Discipline Environmental Restoration Page No. 1

Project Southwest Plume Focused Feasibility Study Job No. NA

Calculation Number	Subject	Originator and Date	Type*		
			C	P	S
CAV-0000ES-P011	Alternative #5 Calculation for the SW Plume Feasibility Study	J. Towers 11/23/09		x	

*C = Committed P = Preliminary S = Superseded

WCE-F-0034 (8-06) PRS-WCE-1026 Rev. 0

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Form WCE-F-0035
CALCULATION SHEET

Originator J. Towers Date 11/23/09 Calc. No. CAV-0000ES-P011
Rev. No. 5

Project SW Plume Focused Feasibility Study Job No. Checked [signature] Date 12/10/09

Subject Alternative # 5 for SW Plume Focused Feasibility Study Sheet No. _____

Alternative 5 Cost Summary in 2009 Dollars			
	Cost in 2009 dollars	Escalated dollars	Present Value Cost
RAWP Documents	239,270	253,842	239,270
Engineering & Design	note 1	note 1	note 1
Characterization	1,590,344	1,737,769	1,590,344
Confirmation Sampling	note 2	note 2	note 2
System Construction	9,201,934	10,356,776	9,201,934
O&M Costs for 30 yrs	1,680,000	3,174,566	1,113,585
G&A (2.59%)	329,229	402,044	314,559
Fee (8%)	1,043,262	1,274,000	996,775
Total Cost	14,084,039	17,198,997	13,456,467
Total Cost w/Contingency	17,605,049	21,498,746	16,820,584
Total Cost	**17,605,049**	**21,498,746**	**16,820,584**

Note 1 - Engineering and Design costs are in included in ERH costs
Note 2 - Confirmation Sampling costs are included in Characterization

Acronyms used in Alternative 5

bcy	bank cubic yards
DPT	direct push technology
ERH	electrical resistance heating
FRTR	Federal Remediation Technology Roundtable
lf	linear foot
MIP	membrane interface probe
TCE	trichloroethylene
Tc-99	technetium 99

12/10/09
Initials JK Date 12/9/09

ALTERNATIVE 5						
SW PLUME CONCEPTUAL DESIGN CALCULATIONS						
11/5/2008						
Conversions						
cf per cy	27					
sf per acre	43560					
Parameter	Units	SWMU 1	C-720 NE	C-720 SE	Total	Basis
Surface areas and volumes						
Source area surface	sf	5810	1300	3340	10450	
Source area volume	cy	12911	2889	7422	23222	
RD Investigation						
See characterization worksheet		X	X	X		
Treatment and process monitoring						
See Cost estimate sheet		X	X	X		
Confirmation sampling						
See characterization worksheet		X	X	X		
Institutional controls						
5-year reviews for 30 years		X	X	X		

GJH 12/10/09
Initials JK Date 12/9/09

Site Dimensions		
Site	Attainment area, sf	Capped area for Alt 4, sf
SWMU 1	5810	45890
C-720 SE	3340	20380
C-720 NE	1300	20400

Characterization frequency and depth			
Characterization method	Frequency		Units
MIP/soil core sampling location (xy) frequency	1 location per	200	sf
MIP/soil core depth interval	1 sample per	5	ft
Soil gas location (xy) frequency	1 location per	2000	sf
MIP max depth	TD	100	ft
Soil coring max depth	TD	60	ft
RGA well max depth	TD	70	ft

Numbers of measurements or locations per alternative			
Characterization method	Alternative		
	1	4	5
Dedicated SGS			
SWMU 1 (xy)	0	23	0
SWMU 1 (depths per xy location)		4	
C-720 SE (xy)	0	10	0
C-720 SE (depths per xy location)	0	4	0
C-720 NE (xy)	0	10	0
C-720 NE (depths per xy location)	0	4	0
MIP			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
Preliminary Soil Cores			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
Confirmatory Soil Cores			
SWMU 1 (xy)	0	29	29
SWMU 1 (depths per xy location)	0	20	20
C-720 SE (xy)	0	17	17
C-720 SE (depths per xy location)	0	20	20
C-720 NE (xy)	0	7	7
C-720 NE (depths per xy location)	0	20	20
RGA wells			
SWMU 1	0	4	4
C-720 SE	0	4	4
C-720 NE	0	4	4

12/10/09

Alternative 5 Out-Year O&M Costs

Year	Cost (unescalated)	5-Year Reviews	GW Well Maintenance	Multiplier	Escalated Cost
1	30,000			1.1593	34,778
2	30,000			1.1941	35,822
3	30,000			1.2299	36,896
4	30,000			1.2668	38,003
5	30,000	70,000	60,000	1.3048	208,764
6	30,000			1.3439	40,317
7	30,000			1.3842	41,527
8	30,000			1.4258	42,773
9	30,000			1.4685	44,056
10	30,000	70,000	60,000	1.5126	242,014
11	30,000			1.5580	46,739
12	30,000			1.6047	48,141
13	30,000			1.6528	49,585
14	30,000			1.7024	51,073
15	30,000	70,000	60,000	1.7535	280,561
16	30,000			1.8061	54,183
17	30,000			1.8603	55,809
18	30,000			1.9161	57,483
19	30,000			1.9736	59,208
20	30,000	70,000	60,000	2.0328	325,247
21	30,000			2.0938	62,813
22	30,000			2.1566	64,698
23	30,000			2.2213	66,639
24	30,000			2.2879	68,638
25	30,000	70,000	60,000	2.3566	377,050
26	30,000			2.4273	72,818
27	30,000			2.5001	75,002
28	30,000			2.5751	77,252
29	30,000			2.6523	79,570
30	30,000	70,000	60,000	2.7319	437,105
	900,000	420,000	360,000		3,174,566

Total Unescalated Costs	1,680,000
Total Escalated Costs	**3,174,566**

Note: Year 1 would be 2013 in the current schedule

Alternative 5 - Electrical Resistance Heating											
			Material				Labor				
Task	Item	Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Project Plans											Labor rate is an average rate based on seven recent plans (total cost for the plans/total hours) including work plans, RI/FS, etc. with costs through 2008 (Paducah Cost Documents)
Remedial Action Work Plan											
	Labor - D-1					560	67.4	37,744	37,744		
	Labor - D0					420	67.4	28,308	28,308		
	Labor - D1					210	67.4	14,154	14,154		
	Labor - D2					210	67.4	14,154	14,154		
Health and Safety Plan							67.4				
	Labor - D-1					100	67.4	6,740	6,740		
	Labor - D0					40	67.4	2,696	2,696		
	Labor - D1					40	67.4	2,696	2,696		
	Labor - D2					40	67.4	2,696	2,696		
Security Plan							67.4				
	Labor - Draft					80	67.4	5,392	5,392		
	Labor - D0					40	67.4	2,696	2,696		
QA Plan							67.4				
	Labor - D-1					240	67.4	16,176	16,176		
	Labor - D0					180	67.4	12,132	12,132		
	Labor - D1					80	67.4	5,392	5,392		
	Labor - D2					80	67.4	5,392	5,392		
Sampling and Analysis Plan							67.4				
	Labor - D-1					210	67.4	14,154	14,154		
	Labor - D0					160	67.4	10,784	10,784		
	Labor - D1					80	67.4	5,392	5,392		
	Labor - D2					80	67.4	5,392	5,392		
Waste Management Plan							67.4				
	Labor - D-1					120	67.4	8,088	8,088		
	Labor - D0					60	67.4	4,044	4,044		
	Labor - D1					60	67.4	4,044	4,044		
	Labor - D2					60	67.4	4,044	4,044		
LUCIP	Labor - D0					200	67.4	13,480	13,480		
	Labor - D1					100	67.4	6,740	6,740		
	Labor - D2					100	67.4	6,740	6,740		
								Total	239,270		Plans cost
								Escalated	253,842		2011 dollars

Initials _____ Date 12/10/09

Alternative 5 - Electrical Resistance Heating											
			Material				Labor				
Task	Item	Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Characterization											See Characterization worksheet
MIP Sampling	equipment	13	day	7000.00	91,000				91,000		MIP rig and onsite lab,from Cluin.org
	labor					80	75	6,000	6,000		MIP report
	excavation permits	53	each	360.00	19,080				19,080		Paducah Cost Documents
	civil survey	53	each	282.00	14,946				14,946		Elevations and coordinates, Paducah Cost Documents
	H&S	1				140	67	9,387	9,387		
	Radcon	1				140	38	5,278	5,278		
	escort	1				140	31	4,350	4,350		
Soil Cores											
Preliminary samples	DPT	3180	lf	40.00	127,200				127,200		53 cores to 60', direct push technology, cost per foot, Paducah Cost Documents
	analysis	1060	each	235.00	249,100				249,100		53 positions, 20 depths, analyzed for TCE and Tc-99, USEC lab analysis costs
	excavation permits	53	each	360.00	19,080				19,080		Paducah Cost Documents
	civil survey	53	each	282.00	14,946				14,946		Elevations and coordinates, Paducah Cost Documents
	equipment	20	each	565.00	11,300				11,300		Forestry Suppliers, split samplers
Confirmatory samples	analysis	1060	each	235	249,100				249,100		53 positions, 20 depths, analyzed for TCE and Tc-99, USEC lab analysis costs
	DPT	3180	lf	40	127,200				127,200		53 cores to 60'
	excavation permits	53	each	360	19,080				19,080		
	civil survey	53	each	282	14,946				14,946		
Data management costs		1	lump sum	79712	79,712				79,712		16% of analysis costs, Paducah Cost Documents
	samplers	2				432	55	23,630	23,630		2 samplers, 27 days for both preliminary and confirmatory sampling events
	Radcon	1				216	38	8,143	8,143		27 days for both sampling events
	H&S	1				216	67.05	14,483	14,483		27 days for both sampling events
Install RGA wells											Installation of 12 RGA wells to a depth of 70', well costs are actuals from SWOU RI

Alternative 5 - Electrical Resistance Heating											
			Material				Labor				
Task	Item	Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Temporary decon pad and tear down		1	lump sum	100000	100,000				100,000		For drill rig and equipment, demolition waste disposal on-site (U-landfill), including labor, materials, and waste certification documentation for disposal
Mob/demob drill rig		1	lump sum	44335	44,335				44,335		Includes cost of standard per diem for 3 man drilling crew for 15 weeks and drill rig travel to and from Paducah (Paducah Cost Documents) based on 1 week drilling and well development time per well
Construction trailer		6	month	1000	6,000				6,000		Includes cost of delivery, setup, furniture rental, and return (44'x12')(Williams Scotsman, Inc., Hamilton Ohio)
Change trailer		6	month	1200	7,200				7,200		Includes cost of delivery, setup, furniture rental, and return (Williams Scotsman, Inc., Hamilton Ohio)
	drilling	840	lf	94	78,960				78,960		
	well installation	12	each	17974	215,688				215,688		Costs include installation, surveying, permit, waste
	gw sampling	24	each	1250	30,000				30,000		2 samples/yr for 12 wells, analysis and labor included
	data management	1	lump sum	200	200				200		16% of analysis costs, Paducah Cost Documents
								Total	1,590,344		Characterization costs
								Escalated	1,737,769		2012 dollars

Alternative 5 - Electrical Resistance Heating											
			Material				Labor				
Task	Item	Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
ERH Treatment		1	lump sum	8,519,905	8,519,905				8,519,905		Costs based on conceptual design provided by McMillan and McGee Corporation.
RACR		1	each	103000	103,000				103,000		Remedial Action Completion Report based on actuals from Paducah Dissolved Phase Treatability Reports
Professional labor											
						2080	98.17	204,194	204,194		PM Level IV
						1040	83.93	87,287	87,287		Geologist Level III
						2080	64.05	133,224	133,224		Site superintendent Level II
		1				640	67.5	43,200	43,200		Health & Safety Level II
	Radcon	1				640	37.7	24,128	24,128		Radcon Level II
	escorts/laborer	4				2800	31.07	86,996	86,996		escorts
								Total	9,201,934		Treatment system and treatment cost
								Escalated	10,356,776		2013 dollars
Long-Term Monitoring											Monitoring of RGA wells 2X per year and cost of 5-yr reviews for next 30 yrs based on current 2009 dollars (Paducah actuals)
	Monitoring	720	each	1250	900,000				900,000		24 samples per yr at $1250/sample (Paducah actuals SW OU)
	GW wells	72	each	5000	360,000				360,000		GW well maintenance ($5k/well/5 yrs for 12 wells)
	5 year reviews	6	each	70000	420,000				420,000		6 5-yr review at $70,000/review (based on Paducah actuals for Surface Water OU)
								Total	1,680,000		
								Escalated	3,174,566		Out-year O&M sheet
Total Cost w/o G&A and Fee									**12,711,548**		Cost in 2009 dollars (unescalated)
								Escalated	15,522,953		
G&A									**329,229**		G&A rate of 2.59%
								Escalated	402,044		
Fee									**1,043,262**		Fee of 8%
								Escalated	1,274,000		
Total Cost with G&A and Fee									**14,084,039**		2009 dollars
								Escalated	17,198,997		

Alternative 5 - Electrical Resistance Heating											
			Material				Labor				
Task	Item	Quantity	Unit	Unit Price	Total	Hours	Rate	Total	Total Cost in 2009 Dollars		Basis of Estimate
Total Cost with G&A, Fee, and Contingency of 25%									**17,605,049**		2009 dollars
								Escalated	21,498,747		

Alternative 5 Cost Breakdown by Site					
Unescalated Costs					
	Oil Landfarm (SWMU-1)	C-720NE	C-720SE	Total	
Area (ft^2)	5810	1300	3340	10450	
% of total area	55.60%	12.40%	32%		
Alt 5 Capital Costs ($)	6,133,552	1,367,914	3,530,102	11,031,568	
Alt 5 - O&M ($)	934,080	208,320	537,600	1,680,000	
Alt 5 - Total ($)	**7,067,632**	**1,576,234**	**4,067,702**	**12,711,568**	
Total with 2.59% G&A and 8% Fee				14,084,039	
With 25% Contingency				17,605,049	
Escalated Costs					
	Oil Landfarm (SWMU-1)	C-720NE	C-720SE	Total	
Area (ft^2)	5810	1300	3340	10450	
% of total area	55.60%	12.40%	32%		
Alt 5 - Capital Costs ($)	6,865,703	1,531,200	3,951,484	12,348,387	
Alt 5 - O&M ($)	1,765,059	393,646	1,015,861	3,174,566	
Alt 5 - Total ($)	**8,630,762**	**1,924,846**	**4,967,345**	**15,522,953**	
Total with 2.59% G&A and 8% Fee				17,198,997	
With 25% Contingency				21,498,746	

Alternative 5 Out-Year O&M Costs
Present Value

Year	Cost (unescalated)	5-Year Reviews	GW Well Maintenance	Multiplier	Present Value Costs
1	30,000			0.9737	29,211
2	30,000			0.9481	28,443
3	30,000			0.9232	27,696
4	30,000			0.8989	26,967
5	30,000	70,000	60,000	0.8753	140,045
6	30,000			0.8523	25,568
7	30,000			0.8299	24,896
8	30,000			0.8080	24,241
9	30,000			0.7868	23,604
10	30,000	70,000	60,000	0.7661	122,579
11	30,000			0.7460	22,379
12	30,000			0.7264	21,791
13	30,000			0.7073	21,218
14	30,000			0.6887	20,660
15	30,000	70,000	60,000	0.6706	107,291
16	30,000			0.6529	19,588
17	30,000			0.6358	19,073
18	30,000			0.6191	18,572
19	30,000			0.6028	18,084
20	30,000	70,000	60,000	0.5869	93,910
21	30,000			0.5715	17,145
22	30,000			0.5565	16,694
23	30,000			0.5419	16,256
24	30,000			0.5276	15,828
25	30,000	70,000	60,000	0.5137	82,198
26	30,000			0.5002	15,007
27	30,000			0.4871	14,612
28	30,000			0.4743	14,228
29	30,000			0.4618	13,854
30	30,000	70,000	60,000	0.4497	71,946
	900,000	420,000	360,000		1,113,585

Total Unescalated Costs 1,680,000
Present Value Costs **1,113,585**

Cost element	Oil Landfarm	C-720 NE Site	C-720 SE Site	Total
Non-escalated cost[1]				
Capital cost	8,494,739	1,894,510	4,889,059	15,278,308
O&M&M	1,293,668	288,516	744,557	2,326,741
Subtotal	9,788,407	2,183,026	5,633,616	17,605,049
Escalated cost[1]				
Capital cost	9,508,759	2,120,658	5,472,667	17,102,084
O&M&M	2,444,545	545,186	1,406,932	4,396,663
Subtotal	11,953,303	2,665,845	6,879,599	21,498,747
Present Worth[1, 2]				
Capital cost	8,494,739	1,894,510	4,889,059	15,278,308
O&M&M	857,506	191,242	493,528	1,542,276
Subtotal	9,352,245	2,085,752	5,382,587	16,820,584
1: Includes G&A, fee and contingency				
2: Present worth costs are based on an assumption that outyear costs will be financed by investments made in year 0,				

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APPENDIX C

MODELING RESULTS

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MODELING METHODOLOGY

C.1. INTRODUCTION

Groundwater modeling analyses were previously completed in the Southwest Plume Site Investigation (SI) Report. Additional groundwater modeling was conducted in support of this Focused Feasibility Study (FFS) to evaluate the following:

1. Soil remediation goals based on groundwater maximum contaminant limits (MCLs) using deterministic modeling;

2. Time required for residual volatile organic compound (VOC) mass leaching to the Regional Gravel Aquifer (RGA) from each Southwest Plume source area to diminish to levels that are less than the MCL, for each alternative using deterministic modeling;

3. Time required to meet the remediation goals (RGs) for the soil vapor extraction (SVE) alternative with an infiltration reducing cap using deterministic modeling; and

4. Uncertainties in the trichloroethene (TCE) remediation goals using probabilistic analysis.

These additional modeling analyses were based on the methodology and parameterization previously presented in the Southwest Plume SI report.

Fate and transport modeling, based upon the methodology presented in the Site Investigation Report for the Southwest Groundwater Plume (SI Report) (DOE 2007), was completed using these models: Seasonal Soil Compartment Model (SESOIL) (Brar 1996) and Analytical Transient 1-, 2-, 3-Dimensional Model (AT123D) (Odencrantz 1992).

C.2. HU3/HU4 UNIT CONTACT LOCATION

The UCRS consists of the surface alluvium and Upper Continental Recharge System (UCRS). The UCRS consists of clayey silt with lenses of sand and occasional gravel. Paducah Gaseous Diffusion Plant (PGDP) hydrogeologists have differentiated the UCRS into 3 general horizons (DOE 1999; DOE 2007):

- Hydrologic Unit 1 (HU1)—an upper silt and clay interval,
- Hydrologic Unit 2 (HU2)—an intervening sand and gravel interval, and
- Hydrologic Unit 3 (HU3)—a lower silt and clay interval.

Where the HU3 confining unit is clearly defined, it consists of yellowish brown and grayish brown silty clay with minor sand content.

The dominant lithology of the Lower Continental Deposits is poorly sorted chert gravel with occasional sand and silt at various intervals. Above the gravel facies, a fine-grading downward-to-medium-grained sand is present in some areas. This sand is considered to be the HU4 at PGDP (DOE 2007).

The location of the HU3/HU4 contact was determined based on lithologic logs for boreholes and monitoring wells at Solid Waste Management Unit (SWMU) 1 and C-720 provided in the Waste Area

Grouping (WAG) 27 RI (DOE 1999) and the SI Report (DOE 2007). The location of the contact was determined using the following evaluation steps:

1. Locate the gravel layer in the RGA in the well logs,

2. Locate the sand layers above the gravel layer,

3. For purposes of this modeling effort, the top of the HU4 layer, where present, is considered to be the top of the saturated sand unit, not containing significant silts or clays, immediately overlying the HU5 gravel layer. If the HU4 is not present then the top of the HU5 gravel is considered to be the contact.

The methodology for choosing the HU3/HU4 contact considers the clay content of the sand layer since significant clay content would reduce the capacity of the sand to the extent that its hydraulic properties would be more similar to the HU3 unit.

Table C.1 and Figure C.1 provide the SWMU 1 location of the HU3/HU4 contact location based on the well logs. The average location of the HU3/HU4 contact is at 53 ft below the surface at SWMU 1.

Table C.2 and Figure C.2 provide the C-720 location of the HU3/HU4 contact location based on the well logs. The average location of the HU3/HU4 contact is at 58.4 ft below the surface at C-720.

The well logs used in the analysis are provided in Appendix C, Attachments 1 and 2, respectively for SWMU 1 and C-720.

Table C.1. HU3/HU4 Contact Location Determination at SWMU 1

Borehole	**Depth to H3/H4 contact (ft below ground surface)**
001-075	55
001-082	53
001-083	45
001-084	50
MW-161	50.6
Additional Boreholes	
001-076b	58
001-078	55
001-080	57
001-081	53
Statistics	
Minimum	45
Maximum	58
Average	**53.0**

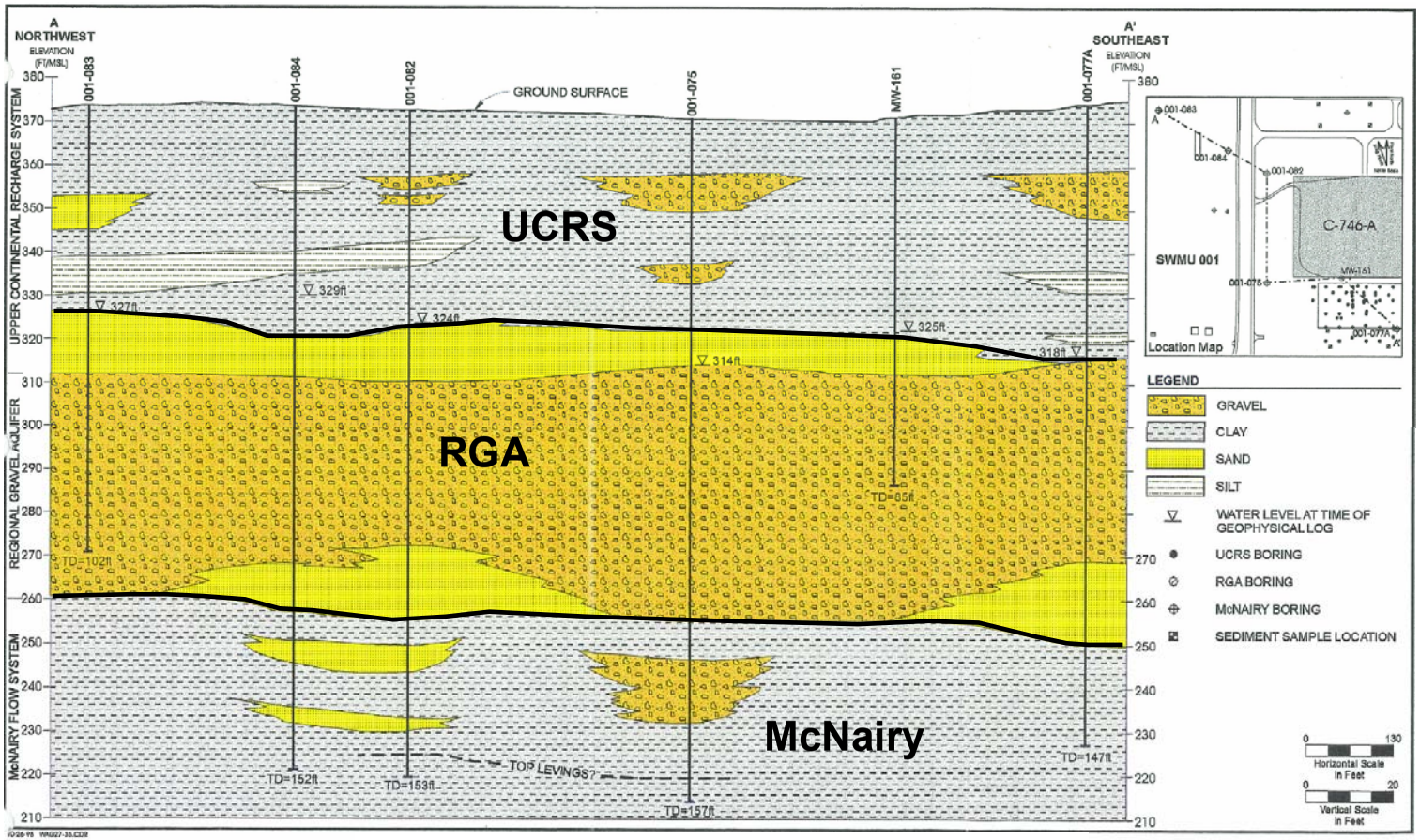

Figure C.1. Northwest-Southeast Geologic Cross Section A-A' at SWMU 1

Table C.2. HU3/HU4 Contact Location Determination at C-720

Borehole	Depth to H3/H4 contact (ft below ground surface)
720-011	65
720-016	50
720-017	45
720-018	54
720-028	66
Additional Boreholes	
720-010	66
MW-203	63
Statistics	
Minimum	45
Maximum	66
Average	**58.4**

C.3 DETERMINISTIC MODELING TO EVALUATE REMEDIATION GOALS

Groundwater modeling was conducted deterministically to determine the remediation goals in soil to meet the MCLs at the downgradient edge of the source area. The hydrologic modeling parameters used in the SESOIL modeling were based on those presented in the Southwest Plume SI Report. The modeling parameters were selected so that they would represent site conditions, could account for expected variability in the hydraulic system, and would be unlikely to underestimate contaminant release and transport. Table C.3 presents the site parameters used for SESOIL modeling.

The chemical-specific parameters used in the SESOIL modeling for each contaminant of concern (COC) included solubility in water, organic carbon partition coefficient (K_{oc}), Henry's Law constant, distribution coefficient (K_d), diffusion coefficients in air and water, and, for TCE, degradation rate constant. These chemical parameters are presented in Table C.4. The K_d values for TCE; *cis*- and *trans*-1, 2-dichloroethene (DCE); vinyl chloride (VC), and 1,1-DCE, which are VOCs, were derived using the following relationship.

$$K_d = K_{oc} \times f_{oc}$$

where: K_d is the distribution coefficient,
K_{oc} is the organic carbon partition coefficient, and
f_{oc} is the fraction of organic carbon for source area soils.

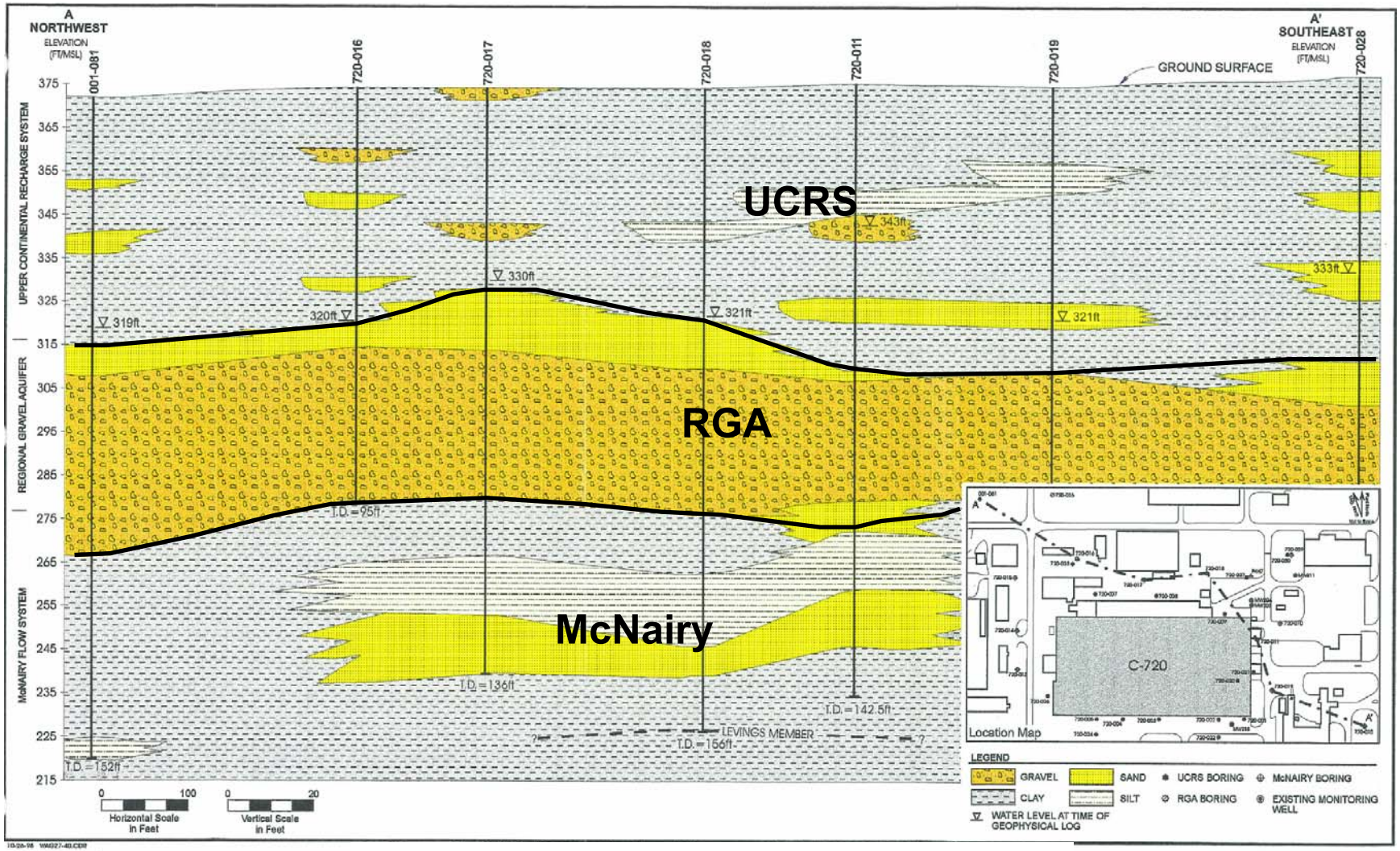

Figure C.2. Northwest-Southeast Geologic Cross Section A-A' at C-720

The f_{oc} used for the unsaturated zone at SWMU 1 was 0.08%, and that used for the C-720 Building area was 0.09%. The mechanisms and rates of degradation within the UCRS have not yet been substantively assessed. Consequently a range of degradation rates were used in this assessment to determine the potential effects of degradation on overall remedy time frames. The degradation rate used for TCE was varied for the UCRS using half-life values of 5, 25, and 50 years, generally representing high, moderate, and low rates of degradation, respectively.

Table C.3. Soil Parameters Used in SESOIL Modeling of SWMU 1 and the C-720 Building Area[a]

Input Parameter	SWMU 1	C-720 Building	Source
Soil type	Silty clay	Silty clay	PGDP site-specific
Bulk density (g/cm^3)	1.46	1.46	Laboratory analysis
Percolation rate (cm/year)	11	11	PGDP Calibrated Model
Intrinsic permeability (cm^2)	1.65E-10	1.65E-10	Calibrated
Disconnectedness index	10	10	Calibrated
Porosity	0.45	0.45	Laboratory analysis
Depth to water table (m)	16.76	18.29	Site specific (to RGA) based on field observation
Organic carbon content ($f_{oc)}$ (%)	0.08	0.09	Laboratory analysis
Frendlich equation exponent	1	1	SESOIL default value

[a]Parameter values from the Southwest Plume SI Report
PGDP = Paducah Gaseous Diffusion Plant
RGA = Regional Gravel Aquifer

Table C.4. Chemical-Specific Parameters of the Contaminants of Concern Used in SESOIL Modeling[a]

Contaminant of Concern	Mol. Wt. (MW) (g/gmol)	Solubility in water (mg/L)	Diffusion in air (cm2/s)	Diffusion in water (m2/hr)	Henry's Constant (atm.m3/mol)	K_{oc} (L/kg)	K_d[a] (L/kg) SWMU-1	K_d[a] (L/kg) C-720	Degradation Half Life[b] (years)
Trichloroethene	131	1,100	0.08	3.28E-06	0.0103	94	0.0752	0.0846	5, 25, 50
cis-1,2-Dichloroethene	97	3,500	0.07	4.07E-06	0.00408	36	0.0288	0.0324	infinite
trans-1,2-Dichloroethene	97	6,300	0.07	4.28E-06	0.00938	38	0.0304	0.0342	infinite
Vinyl Chloride	63	2,760	0.11	4.43E-07	0.0270	19	0.0152	0.0171	infinite
1,1-DCE	97	2,250	0.09	3.74E-06	0.0261	65	0.0520	0.0585	infinite

[a]Parameter values from the Southwest Plume SI Report
[b]K_d of an organic compound depends on the soil's organic carbon content (f_{oc}) and compound's organic carbon partition coefficient (K_{oc})

For this modeling effort, the source zones were arranged in four layers similar to those presented in the Southwest Plume SI Report. Additional discretization was added to the lower layers in comparison to the Southwest Plume SI Report to improve the flux mass balance, while preserving the original mass concentrations in each layer. For SWMU 1, the first layer (914.4 cm) was discretized into 3 sublayers, the second layer (609.6 cm) was discretized into 2 sublayers, the third layer (121.92 cm) was discretized into 4 layers, while the fourth layer (30.48 cm) was discretized into 1 sublayer. For C-720, the first layer (914.4 cm) was discretized into 3 sublayers, the second layer (609.6 cm) was discretized into 2 sublayers, the third layer (152.4 cm) was discretized into 1 sublayer, while the fourth layer (152.4 cm) was discretized into 5 sublayers. The layer discretization is shown in Table C.5 for SWMU 1 and Table C.6 for C-720. For the calculation of the soil remediation goals based on groundwater MCLs, a unit concentration (i.e., 1 mg/kg) was used in each layer that had a source concentration in Tables C.5 and C.6 from the Southwest Plume SI analysis.

The SESOIL model was used to calculate the peak COC concentrations in the UCRS at the U3/U4 contact based on unit concentration (i.e., 1 mg/kg) in each model layer. The resulting COC concentrations at the U3/U4 contact are provided in Figures C.3 through C.9 for SWMU 1 and Figures C.10 through C.16 for C-720. The groundwater concentration in the RGA was then calculated based on the dilution attenuation factor (DAF) equation shown below:

The DAF was calculated using the following equation:

$$DAF = 1 + \frac{Kid}{IL}$$

Where:

i = gradient (m/m)
d = mixing zone depth (m)
I = infiltration rate (m/yr)
L = length of area of concern parallel to groundwater flow (m)
K = aquifer hydraulic conductivity (m/yr)

The equation for calculating the aquifer mixing zone depth, d:

$$d = \left(0.0112\, L^2\right)^{0.5} + d_a \left\{1 - e^{\left[\frac{(-L\, I)}{(K\, i\, d_a)}\right]}\right\}$$

Where:

d_a = aquifer thickness (m)

The first term, d_{av}, estimates the depth of the mixing due to vertical dispersivity along the length of the groundwater flow path:

$$d_{av} = \left(0.0112\, L^2\right)^{0.5}$$

The second term, d_{iv}, estimates the depth of mixing due to the downward velocity of infiltrating water:

$$d_{iv} = d_a \left\{1 - e^{\left[\frac{(-L\, I)}{(K\, i\, d_a)}\right]}\right\}$$

The parameter values in Table C.7 from the SI Report for SWMU 1 were used in the calculation of the mixing depth and DAF. The aquifer hydraulic conductivity for the RGA was calculated as an average of the RGA hydraulic conductivity 0.53 cm/s for the RGA depth of 9.14 m and a hydraulic conductivity for a silty-sand of 0.001 cm/s for a conservative depth of 1.5 m for the HU4. This resulted in an average hydraulic conductivity for the HU4/RGA aquifer of 0.45 cm/s (1.42E+05 m/yr).

The parameter values in Table C.8 from the SI Report for C-720 were used in the calculation of the mixing depth and DAF. The mixing zone depth was calculated to be 4.02 m for the gravel aquifer. However, the DAF was found to be the same as SWMU 1 with a value of 59.

The DAF value was then used to evaluate the RGs in the unsaturated zone above the saturated HU-4, based on the DAF. The evaluation was completed using the SESOIL model:

The UCRS leachate concentrations at the HU3/HU4 contact were divided by the DAF to obtain the groundwater concentration. The groundwater concentrations based on the DAF were then compared to the MCL to determine the remediation goal (RG) using the following equation:

$$RG = \frac{(MCL) \times (C_s)}{C_{gw}}$$

Where:

RG = soil remediation goal (mg/kg)
MCL = MCL for the COC (ug/L)
C_s = unit soil concentration (1 mg/kg)
C_{gw} = groundwater concentration based on a unit soil concentration (ug/L)

Since unit soil concentrations were used in the analysis to obtain the groundwater concentrations, the equation reduces to

$$RG = \frac{(MCL)}{C_{gw}}$$

Tables C.9 and C.10 present the leachate MCLs and RGs for SWMU 1 and C-720, respectively.

Table C.5. Summary of Source Term Characteristics for SWMU 1[a]

Layer	Depth (ft)	No Action (mg/kg)	Area (ft^2)	Volume (ft^3)	Mass[b] (g)	ERH (mg/kg)	SVE (mg/kg)
			Trichloroethene				
Layer 1	00–10	7.59	4,375	43,750	13,723	0.15	0.76
Layer 2	10– 0	110.8	3,125	31,250	143,177	2.22	11.08
Layer 3	20–30	17.6	6,250	62,500	45,503	0.35	1.76
Layer 4	30–40	13	5,625	56,250	30,283	0.26	1.30
Layer 5	40–50	13.6	5,625	56,250	31,516	0.27	1.36
Layer 6–9	50–54	5.74	7,500	30,000	7,119	0.11	0.57
Layer 10	54–55	5.74	7,500	7,500	1,780	0.11	0.57
		Total Mass			273,068		
			cis-1,2-Dichloroethene				
Layer 1	00–10	6	4,375	43,750	10,852	0.12	0.60
Layer 2	10–20	0.046	3,125	31,250	59	0.0009	0.0046
Layer 3	20–30	0.086	6,250	62,500	222	0.0017	0.0086
Layer 4	30–40	1.7	5,625	56,250	3,953	0.034	0.17
Layer 5	40–50	1	5,625	56,250	2,326	0.02	0.10
Layer 6–9	50–55	0.02	7,500	30,000	29	0.0004	0.002
Layer 10	54–55	0.02	7,500	7,500	7	0.0004	0.002
		Total Mass			17,449		
			trans-1,2-Dichloroethene				
Layer 1	00–10	16	4,375	43,750	28,940	0.32	1.60
Layer 2	10–20	1.5	3,125	31,250	1,938	0.03	0.15
Layer 3	20–30	1.5	6,250	62,500	3,876	0.03	0.15
Layer 4	30–40	0.6	5,625	56,250	1,395	0.012	0.06
Layer 5	40–50	1.4	5,625	56,250	3,256	0.028	0.14
Layer 6–9	50–55	0	7,500	30,000	0	0	0
Layer 10	54–55	0	7,500	7,500	0	0	0
		Total Mass			39,405		
			Vinyl Chloride				
Layer 1	00–10	0.7	4,375	43,750	1,266	0.014	0.07
Layer 2	10–20	0.0033	3,125	31,250	4	0.00007	0.00033
Layer 3	20–30	0.088	6,250	62,500	227	0.00176	0.0088
Layer 4	30–40	0.012	5,625	56,250	28	0.00024	0.0012
Layer 5	40–50	0.0095	5,625	56,250	22	0.00019	0.00095
Layer 6–9	50–55	0.02	7,500	30,000	22	0.0004	0.002
Layer 10	54–55	0.02	7,500	7,500	6	0.0004	0.002
		Total Mass			1,576		
			1,1-DCE				
Layer 1	00–10	0.01	500	5,000	2	0.0002	0.001
Layer 2	10–20	0	0	0	0	0	0
Layer 3	20–30	0.04	1,000	10,000	17	0.0008	0.004
Layer 4	30–40	0.04	1,600	16,000	26	0.0008	0.004
Layer 5	40–50	0.03	2,800	28,000	29	0.0006	0.003
Layer 6–9	50–55	0.06	850	3,400	8	0.0012	0.006
Layer 10	54–55	0.06	850	850	2	0.0012	0.006
		Total Mass			84		

[a]Layer concentrations from the Southwest Plume SI Report
[b]Mass calculated using an average bulk density of 1.46 g/cm^3

Table C.6. Summary of Source Term Characteristics for the C-720 Building Area Southeast Source[a]

Layer	Depth (ft)	No Action (mg/kg)	Area (ft2)	Volume (ft3)	Mass*b* (g)	ERH (mg/kg)	SVE (mg/kg)
			Trichloroethene				
Layer 1	00–10	2.96	7,500	75,000	9,185	0.06	0.30
Layer 2	10–20	6.37	7,500	75,000	19,751	0.13	0.64
Layer 3	20–30	11.9	15,000	150,000	73,900	0.24	1.19
Layer 4	30–40	1.55	6,875	68,750	4,393	0.03	0.16
Layer 5	40–50	1.2	6,875	68,750	3,411	0.02	0.12
Layer 6–10	50–55	0.1	3,438	34,375	141	0.002	0.01
Layer 11–15	55–60	0.1	3,438	34,375	141	0.002	0.01
		Total Mass			110,922		
			***cis*-1,2-Dichloroethene**				
Layer 1	00–10	3.2	7,500	75,000	9,922	0.06	0.32
Layer 2	10–20	0.75	7,500	75,000	2,326	0.02	0.08
Layer 3	20–30	0.019	15,000	150,000	118	0.00038	0.0019
Layer 4	30–40	0.052	6,875	68,750	148	0.00104	0.0052
Layer 5	40–50	0	6,875	68,750	0	0	0
Layer 6–10	50–55	0	6,875	34,375	0	0	0
Layer 11–15	55–60	0	6,875	34,375	0	0	0
		Total Mass			12,513		
			***trans*-1,2-Dichloroethene**				
Layer 1	00–10	0	7,500	75,000	0	0	0
Layer 2	10–20	0.4	7,500	75,000	1,240	0.008	0.04
Layer 3	20–30	0	15,000	150,000	0	0	0
Layer 4	30–40	0	6,875	68,750	0	0	0
Layer 5	40–50	0	6,875	68,750	0	0	0
Layer 6–10	50–55	0	6,875	34,375	0	0	0
Layer 11–15	55–60	0	6,875	34,375	0	0	0
		Total Mass			1,240		
			Vinyl Chloride				
Layer 1	00–10	0.4	7,500	75,000	1,240	0.008	0.04
Layer 2	10–20	0.4	7,500	75,000	1,240	0.008	0.04
Layer 3	20–30	0	15,000	150,000	0	0	0
Layer 4	30–40	0	6,875	68,750	0	0	0
Layer 5	40–50	0	6,875	68,750	0	0	0
Layer 6–10	50–55	0	6,875	34,375	0	0	0
Layer 11–15	55–60	0	6,875	34,375	0	0	0
		Total Mass			2,481		
			1,1-DCE				
Layer 1	00–10	0	0	0	0	0	0
Layer 2	10–20	0	0	0	0	0	0
Layer 3	20–30	0	0	0	0	0	0
Layer 4	30–40	0.18	5,600	56,000	417	0.0036	0.018
Layer 5	40–50	0.0305	15,000	150,000	189	0.00061	0.00305
Layer 6–10	50–55	0.002	2,150	10,750	1	0.00004	0.0002
Layer 11–15	55–60	0.002	2,150	10,750	1	0.00004	0.0002
		Total Mass			611		

[a]Layer concentrations from the Southwest Plume SI Report
[b]Mass calculated using an average bulk density of 1.46 g/cm^3

Table C.7. SWMU 1 Parameter Values for Calculation of the DAF

Parameter	Value	Description
L	17.04	Source length parallel to groundwater flow (m) from Table F.28 SI report - taking squareroot of areas from 17.04 m
d_a	9.14	Aquifer thickness (m) Table F.34 SI report
I	0.1054	Infiltration rate (m/yr) 10.54 cm/yr SESOIL net recharge rate to groundwater
K	1.42E+05	Aquifer hydraulic conductivity (m/yr) average of silty sand (5 ft) at 10-3 cm/s and gravel (30 ft) at 0.529 cm/s from SI Table F.34
i	4.00E-04	Hydraulic gradient (m/m) Table F.34 SI report

Table C.8. C-720 Parameter Values for Calculation of the DAF

Parameter	Value	Description
L	37.3	Source length parallel to groundwater flow (m) from Table F.28 SI report - taking squareroot of areas from 17.04 m SADA
d_a	9.14	Aquifer thickness (m) Table F.34 SI report
I	0.1054	Infiltration rate (m/yr) 10.54 cm/yr SESOIL net recharge rate to groundwater
K	1.42E+05	Aquifer hydraulic conductivity (m/yr) average of silty sand (5 ft) at 10-3 cm/s and gravel (30 ft) at 0.529 cm/s from SI Table F.34
i	4.00E-04	Hydraulic gradient (m/m) Table F.34 SI report

Table C.9. SWMU 1 Soil Remediation Goals for Groundwater Based on a DAF

COC	Leachate Concentration at HU3/HU4 (µg/L)	Groundwater Concentration (µg/L)[a]	MCL (µg/L)	Soil RG for units above HU-4 (mg/kg)
TCE (5 yr UCRS half-life)	295	5	5	0.085
TCE (25 yr UCRS half-life)	295	5	5	0.080
TCE (50 yr UCRS half-life)	295	5	5	0.073
1.1-DCE	413	7	7	0.130
cis-1,2-DCE	4,130	70	70	0.600
trans-1,2-DCE	5,900	100	100	1.080
Vinyl Chloride	118	2	2	0.034

[a]DAF = 59

Table C.10. C-720 Soil Remediation Goals for Groundwater Based on a DAF

COC	Leachate Concentration at HU3/HU4 (µg/L)	Groundwater Concentration (µg/L)[a]	MCL (µg/L)	Soil RG for units above HU-4 (mg/kg)
TCE (5 yr UCRS half-life)	295	5	5	0.092
TCE (25 yr UCRS half-life)	295	5	5	0.083
TCE (50 yr UCRS half-life)	295	5	5	0.075
1.1-DCE	413	7	7	0.137
cis-1,2-DCE	4,130	70	70	0.619
trans-1,2-DCE	5,900	100	100	5.29
Vinyl Chloride	118	2	2	0.450

[a]DAF = 59

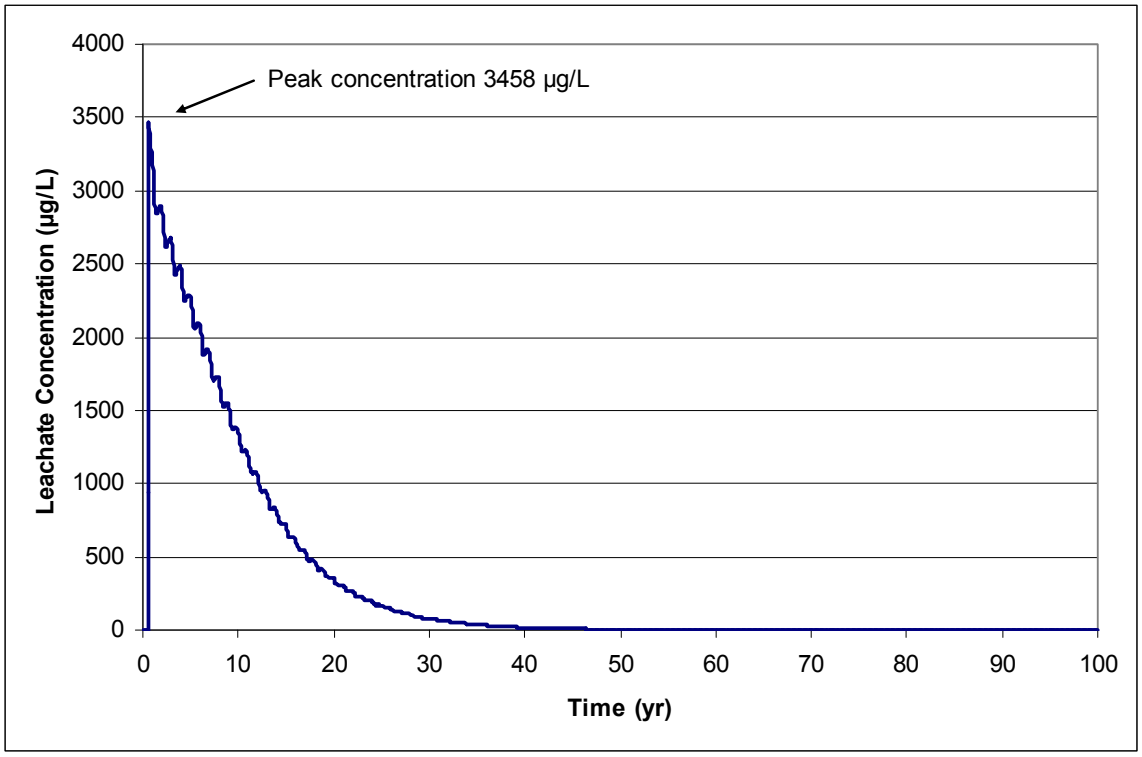

Figure C.3. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from SWMU 1 (Half-Life for TCE in UCRS = 5 Years)

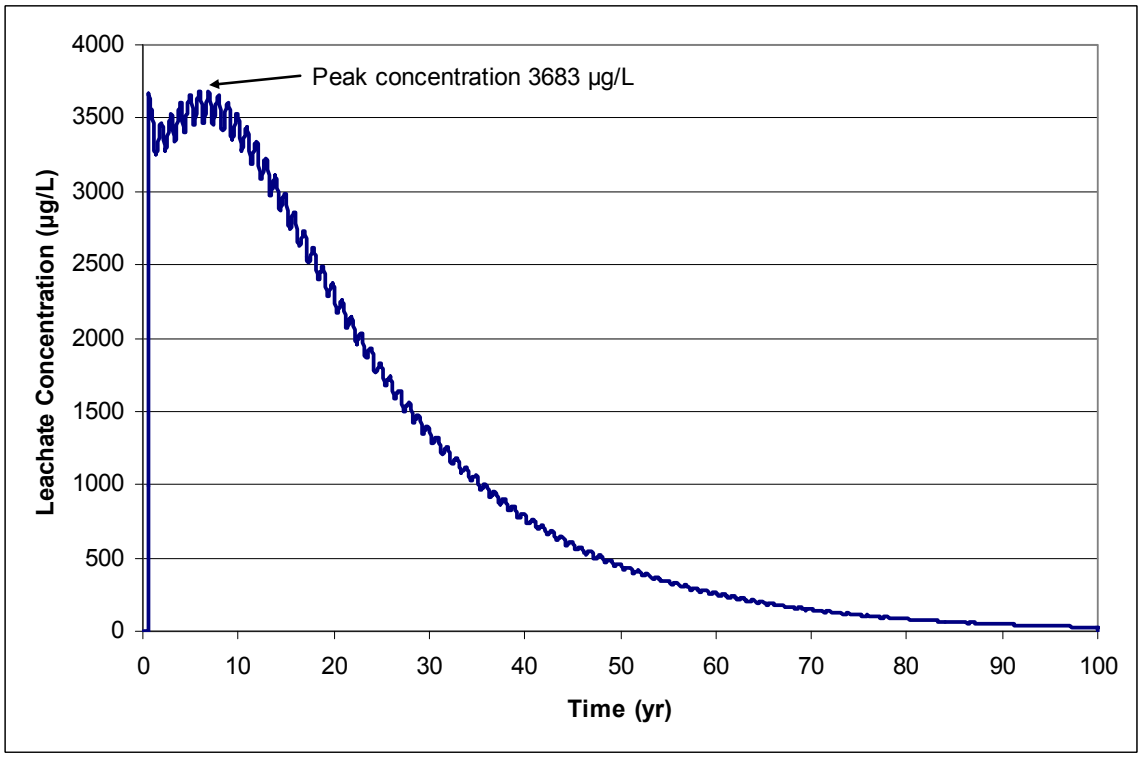

Figure C.4. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from SWMU 1 (Half-Life for TCE in UCRS = 25 Years)

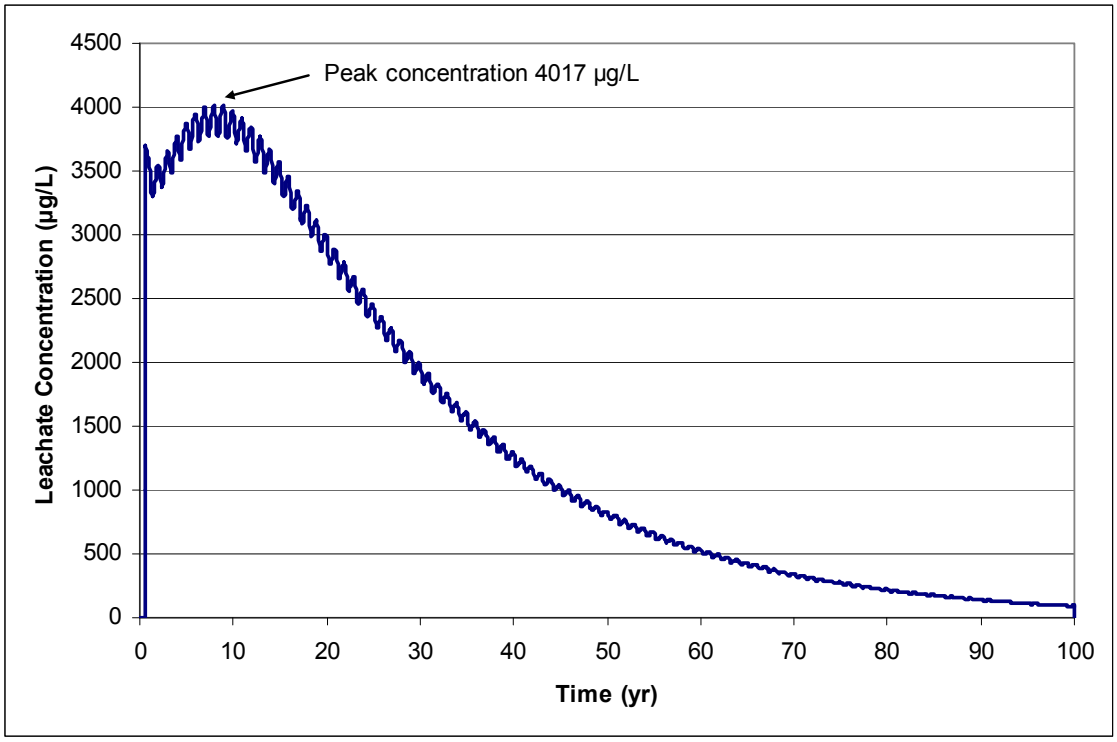

Figure C.5. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from SWMU 1 (Half-Life for TCE in UCRS = 50 Years)

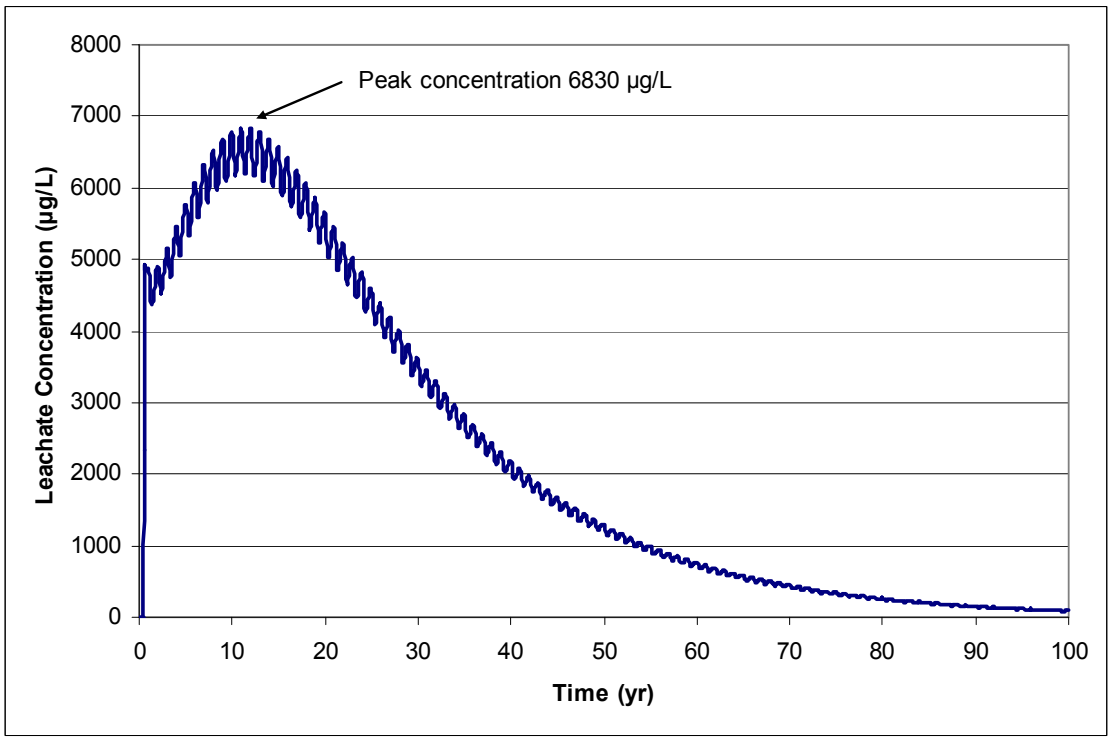

Figure C.6. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of *cis*-1,2-DCE from SWMU 1

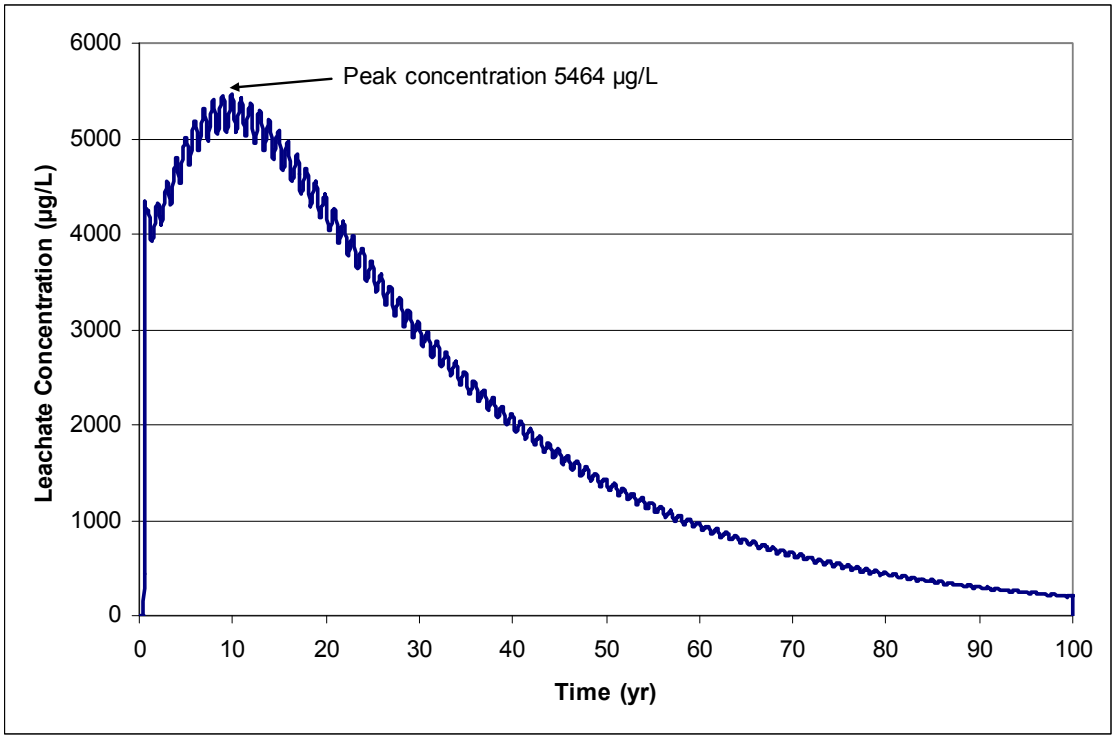

Figure C.7. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of *trans*-1,2-DCE from SWMU 1

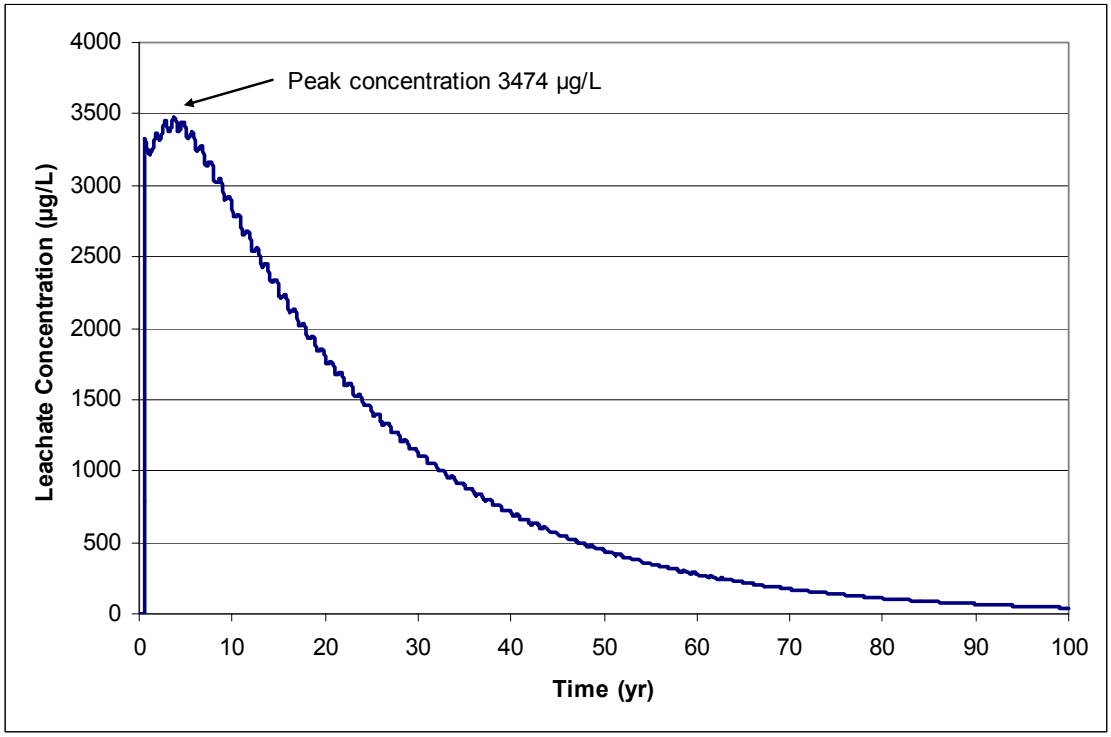

Figure C.8. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of Vinyl Chloride from SWMU 1

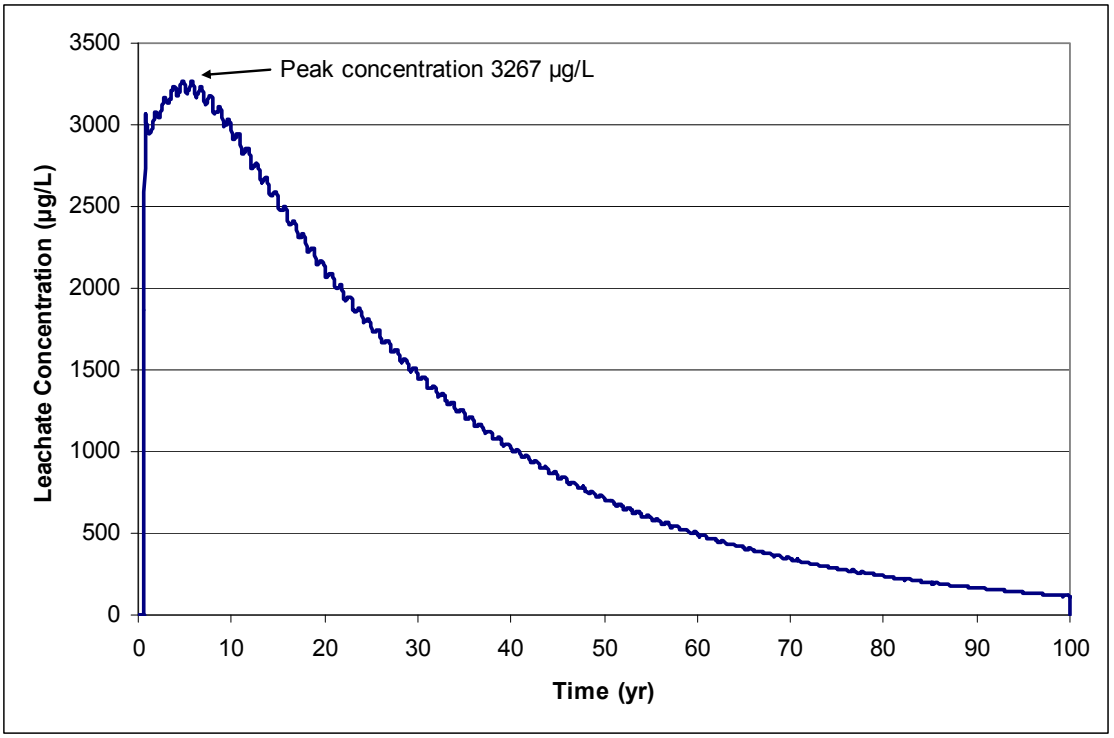

Figure C.9. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of 1,1-DCE from SWMU 1

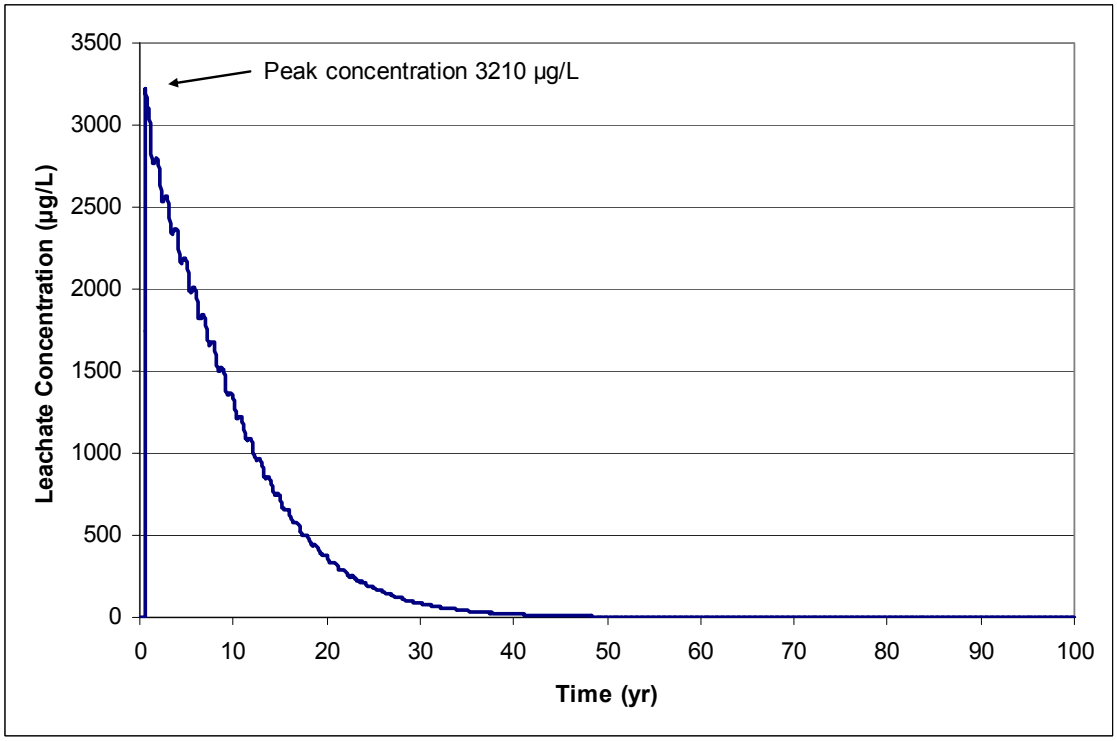

Figure C.10. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from C-720 (Half-Life for TCE in UCRS = 5 Years)

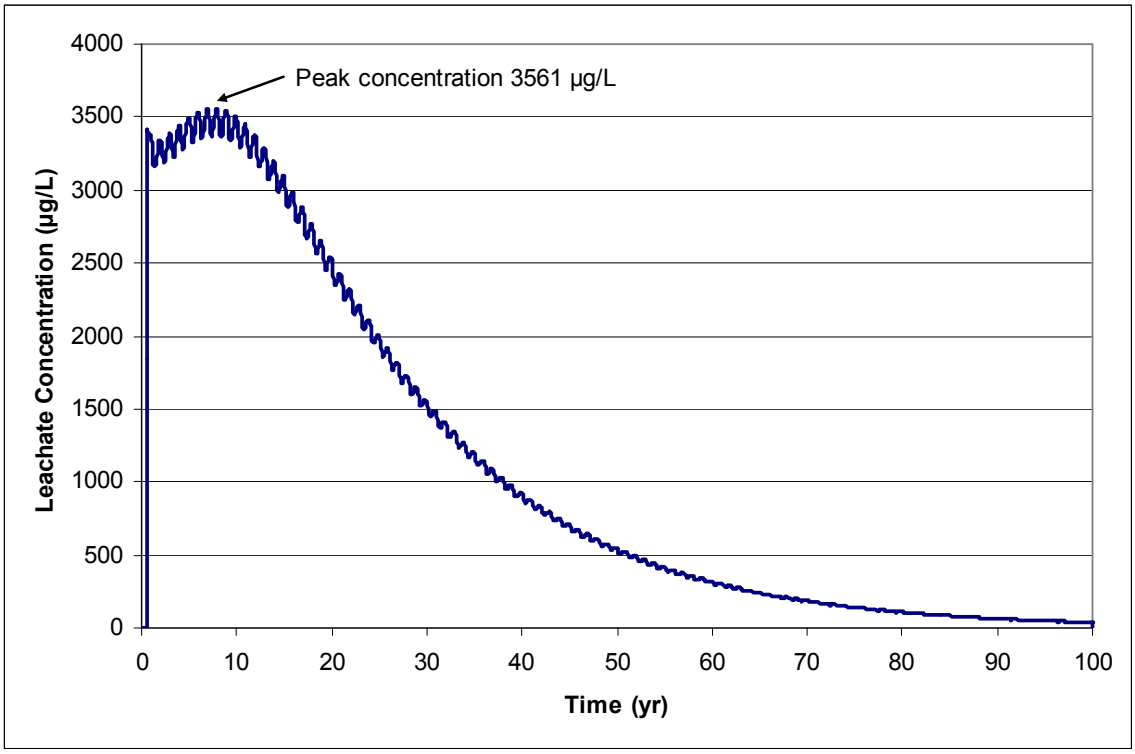

Figure C.11. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from C-720 (Half-Life for TCE in UCRS = 25 Years)

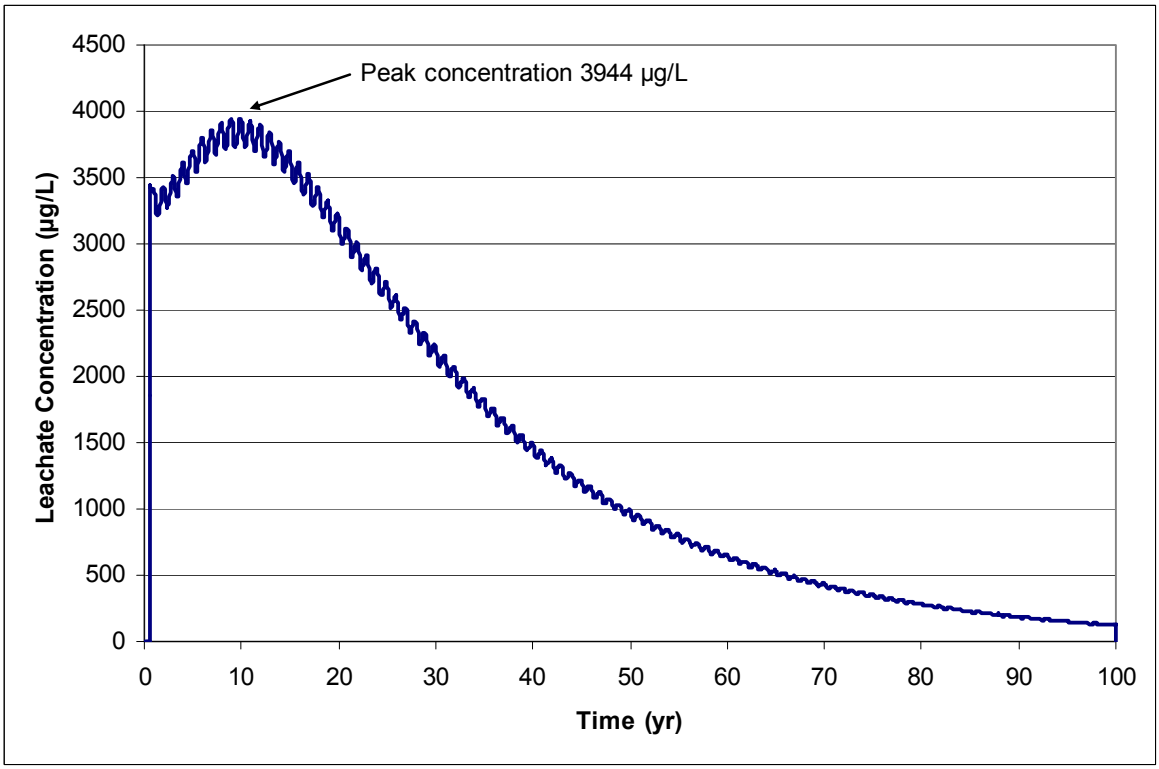

Figure C.12. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of TCE from C-720 (Half-Life for TCE in UCRS = 50 Years)

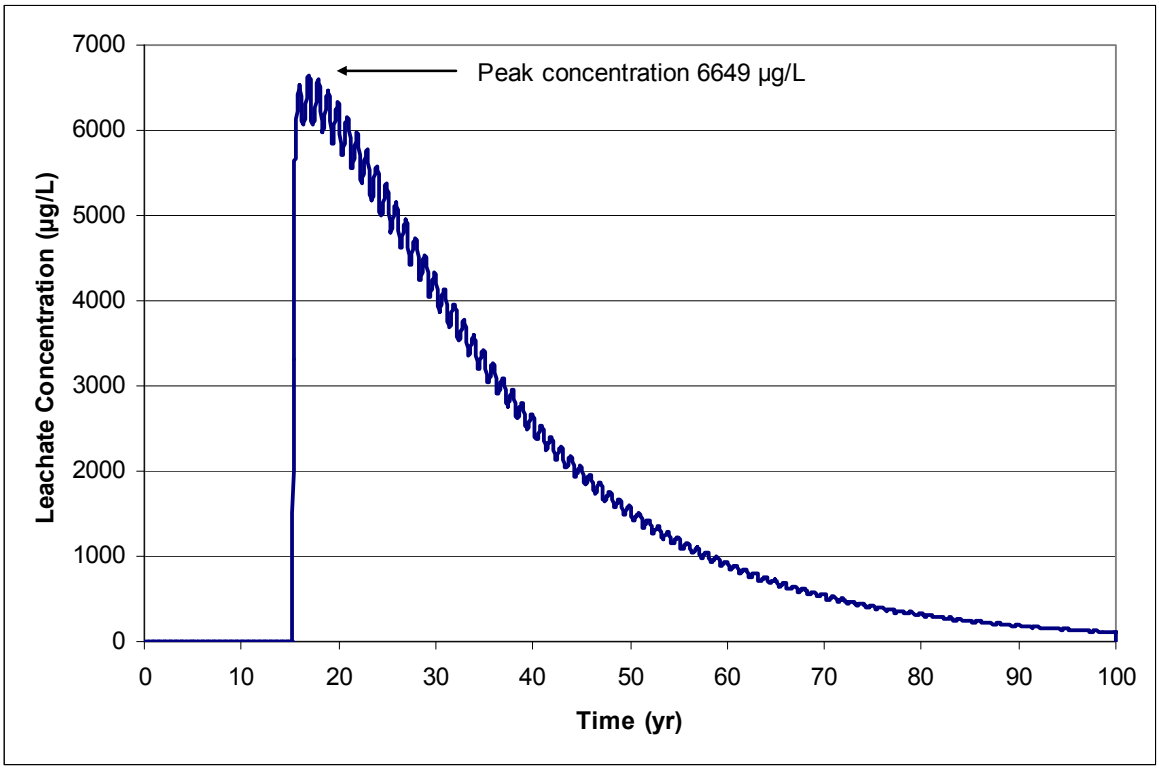

Figure C.13. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of *cis*-1.2-DCE from C-720

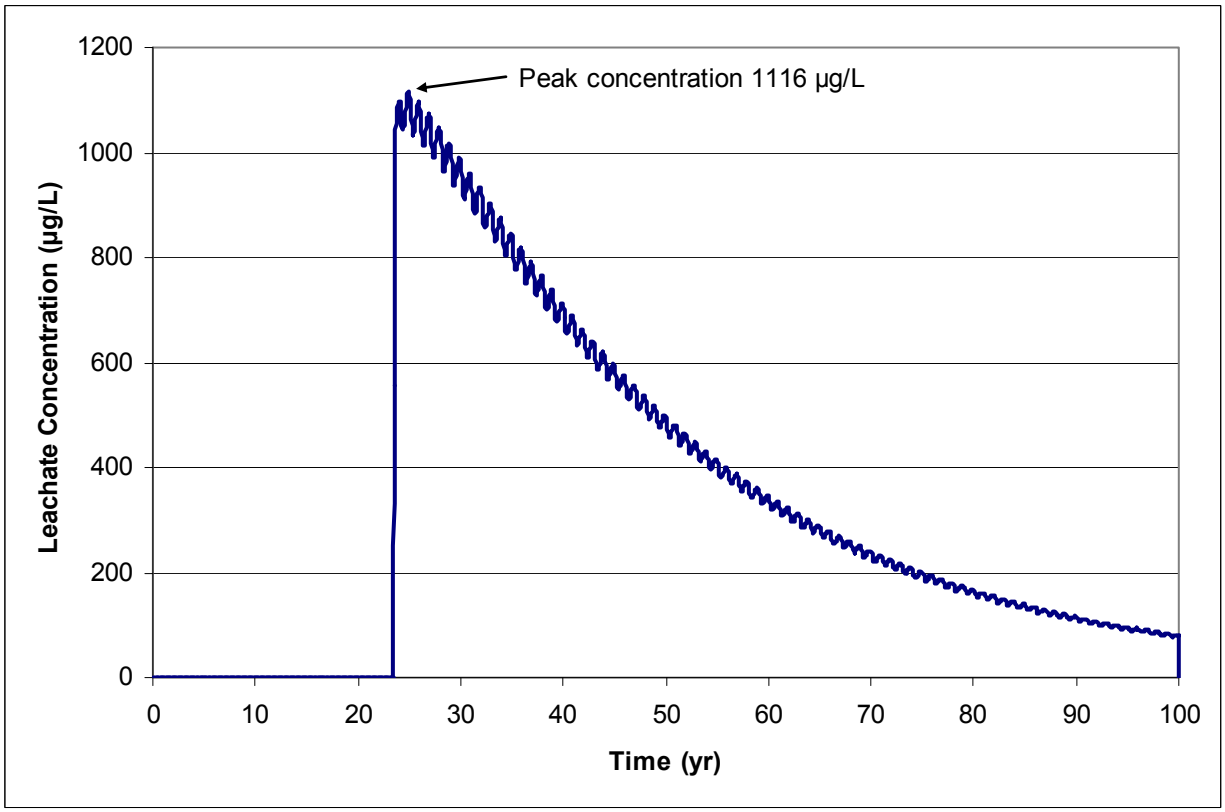

Figure C.14. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of *trans*-1.2-DCE from C-720

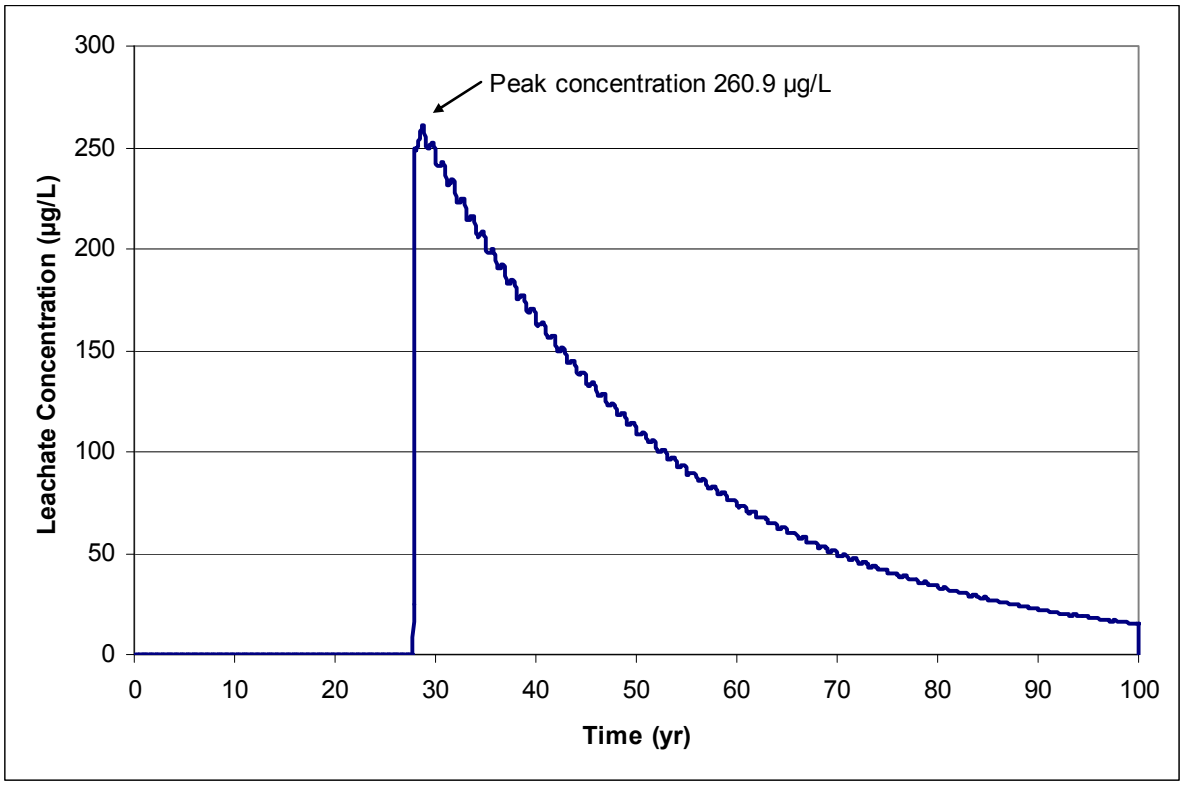

Figure C.15. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of Vinyl Chloride from C-720

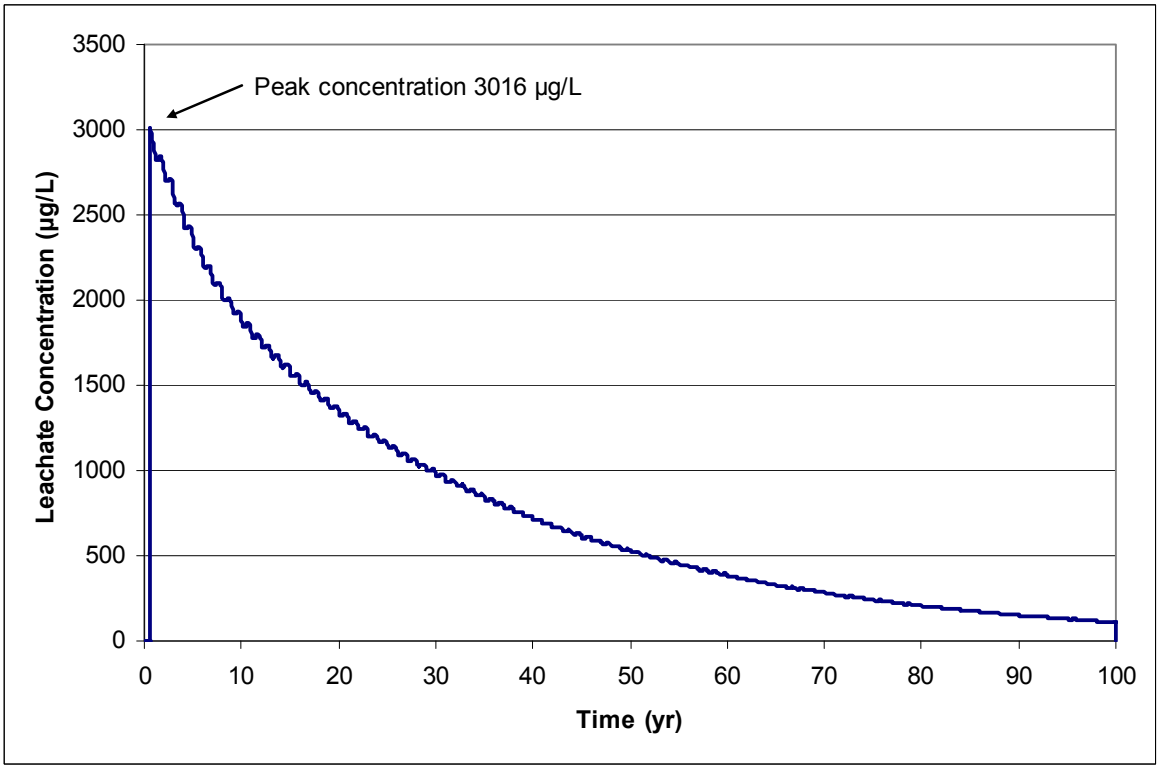

Figure C.16. U3/U4 Contact Leachate Concentrations Based on 1 mg/kg of 1,1-DCE from C-720

C.4 TIME REQUIRED FOR RESIDUAL VOC MASS IN THE SOUTHWEST PLUME SOURCE AREAS TO DIMINISH TO SUB-MCL LEVELS IN RGA

The time required for concentrations of residual VOC COC mass, leaching from Southwest Plume source areas to the RGA beneath the source areas, to diminish to sub-MCL values was estimated for the no action alternative, electrical resistance heating (ERH), and soil vapor extraction (SVE). The SESOIL model was used to evaluate the contaminant flux to the aquifer using the source distributions shown in Tables C.5 and C.6 for SWMU 1 and C-720, respectively, for the no action ERH and SVE alternatives. The source concentrations were reduced by 98 percent for the ERH alternative and 90 percent for the SVE alternative. The parameter values for the SESOIL model shown in Table C.3 were used in the analysis. Ambient VOC contamination in the RGA from potential sources other than the Oil Land farm and C-720 areas was not evaluated.

The hydrogeologic parameters used in AT123D modeling were based on the Southwest Plume SI Report and are presented in Table C.11. The chemical-specific parameters match those used in SESOIL modeling (see Table C.4), except the degradation rate of TCE in the RGA, was assumed to be based on a half-life of 11.3 years, which is the maximum of the range of accepted values for the RGA (i.e., 3.2 to 11.3 years).

Table C.11. Hydrogeologic Parameters Used in AT123D Modeling[a]

Input Parameter	SWMU 1	C-720 Building	Source
Bulk density (kg/m^3)	1,670	1,670	Laboratory analysis
Effective porosity	0.3	0.3	PGDP sitewide model calibrated value
Hydraulic conductivity (m/hour)	16.2	16.2	Average value from Tables C.7 and C.8
Hydraulic gradient	0.0004	0.0004	PGDP sitewide model calibrated value
Aquifer thickness	9.14 m 30 ft	9.14 m 30 ft	Site average
Longitudinal dispersivity (m)[b]	1.5	1.5	
Density of water (kg/m^3)	1,000	1,000	Default
Fraction of organic carbon (%)	0.02	0.02	Laboratory analysis
Well screen length (m)	3	3	Assumed a 10 ft well screen mixing zone

[a]Parameter values from the Southwest Plume SI Report
[b]The dispersivity value was decreased from the PGDP value of 15m to account for the limited dispersion from transport to the downgradient unit boundary.

The projected time to attainment of MCLs for each remedial alternative for SWMU 1 is provided in Table C.12. Figures C.17 through C.23 also depict groundwater concentrations over time at the down-gradient boundary of SWMU 1 for each alternative and COC. The SVE alternative includes an infiltration reduction cap that reduces infiltration by 90 percent. Due to the limitations of the SESOIL model, in which the infiltration rate cannot be altered, the cap was left in place throughout the simulations.

Trans-1,2-DCE in Figure C.21 shows a sharp concentration increase in concentration at 38 years for the SVE alternative. The sharp increase is an artifact of SESOIL and the method used to model the alternative soil concentration reductions. SESOIL calculates the contaminant flux to the groundwater using the infiltration rate and groundwater recharge rate computed by the hydrologic cycle of the model. The model computes the depth of the contaminant front based on layer thicknesses and the flow velocity accounting for retardation. Referring to the contaminant concentrations Table C.5, there are no contaminant concentrations in the lower layers for *trans*-1,2-DCE. SVE treatment was modeled by assuming that the soil concentrations were reduced by 90% of the original concentrations in their original soil layer

positions; therefore, SESOIL predicted when this new reduced mass reaches the water table. This is the reason for the sharp increases seen in the Figure C.21.

Table C.12. SWMU 1 Time to Attain MCL Compliance

Analyte	TCE Half-Life in UCRS (yr) [a]	Time to Attain MCL Compliance (years)		
		No Action	ERH	SVE
TCE	5	41	15	5
TCE	25	>100	41	5
TCE	50	>100	52	5
cis-1,2-DCE	infinite	26	0	0
trans-1,2-DCE	infinite	32	0	0
Vinyl Chloride	infinite	0	0	0
1,1-DCE	infinite	0	0	0

[a]TCE degradation rate in the RGA based on a half-life of 11.3 yr–all other analytes were infinite half-lives

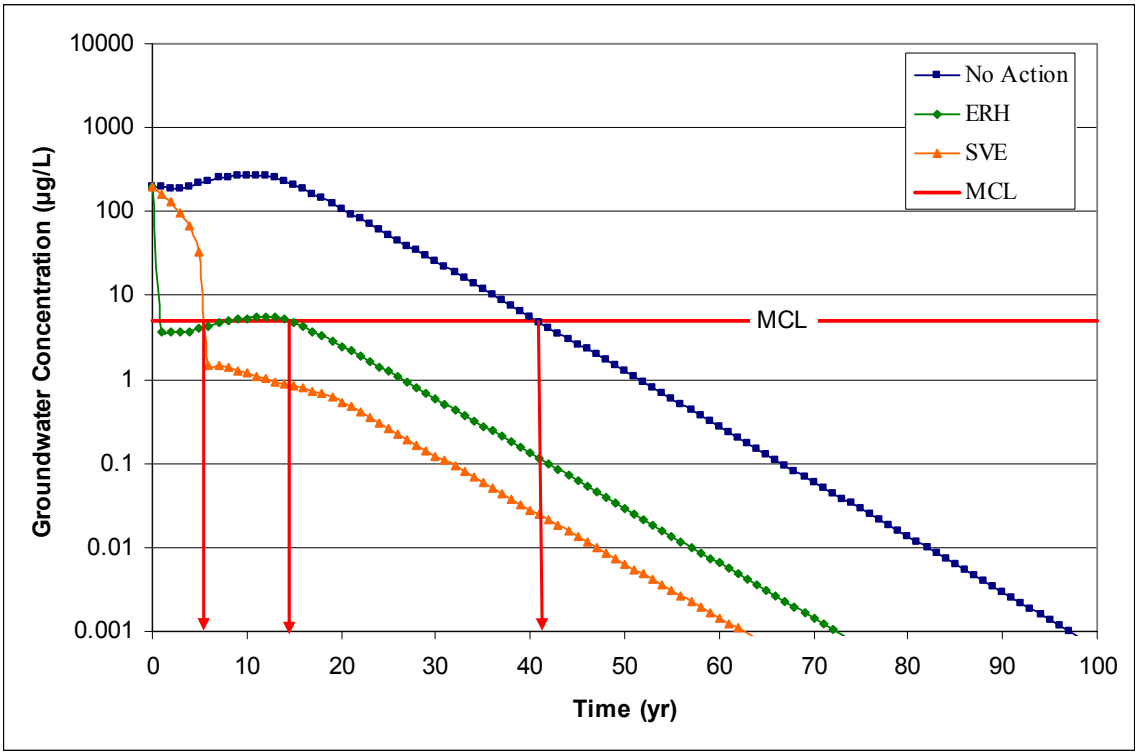

Figure C.17. Time Required for Residual TCE Mass from SWMU 1 to Reach MCL in RGA (5µg/L) (Half-life for TCE in UCRS = 5 years)

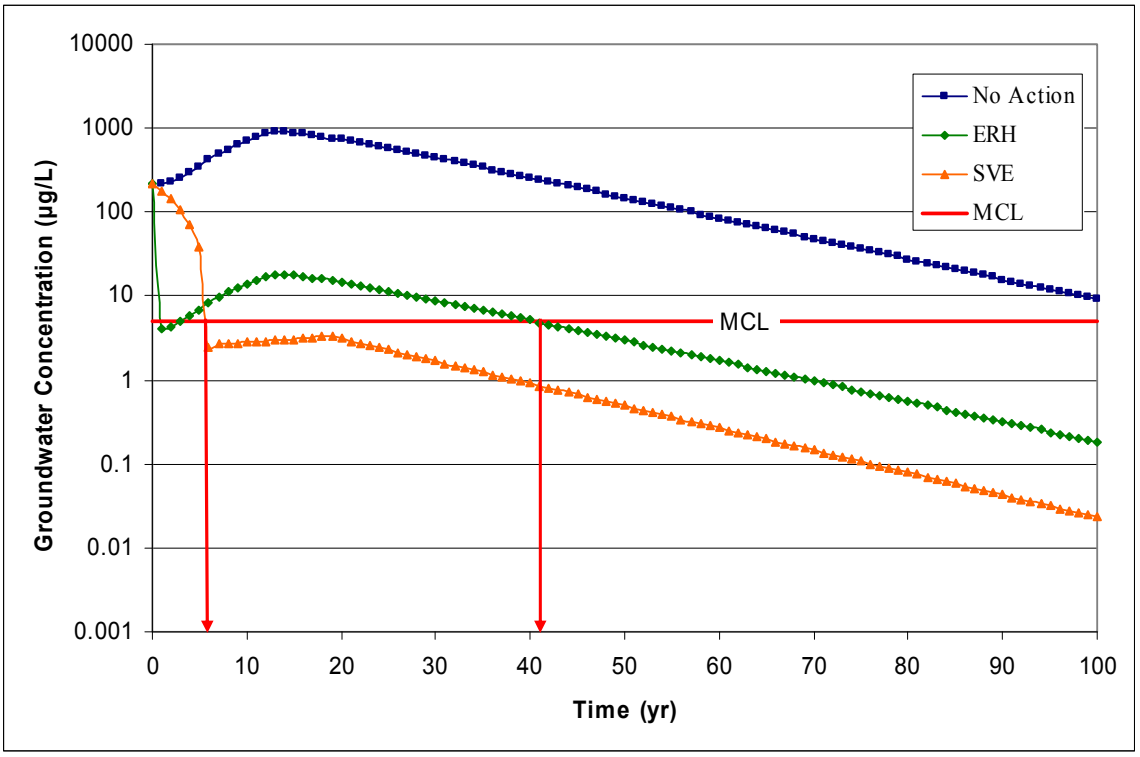

Figure C.18. Time Required for Residual TCE Mass from SWMU 1 to Reach MCL in RGA (5 µg/L) (Half-life for TCE in UCRS = 25 years)

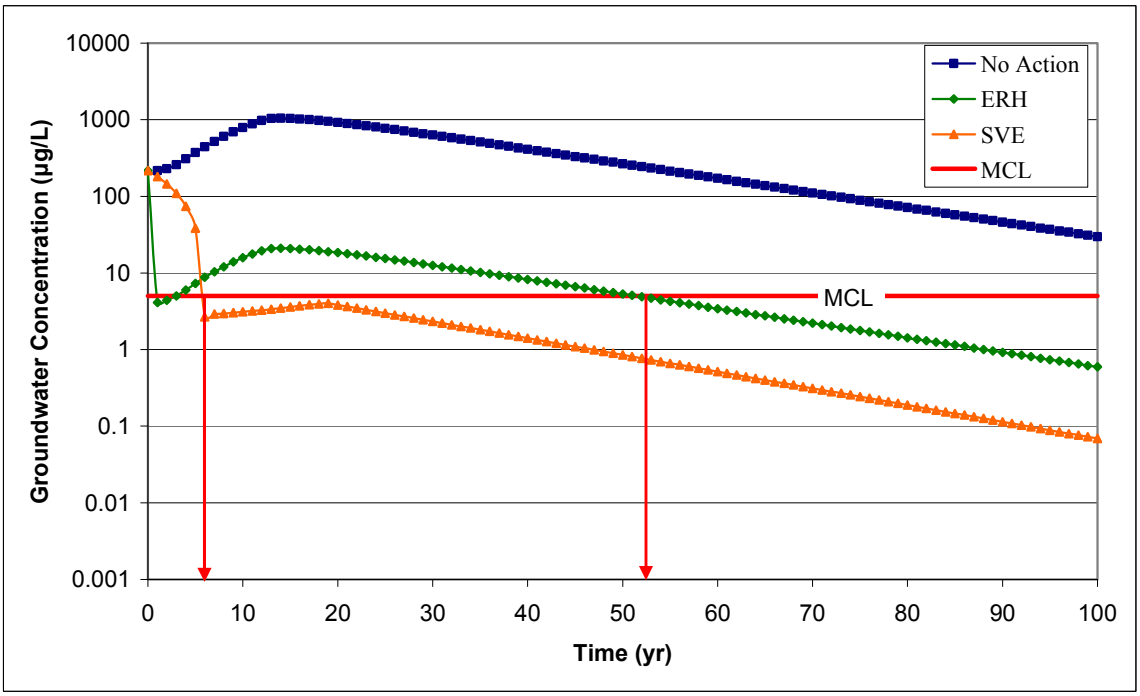

Figure C.19. Time Required for Residual TCE Mass from SWMU 1 to Reach MCL in RGA (5 µg/L) (Half-life for TCE in UCRS = 50 years)

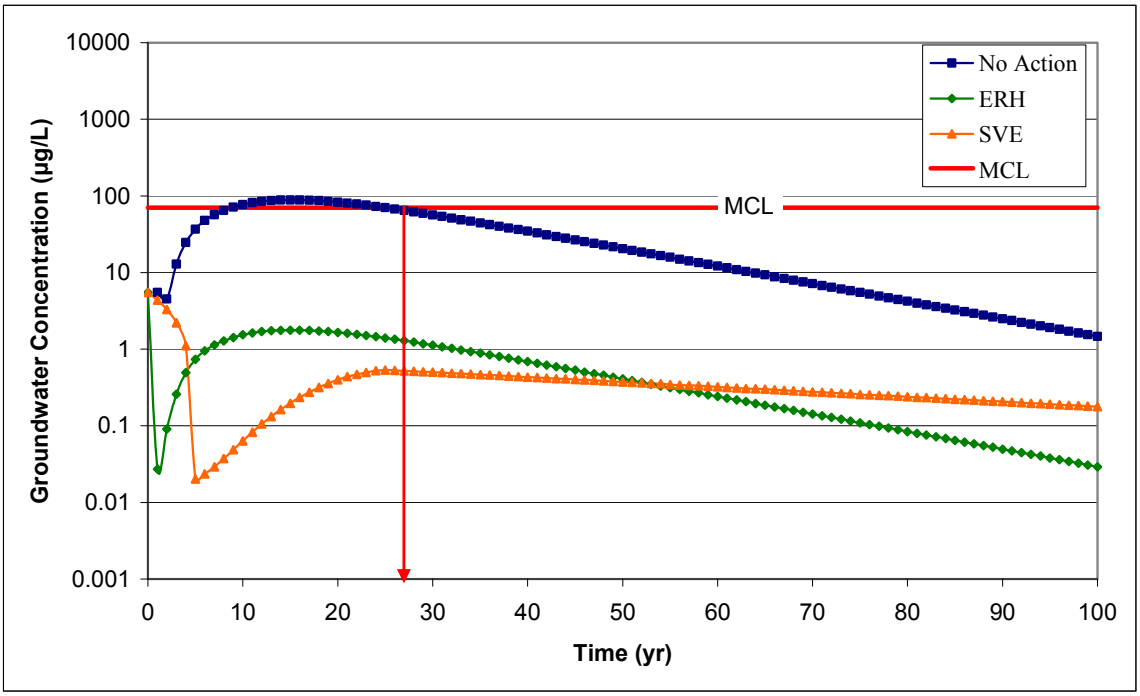

Figure C.20. Time Required for Residual *cis*-1,2-DCE Mass from SWMU 1 to Reach MCL in RGA (70 µg/L)

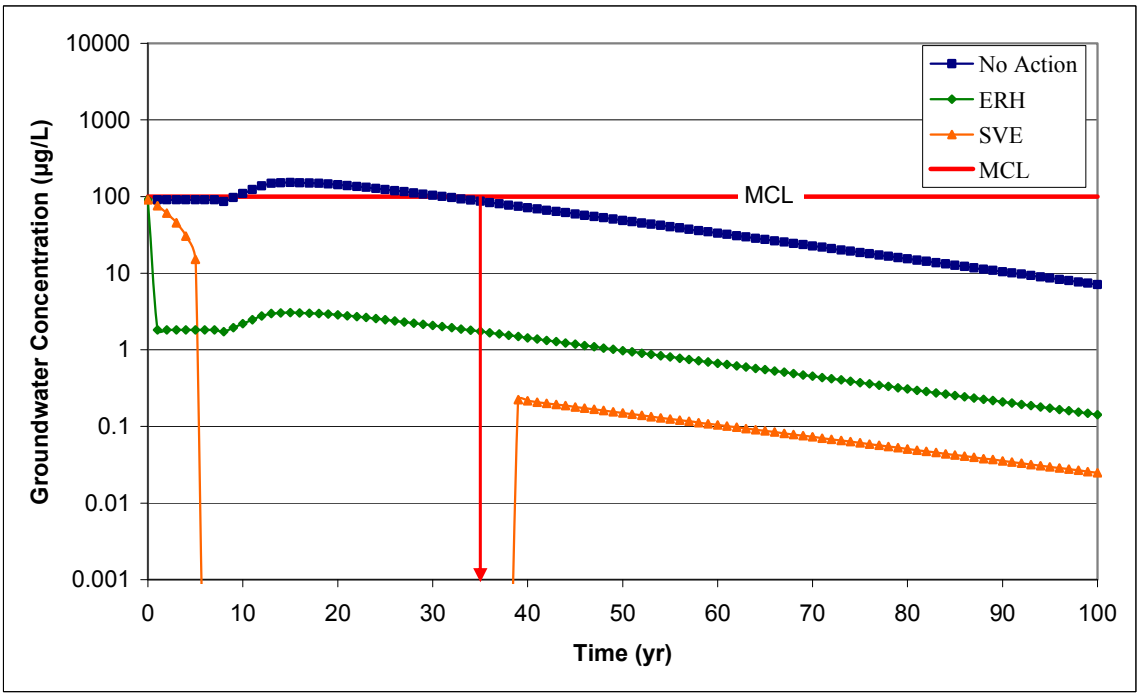

Figure C.21. Time Required for Residual *trans*-1,2-DCE Mass from SWMU 1 to Reach MCL in RGA (100 µg/L)

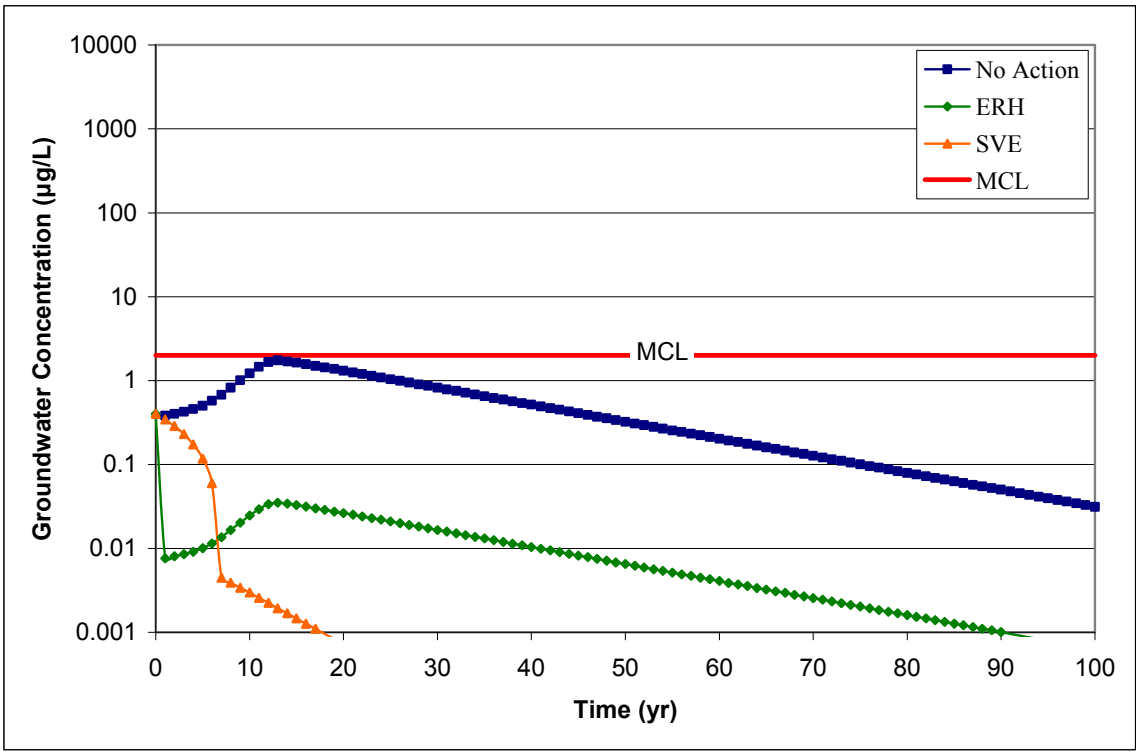

Figure C.22. Time Required for Residual Vinyl Chloride Mass from SWMU 1 to Reach MCL in RGA (2 µg/L)

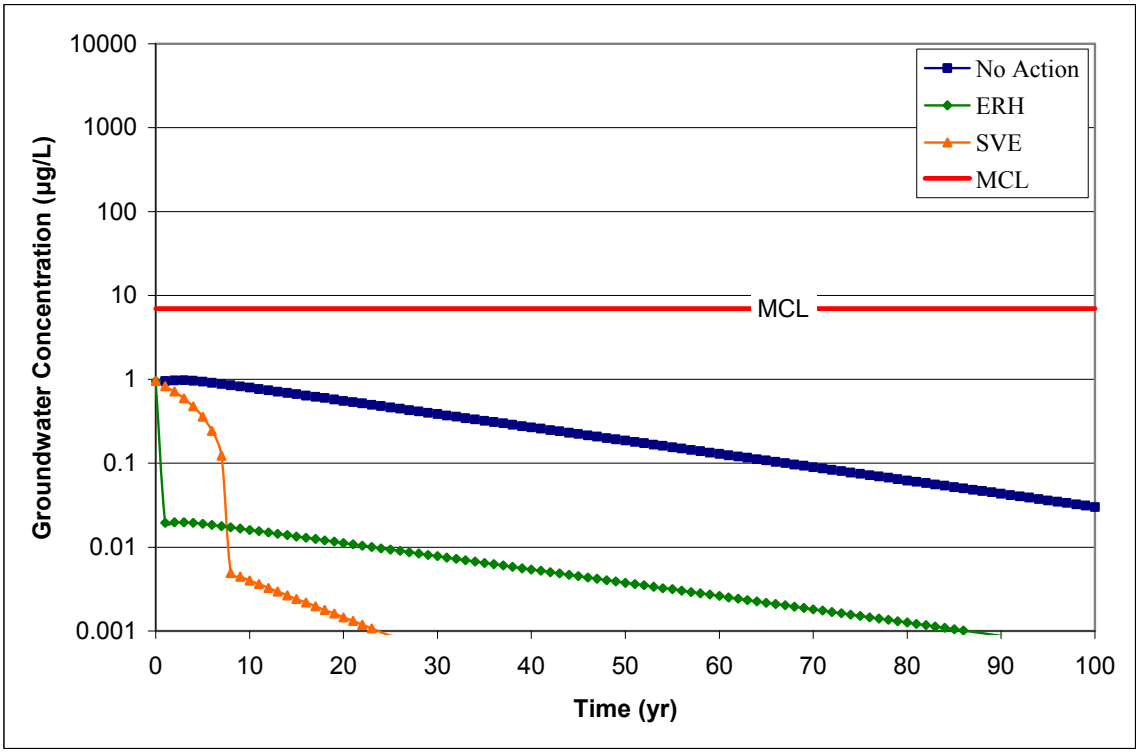

Figure C.23. Time Required for Residual 1,1-DCE Mass from SWMU 1 to Reach MCL in RGA (7 µg/L)

The time to attainment of MCLs for each remedial alternative for C-720 are provided in Table C.13. Figures C.24 through C.30 depict groundwater concentrations over time at the downgradient boundary of C-720 for each alternative and COC. The SVE alternative includes an infiltration reduction cap that reduces infiltration by 90 percent. Due to the limitations of the SESOIL model in which the infiltration rate cannot be altered, the cap was left in place throughout the simulations.

Cis-1,2-DCE in Figure C.27, *trans*-1,2-DCE in Figure C.28, and vinyl chloride in Figure C.29 show a sharp concentration increase in concentration. The sharp increase is an artifact of SESOIL and the method used to model the alternative soil concentration reductions. SESOIL calculates the contaminant flux to the groundwater using the infiltration rate and groundwater recharge rate computed by the hydrologic cycle of the model. The model computes the depth of the contaminant front, based on layer thicknesses and the flow velocity accounting for retardation. Referring to the contaminant concentrations Table C.6, there are no contaminant concentrations in the lower layers for these COCs; therefore, SESOIL predicted when this new reduced mass reaches the water table.

Table C.13. C-720 Time to Attain MCL Compliance

Analyte	TCE Half-Life in UCRS (yr) [a]	Time to Attain MCL Compliance (years)		
		No Action	ERH	SVE
TCE	5	35	1	2
TCE	25	97	22	3
TCE	50	>100	29	3
1,1-DCE	infinite	0	0	0
cis-1,2-DCE	infinite	36	0	0
trans-1,2-DCE	infinite	0	0	0
Vinyl Chloride	infinite	34	0	0

[a]TCE degradation rate in the RGA based on a half-life of 11.3 yr–all other analytes were infinite half-lives

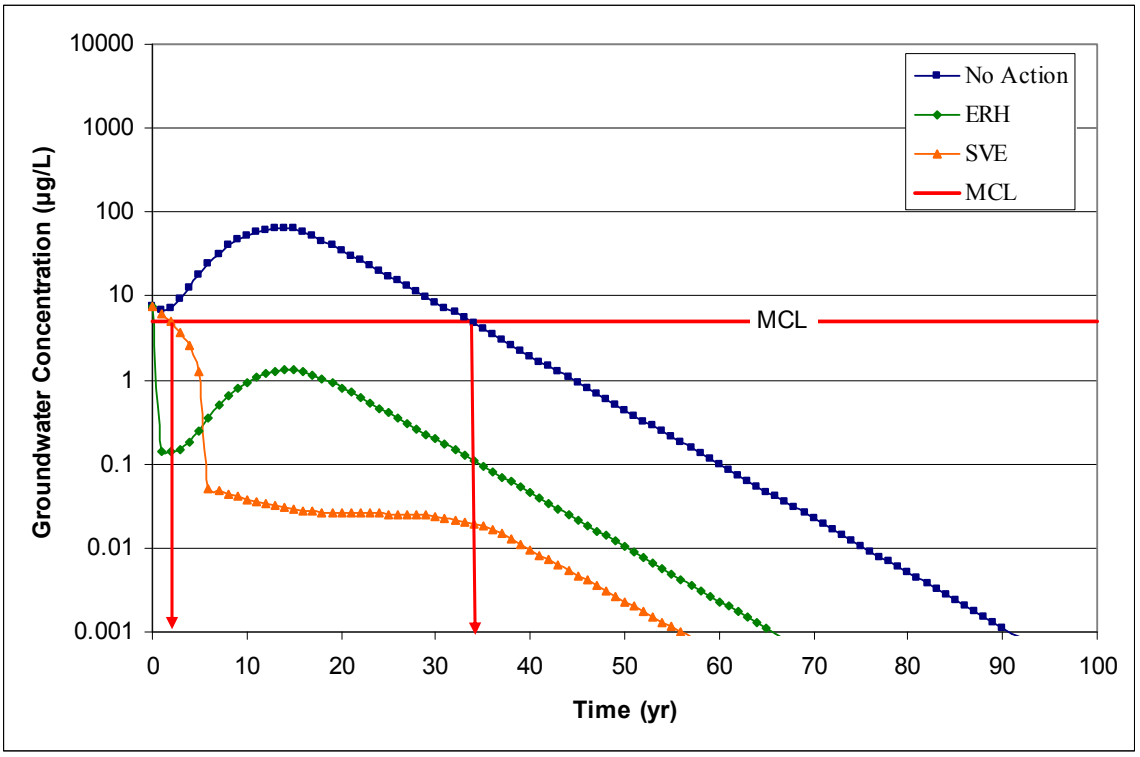

Figure C.24. Time Required for Residual TCE Mass from C-720 to Reach MCL in RGA (5 µg/L)(Half-life for TCE in UCRS = 5 years)

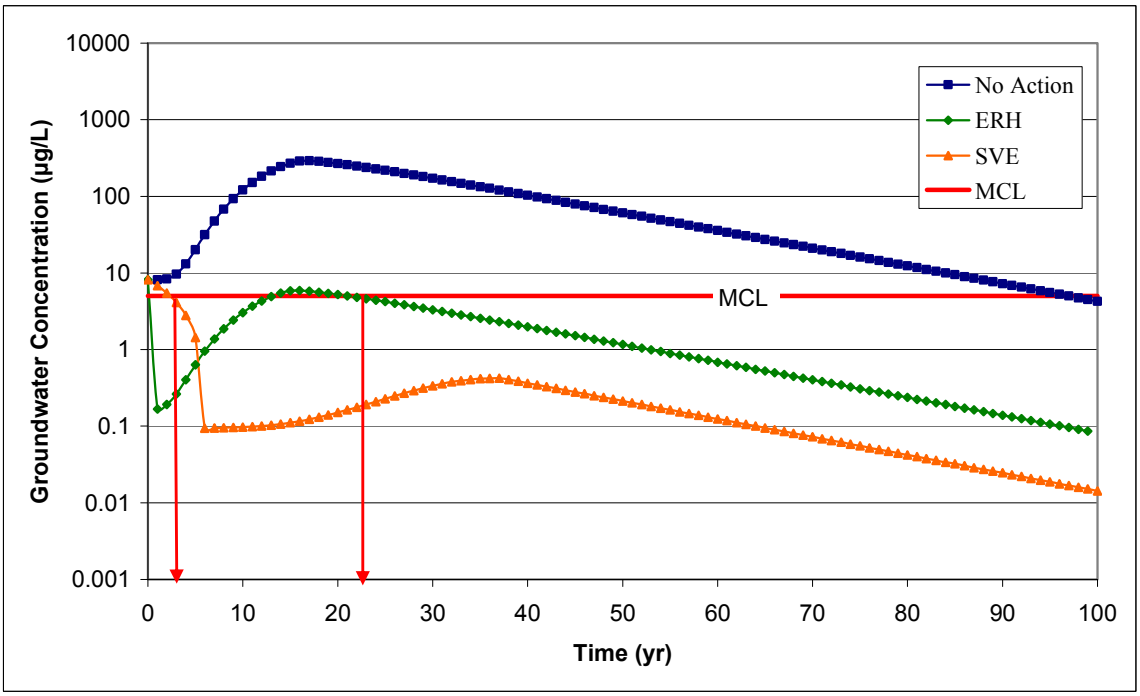

Figure C.25. Time Required for Residual TCE Mass from C-720 to Reach MCL in RGA (5 µg/L) (Half-life for TCE in UCRS = 25 years)

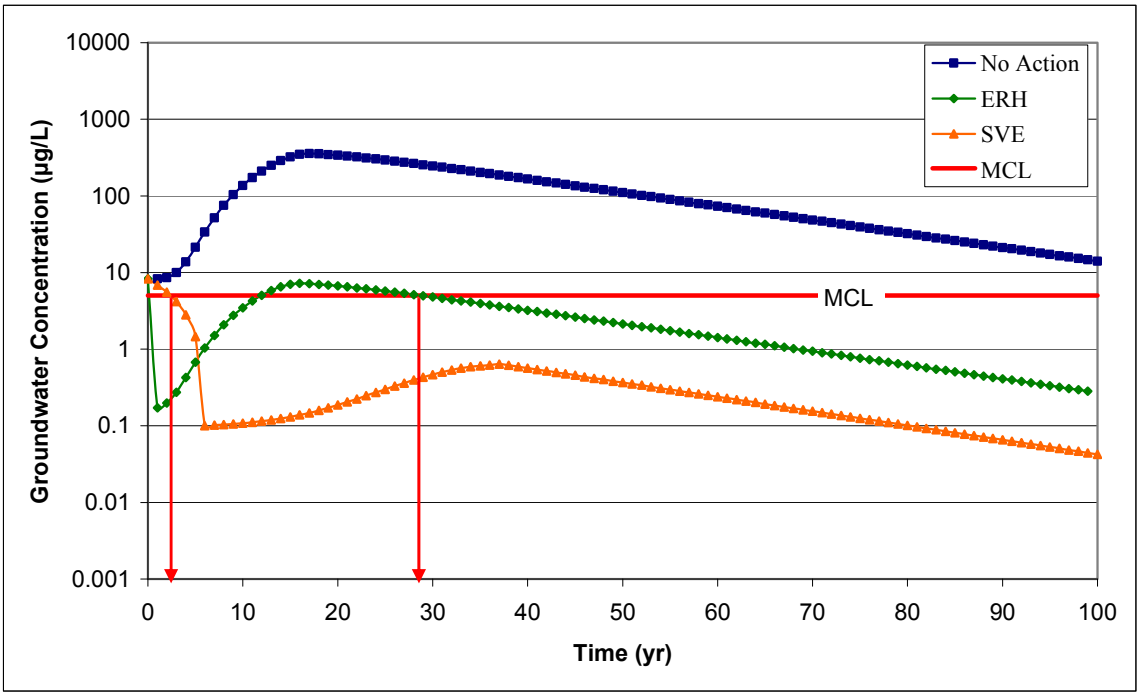

Figure C.26. Time Required for Residual TCE Mass from C-720 to Reach MCL in RGA (5 µg/L) (Half-life for TCE in UCRS = 50 years)

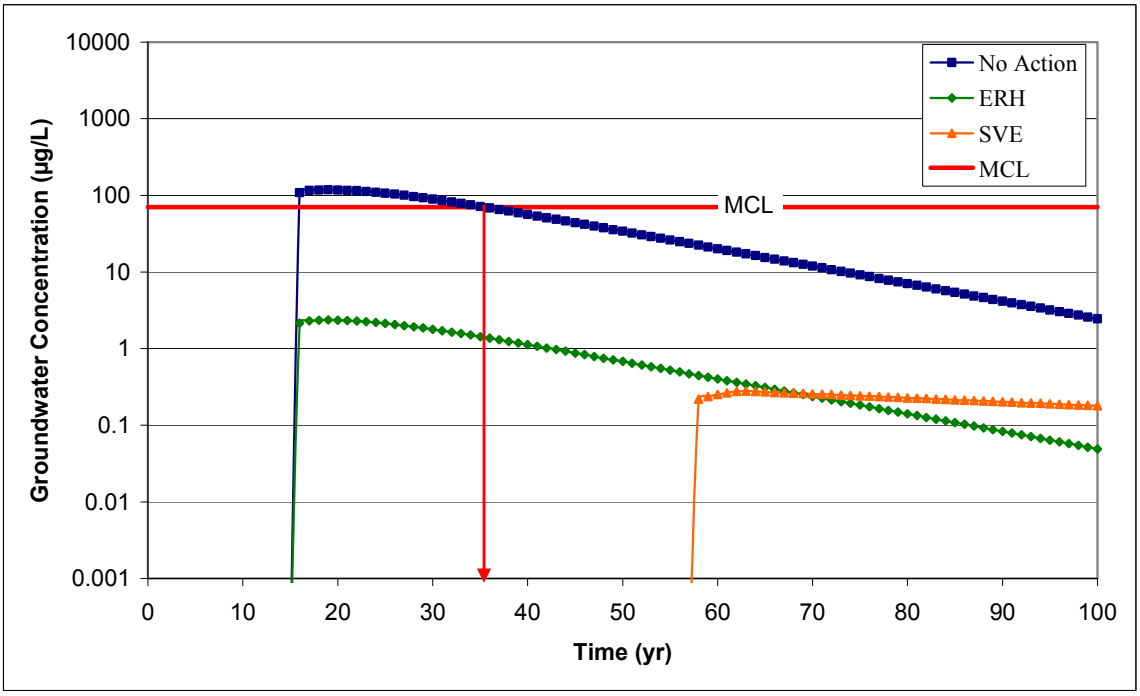

Figure C.27. Time Required for Residual *cis*-1,2-DCE Mass from C-720 to Reach MCL in RGA (70 µg/L)

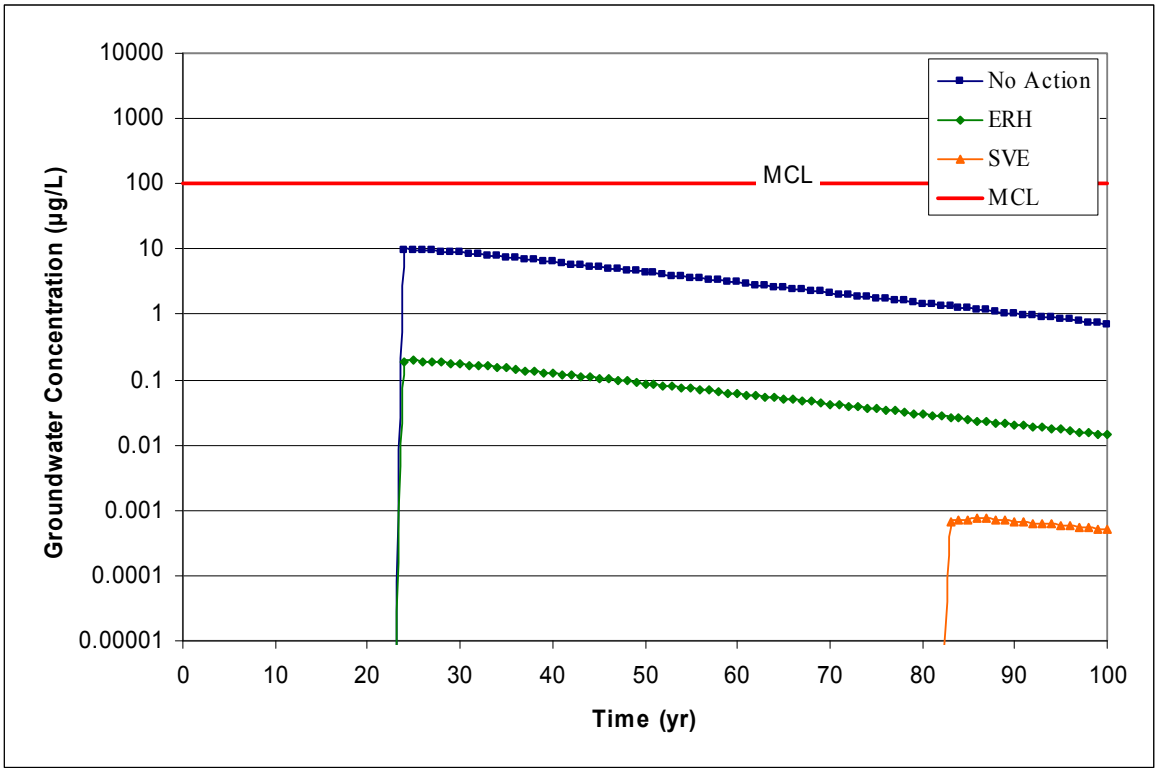

Figure C.28. Time Required for Residual *trans*-1,2-DCE Mass from C-720 to Reach MCL in RGA (100 µg/L)

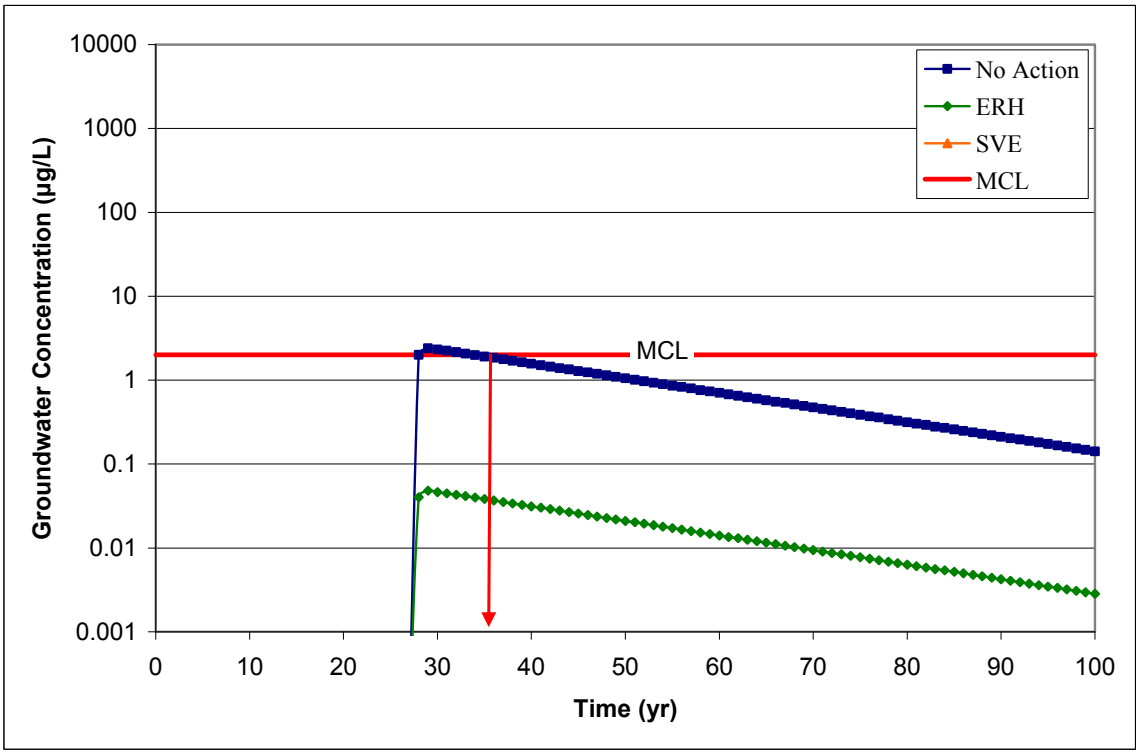

Figure C.29. Time Required for Residual Vinyl Chloride Mass from C-720 to Reach MCL in RGA (2 µg/L)

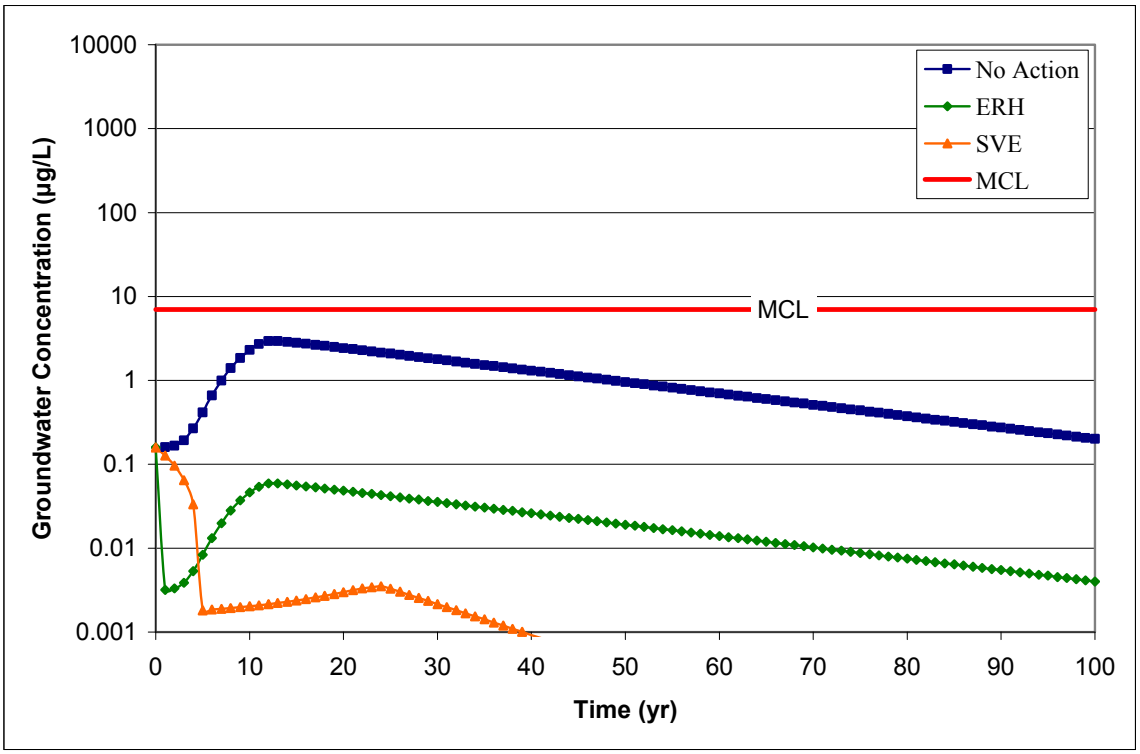

Figure C.30. Time Required for Residual 1,1-DCE Mass from C-720 to Reach MCL in RGA (7 µg/L)

C.5. TIME REQUIRED TO MEET RGs FOR THE ERH AND SVE ALTERNATIVES

The SVE alternative includes an infiltration reduction cap, which reduces infiltration by 90 percent. Due to the limitations of the SESOIL model in which the infiltration rate cannot be altered, the cap was left in place throughout the model time frame. This essentially reflects maintenance of the infiltration reduction cap throughout the model time frame. The ERH alternative does not have an infiltration reduction cap. Accordingly, an analysis was conducted to evaluate the time required to meet the soil RGs presented in Tables C.9 and C.10 for SWMU 1 and C-720, respectively, to provide another measure of comparison between the two alternatives.

The time required to meet the RGs for the ERH and SVE alternative was based on the SESOIL concentrations in each soil sublayer. The time when all soil layers was determined to be less than the RG was chosen as the metric. The results of the analysis are provided in Tables C.14 and C.15.

Table C.14. SWMU 1–Time Required for ERH with No Cap and SVE with Infiltration Reduction Cap to Reach the Soil RG in all Soil Layers

Analyte	TCE Half-Life in UCRS (yr) [a]	Soil RG (mg/kg)	Time (years)	
			ERH	SVE
TCE	5	0.085	20	29
TCE	25	0.080	55	64
TCE	50	0.073	69	77
cis-1,2-DCE	infinite	0.600	0	5
trans-1,2-DCE	infinite	1.080	0	6
Vinyl Chloride	infinite	0.034	0	6
1,1-DCE	infinite	0.130	0	0

Table C.15. C-720–Time Required for ERH with No Cap and SVE with Infiltration Reduction Cap to Reach the Soil RG in all Soil Layers

Analyte	TCE Half-Life in UCRS (yr) [a]	Soil RG (mg/kg)	Time (years)	
			ERH	SVE
TCE	5	0.092	5	21
TCE	25	0.083	19	56
TCE	50	0.075	30	73
cis-1,2-DCE	infinite	0.619	0	5
trans-1,2-DCE	infinite	5.29	0	0
Vinyl Chloride	infinite	0.45	0	0
1,1-DCE	infinite	0.137	0	5

C.6 UNCERTAINTY ANALYSIS–SITE PHYSICAL PARAMETERS

Uncertainty in the values of physical parameters may affect RG model predictions, along with time to reach the water table, peak leachate concentration, and leachate concentration over time. Data from previous site investigations have narrowed the realistic ranges of most of these parameters, but the potential exists for variation in many of them, including recharge, porosity, moisture content, and intrinsic permeability. Porosity and intrinsic permeability of the UCRS were evaluated in the probabilistic modeling uncertainty analysis (Section C.5), while formal uncertainty analysis of other parameters such as recharge and moisture content was not conducted. A qualitative discussion of the impacts of variability in these parameters is provided.

C.6.1 POTENTIAL DEVIATIONS IN THE SITE CONCEPTUAL MODEL

C.6.1.1 Recharge

The rate of recharge is an area of uncertainty. An average rate of recharge of 13 cm per year was calibrated with the hydraulic conductivity field in the sitewide PGDP model update in 2008; however, the calibration of recharge does not necessarily produce a unique model solution. Similar groundwater elevations could be achieved with a lower recharge rate by decreasing the transmissivity of the aquifer, increasing anisotropy (i.e., decreasing vertical K), or by restricting outflow at the model boundaries by reducing the conductance terms that allow water to flow through the boundary. In addition, anthropogenic sources of recharge are possible at the Oil Landfarm and C-720 sites. The amount of recharge from these

sources may substantially exceed that of natural recharge and result in locally elevated water tables in the UCRS.

C.6.1.2 Intrinsic Permeability and Porosity

The value of intrinsic permeability was estimated based on measured values of vertical hydraulic conductivity in the UCRS. The porosity value of 0.45 for the UCRS is based on laboratory analysis [Waste Area Grouping (WAG) 27 Remedial Investigation] (DOE 1999). Physical hydrogeologic parameters, such as hydraulic conductivity and effective porosity, vary spatially depending on geologic characterization of the hydrologic systems. These spatial variations, often referred to as heterogeneities, generally cannot be quantified adequately during data collection or model calibration efforts. As a result, estimates of these parameters always contain a degree of uncertainty.

C.6.1.3 Saturation

The degree of saturation in the URCS at the Oil Landfarm and C-720 sites is complicated by the heterogeneous nature of the hydraulic conductivity field at the site and the fact that significant variability in recharge may be present due to anthropogenic sources. Anthropogenic recharge may result in significant elevation of the water table into the URCS. Low-permeability silty-clay and clayey-silt units may contain discontinuous zones of silty-sand and/or sandy- or silty-gravel. These lithologic heterogeneities, along with potential variations in recharge volume, may result in variable conditions of saturation/soil moisture throughout the UCSR soil column.

C.6.2 IMPACTS OF UNCERTAINTY ON RG

Studies have been conducted evaluating the sensitivity of SESOIL to parameters such as recharge, intrinsic permeability, and porosity (Odencrantz 1992; Brar 1996). While these studies are site- and contaminant-specific, they may be used generally to address the behavior of SESOIL predictions when varying values of specific parameters.

C.6.2.1 Recharge

Previous studies of the sensitivity of SESOIL to increased recharge have indicated the higher values of recharge result in higher peak concentrations and a shorter time to reach peak concentration (Odencrantz 1992). The higher values of recharge result in faster travel time through the unsaturated zone with less opportunity for volatilization or biodegradation.

C.6.2.2 Intrinsic Permeability and Porosity

Lower intrinsic permeability results in a decrease in predicted peak leachate concentration and an increased time to peak concentration (Odencrantz 1992). Conversely, increasing intrinsic permeability results in an increase in predicted peak leachate concentration and a decreased time to peak concentration. This behavior is significantly affected by the rates of biodegradation used.

An increase in effective porosity generally results in a decrease in peak concentration and an increase in peak leach time (Brar 1996). This may be the result an increase in volatilization due to more air-filled voids.

C.6.2.3 Saturation

Simulating near-saturated or saturated conditions in SESOIL is difficult, due to the limitations of available input parameters. Moisture content in SESOIL is not an input parameter, but rather is calculated based on the values of other model inputs. Other parameters such as recharge rate and intrinsic permeability parameters directly affect moisture content values in SESOIL. While recharge rate cannot be modified directly in SESOIL, intrinsic permeability of the soil may be modified. The result of changes in values of intrinsic permeability within realistic ranges for SESOIL model results and RG predictions is included in Section C.5. Another method of increasing moisture content is to reduce the soil pore disconnectedness index in SESOIL. However, significant increases in saturation require soil pore disconnectedness index values that are unrealistic for the Oil Landfarm and C-720 sites.

Conceptually, assuming an instantaneous source release with an increase in recharge and corresponding increase in the water table elevation, this would result in a shorter travel time to the water table with higher leachate concentrations. This is, in part, due to the shorter travel distance from the source, but also due to the additional recharge driving water through the unsaturated zone. There is less opportunity for chemical and physical processes such as biodegradation, adsorption and volatilization to attenuate concentrations prior to reaching the water table. However, time to reach MCLs at the boundary should be lower since the majority of the mass would be flushed through the system faster. Based on this conceptualization, the SESOIL modeling of this scenario presented here is conservative with regard to time to reach the MCL, with more persistent concentrations at the boundary, but may under-predict concentrations at the water table.

C.7. TCE RG UNCERTAINTY ANALYSIS–PROBABILISTIC MODELING

An uncertainty analysis was conducted, using probabilistic analyses, to evaluate the soil remediation goals for TCE. The probabilistic analyses were based on the parameter distributions presented in the Southwest Plume SI. The modeling was conducted using unit soil concentrations (i.e., 1 mg/kg) in each layer that exhibited contamination shown in Tables C.5 and C.6 to facilitate the back calculation of the soil remediation goals.

The parameter distributions used in the probabilistic modeling are provided in Table C.16 for the vertical hydraulic conductivity and organic carbon content. SESOIL uses the intrinsic permeability, which is based on the vertical hydraulic conductivity values multiplied by 1×10^{-5} cm-sec; therefore, the monte carlo sampling results for the hydraulic conductivity parameter are used to estimate the intrinsic permeability.The parameter values used in the analysis are provided in Table C.17 for SWMU 1 SESOIL model, Table C.18 for the C-720 SESOIL model, with the exception that the TCE degradation rate in the UCRS was infinite.

Each of the 100 sets of input parameters for SWMU 1 and C-720 were used to generate TCE concentrations at the HU3/HU4 contact. The groundwater concentrations then were based on a DAF of 59 as discussed in Section C.3, as part of determination of the soil remediation goals.

C.7.1 SWMU 1 TCE RESULTS

Figure C.31 provides a histogram of the remediation goals based on the maximum predicted groundwater concentrations for each of the 100 sets of input parameters. Table C.19 provides the soil remediation goals based on the 75% quartile, mean, median, geometric mean, and 25% quartile based on the maximum predicted groundwater concentrations for each of the 100 sets of input parameters.

Table C.16. Inputs Used in Monte Carlo Runs for SESOIL Modeling

Name	Vertical Hydraulic Conductivity (K_v)		Organic Carbon (F_{oc})	
	SWMU 1	**C-720**	**SWMU 1**	**C-720**
Unit	(m/hr)	(m/hr)	(%)	(%)
Minimum Value	3.60E-07	3.60E-07	0.02	0.02
Likeliest Value	5.92E-04	5.92E-04	0.08	0.08
Maximum Value	1.15E-03	1.15E-03	0.46	0.46
Standard Deviation	NA	NA	0.05	0.05
Correlation Pair	None	None	None	None
Distribution	Triangular	Triangular	Log normal	Log normal

Table C.17. SWMU 1 SESOIL Input Parameters Used in Probabilistic Modeling

Run (#)	Layer 1 Conc (mg/kg)	Layer 2 Conc (mg/kg)	Layer 3 Conc (mg/kg)	Layer 4 Conc (mg/kg)	Layer 5 Conc (mg/kg)	Layer 6 Conc (mg/kg)	Organic Carbon (%)	Degradation Rate (/hr)	Vertical Hydraulic Conductivity (m/hr)	Intrinsic Permeability (cm^2)
001	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	8.61E-04	2.44E-10
002	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	6.02E-04	1.70E-10
003	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	5.33E-04	1.51E-10
004	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	7.38E-04	2.09E-10
005	1.00	1.00	1.00	1.00	1.00	1.00	0.13	infinite	2.85E-04	8.07E-11
006	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	3.47E-04	9.84E-11
007	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	3.51E-04	9.95E-11
008	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	9.02E-04	2.55E-10
009	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.75E-04	2.48E-10
010	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	4.20E-04	1.19E-10
011	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	2.09E-04	5.91E-11
012	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	6.59E-04	1.87E-10
013	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	7.87E-04	2.23E-10
014	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	6.35E-04	1.80E-10
015	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	6.43E-04	1.82E-10
016	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	3.16E-04	8.94E-11
017	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	7.18E-04	2.03E-10
018	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.37E-04	1.52E-10
019	1.00	1.00	1.00	1.00	1.00	1.00	0.17	infinite	8.23E-04	2.33E-10
020	1.00	1.00	1.00	1.00	1.00	1.00	0.16	infinite	2.69E-04	7.63E-11
021	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	2.81E-04	7.95E-11
022	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	4.10E-04	1.16E-10
023	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	1.38E-04	3.90E-11
024	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	9.77E-04	2.77E-10
025	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	5.22E-04	1.48E-10
026	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	3.07E-04	8.69E-11
027	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	6.43E-04	1.82E-10
028	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	3.80E-04	1.08E-10
029	1.00	1.00	1.00	1.00	1.00	1.00	0.19	infinite	9.52E-04	2.70E-10
030	1.00	1.00	1.00	1.00	1.00	1.00	0.12	infinite	8.54E-04	2.42E-10
031	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	5.51E-04	1.56E-10
032	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.93E-04	1.68E-10
033	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	5.45E-04	1.54E-10
034	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	2.20E-04	6.23E-11
035	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	5.15E-04	1.46E-10
036	1.00	1.00	1.00	1.00	1.00	1.00	0.27	infinite	4.16E-04	1.18E-10
037	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	2.50E-04	7.09E-11
038	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	9.68E-04	2.74E-10
039	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	5.88E-04	1.66E-10
040	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	8.88E-04	2.52E-10
041	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	9.33E-04	2.64E-10
042	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.65E-04	2.45E-10
043	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	7.92E-04	2.24E-10
044	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.39E-04	1.24E-10
045	1.00	1.00	1.00	1.00	1.00	1.00	0.12	infinite	1.99E-04	5.63E-11
046	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	7.84E-04	2.22E-10
047	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	7.05E-04	2.00E-10
048	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	6.20E-04	1.76E-10
049	1.00	1.00	1.00	1.00	1.00	1.00	0.13	infinite	3.56E-04	1.01E-10
050	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	7.07E-04	2.00E-10

Table C.17. SWMU 1 SESOIL Input Parameters Used in Probabilistic Modeling (Continued)

Run (#)	Layer 1 Conc (mg/kg)	Layer 2 Conc (mg/kg)	Layer 3 Conc (mg/kg)	Layer 4 Conc (mg/kg)	Layer 5 Conc (mg/kg)	Layer 6 Conc (mg/kg)	Organic Carbon (%)	Degradation Rate (/hr)	Vertical Hydraulic Conductivity (m/hr)	Intrinsic Permeability (cm^2)
051	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	2.15E-04	6.07E-11
052	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	9.87E-04	2.80E-10
053	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.11E-04	2.30E-10
054	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	3.78E-04	1.07E-10
055	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	5.39E-04	1.52E-10
056	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	3.40E-04	9.64E-11
057	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	8.75E-04	2.48E-10
058	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	6.63E-04	1.88E-10
059	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	6.60E-04	1.87E-10
060	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	1.22E-04	3.45E-11
061	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	8.27E-04	2.34E-10
062	1.00	1.00	1.00	1.00	1.00	1.00	0.22	infinite	9.60E-04	2.72E-10
063	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	6.54E-04	1.85E-10
064	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	4.44E-04	1.26E-10
065	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	1.64E-04	4.64E-11
066	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	6.71E-04	1.90E-10
067	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	3.73E-04	1.06E-10
068	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.80E-04	1.64E-10
069	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.90E-04	1.67E-10
070	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.66E-04	1.60E-10
071	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	5.96E-04	1.69E-10
072	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	8.64E-04	2.45E-10
073	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	8.74E-04	2.47E-10
074	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	5.09E-04	1.44E-10
075	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	7.80E-04	2.21E-10
076	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	3.41E-04	9.65E-11
077	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	1.69E-04	4.78E-11
078	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	4.86E-04	1.38E-10
079	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	4.38E-04	1.24E-10
080	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	6.46E-04	1.83E-10
081	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	7.35E-04	2.08E-10
082	1.00	1.00	1.00	1.00	1.00	1.00	0.17	infinite	5.91E-04	1.67E-10
083	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	9.89E-05	2.80E-11
084	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	7.33E-04	2.08E-10
085	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	4.80E-04	1.36E-10
086	1.00	1.00	1.00	1.00	1.00	1.00	0.28	infinite	6.47E-04	1.83E-10
087	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.24E-04	1.20E-10
088	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	1.29E-04	3.66E-11
089	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	8.04E-04	2.28E-10
090	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	6.26E-04	1.77E-10
091	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	8.38E-04	2.37E-10
092	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	9.25E-04	2.62E-10
093	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	5.94E-04	1.68E-10
094	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	6.82E-04	1.93E-10
095	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	4.44E-04	1.26E-10
096	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.50E-04	1.27E-10
097	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	4.54E-04	1.29E-10
098	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	5.26E-04	1.49E-10
099	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	1.01E-03	2.87E-10
100	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	4.22E-04	1.20E-10

Table C.18. C-720 SESOIL Input Parameters Used in Probabilistic Modeling

Run (#)	Layer 1 Conc (mg/kg)	Layer 2 Conc (mg/kg)	Layer 3 Conc (mg/kg)	Layer 4 Conc (mg/kg)	Layer 5 Conc (mg/kg)	Layer 6 Conc (mg/kg)	Organic Carbon (%)	Degradation Rate (/hr)	Vertical Hydraulic Conductivity (m/hr)	Intrinsic Permeability (cm^2)
001	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	2.09E-04	5.91E-11
002	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	6.59E-04	1.87E-10
003	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	7.87E-04	2.23E-10
004	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	6.35E-04	1.80E-10
005	1.00	1.00	1.00	1.00	1.00	1.00	0.19	infinite	6.43E-04	1.82E-10
006	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	3.16E-04	8.94E-11
007	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	1.07E-04	3.04E-11
008	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	6.04E-04	1.71E-10
009	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	2.69E-04	7.63E-11
010	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	6.43E-04	1.82E-10
011	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	2.81E-04	7.95E-11
012	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	4.10E-04	1.16E-10
013	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	1.38E-04	3.90E-11
014	1.00	1.00	1.00	1.00	1.00	1.00	0.13	infinite	9.77E-04	2.77E-10
015	1.00	1.00	1.00	1.00	1.00	1.00	0.21	infinite	5.22E-04	1.48E-10
016	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	9.21E-04	2.61E-10
017	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	3.07E-04	8.69E-11
018	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	6.43E-04	1.82E-10
019	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	3.80E-04	1.08E-10
020	1.00	1.00	1.00	1.00	1.00	1.00	0.19	infinite	9.52E-04	2.70E-10
021	1.00	1.00	1.00	1.00	1.00	1.00	0.12	infinite	8.54E-04	2.42E-10
022	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	5.51E-04	1.56E-10
023	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.93E-04	1.68E-10
024	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	5.45E-04	1.54E-10
025	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	2.20E-04	6.23E-11
026	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	5.15E-04	1.46E-10
027	1.00	1.00	1.00	1.00	1.00	1.00	0.27	infinite	4.16E-04	1.18E-10
028	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	2.50E-04	7.09E-11
029	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	9.68E-04	2.74E-10
030	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	5.88E-04	1.66E-10
031	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.88E-04	2.52E-10
032	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	9.33E-04	2.64E-10
033	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.65E-04	2.45E-10
034	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	7.92E-04	2.24E-10
035	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.39E-04	1.24E-10
036	1.00	1.00	1.00	1.00	1.00	1.00	0.12	infinite	1.99E-04	5.63E-11
037	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	7.84E-04	2.22E-10
038	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	7.05E-04	2.00E-10
039	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	6.20E-04	1.76E-10
040	1.00	1.00	1.00	1.00	1.00	1.00	0.13	infinite	3.56E-04	1.01E-10
041	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	7.07E-04	2.00E-10
042	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	2.15E-04	6.07E-11
043	1.00	1.00	1.00	1.00	1.00	1.00	0.15	infinite	9.87E-04	2.80E-10
044	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	8.11E-04	2.30E-10
045	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	3.78E-04	1.07E-10
046	1.00	1.00	1.00	1.00	1.00	1.00	0.13	infinite	5.39E-04	1.52E-10
047	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	3.40E-04	9.64E-11
048	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	8.75E-04	2.48E-10
049	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	6.63E-04	1.88E-10
050	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	6.60E-04	1.87E-10

Table C.18. C-720 SESOIL Input Parameters Used in Probabilistic Modeling (Continued)

Run (#)	Layer 1 Conc (mg/kg)	Layer 2 Conc (mg/kg)	Layer 3 Conc (mg/kg)	Layer 4 Conc (mg/kg)	Layer 5 Conc (mg/kg)	Layer 6 Conc (mg/kg)	Organic Carbon (%)	Degradation Rate (/hr)	Vertical Hydraulic Conductivity (m/hr)	Intrinsic Permeability (cm^2)
051	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	1.22E-04	3.45E-11
052	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	8.27E-04	2.34E-10
053	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	9.60E-04	2.72E-10
054	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.44E-04	1.26E-10
055	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	1.64E-04	4.64E-11
056	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	6.71E-04	1.90E-10
057	1.00	1.00	1.00	1.00	1.00	1.00	0.15	infinite	3.73E-04	1.06E-10
058	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	5.80E-04	1.64E-10
059	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	5.90E-04	1.67E-10
060	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	5.66E-04	1.60E-10
061	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	5.96E-04	1.69E-10
062	1.00	1.00	1.00	1.00	1.00	1.00	0.15	infinite	8.64E-04	2.45E-10
063	1.00	1.00	1.00	1.00	1.00	1.00	0.04	infinite	8.74E-04	2.47E-10
064	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	5.09E-04	1.44E-10
065	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	7.80E-04	2.21E-10
066	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	3.41E-04	9.65E-11
067	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	1.69E-04	4.78E-11
068	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	4.86E-04	1.38E-10
069	1.00	1.00	1.00	1.00	1.00	1.00	0.17	infinite	4.38E-04	1.24E-10
070	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	6.46E-04	1.83E-10
071	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	7.35E-04	2.08E-10
072	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	5.91E-04	1.67E-10
073	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	9.89E-05	2.80E-11
074	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	7.33E-04	2.08E-10
075	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.80E-04	1.36E-10
076	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	6.47E-04	1.83E-10
077	1.00	1.00	1.00	1.00	1.00	1.00	0.35	infinite	4.24E-04	1.20E-10
078	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	3.06E-04	8.66E-11
079	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	8.04E-04	2.28E-10
080	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	6.26E-04	1.77E-10
081	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	8.38E-04	2.37E-10
082	1.00	1.00	1.00	1.00	1.00	1.00	0.05	infinite	9.25E-04	2.62E-10
083	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	5.94E-04	1.68E-10
084	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	6.82E-04	1.93E-10
085	1.00	1.00	1.00	1.00	1.00	1.00	0.12	infinite	4.44E-04	1.26E-10
086	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	4.50E-04	1.27E-10
087	1.00	1.00	1.00	1.00	1.00	1.00	0.17	infinite	4.54E-04	1.29E-10
088	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	5.26E-04	1.49E-10
089	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	1.01E-03	2.87E-10
090	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	4.22E-04	1.20E-10
091	1.00	1.00	1.00	1.00	1.00	1.00	0.08	infinite	1.02E-04	2.89E-11
092	1.00	1.00	1.00	1.00	1.00	1.00	0.07	infinite	4.35E-04	1.23E-10
093	1.00	1.00	1.00	1.00	1.00	1.00	0.03	infinite	6.87E-04	1.95E-10
094	1.00	1.00	1.00	1.00	1.00	1.00	0.14	infinite	6.68E-04	1.89E-10
095	1.00	1.00	1.00	1.00	1.00	1.00	0.10	infinite	3.34E-04	9.46E-11
096	1.00	1.00	1.00	1.00	1.00	1.00	0.06	infinite	4.72E-04	1.34E-10
097	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	7.38E-04	2.09E-10
098	1.00	1.00	1.00	1.00	1.00	1.00	0.11	infinite	1.02E-03	2.89E-10
099	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	2.67E-04	7.57E-11
100	1.00	1.00	1.00	1.00	1.00	1.00	0.09	infinite	6.45E-04	1.83E-10

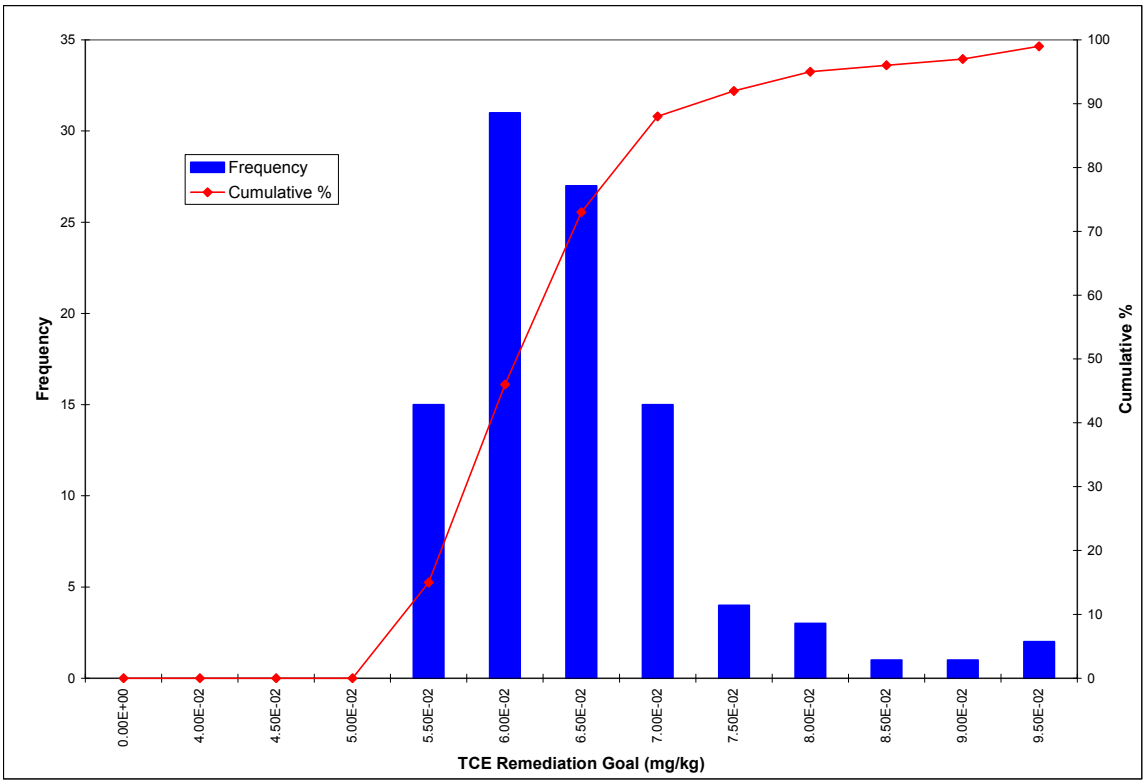

Figure C.31. Histogram of SWMU 1 TCE RGs Based on the Maximum Predicted TCE Groundwater Concentrations

Table C.19. SWMU 1TCE Remediation Goals Based on the 75% Quartile, Mean, Median, Geometric Mean, and 25% Quartile for Statistical Parameters Evaluated for the Maximum Groundwater Concentrations

Result	Remediation Goal (mg/kg)
75% Quartile	0.065
Mean	0.062
Median	0.061
Geometric Mean	0.062
25% Quartile	0.057

The results of the uncertainty analysis for SWMU 1 indicate that the soil remediation goal ranges from 0.057 to 0.065 mg/kg. The deterministic modeling in Section C.3 resulted in a TCE soil remediation goal of 0.073 mg/kg for TCE with a UCRS degradation rate based on a 50 year half-life, which is most comparable with the probabilistic results based on an infinite TCE half-life in the UCRS. This value is

approximately a factor of 1.2 times higher than the median soil remediation goal of 0.061 mg/kg shown in Table C.19.

C.7.2 C-720 TCE RESULTS

Figure C.32 provides a histogram of the remediation goals based on the maximum predicted groundwater concentrations for each of the 100 sets of input parameters. Table C.20 provides the soil remediation goals based on the 75% quartile, mean, median, geometric mean, and 25% quartile based on the maximum predicted groundwater concentrations for each of the 100 sets of input parameters.

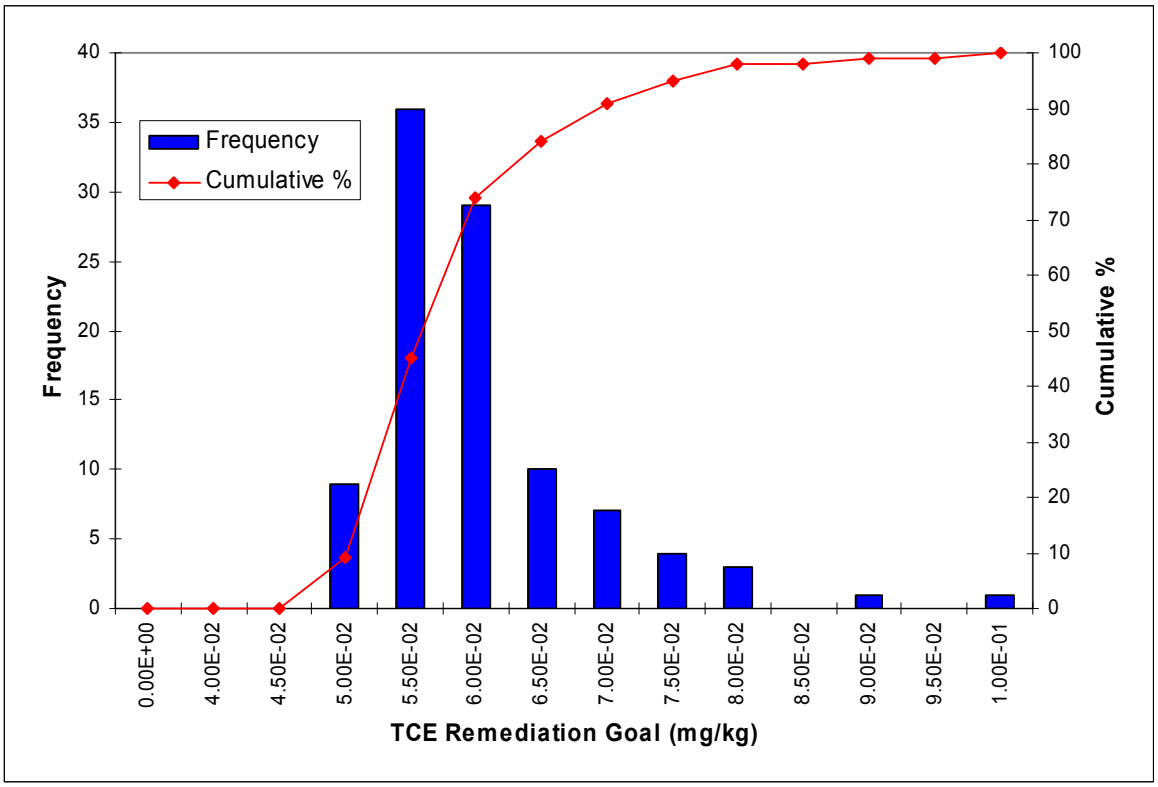

Figure C.32. Histogram of C-720 TCE RGs Based on the Maximum Predicted TCE Groundwater Concentrations

Table C.20. C-720 TCE Remediation Goals Based on the 75% Quartile, Mean, Median, Geometric Mean, And 25% Quartile for Statistical Parameters Evaluated for the Maximum Groundwater Concentrations

Result	Remediation Goal (mg/kg)
75% Quartile	0.060
Mean	0.058
Median	0.056
Geometric Mean	0.058
25% Quartile	0.053

The results of the uncertainty analysis for C-720 indicate that the soil remediation goal ranges from 0.053 to 0.060 mg/kg. The deterministic modeling in Section C.3 resulted in a TCE soil remediation goal of 0.075 mg/kg for TCE with a UCRS degradation rate based on a 50 year half-life, which is most comparable with the probabilistic results based on an infinite TCE half-life in the UCRS. This value is approximately a factor of 1.3 times higher than the median soil remediation goal of 0.056 mg/kg shown in Table C.20.

REFERENCES

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DOE 2007. *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1, U.S. Department of Energy, Paducah, KY, June.

DOE 2009. *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0186&D1, U.S. Department of Energy, Paducah, KY, January.

Odencrantz, Joseph E., John M. Farr, and Charles E. Robinson 1992. *Transport Model Sensitivity for Soil Cleanup Level Determinations Using SESOIL and AT123D in the Context of the California Leaking Underground Fuel Tank Field Manual*, *Journal of Soil Contamination*, 1(2):159-182.

APPENDIX D

BASELINE RISK ASSESSMENT FROM THE SOUTHWEST PLUME SI

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BASELINE RISK ASSESSMENT FROM THE SOUTHWEST PLUME SI

PREVIOUS BASELINE RISK ASSESSMENT. The Southwest Plume SI (DOE 2007) used historical information and newly collected data to develop a site model for each source area and presented a baseline risk assessment (BRA) that was conducted in two parts: the baseline human health risk assessment (BHHRA) and the screening ecological risk assessment (SERA). In these assessments, information collected during the Southwest Plume SI and results from previous risk assessments were used to characterize the baseline risks posed to human health and the environment resulting from contact with contaminants in groundwater drawn from the Southwest Plume in the Regional Gravel Aquifer (RGA) at the source areas. In addition, fate and transport modeling was conducted, and the BRA used these modeling results to estimate the future baseline risks that might be posed to human health and the environment through contact with groundwater impacted by contaminants migrating from the Oil Landfarm and C-720 Building Area to four points of exposure (POEs). The POEs assessed were at the source, the plant boundary, property boundary, and near the Ohio River. Vapor transport modeling was conducted, and the potential air concentrations used as the predicted household air concentrations for estimating excess lifetime cancer risk (ELCR) and hazard for the hypothetical future on and off-site rural resident.

Because data collected during the Southwest Plume SI focused on the collection of subsurface soil and groundwater data to delimit the potential sources of contamination to the Southwest Plume, new material developed in the BHHRA and SERA was limited to risks posed by contaminants from potential source areas to RGA groundwater and with direct contact with contaminated groundwater in the source areas. Risks from direct contact with other media at the potential sources (e.g., surface and subsurface soil, sediment, surface water, and McNairy Formation groundwater) and future industrial risk from use of contaminated groundwater were taken from the following assessments and studies.[1]

- *Results of the Public Health and Ecological Assessment, Phase II, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Vol. 6, in Results of the FFS, Phase II, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (CH2M HILL 1992).

- *Residual Risk Evaluation for Waste Area Grouping 23 and Solid Waste Management Unit 1 of Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1999).

- *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1999).

- *Feasibility Study for the Groundwater Operable Unit at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2001).

- *Contaminant Migration from SWMU 1 and the C-720 Area at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (BJC 2003).

Consistent with the approved PGDP Risk Methods Documents (DOE 2001), the BHHRA reports risks for scenarios that encompass current use and several hypothetical future uses. The scenarios discussed in the BHHRA are as follows.

[1]Baseline risks taken from earlier reports are presented without modification in Section 2 of the BHHRA and in the SERA. Updated revisions of these risk estimates are presented in this section and in Section 7 of the BHHRA. Reasons for revising risk estimates are discussed in the BHHRA and include updated toxicity values and regulatory guidance.

- Current On-Site Industrial Use[2]—Direct contact with surface soil [soil found 0 to 0.3 m (0 to 1 ft) bgs], sediment, and surface water. Risk results presented in the BHHRA for this scenario were taken from assessments completed earlier.

- Future On-Site Industrial Use—Direct contact with surface soil, sediment, and surface water and groundwater use. Risk results presented in the BHHRA for this scenario were taken from assessments completed earlier.

- Future On-Site Excavation—Direct contact with surface and subsurface soil [soil 0 to 4.9 ms (0 to 16 ft) bgs]. Risk results presented in the BHHRA for this scenario were taken from assessments completed earlier.

- Future Recreational User—Direct contact with sediment and surface water and consumption of game exposed to contaminated surface soil. Risk results presented in the BHHRA for this scenario were taken from assessments completed earlier.

- Future Off-Site Recreational User—Direct contact with surface water impacted by contamination migrating from sources and consumption of game exposed to this surface water. Risk results presented in the BHHRA for this scenario were taken from assessments completed earlier.

- Future On-Site Rural Resident—Direct contact with surface soil at and use of groundwater drawn from the RGA and McNairy at source areas, including consumption of vegetables that are posited to be raised in these areas. Risk results presented in the BHHRA for use of RGA groundwater in the home as well as vapor intrusion into basement are newly derived from measured and modeled data with both results presented. Risk results presented in the BHHRA for other media were taken from assessments completed earlier.

- Future Off-Site Rural Resident—Use in the home of groundwater drawn from the RGA as well as vapor intrusion into basements at the DOE plant boundary, the DOE property boundary, and in a groundwater well at the Ohio River. Risk results for this receptor are newly derived from measured and modeled data, with both results presented in the BHHRA; however, risks estimated in earlier assessments for this receptor also are presented in the BHHRA.

Also consistent with the approved PGDP Risk Methods Documents (DOE 2001), the SERA reports the potential risks under both current and potential future conditions to ecological receptors that may come into contact with contaminated media at the potential source areas associated with the Southwest Plume. Because all new data collected during the FFS were from soil samples collected below 4.6 ms (15 ft) bgs or were groundwater samples, all results presented in the SERA are taken from earlier BERAs. Risk to the future industrial worker from uses of contaminated groundwater at the Oil Landfarm and the C-720 Building Area were derived in the WAG 27 RI (DOE 1999), which included all data collected from 1989 to completion of the WAG 27 project in 1999, and were not further evaluated in the Southwest Plume SI.

For two of the three potential sources discussed in the Southwest Plume SI BHHRA (i.e., Oil Landfarm and C-720 Building Area), the cumulative human health ELCRs and systemic toxicity (i.e., hazard) exceed the *de minimis* levels [i.e., a cumulative ELCR of 1×10^{-6} or a cumulative hazard index (HI) of 1 as defined in DOE 2001] in the PGDP Risk Methods Document for one or more scenarios. For the Storm Sewer, only the ELCR exceeded acceptable standards. The land uses and media assessed for ELCR and

[2]As noted earlier, the current industrial land use scenario assessed in the WAG 27 RI did not include or take into account existing DOE controls on worker exposures, such as controls on access to areas containing contaminated soils or sediment or the use of personal protective equipment (PPE).

HI for human health for each potential source area are presented in Table D.1. As shown, only results for groundwater use and vapor intrusion from groundwater by the hypothetical future on- and off-site rural residents are newly derived in the Southwest Plume SI BHHRA.

Table D.1. Land Uses and Media Assessed for Each Source Area Included in the FFS for the Southwest Plume

Scenario	Location		
	Oil Landfarm	C-720 Building Area	Storm Sewer
Current On-site Industrial Worker			
Surface Soil	P	NA	NA
Sediment[a]	P	NA	NA
Surface Water	NA	NA	NA
Future On-site Excavation Worker			
Surface and Subsurface Soil	P	P	NA
Future On-site Recreational User			
Game (Soil)	P	NA	NA
Sediment[a]	P	NA	NA
Surface Water	NA	NA	NA
Future Off-site Recreational User			
Surface Water	P	NA	NA
Game	NA	NA	NA
Future On-site Rural Resident			
Soil	P	NA	NA
Groundwater[b]	X	X	X
Vapor Intrusion[d]	X	X	NA
Future Off-site Rural Resident			
Groundwater[c]	X	X	X
Vapor Intrusion[d]	X	X	NA
Future On-site Terrestrial Biota			
Soil	P	NA	NA
Sediment[a]	P	NA	NA
Surface Water	NA	NA	NA

Notes: Scenarios that were assessed in the Southwest Plume SI BRA are marked with an X. Scenarios assessed in previous BRAs are marked with a P. Scenarios not assessed because the scenario is not applicable, or for which the medium is not present, are marked with an NA.
Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).
[a]Sediment considered in earlier assessments was in ditches surrounding the source area.
[b]The earlier BHHRAs assessed risks from use of water drawn from the RGA separately from use of water drawn from the McNairy Formation. The risks assessed in the Southwest Plume SI BRA are for use of water drawn from the RGA.
[c]Modeling results were used to assess risk to the off-site rural resident in the Southwest Plume SI. POEs are at the PGDP plant boundary, at the PGDP property boundary, and in a groundwater well at the Ohio River.
[d]Vapor intrusion was modeled for residential basements for TCE, 1,2-DCE, and VC only, as these COCs and antimony are identified in the WAG 27 RI as migrating from sources at the Oil Landfarm and the C-720 Building Area and result in risks above *de minimis* levels. Monitoring results document that TCE and its degradation products are the primary COCs that define the Southwest Plume. Antimony was not included in vapor intrusion modeling because it is not a volatile compound.

The scenarios for which risk exceeds *de minimis* levels are summarized in Table D.2. Information is taken from a series of risk summary tables presented at the end of this section [i.e., Tables D.3 through D.5, which present cumulative risk values for each scenario, the contaminants of concern (COCs), and the pathways of concern (POCs)].

Table D.2. Scenarios for Which Human Health Risk Exceeds *De Minimis* Levels[a]

Scenario	Location		
	Oil Landfarm	C-720 Building Area	Storm Sewer
Results for Excess Lifetime Cancer Risk:			
Current On-site Industrial Worker			
Exposure to Soil	NA	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA
Future On-site Industrial Worker			
Exposure to Soil	NA	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA
Exposure to Groundwater	X	X	NA
Future On-site Excavation Worker			
Exposure to Soil	X	---	NA
Future On-site Recreational User			
Exposure to Game	---	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA
Future Off-site Recreational User			
Exposure to Surface Water	---	NA	NA
Exposure to Game	---	NA	NA
Future On-site Rural Resident			
Exposure to Soil	---	NA	NA
Exposure to Groundwater[b]	X	X	X
Vapor Intrusion[e]	X	X	NA
Future Off-site Rural Resident			
Exposure to Groundwater[d]	X	X	---
Vapor Intrusion[e]	---	---	NA
Results for Systemic Toxicity[c]:			
Current On-site Industrial Worker			
Exposure to Soil	NA	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA
Future On-site Industrial Worker			
Exposure to Soil	NA	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA

Table D.2. Scenarios for Which Human Health Risk Exceeds *De Minimis* Levels[a] (Continued)

Scenario	Location		
	Oil Landfarm	C-720 Building Area	Storm Sewer
Future On-site Excavation Worker			
Exposure to Soil	X	X	NA
Future On-site Recreational User			
Exposure to Game	---	NA	NA
Exposure to Sediment	X	NA	NA
Exposure to Surface Water	NA	NA	NA
Future Off-site Recreational User			
Exposure to Surface Water	---	NA	NA
Exposure to Game	---	NA	NA
Future On-site Rural Resident			
Exposure to Soil	---	NA	NA
Exposure to Groundwater[b]	X	X	---
Vapor Intrusion[e]	X	X	NA
Future Off-site Rural Resident			
Exposure to Groundwater[d]	---	---	---
Vapor Intrusion[e]	---	---	NA

Notes: Scenarios where risk exceeds *de minimis* levels are marked with an X. Scenarios where risk did not exceed *de minimis* levels are marked with a ---. NA indicates that the scenario/land use combination was not assessed because the scenario is not applicable, or the medium is not present.

Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).

[a]Consistent with the PGDP Risk Methods Document (DOE 2001b), the *de minimis* levels used are a cumulative ELCR of 1×10^{-6} or a cumulative Hazard Index (HI) of 1.

[b]The BHHRA assessed risks from use of water drawn from the RGA separately from use of water drawn from the McNairy Formation. The value reported here is for use of water from the RGA.

[c]Systemic toxicity results summarized here for the resident and recreational user are for the child. The off-site POE considered is the property boundary.

[d]Based on results of preliminary deterministic and probabilistic contaminant transport modeling. The POE is the property boundary. X indicates that the location contains a source of unacceptable off-site contamination, and --- indicates that the location is not a source of off-site contamination (see Tables G.72 and G.73 in the Southwest Plume SI).

[e]Vapor intrusion was modeled for residential basements for TCE, 1,2-DCE, and VC only, as these COCs and antimony are identified in the WAG 27 RI as migrating from sources at the Oil Landfarm and the C-720 Building Area and result in risks above *de minimis* levels. Monitoring results document that TCE and its degradation products are the primary COCs that define the Southwest Plume. Antimony was not included in vapor intrusion modeling because it is not a volatile compound.

Table D.3. Summary of Risk Characterization for the Oil Landfarm[a]

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Current industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Current industrial worker at current concentrations (sediment)	3.4×10^{-5}	Arsenic Cesium-137 Neptunium-237 Uranium Uranium-235	27 11 48 6 3	Ingestion of sediment Dermal contact External exposure	5 26 69	1.7	Chromium Iron Manganese Vanadium	16 23 25 23	Dermal contact	99
Future industrial worker at current concentrations (sediment only)	3.4×10^{-5}	Arsenic Cesium-137 Neptunium-237 Uranium Uranium-238	27 11 48 6 3	Ingestion of sediment Dermal contact External exposure	5 26 69	1.7	Chromium Iron Manganese Vanadium	16 23 25 23	Dermal contact	99
Future industrial worker at current concentrations (RGA groundwater)	1.9×10^{-3}	Arsenic Beryllium 1,1-dichloroethene Bis(2-ethylhexyl)phthalate Trichloroethene Americium-241 Cesium-137 Neptunium-237 Radon-222 Technetium-99 Uranium-235 Uranium-238	53 10 1 <1 <1 3 <1 2 25 <1 <1 4	Ingestion of groundwater; Dermal contact; Inhalation while showering	71 3 26	14.2	Aluminum Antimony Arsenic Barium Chromium Iron Manganese Vanadium Trichloroethene	4 1 45 1 1 18 21 3 1	Ingestion of groundwater Dermal contact	95 5

Table D.3. Summary of Risk Characterization for the Oil Landfarm [a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future industrial worker at current concentrations (McNairy groundwater)	3.9×10^{-4}	Arsenic Beryllium Americium-241 Cesium-137 Uranium-235 Uranium-238	6 15 36 <1 <1 41	Ingestion of groundwater; Dermal contact	96 4	2.99	Arsenic Iron Manganese Uranium Vanadium	5 58 9 12 7	Ingestion of groundwater Dermal contact	95 5
Future child rural resident at current concentrations (RGA groundwater only)	NA	NA	NA	NA	NA	99	Arsenic Barium Cobalt Iron Manganese Nickel Chloroform Trichloroethene *cis*-1,2-Dichlroethene	1 <1 <1 1 11 <1 11 71 3	Ingestion of groundwater Dermal contact Inhalation while showering Inhalation household use Vapor Intrusion	23 2 6 44 22
Future child rural resident at current concentrations[c] (McNairy groundwater)	NA	NA	NA	NA	NA	20	Aluminum Arsenic Barium Beryllium Chromium Iron Manganese Nickel Uranium Vanadium Trichloroethene	2 5 1 <1 2 58 9 <1 12 6 2	Ingestion of groundwater Dermal contact Inhalation household use	96 2 2

Table D.3. Summary of Risk Characterization for the Oil Landfarm [a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future adult rural resident at current concentrations (RGA groundwater only)	6.8×10^{-4}	Arsenic 1,1-Dichloroethene Chloroform Trichloroethene Technetium-99	18 2 2 74 <1	Ingestion of groundwater Dermal contact Inhalation while showering Inhalation household use Vapor Intrusion	43 4 5 36 11	26	Arsenic Barium Iron Manganese Nickel Chloroform Trichloroethene *cis*-1,2-Dichloroethene	2 <1 2 18 <1 9 64 3	Ingestion of groundwater Dermal contact Inhalation while showering Inhalation household use Vapor Intrusion	37 4 5 36 18
Future adult rural resident at current concentrations[c] (McNairy groundwater)	1.4×10^{-3}	Arsenic Trichloroethene Americium-241 Cesium-137 Uranium-235 Uranium-238	9 <1 42 <1 <1 47	Ingestion of groundwater Inhalation household use	100 <1	8.2	Aluminum Arsenic Barium Chromium Iron Manganese Uranium Vanadium Trichloroethene	2 5 1 2 58 9 12 6 1	Ingestion of groundwater Dermal contact	97 3

Table D.3. Summary of Risk Characterization for the Oil Landfarm [a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future child rural resident at modeled concentrations (RGA groundwater drawn at property boundary variable degradation)	NA	NA	NA	NA	NA	0.4	Trichloroethene *cis*-1,2-Dichloroethene	56 29	NE	NE
Future child rural resident at modeled concentrations (RGA groundwater drawn at property boundary fixed degradation)	NA	NA	NA	NA	NA	1.4	Trichloroethene *cis*-1,2-Dichloroethene	83 10	NE	NE
Future adult rural resident at modeled concentrations (RGA groundwater drawn at property boundary variable degradation)	1.4×10^{-6}	Trichloroethene Vinyl chloride	39 61	Not determined	---	0.1	NE	NE	NE	NE
Future adult rural resident at modeled concentrations (RGA groundwater drawn at property boundary fixed degradation)	6.1×10^{-6}	Trichloroethene Vinyl chloride	87 14	Not determined	---	0.2	NE	NE	NE	NE
Future child recreational user at current concentrations (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE

Table D.3. Summary of Risk Characterization for the Oil Landfarm [a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future child recreational user at current concentrations (sediment)	NA	NA	NA	NA	NA	3.4	Aluminum Arsenic Chromium Iron Manganese Vanadium	7 4 19 28 10 28	Dermal contact	98
Future teen recreational user at current concentrations (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future teen recreational user at current concentrations (sediment)	NA	NA	NA	NA	NA	2.2	Aluminum Chromium Iron Manganese Vanadium	6 19 28 10 28	Dermal contact	99
Future adult recreational user at current concentrations (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future adult recreational user at current concentrations (sediment)	1.9×10^{-5}	Arsenic Neptunium-237	78 10	Ingestion of sediment Dermal contact External exposure	9 74 13	0.5	NE	NE	NE	NE

Table D.3. Summary of Risk Characterization for the Oil Landfarm [a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future excavation worker at current concentrations	1.3×10^{-4}	Arsenic	18	Ingestion of soil	24	1.9	Arsenic	7	Ingestion of soil	17
		PAHs	25	Dermal contact	54		Chromium	16	Dermal contact	74
		Bis(2-chloroethyl)ether	1	Inhalation of VOCs and particulates	6		Manganese	14	Inhalation of VOCs and particulates	9
		Dieldrin	1				Vanadium	14		
		Heptachlorodibenzofuran	3		6		2-Nitroanaline	12		
		Hexachlorobenzene	2	External exposure			PCBs	7		
		N-Nitroso-di-n-propylamine	12				Trichloroethene	6		
		PCBs	9				*cis*-1,2-dichloroethene	7		
		Trichloroethene	2							
		Vinyl chloride	12							
		Cobalt-60	1							
		Uranium	5							

Note: NA = ELCR not applicable to child and teen cohorts. ELCR for adult is for lifetime exposure and takes into account exposure as child and teen.
NE = Land use scenario not of concern or land use not evaluated because contact with medium is not possible.
Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).
[a]Total ELCR and total HI columns reflect values from BHHRAs completed earlier and as part of the Southwest Plume SI.
[b]A response action for the Oil Landfarm has addressed PCBs and dioxins surface soil. Please see the BHHRA in Southwest Plume SI for additional information.
[c]In the earlier assessments, ELCR and hazard from exposure to groundwater water drawn from the RGA and McNairy were assessed. In the Southwest Plume SI BHHRA, results for use of water drawn from the RGA were reassessed, and the results for use of water drawn from the McNairy were recalculated for the residential scenario.
[d]Based on results of preliminary deterministic and probabilistic contaminant transport modeling (see Tables G.72 and G.73 in the Southwest Plume SI).
[e]Vapor intrusion was modeled for residential basements for TCE, 1,2-DCE, and VC only, as these COCs and antimony are identified in the WAG 27 RI as migrating from sources at the Oil Landfarm and the C-720 Building Area and result in risks above *de minimis* levels. Monitoring results document that TCE and its degradation products are the primary COCs that define the Southwest Plume. Antimony was not included in vapor intrusion modeling because it is not a volatile compound.

Table D.4. Summary of Risk Characterization for C-720 Building Area[a]

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Current industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Current industrial worker at current concentrations[b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations [b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations (RGA groundwater)	6.0×10^{-4}	Arsenic Beryllium 1,1-dichloroethene Carbon tetrachloride Tetrachloroethene Trichloroethene Vinyl chloride Americium-241 Cesium-137 Neptunium-237 Plutonium-239/240 Technetium-99 Thorium-230 Uranium-235 Uranium-238	1 10 4 <1 <1 2 <1 23 <1 12 <1 <1 <1 6 38	Ingestion of groundwater; Dermal contact; Inhalation while showering	94 3 3	3.03	Antimony Iron Manganese Carbon tetrachloride Trichloroethene	6 45 11 6 17	Ingestion of groundwater Dermal contact Inhalation while showering	85 8 7

Table D.4. Summary of Risk Characterization for C-720 Building Area[a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future industrial worker at current concentrations (McNairy groundwater)	6.6×10^{-4}	Arsenic Beryllium 1,1-dichloroethene Vinyl chloride Americium-241 Cesium-137 Neptunium-237 Uranium-235 Uranium-238	<1 30 2 <1 19 <1 11 4 32	Ingestion of groundwater; Dermal contact; Inhalation while showering	91 8 <1	9.75	Aluminum Chromium Iron Manganese Vanadium	9 3 72 6 7	Ingestion of groundwater Dermal contact	95 5
Future child rural resident at current concentrations (RGA groundwater only)	NA	NA	NA	NA	NA	102	Arsenic Barium Iron Manganese Nickel 1,1-Dichloroethene Trichloroethene *cis*-1,2-Dichlroethene *trans*-1,2 Dichloroethene	1 <1 7 12 2 2 73 1 <1	Ingestion of groundwater Dermal contact Inhalation while showering Inhalation household use Vapor Intrusion	43 2 7 48 5
Future child rural resident at current concentrations[c] (McNairy groundwater)	NA	NA	NA	NA	NA	64.4	Aluminum Arsenic Barium Beryllium Chromium Iron Manganese Nickel Uranium Vanadium 1,1-Dichloroethene Trichloroethene	9 <1 <1 <1 3 73 6 <1 <1 6 <1 <1	Ingestion of groundwater Dermal contact Inhalation during household use	97 2 <1

Table D.4. Summary of Risk Characterization for C-720 Building Area[a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future adult rural resident at current concentrations (RGA groundwater only)	1.8×10^{-3}	Arsenic 1,1-Dichloroethene Trichloroethene Vinyl chloride Technetium-99	7 64 24 5 <1	Ingestion of groundwater; Dermal contact; Inhalation while showering; Inhalation household use; Vapor Intrusion	53 2 5 38 2	23	Arsenic Barium Iron Manganese Nickel 1,1-Dichloroethene Trichloroethene *cis*-1,2-Dichlroethene	2 <1 12 22 4 2 53 2	Ingestion of groundwater Dermal contact Inhalation while showering Inhalation household use Vapor Intrusion	56 4 4 31 3
Future adult rural resident at current concentrations[c] (McNairy groundwater)	2.2×10^{-3}	Arsenic 1,1-Dichloroethene Trichloroethene Vinyl chloride Americium-241 Cesium-137 Neptunium-237 Technetium-99 Uranium-235 Uranium-238	2 12 <1 1 24 <1 14 <1 6 40	Ingestion of groundwater; Dermal contact; Inhalation while showering; Inhalation household use	54 2 5 39	26.7	Aluminum Arsenic Barium Beryllium Chromium Iron Manganese Nickel Uranium Vanadium Trichloroethene	9 <1 <1 <1 3 73 6 <1 <1 6 <1	Ingestion of groundwater Dermal contact	97 3
Future child rural resident at modeled concentrations (RGA groundwater drawn at property boundary variable degradation)	NA	NA	NA	NA	NA	<0.1	NE	NE	NE	NE
Future child rural resident at modeled concentrations (RGA groundwater drawn at property boundary fixed degradation)	NA	NA	NA	NA	NA	0.3	Trichloroethene *cis*-1,2-Dichloroethene	69 30	NE	NE

Table D.4. Summary of Risk Characterization for C-720 Building Area[a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future adult rural resident at modeled concentrations (RGA groundwater drawn at property boundary variable degradation)	1.1×10^{-6}	Vinyl chloride	>95	Not determined	---	<0.1	NE	NE	NE	NE
Future adult rural resident at modeled concentrations (RGA groundwater drawn at property boundary fixed degradation)	2.4×10^{-6}	Trichloroethene Vinyl chloride	51 48	Not determined	---	0.2	Trichloroethene *cis*-1,2-Dichloroethene	82 11	NE	NE
Future child rural resident at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future adult rural resident at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future child recreational user at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future child recreational user at current concentrations[b] (sediment)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future teen recreational user at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE

Table D.4. Summary of Risk Characterization for C-720 Building Area[a] (Continued)

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	% Total HI
Future teen recreational user at current concentrations[b] (sediment)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future adult recreational user at current[b] concentrations (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future adult recreational user at current concentrations[b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future excavation worker at current concentrations	1.5×10^{-5}	Arsenic Vinyl chloride	59 33	Ingestion of soil Dermal contact Inhalation of VOCs and particulates	37 46 12	0.4	NE	NE	NE	NE

Note: NA = ELCR not applicable to child and teen cohorts. ELCR for adult is for lifetime exposure and takes into account exposure as child and teen.
Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).
NE = Land use scenario not of concern or land use not evaluated because contact with medium is not possible.
[a]Total ELCR and total HI columns reflect values from BHHRAs completed earlier and as part of the Southwest Plume SI.
[b]The area around the C-720 Building in covered by gravel and cement; therefore, contact with surface soil is not possible. Please see the Southwest Plume SI BHHRA for additional information.
[c]In the earlier assessments, ELCR and hazard from exposure to groundwater water drawn from the RGA and McNairy were assessed. In the Southwest Plume SI BHHRA, only results for use of water drawn from the RGA were reassessed, and the results for use of water drawn from the McNairy were recalculated for the residential scenario.
[d]Based on results of preliminary deterministic and probabilistic contaminant transport modeling (see Tables G.72 and G.73 in the Southwest Plume SI).

Table D.5. Summary of Risk Characterization for the Storm Sewer[a]

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	%Total HI
Current industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Current industrial worker at current concentrations[b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future industrial worker at current concentrations [b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future child rural resident at current concentrations[c] (RGA groundwater)	NA	NA	NA	NA	NA	0.6	NE	NE	NE	NE
Future child rural resident at current concentrations[c] (McNairy groundwater)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future adult rural resident at current concentrations[c] (RGA groundwater)	7.9×10^{-6}	1,1-dichloroethene Trichloroethene	27 73	Ingestion of groundwater Inhalation household use	41 48	0.2	NE	NE	NE	NE
Future adult rural resident at current concentrations[c] (McNairy groundwater)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future child rural resident at modeled concentrations[d] (RGA groundwater drawn at plant boundary)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future adult rural resident at modeled concentrations[d] (RGA groundwater drawn at plant boundary)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future child rural resident at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE

Receptor	Total ELCR[a]	COCs	% Total ELCR	POCs	% Total ELCR	Total HI[a]	COCs	% Total HI	POCs	%Total HI
Future adult rural resident at current concentrations[b] (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future child recreational user at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future child recreational user at current concentrations[b] (sediment)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future teen recreational user at current concentrations[b] (soil)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future teen recreational user at current concentrations[b] (sediment)	NA	NA	NA	NA	NA	NE	NE	NE	NE	NE
Future adult recreational user at current[b] concentrations (soil)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future adult recreational user at current concentrations[b] (sediment)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Future excavation worker at current concentrations[b]	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

Note: NA = ELCR not applicable to child and teen cohorts. ELCR for adult is for lifetime exposure and takes into account exposure as child and teen.
Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).
NE = Land use scenario not of concern or land use not evaluated because contact with medium is not possible.
[a]Total ELCR and total HI columns reflect values from the BHHRA completed as part of the Southwest Plume SI.
[b]Only results for subsurface soil collected below 3.05 ms (10 ft) bgs were available for the Storm Sewer. Please see the Southwest Plume SI BHHRA for additional information.
[c]In the FFS BHHRA, only results for use of water drawn from the RGA were calculated.
[d]Information collected during the Southwest Plume SI indicates that Storm Sewer is not a source of contamination to the Southwest Plume.

OBSERVATIONS. Specific observations of the BHHRA and SERA are presented here. Consistent with hypothetical rural resident use, observations for source areas focus on risks posed under hypothetical future on-site and off-site residential land use; the observations from the SERA focus on potential future risks.

BHHRA. In the BHHRA, it was determined that the hypothetical rural residential use of groundwater scenario and vapor intrusion is of concern for both ELCR and HI at each source area, except the Storm Sewer, which is of concern for ELCR only. For the hypothetical rural resident at the Oil Landfarm, VOC COCs include chloroform; *cis*-1,2-DCE; and TCE, all of which are "Priority COCs" (i.e., chemical-specific HI or ELCR greater than or equal to 1 or 1×10^{-4}). These VOCs made up 78% of a cumulative ELCR of 6×10^{-4} and 81% of the cumulative HI of 80.

At the C-720 Building Area, the VOC COCs for the hypothetical rural resident include TCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and 1,1-DCE**,** with all except *trans*-1,2-DCE being "Priority COCs." These VOCs made up 93% of a cumulative ELCR of 2×10^{-3} and 69% of the cumulative HI of 70**.** At the Storm Sewer, rural residential COCs included TCE and 1,1-DCE, neither of which was a "Priority COC." The VOCs made up 100% of a cumulative ELCR of 8×10^{-6}. The HI for the storm sewer was less than 1 and, therefore, not of concern.

For the modeled POEs, the COCs for the hypothetical rural resident at the property boundary from VOCs migrating from the Oil Landfarm are TCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and VC, with only TCE being a "Priority COC." The total ELCR for the hypothetical resident at the property boundary was 1.4×10^{-6} and the HI was less an 0.1. The COCs for contaminants migrating from the C-720 Building Area to the hypothetical rural resident at the property boundary are TCE; *cis*-1,2-DCE; and VC with no "Priority COCs." The total ELCR for the hypothetical rural resident at the property boundary from migrating C-720 Building Area VOCs is 1.2×10^{-6} and the HI is 4×10^{-1}.

SERA. The SERA, which used results taken from the Baseline Ecological Risk Assessment completed as part of the WAG 27 RI, concluded that a lack of suitable habitat in the industrial setting at the Oil Landfarm and the C-720 Building Area precluded exposures of ecological receptors under current conditions; therefore, it was determined during problem formulation that an assessment of potential risks under current conditions was unnecessary. Results from earlier assessments presented in the WAG 27 (Oil Landfarm) RI (DOE 1999a) are summarized in Table D.6.

In the BERA for Oil Landfarm, two inorganic chemicals of potential ecological concern (COPECs), chromium and zinc, were identified; however, chromium was found at a maximum concentration similar to its background concentration. Neither organic compound nor radionuclide COPECs were identified.

Table D.6. Summary of Hazard Quotients for Chemicals[a] Posing Potential Future Risks[b,c] to Ecological Receptors

Location	Receptor	Chemicals of Potential Ecological Concern				
		Cr	Cu	Ni	V	Zn
Oil Landfarm	Plant	16.8	–	–	–	1.3
Ditch soil	Worm	42.0	–	–	–	–
	Shrew	–	–	–	–	–
	Mouse	–	–	–	–	–
	Deer	–	–	–	–	–
C-720 Building Area	Plant	NE	NE	NE	NE	NE
	Worm	NE	NE	NE	NE	NE
	Shrew	NE	NE	NE	NE	NE
	Mouse	NE	NE	NE	NE	NE
	Deer	NE	NE	NE	NE	NE
Storm Sewer	Plant	NE	NE	NE	NE	NE
	Worm	NE	NE	NE	NE	NE
	Shrew	NE	NE	NE	NE	NE
	Mouse	NE	NE	NE	NE	NE
	Deer	NE	NE	NE	NE	NE

Notes: Cr = chromium; Cu = copper; Ni = nickel; V = vanadium; Zn = zinc.
Table adapted from SI for the Southwest Groundwater Plume (DOE 2007).
"–" indicates that the hazard quotient for the chemical/receptor combination did not exceed 1 or the chemical was below background in that sector.
"Northeast" indicates that no evaluation was done. For the C-720 Building Area and Storm Sewer, no evaluation was done because surface soil results were not available due to current ground cover and no data were available, respectively.
[a]The table includes values for those chemicals with a maximum concentration above background (or no background available) and at least one hazard quotient > 1.0. If the hazard quotient was less than one or the maximum concentration was less than background, then the hazard quotient is not presented. Analytes for which ecological benchmarks were not available are shown in the SERA in the Southwest Plume SI.
[b]Values in this table are hazard quotients estimated by dividing the dose to the receptor by the benchmark dose.
[c]These results are for the assessment of potential risks due to exposure to contaminants in surface soil, if the industrial infrastructure were to be removed. These results are a point of reference that can be used in future risk management decisions.