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**Report on the Remedial Investigation of Bear Creek Valley
at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee**

**Volume 4. Appendix E—Valley-Wide Fate
and Transport Report**

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Energy Systems Environmental Restoration Program

**Report on the Remedial Investigation of Bear Creek Valley
at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee**

**Volume 4. Appendix E—Valley-Wide Fate
and Transport Report**

Date Issued—September 1996

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Oak Ridge, Tennessee 37831-8169
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
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Science Applications International Corporation

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PREFACE

This Remedial Investigation Report on the Bear Creek Valley Characterization Area at the Oak Ridge Y-12 Plant (DOE/OR/01-1455/V1&D1, -1455/V2&D1, -1455/V3&D1, -1455/V4&D1, -1455/V5&D1, and -1455/V6&D1) was prepared in accordance with requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for reporting the results of a site characterization for public review. This work was performed under Work Breakdown Structure 1.4.12.1.1.02.41 (Activity Data Sheet 2302 "Bear Creek Valley"). Publication of this document on September 15, 1996, will meet a Federal Facilities Agreement milestone. This document provides the Environmental Restoration Program with information on the Bear Creek Valley remedial investigations that include results of the Bear Creek Valley OU 1 (1995) and OU 4 (1994) and Bear Creek Valley Floodplain Soils (1995) investigations, plus results of numerous other investigations and monitoring conducted in Bear Creek Valley. It includes information on risk assessments that have evaluated long-term impacts to human health and the environment. Information provided in this document forms the basis for the development of the Feasibility Study/Environmental Assessment Report.

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ACRONYMS AND ABBREVIATIONS

BCBG	Bear Creek Burial Grounds
BCK	Bear Creek Kilometer
BCV	Bear Creek Valley
bgs	below ground surface
BHHRA	baseline human health risk assessment
BYBY	Boneyard/Burnyard
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	contaminant of potential concern
CRAFLUSH	contaminant transport in fractured porous media
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
EPA	Environmental Protection Agency
FA	functional area
FS	Feasibility Study
HCDA	Hazardous Chemical Disposal Area
IP	integration point
LCL	lower confidence limit
LNAPL	light non-aqueous phase liquid
MCL	maximum contaminant level
NT	North Tributary
ODAST	one-dimensional analytical solution
OLF	Oil Landfarm
OU	Operable Unit
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PRG	preliminary remedial goal
RCRA	Resource Conservation and Recovery Act
RGO	remedial goal objective
RI	Remedial Investigation
RIFA	RI field activities
SESOIL	Seasonal Soil (compartment model)
SL 1	Sanitary Landfill 1
SVOC	semivolatile organic compound
TCA	trichloroethane
TCE	trichloroethene
UCL	upper confidence limit
VOC	volatile organic compound
WIP	Walk-in Pits

EXECUTIVE SUMMARY

This Remedial Investigation (RI) Report characterizes the nature and extent of contamination, evaluates the fate and transport of contaminants, and assesses risk to human health and the environment resulting from waste disposal and other U.S. Department of Energy (DOE) operations in Bear Creek Valley (BCV). BCV, which is located within the DOE Oak Ridge Reservation (ORR) (Fig. ES.1), encompasses multiple waste units containing hazardous and radioactive wastes arising from operations at the adjacent Oak Ridge Y-12 Plant (Fig. ES.2). The primary waste units discussed in this RI Report are the S-3 Site, Oil Landfarm (OLF), Boneyard/Burnyard (BYBY), Sanitary Landfill 1 (SL 1), and Bear Creek Burial Grounds (BCBG). These waste units, plus the contaminated media resulting from environmental transport of the wastes from these units, are the subject of this RI.

Consistent with the Watershed Approach to remedial investigation/feasibility study (RI/FS) planning adopted by the Oak Ridge Federal Facility Agreement (FFA) parties, the environmental media and waste sites in BCV have been combined into a single Characterization Area (CA) encompassing the entire Bear Creek watershed. The benefits of this approach have included:

- a significantly reduced site investigation phase, with more reliance on historical data as the basis for remedial action decisions;
- development of more consistent Remedial Goal Options (RGOs) across the multiple source units;
- an increased focus on development of an integrated prioritization for remedial actions, particularly for sites appropriate for near-term actions; and
- an overall reduction in cost and schedule for the RI/FS process.

Accordingly, the BCV RI Report documents and interprets the results of numerous historical field characterization efforts conducted in BCV prior to 1994 as well as three limited RI field projects covering specific portions of the watershed in 1994 and 1995. This interpretation provides a comprehensive evaluation of the conditions at and risks associated with the waste sites, associated floodplain, and groundwater in the valley.

Inherent in the accelerated watershed approach is the heavy reliance on historical data to form the basis of the RI. For BCV, a significant historical data set existed, thus minimal effort was spent by the watershed RI team in gathering additional extent of contamination information. While this approach greatly reduces the schedule and cost of the RI, it does result in higher levels of uncertainty in the evaluation results. The likelihood of important data gaps in the BCV RI was minimized by adherence to the Data Quality Objective (DQO) process during the planning phase, and by proactive uncertainty management during the data collection and evaluation phases. The resulting FS will accommodate the identified uncertainties through selection of contingent actions that will allow for flexibility within the remedy selection.

This BCV RI Report represents the first major step in the decision-making process for the BCV watershed. The RI results, in concert with the follow-on FS (to be available for public review in April 1997), will form the basis for the Proposed Plan and Record of Decision for all BCV sites. This comprehensive decision document process will meet the objectives of the watershed approach for

LEGEND:

- REACH 1 OF BEAR CREEK
NT-1 and Bear Creek to NT-3
- REACH 2 OF BEAR CREEK
NT-3 To BCK-9.40
- REACH 3 OF BEAR CREEK
BCK-9.47 to ET-4
- REACH 4 OF BEAR CREEK
ET-4 to EFPC
- ⊕..... GROUNDWATER WELL (individual wells not
labeled unless mentioned in text.)
- SS-6..... MAJOR SPRINGS
- / TS1..... SOIL TRANSECT LOCATION

Figure ES.1. Location map for the Bear Creek Valley Characterization Area showing major geographical and hydrological features.

ES-2

SAC CAD DWG: 94020\DWGS\507REACH

A detailed map of the Bear Creek Valley area. The map shows a winding road labeled "Bear Creek Road" and a creek labeled "Bear Creek". Various land parcels are outlined, some with numbers. Labels on the map include "BURIAL GROUND", "OIL LANDFARM", and "S-3 SITE".

LEGEND:

SS4 •

Φ GW-684

ROADS

BEAR CREEK & TRIBUTARIES

OU4 SURFACE WATER

SAMPLE AT SPRINGS

GROUNDWATER WELL

WASTE AREA UNITS

Figure ES.2. Location map for waste areas in the Bear Creek Valley Characterization Area.

BCV, which include: (1) prioritization of remedial action decisions, (2) expeditious implementation of highest priority remedial actions, and (3) increased cost effectiveness of remedial action by setting watershed Remedial Action Objectives (RAOs) based on an integrated, valley-wide, future land use plan. By conducting the evaluation within the watershed framework, DOE can ensure consistent actions that achieve the RAOs across all the units and cost effectively optimize the extent and type of remedies, regardless of location.

ES.1 MAJOR CONCLUSIONS FOR THE RI REPORT

The BCV RI Report contains a detailed analysis of environmental data for BCV. The major conclusions from the analysis are conveyed via conceptual models for the nature and extent of contamination and fate and transport of contaminants. Common to each of the major waste units located on the north side of Bear Creek are the following major conclusions:

- There are a number of physical and chemical aspects of the source sites that will complicate cleanup of the sources areas and will limit the ability to allow unrestricted, e.g., residential or industrial, use at these sites (S-3 Site, BYBY, and the BCBG). These are:
 - large volumes of buried waste exist at each source area in unlined trenches;
 - portions of the waste at each source area are inundated by shallow groundwater;
 - groundwater at the sources is contaminated to over 120 m (400 ft) depth and dense non-aqueous phase liquid (DNAPL) is present; at the S-3 Site and BCBG, contamination in groundwater is a secondary source that is of equal or greater magnitude than the primary waste source; and
 - the sources are situated on low permeability, fractured shale rock. Diffusion of contaminated groundwater into the rock pores has resulted in a reservoir of contaminated groundwater that can only be released from the rock at a slow rate.
- Contaminants migrating from the waste sites in BCV converge at Bear Creek Kilometer (BCK) 9.47/South Spring (SS)-5 (Fig. ES.1): more than 99% of available water from the upper portion of the valley passes through this location as either surface water or groundwater. Thus a north-south line drawn at BCK 9.47/SS-5 is a convenient location to conduct an integrator point/plane (IP) assessment of contaminant fluxes from the waste areas (Note: in some of the FS alternatives, unrestricted land use starts to the west of this line). At the IP, potential risks from exposure to groundwater or surface water exceed 10^{-6} or a Hazard Index (HI) >1 (Fig ES.3). The chemicals of concern (COCs) at the IP are uranium, nitrate, boron, and fluoride. In addition, applicable or relevant and appropriate requirements (ARARs) for nitrate are exceeded in groundwater at the IP and also most likely for uranium (Note: uranium contamination in GW-684 at the IP does not exceed the ARAR; however, groundwater discharge at SS-5 periodically exceeds the uranium ARAR). Although it is not clear how far the elevated hazard and ARAR exceedances extend to the west, they do not extend as far as Highway 95.
- Contaminated groundwater at waste areas migrates along geological strike to nearby tributaries of Bear Creek [i.e., North Tributary (NT) -1, -2, -3, -6, -7, and -8] causing the tributaries and Bear Creek to become contaminated. This is the principal exit pathway for contaminants leaving the waste areas and moving to the IP. Figure ES.3 shows what sources and tributaries contribute the most to contamination at the IP. The S-3 Site (NT-1, NT-2, and Bear Creek above

Potential Risks and Toxic Effects at the Integrator Plane

BCK 9.4/SS-5 Aggregate

GW 684 Groundwater

*COPCs not listed individually have individual potential risk $< 10^{-5}$ or HI < 0.1

Relative Contribution of Uranium and Nitrate at the IP from Source Areas

Uranium Flux

*Assumed distribution of ungauged flux is 70% BYBY, 30% S-3 Site.

Nitrate Flux

Figure ES.3. Potential risks and hazards at the Integrator point/plane and the relative magnitude of the sources for nitrate and uranium.

BCK 12.36) and BYBY (NT-3) sites are currently contributing more than 80% of the potential hazard at the IP through releases of uranium and, to a lesser extent, nitrate. The total flux from NT-1 and NT-2 is expected to increase in the foreseeable future and may result in a greater hazard at the IP. A 50 to 75% reduction in the current contaminant flux through tributaries or shallow groundwater at the S-3 Site and BYBY could reduce the total HI at the IP below 0.8.

- Discharges to surface water from a plume of contaminated groundwater at the S-3 Site are the primary causes of current impacts on the aquatic ecology in Bear Creek, east of BCK 9.47.
- Impacts of contamination at waste areas have been lessened by capping waste areas. In addition, seep collection at BCBG has lessened the downgradient impact of contamination migrating away from this source.

ES.2 BCV HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological system in BCV is governed by the valley's geology. Rocks underlying BCV fall into two broad categories: those that are dominated by clastic lithologies (e.g., Nolichucky Shale) and those that are predominantly carbonates (e.g., Maynardville Limestone). The primary permeability of the rocks underlying BCV is very low. The formations are extensively fractured and, in the case of carbonate formations, karstified, creating a secondary porosity that results in substantially increased permeability.

Groundwater flows through fractures or solution conduits, which are well-connected and mostly parallel to geological strike (Fig. ES.4). Fracture aperture width generally decreases with depth, restricting the depth of active groundwater circulation. The shallow interval [top 30 m (100 ft)] of the Maynardville Limestone contains a well-connected maze of conduits that is able to transport water rapidly along strike, west in the axis of BCV. Groundwater in this interval is closely connected to flow in Bear Creek. Below 30 m (100 ft) in this formation, along strike flow occurs through discrete solution conduits and fractures that are not as well-interconnected than those in the shallow interval.

The Nolichucky Shale is the principal clastic formation that forms the northern flank of BCV. Most groundwater flow in the clastic formations occurs during and immediately following precipitation at the water table and shallow bedrock intervals [probably <15 m (50 ft) depth]. Flow is predominantly along strike, and discharge is to tributaries of Bear Creek after short flowpaths. During storms, flow in these shallow intervals may be rapid (up to 40 m/d).

As a result of predominantly short and shallow flow paths for groundwater in the clastic formations in BCV, although the largest mass of water (and consequently the largest mass of contaminants) exits BCV via surface water, groundwater is the principal pathway for contaminants leaving the waste units. The main flow and contaminant transport pathways in groundwater at the waste units are along strike with the discharge points at tributaries to Bear Creek. Fluxes in flow paths at the waste units (overland flow, soil interflow, and groundwater flow) have not been quantified but recharge followed by groundwater flow to tributaries constitutes the main water flux pathway. During a 10-month surface water monitoring program, an estimated 97% of water available for flow (precipitation and evapotranspiration) exited the section of the valley above BCK 9.47 as surface water flow.

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ES.3 NATURE AND EXTENT OF CONTAMINATION

ES.3.1 Environmental Database

The environmental database used for the BCV RI includes 75,000 soil, sediment, groundwater, surface water, and biota analyses obtained during the RI field projects conducted during 1994 and 1995, and 20,000 soil, sediment, groundwater, and surface water analyses obtained from historical field studies conducted in the 1980s and early 1990s. A detailed data quality assessment review demonstrated that the quality of both the recent and historical chemical data is adequate: <1% of the recent data were considered unacceptable, and only 1.3% of the historical chemical data were rejected. Historical radiological data for groundwater were deemed unacceptable for use in the RI and the Human Health Risk Assessment, therefore, additional groundwater samples were taken during the RI to complete the radiological database.

ES.3.2 Waste Sites

The primary waste sites characterized in this BCV RI report are the S-3 Site, OLF, BYBY, SL 1, and BCBG (Fig. ES.2). Three other primary waste sites within BCV — Spoil Area 1, Rust Spoil Area, and SY-200 Yard — are discussed in the BCV OU 2 RI (Energy Systems 1995). Although these sources were described in the BCV OU 2 RI Report, the watershed approach dictates that their impacts on the environment in BCV are considered in this report. In addition, numerous smaller waste disposal or storage areas throughout BCV, such as the OLF Storage Containment Pad, Bear Creek Road Debris Burial area, and Creekside Debris Burial area, are also considered as potential contaminant sources.

During the DQO process for BCV, the RI team decided that direct sampling to characterize the waste materials was not feasible (DQO meeting minutes). Instead, the physical and chemical characteristics of the contaminant sources were derived from interpretation of historical data and information in waste management records: pre-closure sampling data were used to quantify waste contamination at the S-3 Ponds and OLF sites; a detailed waste inventory was used for BCBG; and data from recent (1994) soil sampling were used for BYBY and SL 1. Where possible, current conditions within each source area were estimated to allow modeling of the potential future releases and assessment of current and future risks.

The waste areas in BCV are located in the upper 3.5 km (2.2 miles) of the valley (east of the IP) (Fig ES.2). Both solid and liquid wastes were disposed of at these sites. Most liquid waste has either infiltrated to groundwater below the waste sites or has migrated in groundwater and surface water away from the source areas. The following volumes of waste, contaminated soil, and contaminated groundwater are estimated to be present in BCV (Note: volume estimates for soils and wastes do not include materials in waste area caps):

S-3 Site	1,600 m ³ waste and contaminated soils 7.1 × 10 ⁶ m ³ (5740 acre-ft) contaminated groundwater
Oil Landfarm	25,000 m ³ waste and contaminated soils
BYBY	90,000 m ³ waste and contaminated soils 0.4 × 10 ⁶ m ³ (320 acre-ft) contaminated groundwater

SL 1	110,000 m ³ waste and contaminated soils
BCBG	190,000 m ³ waste and contaminated soils 4.0 × 10 ⁶ m ³ (3200 acre-ft) contaminated groundwater

In addition, there is an estimated 5.7×10^6 m³ (4600 acre-ft) of contaminated groundwater in the Maynardville Limestone, and < 1,000 m³ of contaminated soils and waste materials on the BCV floodplain.

ES.3.3 Nature and Extent of Contamination in Environmental Media and Wastes

The data available for the BCV CA were divided into four functional areas (FAs), each of which contains data that are logically interpreted together because of location and/or contaminant source. Three of the FAs — the S-3 FA, the OLF FA, and the BCBG FA — include data that relate to the three primary waste areas (Fig. ES.2). The fourth FA is the Maynardville Limestone and Bear Creek FA, which is located downgradient of the source FAs and acts as an integrated exit pathway for contaminants migrating away from the source units, via groundwater in the Maynardville Limestone or surface water flow in Bear Creek.

S-3 Functional Area

The S-3 FA includes the soils, groundwater, and surface water at and immediately downgradient of the S-3 Site.

Sources and contaminants. At the S-3 Site FA, primary contaminant sources are (1) a plume of contaminated groundwater derived from infiltration of nitric acid waste water and density-driven flow downward into bedrock, and (2) sludges remaining in place in the former ponds. Thirty years of disposal of concentrated (~1 molar) nitric acid solutions at the S-3 Site has resulted in a reservoir of contaminated groundwater with high (> 10,000 mg/L) total dissolved solids (TDS) in the Nolichucky Shale at this site. Discharge of groundwater from this contaminated plume results in contaminated surface water with elevated TDS (maximum > 1000 mg/L).

Contamination derived from the S-3 Site can be identified in the Maynardville Limestone as far west as Picket W and in surface water at BCK 4.55. Primary contaminants that have migrated away from the S-3 Site include (1) nitrate, uranium, ⁹⁹Tc, barium, boron, cadmium, strontium, acetone, and tetrachloroethene (PCE) in groundwater, and (2) nitrate, cadmium, uranium, and ⁹⁹Tc in surface water. Contaminant concentrations in groundwater at the S-3 Site exceed ARARs for inorganic and organic chemicals in drinking water.

S-3 Site conceptual model. At the S-3 Site, contaminated groundwater in the Nolichucky Shale is the main source of contaminants to downgradient receptors: more contaminant mass flux is discharging to the creek than is leaching from waste materials that remain in the former ponds. Historically, during operations at the S-3 Ponds, most of the acidic waste water probably migrated rapidly to the main stem of Bear Creek, NT-1, and Upper East Fork Poplar Creek via shallow groundwater flow. At the present time, contaminants in this plume are migrating in shallow and deep groundwater and discharging to Bear Creek, NT-1, and NT-2 (Fig. ES.5).

Figure ES.5. Conceptual model for Bear Creek Valley showing the main contaminant migration pathways.

Contaminants have undergone differential retardation that has resulted in different distributions and exit pathways for the primary contaminants: nitrate, metals, uranium, ⁹⁹Tc, and PCE. Uranium and some metals are made relatively immobile by geochemical reactions and have been held up in the residuum and shallow groundwater close to the S-3 Site. The exit pathway for these contaminants is via discharge of shallow groundwater to Bear Creek. Nitrate, ⁹⁹Tc, PCE, and the more mobile metals have contaminated bedrock groundwater. The main pathway for these contaminants is along strike flow in the intermediate and deep groundwater intervals, followed by upwelling and/or diffusion to the shallow groundwater interval and discharge to NT-1 and NT-2. Nitrate is least retarded and has traveled the farthest from the S-3 Site — its occurrence in groundwater marks the maximum extent of contamination resulting from the S-3 Site.

All contaminants in groundwater at the S-3 Site have been retarded by matrix diffusion. A reservoir of contaminants in the matrix porosity now exists at the S-3 Site, where these contaminants flow and/or diffuse from the rock matrix into the active flow fractures in each pathway.

The maximum concentrations of PCE found at S-3 Site (> 1% of PCE solubility) indicate the potential for PCE bearing DNAPL in the bedrock formations beneath the ponds.

The plume of contaminated groundwater derived from the S-3 Site can be traced in the Nolichucky Shale as far west as NT-2. However, although the extent west of the plume in shallow groundwater is well known, no data points exist until downgradient of SL 1 to identify the leading edge of the plume in intermediate and deep groundwater. Increasing concentrations of nitrate in shallow wells near the NT-2 catchment over the past 10 years suggest that the center of mass of the nitrate plume may be moving along strike to the west in groundwater below 30 m (100 ft) depth. The probable condition is that the plume in deep groundwater extends no further west than the plume in shallow groundwater and that much of the contaminant mass flux in the plume is discharged to NT-2.

Oil Landfarm Functional Area

The OLF FA encompasses the soils, groundwater, and surface water at and immediately downgradient of four sites: OLF, BYBY, Hazardous Chemicals Disposal Area (HCDA), and SL 1.

Sources and contaminants. Both solid and liquid wastes were disposed of at the OLF FA. There are three primary locations of solid wastes: (1) buried waste materials at BYBY, (2) buried waste materials in the SL 1 trench, and (3) contaminated soils on the former OLF plots. In addition, disposals of liquid wastes at BYBY, HCDA, and OLF have resulted in plumes of volatile organic compound (VOC) -contaminated groundwater.

Contamination at the OLF FA is diverse, including metal, radionuclide, and VOC contamination in groundwater, surface water, soils, and waste materials. Frequently detected contaminants in the OLF FA are as follows:

- At BYBY and HCDA: (1) mercury, beryllium, manganese, nickel, vanadium, PCE, trichloroethene (TCE), 1,2-dichloroethene (DCE), and uranium isotopes in groundwater; (2) mercury, lithium, and uranium isotopes in surface water; and (3) mercury, cadmium, copper, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phthalates, uranium isotopes, and ⁹⁹Tc in soils.

- At OLF: (1) PCBs and uranium in soils and wastes, and (2) 1,1,1-trichloroethane (TCA), 1,1-dichloroethane (DCA), 1,1-DCE, 1,2-DCE, PCE, and TCE in groundwater. There is no surface water contamination that can be attributed to OLF.
- At SL 1: (1) mercury, copper, nickel, PCB-1254, and ²³⁵U in soils and wastes, and (2) 1,1-DCA, 1,2-DCE, and vinyl chloride in groundwater. There is no surface water contamination that can be attributed to SL 1.

OLF FA conceptual model. The conceptual models for both OLF and SL 1 are that soils surrounding the waste sites are relatively uncontaminated. Groundwater below and immediately downgradient of each waste area is contaminated with VOCs as a result of liquid waste disposals.

At BYBY, uranium leaches from waste materials (some of which are most likely inundated with groundwater) and contaminated soils to groundwater, which subsequently discharges to surface water in NT-3. Uranium in groundwater that has leached from fill material in the southern portion of BYBY probably migrates directly to the Maynardville Limestone and Bear Creek via shallow groundwater flow (Fig. ES.5). Fate and transport modeling indicates that most inorganic and radiological contaminants in NT-3 have probably reached peak concentrations; however, the presence of a continuous source (leaching from waste materials) suggests that these peak values would be maintained over several hundred years.

The VOC plume at BYBY is partly located in residuum above the Maynardville Limestone and, like uranium, VOCs probably migrate directly into the Maynardville Limestone or Bear Creek. Although VOCs entering groundwater from HCDA or the Burnyard may discharge to surface water in NT-3, the extent of this discharge is low, hence, VOCs volatilize almost immediately.

Bear Creek Burial Grounds Functional Area

Sources and contaminants. At the BCBG FA, both solid and liquid wastes were disposed of in a series of unlined trenches. The waste trenches are grouped into areas BG-A, -B, -C, -D, -F, and Walk-in-Pits (WIP). Uranium dominates the wastes disposed of in each area with a total estimated mass of 18.6 million Kg. Disposals of liquid wastes have also resulted in DNAPL (PCE and TCE) in groundwater that may have reached depths of 180 m (600 ft). Dissolution of DNAPL results in plumes of VOC-contaminated groundwater.

Contamination in the BCBG FA includes VOCs and metals in groundwater, and VOCs, metals, and radionuclides in surface water, soils, waste materials, and leachate from waste trenches. In general, organic contamination of environmental media at BCBG is more widespread than inorganic and radionuclide contamination. Primary contaminants detected at the BCBG are: (1) boron, PCE, TCE, 1,1,1-TCA, and 1,2-DCE in groundwater; (2) beryllium, 1,1,2-TCA, 1,1-DCE, 1,2-DCA, vinyl chloride, 1,1-DCA, 1,1,1-TCA, chloroethane, and uranium isotopes in surface water; (3) arsenic, vanadium, PCBs, acetone, and toluene in soils surrounding the waste areas; and (4) uranium, beryllium, PCBs, TCE, and PCE in wastes. Contaminant concentrations in groundwater at BCBG exceed ARARs for inorganic and organic chemicals in drinking water at many locations.

Contamination of groundwater and surface water is dominated by VOCs at the BCBG FA. Three groundwater plumes were identified: (1) the BG-A plume is dominated by PCE, TCE, and 1,2-DCE, and includes DNAPL; (2) the WIP plume is dominated by PCE; and (3) the plume at the NT-8 catchment is dominated by 1,2-DCE, with lesser concentrations of vinyl chloride.

Radiological contamination is virtually absent from groundwater wells in the BCBG, but uranium is consistently detected in surface water. Collection of leachate in the NT-7 and NT-8 catchments has significantly reduced the concentration of radiological and other contaminants in surface water.

Radiological contamination occurs in soils in the NT-8 floodplain and is probably related to past deposition of contaminated sediments derived from drainage of the BG-B, -C, and -D areas.

BCBG conceptual model. The distribution of contaminants at BCBG reflects the type of waste materials that were disposed. The organic wastes were dense liquids and were disposed of directly into groundwater; uranium is in the solid form and is slowly leaching from trenches. The dominance of the hydrogeologic system by shallow flow restricts inorganic and radionuclide contamination to short flow paths in the shallow groundwater interval, whereas the density-driven flow of DNAPL provides a mechanism for organic contamination to enter the shallow, intermediate, and deep bedrock intervals (Fig. ES.5).

Oils and solvents were disposed of in the BG-A area by pouring the liquids into standpipes in debris- and waste-filled trenches. The bulk of these liquids migrated laterally to surface water and downward to groundwater, ultimately reaching depths of up to 180 m (600 ft) as DNAPL. Free-phase liquids occur in bedrock and probably remain in the trenches as residual droplets that have adhered to waste materials and minerals. Dissolved VOCs in the BG-A and NT-8 plumes have undergone limited chemical or biological degradation. A plume of dissolved PCE is migrating along strike in the Nolichucky Shale to the west of BG-A South. Fate and transport modeling suggests that a PCE plume may take a few hundred years to migrate along strike as far as NT-8.

Maynardville Limestone and Bear Creek Functional Area

The Maynardville Limestone and Bear Creek FA includes (1) soils and sediments in the Bear Creek floodplain, (2) groundwater in the Maynardville Limestone, and (3) surface water in the main stem of Bear Creek and in floodplain springs.

Sources and contaminants. The environmental media in this FA represent the downgradient pathways and receptors of contaminants migrating away from the sources on the Nolichucky Shale. The primary sources of contaminant input to Bear Creek and the Maynardville Limestone from the source sites are:

- S-3 Site: nitrate, radionuclides, and high TDS via discharge from NT-1 and NT-2, shallow groundwater discharges to Bear Creek, and shallow groundwater discharges directly to the Maynardville Limestone.
- BYBY: uranium via discharge from NT-3 and direct runoff to the Floodplain, and uranium and VOCs by shallow groundwater discharge into the Maynardville Limestone.
- SL 1: VOCs via shallow groundwater discharge into the Maynardville Limestone.
- BCBG: VOCs and uranium via discharge from NT-7 and NT-8.
- Past releases of TCE and 1,2-DCE from an unknown site east of BYBY FA or Rust Spoil Area.

- Past releases of TCE and 1,2-DCE from the Fire Training area in the neighboring Upper East Fork Poplar Creek (Fig. ES.1) hydrogeologic regime that may have migrated in karst in the Maynardville Limestone into the Bear Creek hydrogeologic regime at Spoil Area 1.

In addition, the Creekside Debris Burial area and the Bear Creek Road Debris Burial area are two waste areas, first identified during field operations for the BCV RI, with soil contamination on the Floodplain. These sites do not currently contribute to groundwater contamination but may have done so in the past. Primary contaminants in the Maynardville Limestone and Bear Creek FA are:

- nitrate, boron, uranium, strontium, barium, PCE, TCE, 1,2-DCE, and ^{99}Tc in groundwater; concentrations of these contaminants exceed ARARs for drinking water at many locations in the valley upgradient of BCK 9.47;
- barium, cadmium, manganese, uranium, boron, strontium, TCE, 1,2-DCE, and ^{99}Tc in springs and surface water upstream of BCK 9.47;
- nitrate, boron, strontium, and uranium in surface water downstream of BCK 9.47; and
- cadmium, uranium, and PCBs in Floodplain soils and sediments at a few locations [in general, contaminant concentrations are higher in sediments than in soils, and the highest concentrations in soils occur in the top 10 cm (4 in.) of soil].

Nitrate, uranium, and ^{99}Tc contamination occurs close to the S-3 Site and continues west as far as BCK 9.47 and Picket A. Nitrate contamination in groundwater occurs 2590 m (8500 ft) west of Picket A in Picket W, but uranium and ^{99}Tc have not reached this far west. TCE- and 1,2-DCE contaminated groundwater occurs in groundwater wells at the Spoil Area 1 and Rust Spoil Area. Concentrations of TCE and 1,2-DCE in groundwater increase downgradient of Rust Spoil Area at Picket C and adjacent to BYBY. The furthest west that TCE is detected in groundwater is in Picket B; however, discharge to SS-5 is contaminated with trace concentrations of TCE, which may indicate the presence of the leading edge of the TCE plume at Picket A.

Maynardville Limestone conceptual model. At monitoring points downgradient of BYBY (groundwater and surface water), the plumes from the S-3 Site and BYBY source areas are completely commingled (Fig. ES.5). It is only possible to identify BYBY as a contributor to the inorganic and organic Maynardville Limestone contaminant plumes because of the relative concentrations of contaminants in groundwater, surface water, and springs. Progressive changes in relative concentrations of contaminants in groundwater along the valley reflect the inputs to the Bear Creek/Maynardville Limestone system and suggest that after entering Bear Creek contaminants can migrate downward into the Maynardville Limestone (Fig. ES.5).

Surface water in Bear Creek and shallow groundwater in the Maynardville Limestone are closely interrelated and constitute 96% of water flowing along the valley. Contaminants in these media pathways are quickly diluted by rapid recharge of rainwater and inputs from noncontaminated tributaries. Concentrations of contaminants in the intermediate and deep groundwater pathways [30 to 90 m (100 to 300 ft) depth] are not attenuated as rapidly as those in shallow groundwater because this interval is somewhat isolated from inputs from recharge and tributaries. Plumes of groundwater contaminated above maximum contaminant levels in the 30 to 90 m (100 to 300 ft) depth interval are more continuous and extend further along the valley.

Groundwater contamination at Picket W is attributed both to diffuse contamination as a result of infiltration of contaminated surface water in Bear Creek and along strike migration of contaminated groundwater in intermediate and deep groundwater.

ES.4 CONTAMINANT FATE AND TRANSPORT PATHWAYS

The principal contaminant sources in BCV are located on the outcrop of the Nolichucky Shale (S-3 Site, BYBY, and BCBG), a carbonate-rich fractured shale with low permeability. Solid and liquid waste disposals have caused shallow groundwater contamination. Leaching of solid materials, particularly uranium, is a current source of shallow groundwater contamination. Where dense liquids were disposed of at the S-3 Site and BCBG, contamination of deep groundwater in the Nolichucky Shale has occurred. Contaminants migrate away from the waste disposal units using the following pathways (Fig. ES.5):

- Contaminated shallow groundwater at sources on the Nolichucky Shale migrates through fractures along geological strike and discharges to tributaries or directly to Bear Creek causing the tributaries and Bear Creek to become contaminated.
- Contaminants in deep groundwater in the Nolichucky Shale also migrate through fractures along strike and discharge to tributaries. However, contaminant pathways in the deep groundwater can underflow proximal tributaries and/or springs and be a source of contamination in neighboring tributary subwatersheds.
- After entering tributaries, contaminants migrate in surface water directly to Bear Creek. Bear Creek intermittently loses and gains water from groundwater in the Maynardville Limestone throughout the length of the valley. Losing reaches of Bear Creek cause groundwater contamination in the Maynardville Limestone. Gaining reaches of Bear Creek are associated with large springs at the base of Chestnut Ridge, some of which have contaminated discharge (SS-1, -4, -5, and -6).
- Surface water in Bear Creek and shallow groundwater in the Maynardville Limestone constitute 96% of water flowing along the valley. Contaminants in these media pathways are quickly diluted by rapid recharge of rainwater and inputs from noncontaminated tributaries.
- Deep groundwater in the Maynardville Limestone [30 to 90 m (100 to 300 ft) depth] constitutes <4% of water flowing along the valley. Concentrations of contaminants in this and in the deep groundwater pathway are not attenuated as rapidly as those in shallow groundwater; this pathway is an important source of long distance groundwater transport along the valley.
- Contaminant concentrations in shallow groundwater in the Nolichucky Shale and the Maynardville Limestone and in surface water are diluted by recharge during storm events and show seasonal trends of lower concentrations during periods of high rainfall.

Contaminants migrating from the waste sites in BCV converge at BCK 9.47/SS-5 — more than 99% of available water from the upper portion of the valley passes through this location as either surface water or groundwater.

ES.4.1 Integrator Point/Plane Assessment

To determine the contribution of each FA to the valley-wide contaminant flux migrating off site from the BCV CA, an IP assessment was completed at BCK 9.47/SS-5. Using a mass balance calculation, 69% of uranium measured at BCK 9.47 and SS-5 was measured at monitoring stations in tributaries to Bear Creek (gauged flux on Fig. ES.3). The remaining 31% was not measured in the RI (engaged flux) but is expected to be derived from migration of uranium directly to Bear Creek and the Maynardville Limestone via shallow groundwater at the BYBY and S-3 Site sources.

Assuming a similar distribution of the engaged flux as the gauged flux, then ~ 61% of the uranium found in surface water and groundwater at the IP is derived from BYBY. The S-3 Site is the second major contributor of uranium (26%), and this site contributes approximately 94% of the nitrate contamination at the IP. At the IP, 13% of the uranium is derived from BCBG. VOCs at the IP are mainly derived from BCBG; however, most VOCs (82%) discharged to surface water at source areas volatilize before reaching BCK 9.47. Boron was not measured in tributaries in the RI but is probably mostly derived from the BCBG where it was reported to be a contaminant in waste liquids that accompanied uranium tailings disposal and is found in the current leachate at BCBG.

Using these flux data, the portion of the total risk to human health and total hazard at the IP contributed by each waste site was calculated (Fig. ES.6). BYBY contributes most to the human health risk to the IP (38.5%), followed by BCBG (23.0%), and the S-3 Site (17.4%). Engaged uranium fluxes contribute 20.7% of risk at the IP. As discussed above, most of the engaged uranium flux originates in the BYBY (assumed 70%) and the S-3 Site (assumed 30%).

ES.4.2 Anticipated Future Changes

In the absence of remedial action and assuming maintenance of the current leachate collection system at BCBG, contaminant concentrations in most pathways are expected to remain at concentrations similar to those currently observed with four exceptions. These exceptions are:

- Concentrations of uranium and some metals in groundwater discharged to NT-1 are expected to increase in the foreseeable future (100 to 200 years). Concentrations of VOCs and nitrate may have peaked in this pathway but are expected to remain close to current levels for the next 100 years.
- Concentrations of nitrate, uranium, and some metals in groundwater discharged to NT-2 are expected to increase in the foreseeable future (100 to 1000 years).
- Along strike migration in the Nolichucky Shale of a plume of PCE-contaminated groundwater at BCBG may result in discharge of contaminated groundwater to NT-8 in the next 100 years. However, it is anticipated that volatilization of most of the VOCs in surface water, as is observed today, will lessen the impact of this discharge.
- Along strike migration in the Maynardville Limestone of a plume of TCE- and 1,2-DCE-contaminated groundwater at BCBG may result in discharge of increasingly contaminated groundwater at SS-5 and BCK 9.47 for the next 500 years. In addition, migration of this plume to BCK 9.47/SS-5 may result in unacceptable risk from use of groundwater at these locations and cause additional groundwater ARARs to be exceeded in the future.

Figure ES.6. Relative contributions from source areas to potential risks and hazards at the IP.

In the absence of remedial actions, the resulting effect of these changes on contaminant fluxes will be to increase the fluxes of uranium, nitrate, some metals, and VOCs at the IP during the foreseeable future. The leading edge of the nitrate plume in BCV has reached Picket W wells ~ 2.3 km west of BCK 9.47 (Fig ES.1). Increased fluxes of contaminants at the IP will most likely result in extension of the plumes of contaminated groundwater west of BCK 9.47 and increased concentrations of contaminants at Picket W.

ES.5 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

ARARs and to-be-considered guidance that may be applicable to BCV have been identified so that remedial actions planned for BCV can be fully protective of human health and the environment. Chemical-specific guidance for the BCV include:

- Environmental Protection Agency's (EPA's) insufficient yield criterion for groundwater classification;
- Safe Drinking Water Act maximum contaminant levels;
- National Secondary Drinking Water Standards secondary maximum contaminant levels;
- EPA rule for natural attenuation of contaminants in groundwater in cases where active remediation is not appropriate; and
- Tennessee Department of Environment and Conservation ambient water quality criteria.

Chemical-specific ARARs for soils and sediments and location- and action-specific ARARs applicable to sensitive resources are usually invoked during remedial action. Thus, these ARARs will be analyzed and discussed as remedial alternatives are screened in the BCV FS.

ES.6 BASELINE RISK ASSESSMENT

ES.6.1 Baseline Human Health Risk Assessment

Conclusions on potential human health risks in BCV are based on four hypothetical land uses for which risks to human health were calculated; these are current hypothetical "unprotected" site maintenance workers at the source areas, future industrial workers, future recreational receptors downstream of BCK 9.47, and future residential receptors (Figs. ES.7 and ES.8).

At BCBG, S-3 Site, and OLF, there is an important distinction between contamination due to buried waste materials and soil contamination resulting from mobilization of contaminants in wastes (secondary contamination). In general, although secondary contamination is present in soils immediately surrounding the wastes, the concentrations of contaminants in these soils are lower and pose potential risks that are orders of magnitude less than those from the neighboring waste materials. Soils surrounding waste units generally pose risks to potential future residents but little risks to potential future industrial or unprotected maintenance workers; whereas exposure to contaminants in wastes poses high risks for potential future residents and future industrial workers. With the exception of BYBY and BG-D, -E, and -J, waste materials are buried and covered with multilayer RCRA caps; therefore, the scenario for exposure of future residents and industrial workers assumes degradation of these caps and eventual uncovering of the wastes.

Figure ES.7. Distribution of risks posed to potential future residents and recreational users in Bear Creek Valley.

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Figure ES.8. Distribution of risks posed to potential future industrial workers and unprotected maintenance workers in Bear Creek Valley.

Current "unprotected" maintenance worker. Risks from exposures to an unprotected maintenance worker (rather than a worker having the level of protection currently required for access at BCV sites) were evaluated to provide a conservative estimate of current risk. Assuming that existing caps at the waste areas are maintained, the only risks exceeding 10^{-4} identified for an unprotected maintenance worker at any of the BCV sites are through exposure to three chemicals of concern (COCs) (^{234}U , ^{235}U , and ^{238}U) found in hot spot soils, where waste material was exposed at the surface, at BYBY, and at BCBG (Fig. ES.8).

Future industrial worker. Risks/hazards to a future industrial worker can occur from exposure to 33 COCs:

- buried and capped wastes at the S-3 Site contain 12 COCs (beryllium, PCB-1248, and radionuclides);
- soils adjacent to the OLF cap contain 4 COCs (arsenic and radionuclides);
- soils at BYBY contain 12 COCs (metals, PAHs, and radionuclides);
- soils adjacent to caps, hot spot soils near BG-D East, and buried wastes at BCBG contain 12 COCs (metals, PCBs, VOCs, and radionuclides); and
- inventoried soils at the Disposal Area Remedial Action (DARA) Solids Storage Unit and the OLF Storage Pad contain 6 COCs (dioxins, PCB-1254, and uranium isotopes) and 4 COCs (beryllium, PCBs, and uranium isotopes), respectively.

Future recreational receptor. Risks to a future recreational user of BCV were evaluated for the BCV Floodplain, starting just west of the BCBG (BCK 9.47) and ending near Highway 95. Only one pathway was estimated to pose potential risks under this scenario: ingestion of fish that have bioaccumulated mercury (i.e., methylmercury) and PCBs (Fig. ES.7). However, there is uncertainty whether the fish analyzed in the assessment were exposed to contamination only from Bear Creek. No COCs associated with exposure to surface water, floodplain soils, and sediments were identified.

Future resident. Although a residential exposure scenario at the source areas is unlikely, it was evaluated to obtain a reasonable maximum exposure estimate of the risk to future human receptors in BCV.

West of BCK 9.47 and Picket A, total pathway risks from aggregated data do not exceed 10^{-4} (Fig. ES.7). Two individual locations have COCs associated with them. These are:

- 1 COC, PCB-1254, in soils at SP04 near Highway 95 in the BCV Floodplain;
- 4 COCs, arsenic, chromium, manganese, and PCB-1254 in sediments in Bear Creek near NT-9 and NT-11; and
- 2 COCs, boron and strontium, considered as naturally occurring and not related to activities in BCV, were identified for well GW-711 at Picket W.

In addition, low activities (< 7 pCi/L) of radium, ^{137}Cs , and ^{228}Th in groundwater at Picket W and arsenic, ^{137}Cs , and ^{238}U in surface water in Bear Creek downstream of BCK 9.47 pose risk between 10^{-6} and 10^{-4} . However, there is a high degree of uncertainty associated with these radiological data, and the lack of other radionuclides usually associated with contamination in BCV (e.g., U and ^{99}Tc) in these wells makes their occurrence at Picket W suspect.

At the IP, total pathway risks are between 10^{-4} and 10^{-6} . Specific risks and hazards are as follows:

- Ingestion of isotopic uranium in groundwater in GW-684 poses a risk between 10^{-6} and 10^{-4} to future residents. Nitrate and uranium in groundwater in this well also result in a potential HI = 1 for future residents.
- Ingestion of PCE, TCE, ^{99}Tc , ^{137}Cs , ^{237}Np , and isotopic uranium in surface water poses a potential risk between 10^{-6} and 10^{-4} to future residents. Ingestion of uranium in surface water at the IP also results in an HI > 1 for future residents with boron, fluoride, and nitrate also contributing to the hazard.
- Soils at transect TS4, located at the confluence of NT-8 and Bear Creek (Fig. ES.1), pose a potential risk > 10^{-4} to future residents via incidental ingestion or external exposure from beryllium, PCB-1260, or isotopic uranium.

East of BCK 9.47, risks and hazards posed to potential future residents are numerous, and at nearly all locations cumulative pathway risks exceed 10^{-4} and/or HIs exceed 1 via exposure to waste, soil, groundwater, or surface water (Fig. ES.7). Potential risks/hazards to future residents can occur from exposure to 94 COCs:

- at the S-3 Site FA: 34 COCs in groundwater, 13 COCs in surface water, 2 COCs in soils, and 17 COCs in buried/capped waste;
- at the OLF FA: 28 COCs in groundwater and 11 COCs in surface water, 10 COCs in OLF soils, 6 COCs in OLF Storage Pad soils, 12 COCs in SL 1 soils, and 22 COCs in BYBY soils;
- at the BCBG FA: 23 COCs in groundwater, 14 COCs in surface water, 41 COCs in leachate, 11 COCs in soils adjacent to caps and in hot spots, 16 COCs in buried waste, 7 COCs in DARA soils; an
- for the Maynardville Limestone and Bear Creek FA: 13 COCs in Bear Creek Road Debris Burial area, and 16 COCs in Creekside Debris Burial area.

In addition to the risk/hazard associated with exposure to chemicals in BCV, the BCBG site presents potential physical hazards associated with the burial of pyrophoric and explosive agents. An incompatibility study conducted in 1984 concluded that it is reasonable to expect that excavation at BCBG would foster additional reactions through re-exposure to air and unavoidable mixing as wastes are handled.

ES.6.2 Ecological Risk Assessment

Ecological risk was estimated for fish, benthic invertebrate, soil invertebrate, and plant communities and representative organisms of populations of small mammals (mice and shrew), piscivores (mink and kingfisher), large herbivores (deer), and predator/scavengers (hawks and fox). The baseline ecological risk assessment identified significant ecological risks from chemicals in water, sediment, soil, and shallow groundwater for one or more receptors. Metals and PCBs are the primary contaminants of potential ecological concern, and source area and floodplain soils, including transects west of 9.47, contribute to these risks (Fig. ES.9).

In characterizing risk to the assessment endpoints established for the BCV baseline ecological risk assessment (e.g. species richness and abundance), a 20% or greater reduction in one of the

Figure ES.9. Distribution of risks posed to aquatic and terrestrial biota in Bear Creek Valley.

endpoint properties measured in the field or a 20% reduction in survivorship, growth, or reproduction in a toxicity test was considered to be potentially significant. The assessment endpoints and their associated risks for the BCV are:

Reduction in species richness or abundance in fish communities resulting from toxicity. Risks to fish communities were evaluated for Bear Creek, which was divided into four reaches for the baseline ecological risk assessment (Fig. ES.1), and for tributaries NT-2 through NT-8. Both dissolved phase and total concentrations of metals were used in the exposure assessment for fish. The weight of evidence suggests that water from Bear Creek and NT-2 through NT-8 does not pose a significant risk of a 20% reduction in fish species richness or abundance or in the Tennessee dace population due to a toxic effect.

Reduction in species richness or abundance of benthic macroinvertebrate communities resulting from toxicity. Benthic invertebrates exposed primarily to surface water in erosional areas were evaluated separately from those exposed primarily to fine sediments in depositional areas. For benthic invertebrates in erosional areas, the weight of evidence suggests that water in Reaches 1 and 2, NT-2, SS-1, and SS-4 poses a significant risk of a 20% reduction in species richness and abundance due to a toxic effect from high concentrations of calcium, cadmium, manganese, nickel, and uranium. For benthic invertebrates in depositional areas, the weight of evidence suggests that sediment from 3 of 18 sites poses a significant risk due to a toxic effect, probably from manganese and, potentially, selenium and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). However, it is unlikely that the soft-sediment benthic invertebrate community as a whole is reduced by 20% in species richness or abundance.

Reduction in production of soil/litter invertebrates resulting from toxicity. Risk to soil invertebrates was evaluated for four source areas (S-3 Site, BYBY, combined SL 1 and OLF, and BCBG) and for the Bear Creek Floodplain. Risks of a toxic effect to soil invertebrates from mercury and, possibly, chromium, copper, and zinc, are estimated to be significant in the S-3 Site, SL 1/OLF, BYBY, Creekside Debris Burial area, and Bear Creek Road Debris Burial area.

Reduction in production of terrestrial plant communities resulting from toxicity. The plant communities in the BYBY area near HCDA are probably adversely affected by metals in shallow groundwater if they are exposed by root uptake. Soils at isolated locations along two Floodplain transects in Upper Bear Creek (transects TS3 and TS4, Fig. ES.1)) appear to pose a significant risk to plants.

Reduction in abundance or production of terrestrial wildlife populations resulting from toxicity. Risks to wide-ranging species were evaluated for the BCV as a whole. Risks to small mammals, which have more limited spatial requirements, were evaluated within the source areas and for BCV as a whole. Among the wide-ranging species, only fox were estimated to be significantly at risk of a 20% reduction in population production; this risk results from soil contamination by: antimony at BYBY; mercury at S-3 Site, BYBY, OLF, and Floodplain transect TS1; and PCBs in BCBG and Floodplain transects TS4 and TS10. Shrews are estimated to be significantly at risk of a 20% reduction in population production from high soil concentrations of metals at S-3 Site, BYBY, and OLF and PCBs at BCBG. Shrews are also estimated to be at risk from elevated chromium and PCBs in Floodplain soils in transects west of BCK 9.47. There were no risks to shrew, mouse, deer, hawk, and fox from uptake of radionuclides.

Reduction in abundance or production of piscivorous wildlife populations resulting from toxicity. Because piscivorous wildlife are highly mobile, risks to piscivores were evaluated for the BCV as a whole. Kingfishers inhabiting the watershed were estimated to be significantly at risk of a 20% reduction in population production because of mercury in fish.

ES.6.3 Conclusions about Potential Risk

At nearly all locations in BCV east of the IP, potential cumulative pathway risks posed to future residents exceed 10^{-4} and/or HIs exceed 1 via potential exposure to contaminants in waste, soil, groundwater, or surface water (Fig. ES.7). Cumulative pathway potential risks posed to future industrial workers or unprotected maintenance workers vary between 10^{-6} and 10^{-1} via exposure to buried waste and contaminated soil at hot spots (Fig. ES.8). Contamination both at the waste areas and in the floodplain poses risks to wide ranging predatory animals, fish-eating wildlife, small mammals, soil invertebrates, and plant communities (Fig. ES.9). Contaminants in surface water upstream of BCK 9.47 and in sediments in NT-2, NT-6, and reach 4 of Bear Creek pose risks to benthic invertebrates (Fig ES.9). In addition, ARARs are exceeded in groundwater at many locations east of the IP.

At the IP, potential human health risks posed from use of groundwater or surface water exceed 10^{-6} or an HI>1. The COCs at the IP are uranium, nitrate, boron, and fluoride. In addition, ARARs for nitrate, uranium, and VOCs are most likely exceeded in groundwater.

In the portion of the valley west of the IP, environmental media are contaminated as a result of releases from the waste areas east of the IP, but contamination is slight and poses relatively little risk (Figs. ES.7 to ES.8). West of the IP, the most prevalent contaminants in groundwater and surface water are chloride, fluoride, nitrate, boron, strontium, and uranium, but contamination does not exceed ARARs. For a potential future residential receptor, four COCs (As, Cr, Mn, and PCB-1254) were identified in sediments from Bear Creek at two locations, and one COC (PCB-1254) in soils at one location in the Bear Creek floodplain.

ES.7 REMEDIAL GOAL OPTIONS

Media- and chemical-specific RGOs have been developed for each chemical of concern in BCV. RGOs are target cleanup goals to be used in identifying effective remedial technologies. They are not proposed final cleanup levels. RGOs were calculated for the following three criteria:

- Chemicals of concern identified in the baseline human health risk assessment. For these chemicals of concern, RGOs were calculated to be protective of human health at target risk levels of 10^{-4} , 10^{-5} , and 10^{-6} and target HIs of 0.1, 1, and 3.
- Chemicals of concern identified in the baseline ecological risk assessment. For these chemicals of concern, RGOs represent benchmarks, probable effects levels, ambient water quality criteria, and naturally occurring background levels.
- Chemicals of concern identified as chemicals that exceed ARARs. For these COCs, RGOs represent the ARAR.

In addition, results of fate and transport modeling were used to identify chemicals that are likely to exceed ARARS or preliminary remediation goals as a result of leaching from soils to groundwater

or transport to surface water in the future. These chemicals are also considered chemicals of concern, and the RGOs for these chemicals are considered the maximum contaminant level or preliminary remediation goal in the receptor medium.

The ability to meet RGOs for primary risk drivers will be evaluated in the FS. Based on the results of the baseline risk assessments, primary risk drivers include uranium, nitrate, and VOCs in the upper third section of BCV.

ES.8 TECHNICAL CONSIDERATIONS FOR REMEDIAL ACTIONS

Contamination in groundwater and surface water at, and west of, the IP is derived from migration away from the source sites. A remedial strategy with the goal of reducing contaminant fluxes at the IP to acceptable levels will have two general options: (1) take actions at the IP to mitigate exposures downstream, or (2) take actions upstream and east of the IP that will result in achieving the remedial goals at the IP.

Actions taken at the IP would be groundwater and surface water capture/treatment type actions. Actions taken upstream of the IP would involve interception of contaminant pathways to tributaries (i.e., actions taken closer to the sources) that would result in remediation of nitrate and uranium in contaminated surface water in Bear Creek and groundwater in the Maynardville Limestone. These actions may also be groundwater and surface water treatment actions taken closer to the sources, but could also include source isolation/treatment/removal to mitigate three pathways. In addition, a plume of VOC-contaminated water in the Maynardville Limestone that has no apparent source would also need to be addressed.

The following physical, chemical, and hydrological parameters will need to be addressed to achieve the remedial action objectives for BCV.

ES.8.1 Considerations for Remedial Actions for Groundwater and Surface Water at the Sources

- Large volumes of contaminated groundwater exist in the Nolichucky Shale at the contaminant sources ($7.1 \times 10^6 \text{ m}^3$ at the S-3 Site, $0.4 \times 10^6 \text{ m}^3$ at BYBY, and $4.0 \times 10^6 \text{ m}^3$ at BCBG). Due to the fractured nature of the Nolichucky Shale, < 10% of this contaminated volume occurs in fractures that are accessible for withdrawal of water. More than 90% of this volume occurs in the very low permeability matrix and contains the highest concentrations of contaminants. The mechanism for migration of contaminants from the matrix to flowing fractures is by chemical diffusion and is termed matrix diffusion. The result of matrix diffusion is that, if pump and treat technology is used to remediate a plume in fractured bedrock, many times the contaminated volume of water will require pumping before acceptable concentrations can be achieved.
- DNAPL occurs at two locations in the Nolichucky Shale, the S-3 Site and BCBG (Fig. ES.5). The nature of migration of DNAPL in the subsurface means that small droplets of residual DNAPL exist rather than large and identifiable pools of liquids. Thus, identification and extraction of DNAPL is not possible. Dissolution of DNAPL at these sites will, therefore, act as a dispersed source of contamination to groundwater.

- Some of the solid waste at BYBY, BCBG, and most likely at the S-3 Site is inundated by shallow groundwater and will be a continuing source for groundwater contamination unless it is hydraulically isolated from groundwater.
- Contaminated shallow and deep groundwater in the Nolichucky Shale migrates rapidly through discrete fractures or preferential pathways along geological strike to discharge to tributaries or directly to Bear Creek. Most of the groundwater flux most likely flows through a few discrete fracture zones; however, the specific locations and depths of these fracture zones are not known at this time and may be difficult to ascertain.
- Flow in shallow groundwater and tributaries is "flashy." For example, flow in NT-3 varies from extremes of 0 L/s to over 150 L/s (2400 gpm). Average baseflow in NT-3 varies from 0 L/s in summer to almost 10 L/s (160 gpm) during winter months.

ES.8.2 Considerations for Remedial Actions for Groundwater and Surface Water in the Maynardville Limestone

- Water flows through a network of interconnected cavities and fractures up to 150 m (500 ft) deep in the Maynardville Limestone. Most of the groundwater flux most likely flows through a few discrete cavities, however, the flux through these cavities and the specific locations and depths of these cavities are not known at this time and may be difficult to ascertain.
- The total flux of groundwater flow at the IP was calculated as 54,000 m³ during the 10-month monitoring period for the RI (~65,000 m³/a or 52.5 acre ft/a).
- Flow in Bear Creek at BCK 9.47 is flashy and varies from extremes of < 1 L/s (~16 gpm) to over 10,000 L/s (16,000 gpm). Average baseflow varies from < 1 L/s in summer to 100 L/s (1,600 gpm) during winter months. Flow in SS-5 is more steady than in Bear Creek and varies from extremes of < 3 L/s (~48 gpm) to over 100 L/s (1600 gpm). Average baseflow varies from < 3 L/s in summer to 10 L/s (160 gpm) during winter months.
- Concentrations of contaminants in BCK 9.47 and SS-5 are relatively dilute. For example, at BCK 9.47, uranium ranges from 52 to 152 µg/L and nitrate ranges from < 1 mg/L to 46.2 mg/L.

ES.8.3 Considerations for Remedial Actions for Soils at Sources

- Large volumes of buried waste materials exist at the BCBG, some of which are potentially pyrophoric or explosive. In addition, large volumes of waste materials and contaminated fill exist at BYBY, SL 1, and the S-3 Site.
- At some locations in BCBG and BYBY, and probably at the S-3 Site, waste materials are inundated by shallow groundwater.
- At some locations in BYBY and BCBG, waste materials occur at the surface of the soil. These locations constitute the most likely areas where direct exposure to waste could occur with unrestricted use.
- Many of the source areas are covered with RCRA caps that limit the possibility of direct exposure to waste materials under the current land use.

ES.8.4 Consideration for Remedial Actions for Soils/Sediments in the Bear Creek Floodplain

- The sampling strategy for floodplain soils and sediments was, by intention, biased towards likely sediment accumulation areas. The relatively small number of samples for the area of land that constitutes the Bear Creek floodplain means that volumes of contaminated soils are not well defined. The data indicate that contaminant concentrations are low and soil volumes are small (most likely < 1000 m³).

ES.8.5 Relative Importance of Pathways

For actions taken close to the sources, the relative importance of the pathways with regard to the contaminant mass flux is a consideration for which remedial actions will be most effective from a watershed perspective. The following parameters, therefore, also need to be considered:

- Figure ES.3 shows the potential human health risk/hazard from surface water and groundwater at the IP posed by exposure to the individual COCs. Figure ES.3 also lists the relative proportions of the flux of the two principal COCs, nitrate and uranium, derived from sources in BCV. Based on this ranking of source contributions to the total potential risk/hazard at the IP (refer to Sect. 3.2.7 and Appendix E), most of the potential risk/hazard is from uranium migrating from BYBY and the S-3 Site. In addition, most of ungauged flux is most likely from BYBY and the S-3 Site, further increasing the proportion of uranium flux derived from these sites. Nitrate is the second most important COC at the IP and is 94% derived from the S-3 Site.
- Reduction of the contaminant mass flux through shallow groundwater and/or surface water discharge in tributaries at BYBY and S-3 Site will reduce the overall mass flux of uranium and nitrate at the IP and achieve a reduction of potential risks and hazards at this location. For example, a reduction of 70% in the uranium flux from NT-3 and a similar reduction in the ungauged flux derived from this site (assumed to be 70% of the total ungauged flux) would result in a 43% reduction in the total uranium flux at the IP. A reduction of 70% in the contaminant flux from S-3 Site (NT-1 and NT-2) and a similar reduction in the ungauged flux derived from this site (assumed to be 30% of the total ungauged flux) would result in an 18% reduction in the total uranium flux at the IP, and a 66% reduction in the total nitrate flux.
- COCs for ecological receptors in Bear Creek are mainly metals in reaches 1 and 2 that are derived from discharge in NT-1, -2, and -3 (with the exception of mercury for which no sources have been defined in BCV). It can be expected that actions taken to reduce the contaminant flux in any of these pathways will result in a reduction of ecological impacts in Bear Creek east of the IP and reduce impacts to piscivores in all of BCV.

ES.9 DOCUMENT LAYOUT

The BCV RI Report is contained in six volumes. Volume 1, the RI Report, summarizes the extensive data analysis and interpretation that have been completed for the RI. The eight chapters of the Report address (1) the strategy used to satisfy the regulatory requirements in BCV; (2) physical and hydrogeological properties of BCV; (3) results of environmental investigations conducted to determine the nature, extent, fate, and transportation of contamination; (4) ARARs; (5) results of baseline human health risk assessment; (6) results of baseline ecological risk assessment; (7) RGOs derived from the RI; and (8) conclusions.

The RI Report is supported by seven appendices (A through G), contained in five volumes, that provide detailed analysis and discussion corroborating the information provided and conclusions reached in Volume 1. Volume 2 contains three appendices addressing (A) the operational histories of BCV waste sites and detailed analysis of inventory records of the BCBG; (B) the historical database for BCV and a detailed description of the field activities conducted during 1994 and 1995; and (C) the valley-wide hydrogeological conceptual model for BCV. Volumes 3 through 6, each containing one appendix, address (D) nature and extent of contamination in BCV; (E) fate and transport of contaminants in BCV; (F) baseline human health risk assessment; and (G) baseline ecological risk assessment.

APPENDIX E

VALLEY-WIDE FATE AND TRANSPORT

E.1 INTRODUCTION

This appendix uses information from previous sections to address contaminant releases and migration pathways from a valley-wide perspective and provide estimates of changes in contaminant fluxes in BCV. The valley-wide perspective provides a framework for comparing current and future contaminant releases in the valley.

One of the primary goals for performing a valley-wide Remedial Investigation/Feasibility Study (RI/FS) is to provide decision-makers with the ability to make remediation decisions that make sense on an individual waste source in terms of the larger, valley-wide scale. Combined, these decisions will achieve Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) clean-up goals for the valley in the most cost-effective manner. Questions that need to be answered to meet this goal include:

- Where are the sources of contamination in the valley?
- Which sources in the valley are currently contributing the most to surface water and groundwater releases?
- Which source releases are likely to contribute the most to surface water and groundwater releases in the future?
- What sources have similar waste and hydrogeologic characteristics, and thus could be addressed with similar response actions?

A second important goal of the valley-wide RI/FS is to develop a single set of clean-up goals for actions in the valley. This section will begin to identify reasonable clean-up actions where the goal of those actions is to protect environmental media at various downgradient locations.

This Appendix is organized to address (1) the conceptual basis for quantitative contaminant transport estimates; (2) the current valley-wide contaminant releases; and (3) the potential future contaminant releases. The layout of the Appendix is:

- Sect. E.2 - Valley-Wide Conceptual Hydrogeologic and Contaminant Transport Model
- Sect. E.3 - Current Valley-Wide Conditions: Identification and prioritization of current releases
- Sect. E.4 - Potential Future Valley-Wide Conditions: Modeling and prioritization of potential future release conditions
- Sect. E.5 - Summary and Conclusions

E.2 VALLEY-WIDE CONCEPTUAL CONTAMINANT TRANSPORT MODEL

This section presents the large scale understanding of contaminant transport in Bear Creek Valley (BCV). This “understanding” is the “conceptual model” used as the basis for quantifying contaminant transport from waste sources to downgradient receptors. It is intended that no new data will be presented in this section. Information presented in Appendix C, “Characterization of Hydrogeologic Setting,” the conceptual models for each of the Bear Creek Valley functional areas (FAs) (Appendix D, Sects. D.6 through D.9) and the valley-wide conceptual model are summarized to emphasize the technical basis for developing the models presented here. The valley-wide conceptual model includes the following components:

- Characteristics of waste sources
 - contaminant characteristics
 - hydrogeologic characteristics
- Contaminant fate and transport pathways

E.2.1 WASTE SOURCE CHARACTERIZATION

BCV waste units are shown in Fig. E.1 and have been described in detail in Appendix A. This figure delineates each source in relation to the subwatershed(s) it falls within, which is defined by the stream basins on Pine Ridge. Some of the sources lie within one subwatershed [e.g., S-3 Ponds Site, Boneyard/Burnyard (BYBY)], and others lie within two watersheds [e.g., Oil Landfarm (OLF), BG-A North, etc.]. Portions of three sources, BYBY, Sanitary Landfill 1 (SL 1) and BG-A South, also drain directly to Bear Creek. No primary waste sources fall within the North Tributary (NT)-2 and NT-5 subwatersheds. Exit points for each subwatershed [e.g., Bear Creek Kilometer (BCK) 12.36, NT-2, NT-3, etc.] were gaged during the 10-month BCV Operable Unit (OU) 4 RI field activities (RIFA) study period (Appendix B, Sect. B.4).

In BCV, a small portion of flow in each tributary may be derived from neighboring subwatersheds due to groundwater flow along strike in the formations that constitute the aquitard. This water volume is proportionately small but is significant where the underflow is contaminated. The only documented example of this is nitrate that originates at the S-3 Ponds Site (NT-1 subwatershed), has migrated along strike in the Nolichucky Shale, and discharges in the NT-2 subwatershed. With the exception of this, contaminant discharges at the gaged points of each tributary appear to have originated at sources within the subwatershed.

There are two primary characteristics of the waste sources in BCV that influence the distribution of contaminant releases: (1) the chemical/physical (liquid or solid) form of the wastes that were disposed in the unit, and (2) the hydrogeologic characteristics of the source.

E.2.1.1 Waste Characteristics

Table E.1 summarizes what is known about the contaminant makeup of the major sources in BCV. This table lists the primary waste units and the contaminant characteristics of waste units based on three different lines of evidence: inventory records, soil sampling results, and characteristics of shallow groundwater in the immediate vicinity of the waste unit. In most cases only one or two types

of evidence were available for determining the waste characteristics. As can be seen by the information in Table E.1, separate lines of evidence may suggest a slightly different definition of the nature of the source term. The difference in what is seen in inventory records and shallow groundwater results reflects three possible effects: (1) lack of complete record of the amount and type of organic wastes placed in the waste units; (2) plumes from one unit that have migrated underneath a second unit, as appears to be the case with the SL 1; and (3) waste that was composed of mobile and immobile contaminants where the mobile contaminants have almost completely migrated away from the source.

Figure E.2 provides a spacial understanding of the distribution of uranium in the waste units throughout the valley. Uranium wastes are distributed throughout the valley with each waste unit probably containing some uranium or uranium-contaminated material. Volatile organic compounds (VOCs) are also present in each waste unit. Larger quantities of volatile organics were known to have been disposed of in the Bear Creek Burial Grounds (BCBG) area than in the other source areas.

The form of the waste material plays an important role in determining the fate and transport of the contaminants away from the waste sites. Both solid and liquid wastes have been disposed of in the BCW. In general, where waste materials were in a liquid form, much of the contaminant mass exited the waste sources soon after their disposal and are now present as secondary contamination in groundwater. In situations where these liquids were denser than ambient groundwater [e.g., dense non-aqueous phase liquid (DNAPL) in the BCBG], the liquids migrated downwards and are currently in the shallow and deep intervals of the Nolichucky Shale acting as a secondary source. DNAPL occurs in bedrock at the BCBG and may be present at the S-3 Site and BYBY. In addition, large volumes of high total dissolved solids nitric acid solution (containing uranium and with a density ~20% greater than ambient groundwater) were disposed of at the S-3 Site. This solution also acted as a dense liquid and migrated downward into the bedrock groundwater intervals. This liquid is currently acting as a secondary contaminant source.

Although both the DNAPL and nitric acid wastes are dense liquids and so have the same driving force for emplacement in groundwater, the mechanisms for contaminant release are different. Non-aqueous phase liquids are retained in fracture by capillary action and acts as a continuous source by dissolution. Conversely, there is no retention force acting on the nitric acid solution, which acts as a source by dilution. In the case of DNAPL, the source remains in place until all the DNAPL is dissolved. The nitric acid solutions are considered a source simply because the low rate of groundwater movement in the Nolichucky Shale has left the waste solutions directly below the S-3 Site virtually undiluted.

As discussed in Appendix D, the depth that these dense liquids have attained in the Nolichucky Shale is uncertain. At the S-3 Site, the maximum depth of groundwater contamination appears to be bound by well GW-125 at 152 m (550 ft) (Vol. 1, Fig. 3.21). At BCBG, the maximum depth of DNAPL migration is not known, however, this depth is probably defined by the maximum depth for groundwater movement where fracture apertures become too small to allow circulation of groundwater. The depth is probably between 150 and 180 m (500 to 600 ft) based on the conceptual model of Dreier and Davidson (1994, Vol. 3, Fig D.102).

Solid wastes were disposed of in the BCBG (mainly solid forms of uranium in many of the BCBG). Where waste materials are present in a solid form, the exit pathway from the waste unit to surrounding media is by leaching from the waste materials by groundwater or infiltrating rainwater. In this situation, where there is no density contrast between the contaminated liquid (leachate) and ambient groundwater, contamination remains in the shallow groundwater intervals and exits the source area via discharge to surface water.

E.2.1.2 Hydrogeologic Characteristics of Sources

How water interacts with buried waste is an important component to understanding how contaminants mobilize in the sources and is an important input to decisions for source remediation. Figure E.3 identifies several hydrogeologic categories that show the different types of interactions between sources and shallow groundwater. The hydrogeologic category is important for identifying the sources that are likely to be actively releasing contaminants to surrounding media. The important parameters are:

- whether waste and subsurface water are in contact with each other enough to result in equilibrium waste-to-water partitioning conditions;
- waste characteristics, such as moisture content of the waste; and
- the mechanisms by which rainwater and groundwater contact the waste, which is critical for determining whether passive hydrogeologic isolation is a viable remedial alternative.

Table E.2 summarizes the probable hydrogeologic conditions for each of the major waste units in BCV. A brief discussion of the hydrogeologic characteristics of each unit is presented in the Appendix D descriptions of the source unit FAs. The best type of data for determining whether a connection exists between a waste trench and the water table is trench piezometer water levels. No such data were available for the BCV waste units. Thus, current understanding of this characteristic has been developed using the following lines of evidence: (1) surface topography; (2) trench depths from inventory and construction records; (3) water levels from nearby wells; (4) historical photographs (Plates A.8, A.9, and A.10 in Appendix A); and (5) shallow groundwater table maps developed as part of the Resource Conservation and Recovery Act (RCRA) monitoring program (Figs. C.13 and C.15 in Appendix C).

Figure E.4 shows the various waste areas in BCV in relation to the geologic formations and topography. In general, the water table is closer to the surface at the lower elevations in the valley, therefore, sources closer to Bear Creek and the floodplain are more likely to be inundated a greater part of the year. One known exception to this is the BG-C West/BG-D West area, where the trenches are located in a low lying area at the source of NT-8 and water is near ground surface much of the year (Fig. D.84 in Appendix D).

E.2.1.3 Summary of Waste Source Characteristics

Based on review of all types of data, the following conclusions were made about the contaminant sources in the valley:

- Large volumes of uranium were buried in BCV. The total uranium inventory is estimated to be >15 million Kg, or ~16,800 tons. This estimate does not include the uranium that was disposed in the S-3 Ponds and is currently in the groundwater below the site. Uranium is the major contaminant of every waste unit in the valley.
- Organics, mainly VOCs, were placed in portions of the S-3 and BYBY Sites; in large quantities in BG-A South and -A North; and, to a lesser extent, in BG-D and -E East. The extent to which volatiles in BCBG are non-aqueous phase versus dissolved is not clear; however, it is known that DNAPL has moved from the sources and is present in the bedrock of Nolichucky Shale.

- The most prevalent volatiles in the valley are tetrachloroethene (PCE), trichloroethene (TCE), and 1,2-dichloroethene (DCE). TCE and PCE were both part of the waste stream from the Oak Ridge Y-12 Plant, and 1,2-DCE is a breakdown product of both these chemicals. Volatiles have been detected in media surrounding most of the sources; however, it appears that the largest mass was placed in BG-A South and BG-A North.
- The nitric acid waste water, which was piped to the S-3 Ponds, is no longer considered a major source contaminant; however, past releases from the Ponds have resulted in a secondary source: the neutralized waste water in the shallow to deep intervals of the Nolichucky Shale. This source contains nitrate, uranium, and ⁹⁹Tc as the main contaminants, also with various metals and VOCs.
- Several additional chemicals complete the contaminant footprint for the valley: lithium is a byproduct of the Y-12 Plant process and has been detected in the S-3 Ponds and BYBY and is in the sources feeding NT-8; boron was used extensively in operations at Y-12 Plant and is present in elevated concentrations throughout the valley; and mercury occurs in groundwater and surface water at most of the waste units in low concentrations but above background values.
- Waste units closer to Bear Creek are more likely to be perennially inundated with groundwater, with the exception of BG-C East/BG-D East. BG-C East and BG-D East are in a low spot and are likely to be actively releasing contaminants throughout the year.

E.2.2 CONTAMINANT FATE AND TRANSPORT

E.2.2.1 BCV Hydrogeological Conceptual Model

E.2.2.1.1 Geology

The hydrogeologic system in BCV is governed by the valley's geology: a lithology that is predominantly shale and limestone; a geologic structure characterized by tilted stratigraphy, faults, and fractures; and a geomorphology of parallel ridges and valleys. Listed below are the key geologic features that affect transmission of fluids in BCV. These points are elaborated in the ensuing discussion and presented in detail in Hatcher et al. (1992), Solomon et al. (1992), and Appendix C.

The geology of BCV displays an inclined layer-cake-style stratigraphy that is observed on a variety of scales: on a regional scale where limestone- and dolomite-dominated rock groups are interbedded with predominantly clastic shale groups, and on the scale of outcrops where clastic beds are interlayered with carbonate beds (Fig. E.5). This layered structure results in anisotropy of permeability and hydraulic conductivity that, especially in the predominantly clastic formations, exerts a strong influence on flow directions. In general the rock units can be grouped into those that are clastic and generally have low permeability, and those that are mainly carbonates and are generally more permeable (Solomon et al. 1992).

Overlying the bedrock on the ORR is unconsolidated material that consists of weathered bedrock (referred to as residuum), man-made fill, alluvium, and colluvium. Residuum comprises a majority of the unconsolidated material in this area. The depths to unweathered bedrock differ throughout BCV because of the different thicknesses of fill and alluvium and the particular

weathering characteristics of the bedrock units. The total thickness of these materials typically ranges from 3 to 15 m (10 to 50 ft) (Hoos and Bailey 1986).

The primary permeability of the rocks underlying BCV is very low. However, diagenesis, fracturing, and solution weathering of bedrock have resulted in secondary porosity and increased permeability through which most fluid movement occurs (Solomon et al. 1992; Shevenell 1994; Goldstrand, Menefee, and Dreier 1995). The formations are extensively fractured and, in the case of carbonate formations, extensively karstified, thereby enhancing their permeability. It is only in the Knox Group and the Maynardville Limestone that cavity systems are highly developed and extensive; however, many of the smaller limestone or dolomite beds within the predominantly clastic formations exhibit solution openings and cavities at shallow depth.

The orientations of well-connected fractures or solution conduits are predominantly parallel to geological strike and enhance the effect of anisotropy caused by layering. This results in dominance of strike-parallel groundwater flow paths. Fracture aperture width generally decreases with depth in all formations and thus restricts the depth of active groundwater circulation hydrology. Active (or open) fractures occur at greater depths in the Knox Group and the Maynardville Limestone than in the siliceous members of the Conasauga Group, and active groundwater circulation is deeper in these formations.

E.2.2.1.2 Hydrology

The hydraulic component of the hydrogeological conceptual model for BCV is presented here as the hypothesis that best describes the main observations of hydraulic parameters in BCV. Figures E.6 and E.7 depict the hydrologic conceptual model for BCV.

One of the main points raised by the conceptual model is that although the largest mass of water (and consequently the largest mass of contaminants) exits BCV via surface water, groundwater is the principal pathway for contaminants leaving the waste units. The main flow and contaminant transport pathways in groundwater at the waste units are along strike with the discharge points at tributaries to Bear Creek. For the 10-month monitoring period of BCV RI field activities, it is estimated that 97% of water available for flow (precipitation - evapotranspiration) exited the upper section of the valley [above Bear Creek Kilometer (BCK) 9.47] as surface water flow (Volume 1, Fig. 2.6). In addition, of water available for flow in the predominantly clastic formations outcropping on Pine Ridge, 94% exited these formations via surface water in tributaries, and 6% via subsurface flow. Fluxes in flow paths at the waste units (overland flow, soil interflow, and groundwater flow) have not been quantified; however, hydraulic monitoring data show that overland flow and soil interflow are only important during storm events, and recharge followed by groundwater flow to tributaries constitutes the main water flux pathway.

Hydrogeology differs significantly between mainly clastic formations (such as the Nolichucky Shale) and mainly carbonate formations (such as the Maynardville Limestone), to the extent that they can almost be treated as separate hydraulic entities. In BCV, the contact between the Maynardville Limestone and the Nolichucky Shale roughly corresponds to the axis of the valley and marks a major transition from predominantly clastic formations in the Conasauga Group to carbonate dominated formations in the overlying Knox Group.

Groundwater movement in the predominantly clastic formations is mainly by way of fracture flow (Solomon et al. 1992; Moline and Schreiber 1995) and more than 95% of flow occurs through the shallow intervals of the formations, principally in the water table interval at the bedrock-residuum interface. In this interval of the groundwater regime, flow rates can be very rapid (up to 40 m/d;

Sanford and Solomon 1995; McKay et al. 1995) and may be even greater during transient storm events. The transient response of surface water streams to precipitation shows that both interflow through soils and groundwater flow through the water table interval are probably major components of the total flow during storm events.

Groundwater movement in the carbonate dominant formations has components of both fracture flow and flow through solution-enlarged cavities and conduits (Shevenell 1994). Although most flow in the carbonate dominant formations probably occurs in the shallow intervals [< 30 m (100 ft) depth], a component of groundwater flow occurs in deeper intervals [> 30 m (100 ft) depth] (Solomon et al. 1992). The shallowest intervals of the Maynardville Limestone in BCV are dominated by a maze-like system of interconnected cavities and solution-enlarged fracture. Bear Creek can be considered as one of the primary conduits for flow in this cavity system.

The dynamic nature of the hydrology of BCV is extremely important, both for clastic- and carbonate-dominated formations. The nature, rate, and direction of groundwater flow are transient and vary based on the climatological conditions. Variations occur on different scales: an annual cyclic variation resulting from seasonal climate changes and short-term variation resulting from the response to individual storm events. Piezometric head in groundwater wells and baseflow in streams relate both to the amount of precipitation and the rate of evapotranspiration. In general, flow in streams as well as groundwater elevations peak during late winter and early spring because annual precipitation is greatest during this time period and moisture demand from plants is at a minimum. Conversely, during the summer and fall, precipitation is usually relatively low and evapotranspiration is high. During this time, flow in most tributaries to Bear Creek ceases and groundwater elevations fall to a minimum.

Additional hydraulic components of the hydrogeological conceptual model are as follows:

Flow in Predominantly Clastic Formations

- Although there are no clearly defined abrupt hydrogeologic changes in the clastic formations with depth, a general hydrogeologic stratigraphy can be defined that separates these formations into shallow, intermediate, and deep flow regimes (Solomon et al. 1992). The boundary between shallow and intermediate intervals is defined by a consistent change in groundwater geochemistry at ~ 30 m (100 ft) depth that indicates flow is considerably slower below this depth (Haase 1991; Dreier, Early, and King 1993). The boundary between intermediate and deep intervals is poorly defined and is indicated by a change in groundwater geochemistry that has been observed between ~ 100 and 150 m (328 and 492 ft) depth (Solomon et al. 1992; Haase 1991; Dreier, Early, and King 1993). The deep interval probably relates to the base of effective flow in the siliceous formations.
- Most flow in siliceous formations occurs in the shallow interval. This interval includes the water table interval that usually occurs close to the bedrock/residuum interface. Most flow in the shallow interval is probably through high conductivity zones that may exist at the bedrock/residuum interface (Soloman et al. 1992) or through other preferential flow pathways in the bedrock. Flow in the shallow interval is oriented predominantly along geological strike, with discharge occurring at the tributaries to Bear Creek.
- Geochemistry indicates that greater groundwater residence times and, thus, slower flow generally occur below 30 m (100 ft) in the intermediate interval (Sect. C.4.2). However, the distribution of contaminant plumes in BCV indicates that more rapid flow than predicted by major ion geochemistry may occur in an along-strike direction along preferential pathways in

this interval up to 200 ft depth [nitrate from the S-3 Site has migrated ~1 km (0.62 mi) or more since 1950, refer to Appendix D].

- An upward hydraulic gradient occurs almost everywhere in the bedrock of the siliceous dominant formations that crop out on the southern flank of Pine Ridge. This upward hydraulic gradient is a function of the anisotropy of the geological formations and the average 45° dip of the beds. Transmissivity along bedding planes may be orders of magnitude greater than that across bedding planes. Groundwater in deep formations is hydraulically connected along the bedding planes to recharge areas located up dip at higher elevations on Pine Ridge. As a result deeper formations tend to have recharge zones further up-slope than shallow formations; therefore, the hydraulic head in successively deeper formations increases.
- During rainfall events, the hydrological system in the siliceous dominant formations responds in changing ways to the influx of water (Volume 1, Fig. 2.7):
 - The shallow portions of the soil profile become saturated, transmitting water laterally downslope to springs and seeps in the banks of streams as interflow.
 - Fractures in the residuum also become saturated, transmitting water rapidly to the shallow groundwater table. As a result, the elevation of the water table rises rapidly during rainfall events.
 - The elevated water table increases the rate of groundwater flow in the water table interval and, subsequently, groundwater discharge to streams increases.
 - During the heaviest precipitation events, flow in streams increases very rapidly as overland flow enters the stream channels.
 - After precipitation has ceased, flow in streams reflects the rate of drainage from three reservoirs of water: overland flow, soil interflow, and groundwater flow. These components of the hydrologic system drain at varying rates: overland flow is the most rapid, stormflow is intermediate, and groundwater discharge declines at the slowest rate and reaches near pre-precipitation levels within a few days.
- Although flow through the porous matrix constitutes a minor component of flow volume through all formations, it probably plays an important role in contaminant migration because matrix diffusion will significantly slow down transport rates.

Flow in Carbonate Dominant Formations

- The Maynardville Limestone crops out along the southern side of the BCV floor. This formation and Copper Ridge Dolomite act as a hydraulic drain for the valley. Flow in these formations is predominantly along strike and parallel to the maximum hydraulic gradient.
- The hydrostratigraphy in the carbonate formations is less well defined than that in the siliceous formations (Solomon et al. 1992). The definitions of shallow, intermediate, and deep regimes are not rigid and rely on cumulative evidence from cavity occurrence (Shevenell, Dreier, and Jago 1992; Shevenell and Beauchamp 1994), hydraulic and geochemical responses during storms (Shevenell 1994; Sect. C.6.2.3 in Supporting Information for Appendix C), and the distribution of contaminant plumes (Appendix D).
- The shallow interval includes groundwater to ~30 m (100 ft) depth. Flow in this interval occurs through a maze of interconnected fractures and solution conduits and cavities (Sect. C.3.3) and is closely associated with flow in Bear Creek (Sect C.4.5). The channel of Bear Creek can be considered conceptually as one of the main hydraulic conduits in this conduit system. In this interval, groundwater flow is relatively rapid and, during storm events, recharge to this interval

occurs as a quickflow. Contaminants are easily flushed through this interval, and dilution effects that arise from rainfall/recharge and quickflow mean that contaminant concentrations attenuate rapidly along strike.

- The intermediate interval occurs between ~30 m and 100 m (100 and 328 ft) depth. Solution cavities and solutionally enlarged fractures exist in the Maynardville Limestone in this interval that are probably well interconnected. Because of its depth, this zone is isolated from dilution effects seen in shallower zones. Thus flow rates in this interval are slower than those in the shallow interval but contaminant plumes persist further along the valley. This zone constitutes an important contaminant transport pathway.
- In the deep interval [>100 m (328 ft) depth] flow through fractures dominates groundwater movement and, as fracture density decreases with depth, flow zones become less frequent.

Figure E.8 shows the modeled “stair-step” progression of a nonreactive modeled tracer as it migrates from the waste units in the aquitard formations to Bear Creek and the Maynardville Limestone (DOE 1996, in preparation). The groundwater model predicts that in shallow groundwater particles move to nearby tributaries relatively quickly; e.g., model output from the BG-A South area suggests that model particles reached NT-7 within 20 years of being deposited in the BCBG trenches. In the deep groundwater intervals, particle tracking suggests that migration pathways along strike can either cross tributary watershed boundaries and eventually discharge directly to the Maynardville Limestone, or resurface in a nearby tributary, suggesting strong upward gradients in the Nolichucky Shale.

E.2.2.2 Contaminant Migration Pathways

E.2.2.2.1 Transport in the Nolichucky Shale

Transport in the Nolichucky Shale is depicted conceptually in Fig. E.9, which shows migration away from the BYBY, into the Nolichucky Shale, and to NT-3. The main pathways shown on this figure are those in shallow groundwater that, for uranium, are derived from leaching of solid waste, and, for VOCs in the groundwater intervals, are derived from DNAPL that may have been emplaced in the bedrock below BYBY. For the shallow migration pathways, contaminant transport is especially active during storms, as indicated by the large masses of contaminants detected in gaged stations on the tributaries during high-flow periods. This is due mainly to the increased volume of flow in the shallow groundwater interval during storms. However, contaminants that have migrated to the water table move to the tributaries even during baseflow conditions, as indicated by the contaminants detected at most of the stations during dry season baseflow conditions.

As noted in the figure, some portion of contaminant releases from a waste source may migrate through the shallow Nolichucky Shale directly to Bear Creek and the Maynardville Limestone without first resurfacing in the nearby tributary. This portion is higher for sources located closer to Bear Creek and is particularly important for BYBY.

Similar concepts for migration pathways apply to the other waste units in the valley. The detailed pathways for each site are described in Sect. E.4.

E.2.2.2.2 Transport in Bear Creek and Maynardville Limestone

Contamination in Bear Creek and in the Maynardville Limestone can be traced to inputs from sources at S-3, BYBY, and an unknown source close to the Rust Spoil Area (Fig. E.10). In

interpreting these data, changes in the rate of contaminant input from these sources to the Maynardville Limestone over the past 20 years should also be considered. Although BYBY has probably been a source that has remained relatively unchanged since the 1950s, the rate of contamination flux from the S-3 Site has changed dramatically since remediation of that site in the 1980s; e.g., concentrations of nitrate in Bear Creek at BCK 12.46 were in excess of 1000 mg/L in 1983 and were probably greater in previous years, whereas the maximum concentration during 1994 monitoring was 171 mg/L. Thus, it is likely that a residual plume of contamination derived from the S-3 Ponds occurs in groundwater in the Maynardville Limestone; identifying current contaminant fluxes from fluxes derived from residual contamination may be complex by this relict contamination.

The main sources of contaminant input to Bear Creek and the Maynardville Limestone from the source sites that have been identified are as follows:

- S-3 Site: nitrate and metals migrate via discharge from NT-1 and NT-2. Uranium migrates via shallow groundwater discharge to Bear Creek, and shallow groundwater discharge into the Maynardville Limestone shallow groundwater.
- BYBY: radionuclides migrate via discharge from NT-3, shallow groundwater discharge to Bear Creek, and shallow groundwater discharge into the Maynardville Limestone; shallow groundwater and VOCs migrate by shallow groundwater discharge to Bear Creek and shallow groundwater discharge into the shallow Maynardville Limestone.
- BCBG: VOCs and radionuclides via discharge from NT-7 and NT-8, and shallow groundwater discharge into the shallow Maynardville Limestone.
- Unknown site or Rust Spoil Area: VOCs by direct recharge to Maynardville Limestone.

At monitoring points downgradient of BYBY (groundwater and surface water), the plumes from the S-3 Site and BYBY source areas appear to be completely commingled. It is only possible to identify BYBY as a contributor to the inorganic and organic Maynardville Limestone contaminant plumes because of the relative concentrations of nitrate, gross α , gross β , TCE, and 1,2-DCE in groundwater and surface water between NT-1/NT-2 and NT-3. Downgradient of NT-3, a losing reach of Bear Creek and downward hydraulic gradients in the Maynardville Limestone have resulted in commingled contaminant plume to depths >30 m (100 ft) in Maynardville Limestone. The plumes, once emplaced at depth in the Maynardville Limestone, recharge to SS-4 and SS-5 and may migrate laterally down the valley (DOE 1996, in preparation).

E.2.2.2.3 Chemical/physical transport properties

The fate and transport of the site-related chemicals are functions of flow characteristics and soil/chemical interactions. Three of the main chemical/physical factors to understanding contaminant migration in BCV are:

- **Adsorption/attenuation characteristics:** The layers found within the shallow overburden material generally have sufficient organic carbon content to cause retardation of organic constituents. In addition, the clay mineralogy results in significant cation retardation of inorganic constituents by adsorption reactions. Adsorption/attenuation occurs at lower rates in the regional aquifer due to the lower organic carbon and clay content in the shale and limestone. Uranium and technetium move as anions and therefore their retardation is low.

- **Fracture flow and matrix diffusion:** This is an effect that results in a body of contaminated water contained in the matrix of the groundwater system that slowly releases contaminants into the actively flowing system in fractures. In a fractured system, contaminants migrate by advective transport along fractures and, during the period of release of contaminants from the source site, concentration gradients drive contaminants into the matrix porosity that usually has a very low conductivity (Harrison et al. 1992). After disposal activities have ceased, flushing of contaminants reduces the concentrations in fractures, and the contaminant concentration gradients reverse, allowing the matrix to slowly release contaminants to the fractures.
- **Movement of non-aqueous phase liquid:** Evidence of multiple fractures both in horizontal and vertical direction is common in the BCV site geology. The vertical set of fractures provides an effective mechanism for separating phases denser than water (DNAPL) from those lighter than water [both dissolved phases and light non-aqueous phase liquid (LNAPL)]. The DNAPL sinks through the vertical fracture set whereas the LNAPL and dissolved phases tend to move in the direction of lower hydrostatic pressure. Both processes introduce contaminants directly to the water table. DNAPLs may remain within the bedrock entrained within fractures and the matrix porosity and may pond in deeper intervals of the bedrock where the apertures and frequency of fractures are reduced to an extent where DNAPL is unable to enter the fractures. DNAPL chemicals dissolve continuously into circulating groundwater forming a secondary source.

Additional physical-chemical properties of individual contaminants play a role in contaminant migration. Such properties include solubility in water, tendency to transform or degrade (usually quantified by a half-life or an environmental half-life in a given medium), and chemical affinity for solids or organic matter (usually quantified by a partitioning coefficient K_d , K_{OC} , or K_{OW}). These properties and how they affect radioactive, inorganic, and organic contaminant behavior are summarized below.

Radionuclides

Radionuclides comprise a special case of inorganic species. Radionuclides undergo spontaneous transformations that involve the emission of particles (most important for BCV are α and β particles) and radiant energy. The resulting daughters (i.e., product nuclides) may be either radioactive themselves, in which case they too will undergo spontaneous decay, or they may be stable nuclides. The decay process can occur by various spontaneous mechanisms. Two of the more important decay modes are α decay and β decay, with the latter differentiated into negatron and positron decay.

The radionuclides present at BCV belong primarily to two decay chain series: the ^{238}U series and the ^{235}U series. Transuranic radionuclides have also been observed, though sparsely. The half-lives of most of the radionuclides of concern at these sites are long (thousands to billions of years) when compared to the age of the sites. Like inorganic and organic chemical species that do not undergo nuclear transformations, the persistence of radionuclide contaminants on BCV sites is related largely to their geochemical mobility in the environment.

The mobility of the radionuclides found at the BCV Site is dependent on the type of complex (cationic or anionic) formed. Cationic species should be adsorbed to soil, while anionic species may be mobile. In groundwater at the S-3 Site, geochemical modeling using MINTEQA2 [a geochemical assessment model for environmental systems (EPA 1991)] indicates that uranium is expected to be present mainly in the anionic uranyl carbonate species (Vol. 3, Fig. D.50). K_d -values reported in literature range over several orders of magnitude. Values for uranium reported by Sheppard and Thibault (1990) for three major soil types indicate ranges of 0.03 to 2200 L/kg, 0.2 to 4500 L/kg, 46 to 395,100 L/kg for sand, loam, and clay soil, respectively. From sorption experiments for cesium,

strontium, technetium, neptunium, and uranium using Nolichucky Shale (ORNL 1987), moderate to significant sorption was observed for all of these radionuclides except technetium. The range of K_d s, radioactive half-lives and the radioactive decay constants for the radionuclides found at the BCV Site are presented in Attachment A1.

Organics

The organic contaminants at the BCV sites include VOCs, semivolatile organic compounds (SVOCs), and polychlorinated biphenyls (PCBs) and pesticides. These contaminants have been degraded in the environment by various processes, including hydrolysis, oxidation/reduction, photolysis, or biodegradation. Half-lives of organic compounds in various media can vary from minutes to years, depending on the chemical and environmental conditions. Degradation may either enhance or reduce the toxicity of a chemical. For the organic chemical, one example of a degradation process has been biodegradation of PCE, and TCE via dechlorination to lower chlorinated compounds, such as 1,2-DCE.

The mobility of the organic compounds is affected by properties including volatility, partitioning behavior between solids and water, water solubility, and concentration. Water solubility and the tendency to adsorb to particles or organic matter can correlate with retardation in groundwater transport.

Chemicals with relatively high volatility, high water solubilities, and low adsorption coefficients (e.g., volatile organics) remain primarily as dissolved phases and have been transported in the subsurface environment close to the same rate as the groundwater flow. As soon as these chemicals move from groundwater to surface water, rapid volatilization occurs.

Chemicals with lower water solubilities and higher adsorption coefficients [polyaromatic hydrocarbons (PAHs), furans, and PCBs and pesticides] remain primarily adsorbed to the surface of the soils, and their transportation in the groundwater is almost negligible.

Inorganics

Inorganic contaminants for BCV site include nitrate, metals, and cyanide. Metals associated with the aqueous phase in soils are subject to movement with soil-water, and may be transported through the vadose zone to groundwater. Metals, unlike hazardous organics, are not naturally degraded but some metals, such as chromium or mercury, can be transformed to other oxidation states in soil, reducing their mobility and toxicity. Metals also react with soils or other solid surfaces by ion exchange, adsorption, precipitation, or complexation. Such reactions are affected by pH, oxidation-reduction conditions, and the type and amount of organic matter, clay, and hydrous oxides present. In general, these reactions are reversible and cause an element's mobility to be retarded.

Inorganic chemical form has a large impact on solubility and therefore mobility in the environment. Chemical speciation, however, is very complex and difficult to distinguish in routine laboratory analysis. In soil, metals are found in one or more of several forms within the soil, as described by Shuman (1991): (1) dissolved in soil solution; (2) occupying exchange sites on inorganic soil constituents; (3) specifically adsorbed on inorganic soil constituents; (4) associated with insoluble soil organic matter; (5) precipitated as pure or mixed solids; (6) present in the structure of the secondary minerals; and/or (7) present in the structure of the primary minerals. In situations where metals have been introduced into the environment through human activities, metals are associated with the first five forms. The dissolved/aqueous fraction and its equilibrium fraction are of primary importance when considering the migration potential of metals associated with soils. The

filtrable inorganics represent the dissolved fraction, which is the more mobile and bioavailable fraction. Of the compounds that are most likely to form, usually the chloride, nitrate, and nitrite forms are the most soluble. Sulfate, carbonate, and hydroxide forms generally have low to moderate solubility. Soluble compounds are transported in aqueous form subject to retardation whereas an insoluble compound remains as a precipitate, which limits the overall mobility of the metal.

E.2.3 SUMMARY

Figure E.10 presents the conceptual contaminant transport model for the BCBG. Based on the evidence presented in Appendix C, Appendix D, and summarized above, critical components of the contaminant migration model for the valley include:

- A large percentage of contaminants buried in the aquitard formations quickly migrates to surface water in the eight major tributaries, and then flows into Bear Creek. Of the water that infiltrates the soils or forms overland flow on the aquitard, 94% moves laterally in shallow groundwater to the tributaries and then to Bear Creek. A further 5% flows in shallow groundwater directly to bedrock and the Maynardville Limestone, and 1% flows down the valley along geological strike.
- Contaminant sources are either solid waste materials that result in shallow groundwater contamination or liquid wastes that have resulted in secondary contamination in shallow to deep bedrock groundwater.
- During storms, shallow lateral groundwater flow “quickens,” moving contaminants to the tributaries or directly to Bear Creek and the Maynardville Limestone.
- Uranium has been detected at all tributaries downgradient of source units and at all major springs in Upper Bear Creek, suggesting that contaminants move between Bear Creek and the Maynardville Limestone as it migrates down the valley.
- Although the greatest mass of uranium is located in the BCBG, the largest releases are associated with the BYBY and S-3 plumes. This is probably because of the form of uranium in the waste at the S-3 Site and BYBY. The location and hydrogeology of the site is such that the uranium waste materials are located closer to the exit pathway than at the BCBG.
- In the BCBG area, DNAPL present in the bedrock acts as a long-term source of organics to the groundwater below the waste areas. Volatiles migrate from groundwater below the trenches to NT-7 and NT-8, and then to Bear Creek. However, large quantities of these organics volatilize prior to reaching BCK 9.47.
- As exemplified best by the relationship between shallow groundwater and the top of the burial units in the BCBG, sources that are perennially inundated appear to be the main sources of releases to shallow groundwater and surface water (e.g., BG-A South, C-West).

E.3 CURRENT VALLEY-WIDE CONTAMINANT MIGRATION

This section consolidates information on existing contaminant releases from the various waste sources in BCV to better view the releases from a valley-wide perspective. This will help compare releases and determine which releases should be addressed first. The section presents a summary of contaminant releases and how they tie to the BCV waste sources, and presents a prioritization of the current releases using an Integrator Point (IP) assessment.

Several new terms are introduced in this section. A common understanding of these terms is important since the results presented may be used for near-term decision making. Table E.4 lists these terms and provides a definition for each.

E.3.1 SUMMARY OF CURRENT CONTAMINANT RELEASES

Contaminant releases from the waste units have been described in detail in Sects. D.6 through D.9 (Appendix D). Figure E.11 summarizes the distribution of two of the primary contaminants releases to Bear Creek: uranium and VOCs. Uranium is present in almost all the tributaries, with the majority of the uranium mass detected at BCK 12.36/SS-1, NT-2, and NT-3. Although this appears inconsistent with the uranium inventory distribution (Fig. E.2), which indicates that the majority of the uranium inventory in BCV is located in the BCBG, it is not inconsistent with the conceptual model for contaminant mobilization and transport (Sect. E.2). Detectable VOC concentrations in surface water occur in tributaries NT-1, NT-6, NT-7, and NT-8, and springs in the floodplain of BCV. Nitrate, a third major contaminant (but not shown on Fig. E.2), comes from a single primary source, the S-3 Site. Nitrate has been detected in BCK 12.36/NT-1, SS-1, and NT-2. No other waste area appears to be a source of nitrate. A summary of contaminants detected in the tributaries is presented in Table E.5. The sources of the contaminants can be inferred from the subwatershed delineation (Fig. E.1) and from the waste source contaminant "footprints."

Figure E.12 presents the general extent of releases of the most prevalent contaminants detected in the groundwater (TCE was chosen to serve as the indicator VOC for the valley). The primary groundwater contaminants in the valley are nitrate, uranium (represented by α results), and VOCs. Concentrations of these contaminants often exceed maximum contaminant levels (MCLs). These releases can be associated with individual sources with a fairly high degree of certainty based on plume patterns and contaminant footprints (Table E.6). One exception to this is the source of some of the VOCs detected in the intermediate and deep intervals of the Maynardville Limestone. Possible sources of this contamination may be sources in Upper East Fork Poplar Creek, or possibly past releases from the S-3 Ponds or BYBY.

Table E.7 provides a summary of the contaminants detected at either BCK 9.47/SS-5 or in one of the downgradient wells along Picket A. As indicated by the list, a small percentage of the contaminants detected in the various environmental media in upper BCV have migrated down the valley in surface water and groundwater and currently pass the IP at BCK 9.47.

E.3.2 PRIORITIZATION OF CURRENT RELEASES

One of the goals of this section is to quantitatively compare the contaminant releases and identify the relative amount each source is contributing to contaminant migration and potential

human health risk down the valley. This comparison can be used to help prioritize current releases from waste sources. Provided below is the approach used to compare contaminant releases from the various waste sources in BCV.

E.3.2.1 Approach

Over the past several years, an assessment technique has been employed at the Oak Ridge National Laboratory site that ranks various waste sources based on each source's contribution to off-site contaminant flux across the White Oak Dam. This method is referred to as an IP assessment, which is a point where contaminant releases from multiple sources converge and can be measured. At this point, releases can be compared and the relative hazard associated with each release can be evaluated. The governing equation for the IP assessment is:

where:

$$RR = \left[\frac{\sum [Risk_{i,IP} \left(\frac{Flux_{i,source} \text{ unit}}{Flux_{i,IP}} \right)]}{Risk_{total,IP}} \right] \times 100, \quad (E.1)$$

- RR = relative contribution to off-site risk associated with each source in BCV,
 Risk_{i,IP} = risk associated with chemical i at the IP (unitless),
 Flux_{i,source} = flux of the ith substance originating at the source (pCi/year; mg/year),
 Flux_{i,IP} = flux of the ith substance identified at the IP (pCi/year; mg/year),
 Risk_{total,IP} = $\sum$ Risk_{i,IP}, or the sum of the risk estimates for the ith substances identified at the IP (unitless).

The same equation can be slightly altered to evaluate the relative toxic hazard associated with each source in the valley. In using "risk" in Equation E.1, one can compare the cancer potential associated with releases from each source. By substituting "hazard index" in the equation in place of "risk," one can compare the potential for different source releases to contribute to chemical toxic effects other than cancer. The steps of the IP assessment are:

- (1) Estimate the total risk associated with all contaminants that have migrated to the IP. For BCV, this risk is estimated using exposure assumptions and toxicity information detailed in the baseline human health risk assessment (BHHRA) for residential ingestion of water (refer to Appendix F).
- (2) Estimate the risk associated with each individual contaminant detected at the IP.
- (3) Estimate the total contaminant flux (mass/time) for each contaminant detected at the IP.
- (4) Estimate the contaminant flux for each contaminant detected at a gaged monitoring station upgradient of the IP using flow and contaminant concentration data from the gaged stations on the Bear Creek tributaries. Gaged monitoring stations are those that, during the RI, were equipped with flow meters and flow proportional samples for the 10-month period from March 1994 to January 1995.
- (5) Compare the fluxes from the tributaries to the flux at the IP (e.g., Flux_{Nt-8}/Flux_{IP}) to determine contaminant-specific, source-specific weighting factors for the risk at the IP.

- 6) Apply the weighting factors to apportion the risk at the IP to the various upstream/upgradient sources (Equation E.1).

The BCV model for contaminant transport off site differs from the off-site transport model for the White Oak Creek watershed. Table E.8 compares the water balance model for BCV and the White Oak Creek watershed. As indicated on the table, subsurface flow plays a more important role in contaminant transport in BCV than it does in the White Oak Creek watershed.

The White Oak Creek IP assessment focuses on contaminant fluxes for the surface water component of the site conceptual model, which is justified since as much as 95% of the flux can be measured in surface water. However, because both Bear Creek and the Maynardville Limestone are conduits for contaminant migration down Bear Creek, an IP assessment that only accounts for gaged surface water and gaged shallow subsurface water would not reflect the ungaged groundwater component of off-site migration.

An integrator *plane* assessment has been suggested for BCV. The integrator “plane” is the plane that is represented by a subsurface cross section of the valley at the IP (Fig. E.13). At this plane, three components of the BCV water balance model are accounted for: gaged surface water (represented by BCK 9.47); gaged shallow subsurface flow (represented by SS-5); and ungaged subsurface flow. The first two components of the model account for most (~ 96%) of the water flow down the valley; however, as indicated in Sect. E.2.2, the ungaged groundwater flow path plays a larger role in the migration of some contaminants, e.g., nitrate and possibly volatiles emanating from DNAPL that have sunk to deeper groundwater.

However, because there is no available method for reliably estimating groundwater contaminant flux across the intermediate/deep groundwater portion of the integrator plane, the assessment will not include fluxes in this flow path. It is believed that the only ramification of not including this flow path in the assessment is that a portion of the current nitrate flux down the valley will not be accounted for quantitatively in the IP assessment. Off-site nitrate flux can be accounted for to some extent using mass balance estimates. This exercise places some bounds on the amount of nitrate flux that is not included in the IP assessment.

E.3.2.1.1 Flux estimates

The essential piece of the IP assessment is the ability to estimate contaminant flux from each source in BCV, and the total contaminant flux leaving the upper portion of the valley at BCK 9.47/SS-5. Contaminant flux is the movement of contaminant mass across a boundary per unit time, and thus is measured in mass per unit time. Contaminant flux is calculated by:

$$CF = C(x) \times V,$$

where:

CF = contaminant flux (pCi/year or mg/year),
 C = contaminant concentration in water (pCi/L or mg/L),
 V = water volume (L/year).

The data and methods used to calculate fluxes are summarized below.

Gaged Surface Water

The surface water component of the flow system in BCV is the largest contributor to current contaminant fluxes down the valley for two reasons: (1) ~80% of all off-site flow occurs in the surface water system, and (2) contaminants move quickly through surface water mainly during storms, unlike the slower contaminant migration that occurs in the groundwater. The surface water IP for BCV is BCK 9.47, the surface water flow and sampling point in Bear Creek just east of NT-8 (Fig. E.13).

Current surface water contaminant fluxes can be estimated with a high degree of certainty for each of the tributaries and seeps in the valley that have been instrumented with flow monitors and flow proportional samplers (Appendix B). Frequent water quality samples and corresponding flow measurements were collected at each of the eight major tributaries and several seeps for a 10-month period, April 1994 through January 1995 (BCV OU 4 RIFA, Appendix B). Samples were collected at all water stages, ranging from dry season baseflow to wet season storm conditions, in order to characterize contaminant concentrations in all flow conditions.

The contaminant concentration in surface water used in the IP assessment, "C(x)," for each gaged station is a flow-weighted average concentration. With flow weighting, concentration values are weighed in proportion to the flow volume at the time the sample was collected. Sample results collected during high-flow conditions are given more weight in estimating the overall average since water volumes leaving the site during water high-flow conditions represent a higher percentage of the total water leaving the site. After flow-composite sampling, flow-weighted averaging is considered the best method for estimating true averages when data are available for all flow conditions (Walling and Webb 1986).

Water volumes for each tributary or seep were calculated for the 10-month period from the continuous stage records from each gaged site (Appendix B). Where data were missing as a result of instrumentation failure (various reasons including loss of power, memory failure, and loss of equipment in floods), the data gaps were estimated by two different ways: (1) by entering the 4-hourly average flow from the gauge hard copy printout when there was a loss of data but not instrument loss, and (2) by estimating likely flow at a gaged site as a function of flow at a working gaged site (the 10-month database flows at each site were compared and the best linear fit was used to estimate flow between sites).

Gaged Shallow Subsurface Flow at SS-5

Off-site contaminant flux via the gaged shallow subsurface has been measured at SS-5, a major spring that feeds Bear Creek just downstream of BCK 9.47. SS-5 was assumed to represent the quality of shallow groundwater at the integrator plane. The water quality of the spring has the contaminant characteristics of the shallow nitrate/uranium plumes in the BCK 9.47 and has similar characteristics to SS-4, which is located upstream on the floodplain. Flow-weighted average concentrations were developed for SS-5 using results of samples collected throughout the 10-month period during various flow conditions (the same sample collection protocol was used for the tributary sampling). Flow at the seep was measured in the same manner as that for the stream site as described.

E.3.2.1.2 Risk estimates

As indicated in the governing equation for the IP assessment, contaminant fluxes from various sources can be compared to each other by evaluating them in terms of their contribution to total risk at the IP. This is critical since, for example, uranium fluxes cannot be directly compared to nitrate

fluxes, but the risk associated with uranium can be compared to the risk associated with nitrate. Thus, the various contaminant fluxes are converted to a common unit, e.g., risk. Once all fluxes have been described in terms of risk, it is possible to compare the relative impact of each source, regardless of the contaminants coming from the source.

Risk estimates used in the IP/integrator plane assessment are calculated using methods presented in the BHHRA (Appendix F). Risks associated with exposure to surface water have been estimated as part of the BHHRA, and details on the exposure scenarios, exposure parameters, and toxicity information are presented in Appendix F.

The sole difference in the risk values estimated for the IP assessment and the risk values estimated in the BHHRA is the value used as the concentration of the contaminant in surface water. The BHHRA uses the 95% upper confidence limit (UCL) on the average concentration, where all sample results are evenly weighted. For the IP assessment, the flow-weighted average concentration is used as the concentration in surface water. This difference is necessary since, for the IP assessment, the values used to estimate fluxes for the various chemicals at the IP must be in relative proportion to the values used to estimate risk, or the assessment results would not represent the relative risk associated with the mass of contaminant flowing across the point. The use of the flow-weighted average in the IP assessment implies that a human receptor would drink more of the high-flow water than baseflow water, which is not the exposure assumption used in the BHHRA. **Only the values presented in the BHHRA should be used as the estimate of the absolute risk value for BCK 9.47 and SS-5. The values estimated using the flow-weighted concentrations should only be used as a step in estimating the relative risk/hazard associated with contaminant fluxes across the IP in the valley.**

As with the BHHRA, cancer-causing substances and chemical toxicants must be treated separately in the IP assessment, since the hazard associated with the two primary human health endpoints cannot be compared. Some chemicals, such as uranium and PCE, are both a potential carcinogen and a chemical toxicant and must be evaluated in both the assessment of relative risk and relative toxicity. Table E.9 identifies which chemicals and radionuclides detected at the integrator point are carcinogens and which are chemical toxicants.

E.3.2.2 Results

E.3.2.2.1 Flux estimates

Table E.10 presents the data used to estimate mass fluxes for the IP assessment. The table presents the total 10-month flows for each gaged station in the valley and the flow-weighted average concentrations for the stations. As shown in Equation E.1, these are the data required for estimating the 10-month fluxes. Contaminant fluxes for each of the gaged surface water stations and the gaged shallow groundwater (SS-5) are presented in Table E.11. Several chemicals detected at BCK 9.47 (Table E.7) were analyzed for during the Groundwater Quality Report sampling (boron, total uranium, total strontium) but were not analyzed during BCV RI sampling. Fluxes could not be estimated for these chemicals since there were no corresponding flow and concentration data with which to determine flow-weighted concentrations. Boron and total Sr were not evaluated in the IP assessment. Isotopic U data from the RI were used to assess both radiocarcinogenic and element U toxicity considerations by converting the isotopic data to uranium mass concentrations, assuming a natural isotopic ratio.

The distribution of fluxes of some of the major contaminants in the valley was presented in Fig. E.11. Uranium fluxes are greatest at NT-3 and BCK 12.38/SS-1. Based on groundwater data and

the radiological walkover survey data, the source of uranium at NT-3 is the BYBY. The source of uranium at BCK 12.38/SS-1 is the contaminated groundwater underlying the S-3 Site. The extent to which the treated S-3 Ponds continue to act as source is unknown, but is assumed to be negligible compared to the extent of contamination already in groundwater at the S-3 Site. The only major source of nitrate in the valley is the plume of nitrate-contaminated groundwater at the S-3 Site. Elevated concentrations of nitrate were not detected in tributaries past NT-2. VOCs are detected at low levels in groundwater and surface water throughout the valley, however, the greatest mass fluxes emanate from the BCBG (NT-6, NT-7, and NT-8).

Flux estimates for several contaminants have a high degree of uncertainty associated with them because of the low frequency of detection for those contaminants. Several VOCs detected at either BCK 9.47 or SS-5 were detected two to three times in the 10-month study period at very low concentrations (e.g., the results were “estimated” values, meaning the concentrations were below the instrument quantitation limit). These VOCs include 1,1-dichloroethane (DCA), 2-butanone, acetone, methylene chloride, and TCE. PCE was detected in 9 out of the 22 samples taken at BCK 9.47; however, the highest detected concentration was 4 $\mu\text{g/L}$. Data for two VOCs detected only during the April sampling, 1,1-DCA and chloroethane, were considered unusable; thus, fluxes have not been estimated for these two chemicals (see Sect. B.7 in Appendix B). Only 1,1-DCE was detected on a frequent enough basis at BCK 9.47 (100% of samples) to translate into a high degree of confidence in the flux estimates.

Several metals, including lithium, nickel, vanadium, and zinc were detected infrequently at concentrations very close to background concentrations. Flux estimates associated with these chemicals also have a high degree of uncertainty associated with them. Vanadium detections are so close to background values that it is questionable that vanadium is even present above background at BCK 9.47.

E.3.2.2.2 Contaminant mass balance

A contaminant mass balance has been performed on the estimated fluxes to check whether the amount of estimated contaminant influx that enters the Upper Bear Creek system from the waste sources is equal to the amount leaving the system. Based on the water balance for the valley (Table E.8), gaged contaminant fluxes at the tributaries should represent a large portion of the total influxes from the waste sources. Gaged fluxes at BCK 9.47 and SS-5 should represent a large portion of the total outfluxes, so that, in general, the mass balance can be performed by equation for the following fluxes:

$$\text{Flux}_{\text{BCK 9.47} + \text{SS-5}} = \text{Flux}_{(\text{BCK12.3} + \text{NT-1} + \text{SS-1})} + \text{Flux}_{\text{NT-2}} + \text{Flux}_{\text{NT-3}} + \text{Flux}_{\text{NT-4}} + \text{Flux}_{\text{NT-5}} + \text{Flux}_{\text{NT-6}} + \text{Flux}_{\text{NT-7}} + \text{Flux}_{\text{NT-8}}$$

In performing the contaminant mass balance in this manner, three situations may occur:

- (1) the influx (sum of fluxes at the tributaries) equals the outflux (sum of fluxes at BCK 9.47 and SS-5), in which case the flux estimate accounts for all inputs and outputs to the system (this is an unlikely scenario);
- (2) the influx is greater than the outflux, in which case, a contaminant “sink” exists in the system prior to the IP; or
- (3) the influx is less than the outflux, in which case, an ungaged contaminant source exists upgradient of the IP.

Table E.11 shows the results of the contaminant mass balance for primary chemicals and radionuclides detected at BCK 9.47 or SS-5. Negative values in the last column of the table suggests that a contaminant “sink” exists between the source releases and the IP. Table E.12 summarizes the results of the contaminant mass balance for the three major contaminant types: uranium, nitrate, and total volatiles. The table also provides the BCV water balance estimates for comparison.

The intermediate/deep groundwater contaminant migration pathway is accounted for in a semiquantitative manner in the mass balance since it is ungauged. The intermediate/deep groundwater may be accounted for as either a contaminant “sink” or an ungauged contaminant source, depending on the contaminant; e.g., nitrate influxes to Bear Creek are greater than outfluxes at BCK 9.47 and SS-5. In the case of nitrate, the contaminant “sink” is likely the nitrate that moves to ungauged intermediate/deep groundwater. In the case of uranium, where total influxes to the creek are greater than outfluxes at BCK 9.47/SS-5, contaminated groundwater at source sites is probably acting as ungauged sources.

In summary, the results of the contaminant mass balance indicate the following:

- Most nitrate flux migrates past the integrator plane in surface water at BCK 9.47 (61%). Approximately 19% of nitrate mass input to Bear Creek cannot be accounted for by fluxes at BCK 9.47 or SS-5. The excess engaged outflux is probably accounted for by three possible sinks for nitrate: (1) ungauged subsurface flow at BCK 9.47; (2) denitrification in groundwater and surface water; and (3) uptake by plants. Assuming an average concentration for nitrate in groundwater at the integrator plane of 11 mg/L (Fig 3.10) and using the calculated 10-month water flux for ungauged groundwater flow at this location (Fig 2.6, 54,000 m³), subsurface flow could account for 590 kg (~12 %) of the ungauged outflux.
- The balance for uranium in the valley differs from nitrate, reflecting that uranium is derived from different sources than nitrate and also has a different geochemistry. A substantial portion (31%) of uranium measured at BCK 9.47 is from an ungauged source(s). The main ungauged source of uranium to Bear Creek and the Maynardville Limestone is surface runoff and subsurface flow from BYBY. The S-3 plume also discharges directly to Bear Creek and amounts for a portion of ungauged uranium flux.
- The majority of the mass of VOCs volatilize prior to BCK 9.47. An estimated 55 Kg of total VOCs volatilized during the 10-month study period. Although the uncertainties associated with the flux estimates for VOCs make contaminant balance results dubious, it is clear that most of the VOC mass from the BCBG area volatilizes prior to moving down the valley. Based on available data, VOCs have not migrated across the integrator plane via the groundwater to date.

E.3.2.2.3 IP assessment results

As indicated by Equation E.1, contaminant flux results are used to proportion the total risk associated with off-site contaminant fluxes (in this case, fluxes measured at BCK 9.47/SS-5) to the various upstream/upgradient waste sources.

A subset of the chemicals and radionuclides that were detected at BCK 9.47/SS-5 have been included in the IP assessment. Reasons for screening chemicals out of the assessment are presented in Table E.13. The primary reason for screening out chemicals is that the detected concentrations were less than the risk-based preliminary remediation goal (based on either a 1×10^{-6} cancer risk goal or a hazard index = 0.1), which indicates that these chemicals do not contribute significantly to off-site risk. This screening process is explained and presented in the BHHRA (Appendix F). Two

chemicals, boron and total strontium, were not included because fluxes could not be estimated for these chemicals.

Results of the IP assessment are presented separately for carcinogens and chemical toxicants since these two different human health endpoints cannot be quantitatively compared. However, uranium and tetrachloroethene are included in both assessments since exposure to these two chemicals may result in both a toxic and carcinogenic effect. It is not the goal of this assessment to determine which hazard – carcinogenicity or chemical toxicity – should drive the priority of remedial actions; however, as indicated by the results presented below, this decision is not an issue at BCK 9.47/SS-5 since uranium appears to pose the most off-site hazard, and it is both a carcinogen and chemical toxicant.

Figure E.14 shows the contribution to total risk and total toxic effects at the IP from the various chemicals and radionuclides included in the IP assessment. As stated in Sect. E.3.2.1.2, risk values at BCK 9.47/SS-5 for the IP assessment were estimated using flow-weighted concentrations. These risk estimates should be used only in the IP assessment process. Baseline risks associated with these sites are presented in the BHHRA.

Tables E.14 and E.15 present the results of the IP assessment for carcinogens and chemical hazards, respectively. The tables present the inputs to the assessment (e.g., chemical-specific and site-specific flux-weighted risks, or the numerator in the IP equation). These inputs are calculated from the fluxes presented in Table E.11 and the risk or hazard index at BCK 9.47/SS-5 estimated using the flow-weighted average concentrations and BHHRA risk equations. The IP results are presented in the last row of the table. Results are also summarized in Table E.16 and Figs. E.15 and E.14.

As indicated in the tables and figures, the greatest contributor to risk and toxic effects at the IP are the uranium fluxes coming from BYBY via NT-3. The second largest contributor appears to be uranium migrating from the shallow groundwater plume underlying the S-3 Site. Much of the uranium from this secondary source resurfaces to tributaries and enters Bear Creek prior to BCK 12.38/NT-1 and at SS-1. Nitrate fluxes also implicate BCK 12.38/NT-1/SS-1 and NT-2, suggesting that the nitrate plume underlying the S-3 Site is actively contributing to hazards at the IP.

Because uranium contributes the most to human health hazard at BCK 9.47/SS-5, and because there is a relatively large mass of ungaged uranium (as indicated by the mass balance results), ungaged sources contribute a relatively large percentage of the risk at the IP. As indicated in Table E.5, the likely ungaged sources include the groundwater plumes underlying BYBY and the S-3 Site, and ungaged runoff from BYBY directly to Bear Creek. Based on the site conceptual models for these sites BYBY is probably the contributor for most of this ungaged flux, especially since BYBY is partly located on the outcrop of the Maynardville Limestone and the Bear Creek floodplain.

Several uncertainties are associated with the results. As indicated earlier, vanadium flux calculations are uncertain because of the low frequency of detection at the IP and the low detected concentrations. The vanadium background concentration for Bear Creek is 0.013 mg/L. The flow-weighted average concentration for vanadium is 0.029 mg/L. TCE and PCE flux calculations are also uncertain for the same reasons. There is little question that PCE and TCE are found at BCK 9.47/SS-5, but there is uncertainty in estimating the mass at the IP. Based on the mass balance estimates, most of the volatile mass detected at BCK 9.47 likely would not continue to migrate down the creek but would quickly volatilize.

E.3.3 SUMMARY

In summary, the results of the IP assessment suggest the following:

- Uranium appears to pose the greatest human health hazard, contributing 98% of the total risk at BCK 9.47 and 64% to total toxic effects.
- Most of the uranium migrating off site via surface water appears to come from BYBY via NT-3. The second greatest identified source is BCK 12.38/NT-1, which captures fluxes coming from the S-3 Site and the S-3 groundwater plume.
- The influx of a significant percentage of the uranium flux measured at BCK 9.47 (~31%) is not gaged. The likely ungaged sources include the groundwater plumes underlying BYBY and the S-3 Site, and ungaged runoff from BYBY directly to Bear Creek. Based on the site conceptual models for these sites, especially since BYBY is partly located on the outcrop of the Maynardville Limestone and the Bear Creek floodplain, BYBY is probably the contributor for most of this ungaged flux.
- Nitrate, which has been the focus of many studies in BCV in the past, does not contribute a high proportion of the toxic hazard associated with surface water migration. However, based on the nitrate mass balance for the various flow paths in the valley, nitrate may be moving off site via the intermediate/deep groundwater.
- VOCs are detected in most of the tributaries in the valley, with the greatest amounts entering Bear Creek at NT-7 (27%) and NT-8 (71%). The primary VOCs in these tributaries are: 1,1-DCE (with concentrations ranging from 33 to 410 $\mu\text{g/L}$), PCE (16 to 120 $\mu\text{g/L}$), 1,1,1-trichloroethane (TCA), 1,1-DCA, 1,2-DCE, TCE, and vinyl chloride. The primary waste source for these VOCs appear to be BG-A South and BG-A North, based on shallow groundwater results.

Large amounts of VOCs have not been detected at BCK 9.47 and it is estimated that >80% (or 55 Kg) of the VOC mass detected in the tributaries during the 10-month study period volatilized prior to reaching BCK 9.47/SS-5.

E.4 POTENTIAL FUTURE VALLEY-WIDE CONTAMINANT MIGRATION

E.4.1 INTRODUCTION

In this section the current conditions and contaminant fluxes in BCV (described in Sect. E.3 and Appendix D) are combined with the conceptual fate and transport model (described in Sect. E.2) to make tentative predictions of future conditions in BCV. The overall objectives of this effort are to evaluate potential future impacts to human health and the environment and to provide a framework for evaluating the effectiveness of proposed remedial alternatives in the FS.

The complex nature of the hydrogeology and contaminants in BCV preclude development of a single numerical computer model to describe fate and transport of contaminants at this site. Rather, a combination of small-scale numerical transport models, an analytical groundwater transport model, a geochemical model, and simple estimates of contaminant attenuation/dilution along specific pathways are combined in the framework of the conceptual model for fate and transport analysis (Sect. E.2). The combination of methods is site-specific and is discussed in detail later in this section.

Receptor locations chosen for this analysis include: (1) groundwater at the boundary of the source sites; (2) Bear Creek tributaries (e.g., NT-2, NT-3, etc.) to evaluate potential human health risk assuming on-site receptors, and to evaluate risks to ecological receptors in the tributaries; and (3) the Integrator Point/Plane to evaluate the impacts of off-site migration of contaminants.

The output of the contaminant fate and transport section is presented as the expected maximum concentration of modeled contaminants at the receptor locations. These data will allow prediction of the approximate locations of future maximum concentrations resulting from the integration of the contributions from multiple sources, and approximate quantification of potential future releases from the various sources within BCV.

E.4.2 MODELING APPROACH

The goal of the modeling effort is to evaluate the fate and transport of constituents as they migrate from the BCV source areas through the migration pathways outlined in Sect. E.2. The conceptual model for contaminant fate and transport away from each source was divided into a set of logical and consistent components (e.g., Fig. E.17). A single computer modeling code or a simple dilution calculation was applied to each contaminant in each component of the conceptual model. When combined, these components form a fate and transport model that has a relatively simple construction but can be applied to this complex site. The next section describes the detailed conceptual model for each source in BCV, and the combination of component calculations that was used to model the fate and transport of contaminants at these sites. The following is a description of the conceptual model components and the method of calculation that was used to depict each component (Supporting Information for Appendix E contains detailed information concerning the computer codes used and general information concerning parameter selection for each model):

Component 1 - Transfer of contaminants from the waste media to the environment. As discussed in Sect. E.2, the form of the waste materials and the hydrogeologic characteristics of the source site control the way in which contaminants leave the source and enter the surrounding

environment. As a result, no single method can be applied to this component; methods were used that suited the specific scenario for each source/waste combination. These are:

- For dense liquid wastes (DNAPL or dense salt solutions), it was assumed that the liquid waste migrated directly into the formations below the waste unit with no dilution or attenuation; no calculations were carried out. In reality, this is the case for DNAPLs and was probably the case for the acid solutions disposed of at the S-3 Site (refer to the conclusions for Sect. D.6 in Appendix D). Using this assumption, the liquid waste materials become a secondary source of contamination for component 2 of the model. In this situation the concentration input to the next component of the model was established from observed concentration in groundwater.
- For solid wastes that are submerged below the water table, a partition coefficient model (applied using *Crystal Ball*; see Supporting Information for Appendix E) was used to calculate the likely equilibrium concentration of the contaminant in solution. This concentration was assumed to be the concentration in groundwater at the source.
- For solid wastes that are above the water table, an unsaturated zone contaminant transport model was used to predict the concentration of contaminants in groundwater at the water table beneath the waste. One of two models was used to carry out this modeling: (1) SESOIL was used to model organic compounds, and (2) ODAST was used to model inorganic compounds and radionuclides (Supporting Information for Appendix E).

Component 2 - Lateral migration in groundwater in the Nolichucky Shale. This component calculates the transfer of contaminants from groundwater at the source site (the output from component 1) along strike to the nearest tributary or across strike to the Maynardville Limestone or Bear Creek. For this component, a one-dimensional contaminant transport model, CRAFLUSH, designed to simulate transport of contaminants in a fracture, was used. Input concentrations were derived from the output from component 1 or the secondary source, if present beneath the primary source area with concentrations greater than the output from component 1.

Component 3 - Discharge into a surface water body. The results from calculations of components 1 and/or 2 were simply converted into likely average surface water concentrations by using dilution factors. These dilution factors were derived from current observations of the difference between concentrations in shallow groundwater and tributaries presented in Table D.26 in Appendix D. These concentrations represent the low-flow period. Although it is known that concentrations of contaminants in surface water vary widely from day to day dependent on the flow in the stream, it was assumed that concentrations during periods of baseflow would represent the smallest dilution factor and, therefore, provide an estimate of the maximum concentration.

Component 4 - Migration to BCK 9.47. Results from components 1, 2, and 3 were utilized to develop a valley-wide mass-balance model to provide estimates of the concentrations for each contaminant of potential concern (COPC) at BCK 9.47. The mass balance model assumes that the current water budget conceptual fate and transport models remain constant for the modeled time frame, and that contaminants plumes are well mixed by the time contaminants reach BCK 9.47.

The above approach was used to model each chemical that was selected for modeling. In order to reduce the number of models used, chemicals were selected based on the level of concern for that chemical. Figure E.18 shows the decision flow chart that was used to develop a comprehensive list of COPCs for modeling at each site. The decision process takes into account the level of potential concern from both the human health and the ecological risk perspective. This decision process also

considers the future potential for a chemical to become a COPC. In this way, the list of chemicals modeled for each site is comprehensive of chemicals of concern, both current and future.

Following the above approach, a combination model was constructed for each of the FAs in BCV. The following sections describe the detailed configuration of the model for each source area.

Other Modeling Investigations. Besides the four components of the fate and transport modeling, two other modeling investigations were performed at this site. These are:

- **CRAFLUSH modeling of TCE in the Maynardville Limestone.** Like component 2 of BCV modeling, the 1-D contaminant transport model, CRAFLUSH was used to simulate transport of TCE in a system of multiple fractures within the deep Maynardville Limestone. The input concentration to the model was derived from the center of the TCE plume in the Maynardville Limestone. The depletion of the secondary source was calculated using the average concentration of the plume, the mass of the plume and the velocity of groundwater within the plume. Details of model calibrations and model applications are presented in Attachment A2.
- **Sharp interface modeling to investigate dissipation of pressure bulge beneath S-3 Site.** A 1-D sharp interface model was applied to investigate the dissipation of the pressure bulge that exists in the Nolichucky Shale beneath S-3 Site (Dreier et al. 1993 and Vol. 3, Fig. D.31) The pressure data from GW-134, which indicates a pressure bulge at a depth of about 450 ft, were utilized to develop the 1-D model. The goal of this modeling study was to simulate a pressure bulge that was consistent with the observed data for GW-134, and predict natural dissipation of this pressure bulge (if any) and pressure dissipation with man-made activities (e.g., groundwater extraction).

E.4.2.1 Modeling Approach for the S-3 FA

The combined model for the S-3 Site is shown on Fig. E.19. The following is a description of each component of the model.

E.4.2.1.1 Component 1

The S-3 Ponds were comprised of four holding ponds $\sim 120 \times 120$ m (400×400 ft) each. Each pond was excavated to ~ 5 m (16 ft) below ground surface (bgs) with an approximate holding capacity of 9.5 million L. The conclusion reached in Appendix D is that waste water disposed in the ponds migrated into the bedrock with little or no attenuation of contaminant concentrations. Once in the groundwater environment, undiluted waste water has migrated to depths of up to 152 m (500 ft) below the ponds; however, there has been considerable selective attenuation of particle reactive contaminants, such as uranium, with the result that the contaminant plume at depth is chemically different from that in the shallow groundwater. Although, since closure of the S-3 Ponds Site in 1985, the waste water source in groundwater has been slowly dissipating as contaminants migrate by advection or diffusion, concentrations of nitrate equivalent to undiluted waste water still remain in bedrock groundwater below 30 m (100 ft) depth. In addition, sludges that could be a potential source of contaminants remain in the former ponds.

For component 1 of the model, it has been assumed that there are two chemical by distinct sources of contamination in groundwater (one shallow, one deep) to account for the differences between source composition resulting from the attenuation of particle reactive contaminants. Groundwater from GW-243 was considered representative of the worst condition in shallow bedrock, and GW-615, worst condition in deep bedrock. In addition, where a COPC had not been detected in

these wells, the maximum values from the S-3 aggregate were used (Table D.30 in Appendix D). In addition, leaching models were run to ensure that the current concentration in groundwater (assumed to be undiluted waste water) are the maximum expected. The results of the leaching models were compared to the current concentrations and, where the leaching model indicated greater maximum concentrations were likely in the future, then these maxima were used for modeling in subsequent components. In addition, in some cases where analytes measured in the sludges in the ponds were not analyzed for in groundwater, the maximum values from the leachate model were used.

Site-Specific Model Parameters - Leachate Modeling

Source Term Parameters. The S-3 Site source term was characterized on the basis of historical disposal records. Analytical data on sludge from all four ponds were utilized to develop the 95% UCL of the mean concentrations for the sludges. Similarly, analytical data for sediment samples from the Blue Lagoon were used to develop the 95% UCL of the mean concentrations for the sediments placed in the Southwest Pond. The estimated volume of sediment from the Blue Lagoon placed in the pond is 850 m³ (1112 yd³), and the volume of sludge in the four ponds is estimated to be 16,000 m³ (20,927 yd³). These volumes represent 95.4% sludge and 4.6% sediments by weight. Therefore the source term concentrations for S-3 Site were estimated using weighted average values of the 95% UCL of the mean concentrations for the sludges and the lagoon sediments. The source term characterizations for S-3 Site are presented in Table E.17.

When applicable, leachate data derived by Lee and Hyder (1987) were used in place of calculated leachate conditions.

Hydrogeologic Parameters. For the S-3 Site, historical data suggest a variable groundwater table with an average depth of 6.1 m (20 ft) bgs. For modeling purposes, the bottom of all ponds was assumed to be 5.2 m (17 ft) bgs with three additional feet of vadose zone separating the waste from water table; however, this assumption does not account for the possibility of seasonal or episodic saturation of the waste by fluctuating groundwater levels.

The intrinsic permeability ($6.10\text{E-}10\text{ cm}^2$) of the model for predicting chemical fate and transport from the S-3 sludge through the vadose zone into the groundwater was calibrated to a percolation value of 4.42 cm/year (1.8 in./year), which is realistic for an asphalt-covered cap. Calibration of the model to percolation resulted in the definition of a moisture content of 19.03 weight % and a surface runoff of 53.681 cm/year (21.5 in./year). A disconnectedness index value of 12 representing clay, a porosity of 0.42, and an organic content of 0.164% were used as the other input parameters for the model (Table E.18). The calibrated parameters: intrinsic permeability of $6.1\text{E-}10\text{ cm}^2$, soil moisture content of 31.0% corresponding to a percolation rate of 4.42 cm/year (1.8 in./year) are shown in Table E.18.

The vadose zone was divided into four layers for the purpose of modeling (Fig. E.32). The second layer, 393 to 518 cm (157 to 207 in.) bgs, received the source term concentration loading as a continuous source. Loading of this layer resulted in a vertical distance of 91.44 cm (36.6 in.) to groundwater corresponding to the third layer. The fourth layer of 91.44 cm (36.6 in.) was included to ensure limited freedom to explore fluctuating groundwater levels if necessary. Each of the bottom two layers were comprised of 10 sublayers.

E.4.2.1.2 Component 2

Contaminants from the source area at the S-3 Site migrate laterally along strike and discharge in tributaries NT-1 and NT-2 (refer to Appendix D). In addition, there is a migration pathway from

the shallow groundwater source across strike and directly to Bear Creek that is probably active close to the former ponds. This component of the model was simulated using three separate CRAFLUSH models: one for along strike migration from the shallow source to NT-1, one for across strike migration from the shallow source to Bear Creek, and one for along strike migration from the deep source to NT-2. The source concentrations used by the model are presented in Tables E.19 and E.20 for shallow and deep intervals, respectively.

This configuration makes the assumption that contaminants in the shallow bedrock migration pathway are effectively captured by discharge to the tributary and that the only pathway by which contaminants can underflow NT-1 and arrive at NT-2 is a deeper pathway. This assumption is consistent with the observed distribution of contaminants in Appendix D.

E.4.2.1.3 Component 3

Component 3 of the S-3 model is a series of simple dilution calculations. Dilution of contaminant concentration occurs at the discharge point where contaminated groundwater discharge mixes with uncontaminated runoff derived from the headwaters of each stream. The dilution factors were calculated by comparing concentration of the COPCs in groundwater to the concentrations in the tributary. The groundwater concentrations from the recent two sampling events were used to derive the dilution factors at NT-1 by comparing with surface water concentrations at NT-1 during the same time (Table D.26). However, at NT-2, well GW-830 was used to represent deep groundwater at NT-2. The maximum concentrations of nitrate in the NT-2 (Table D.30) monitoring points was used to derive the baseflow concentrations. The dilution factor used was 10.4 for deep groundwater discharge to NT-2.

E.4.2.2 Modeling Approach for the Oil Landfarm FA

At the OLF FA, there are three potential sources for contamination in groundwater: OLF, SL 1, and BYBY. However, of the surface water streams in the OLF FA, only NT-3 was contaminated to any great extent and, based on the discussion presented in Appendix D, it was assumed that contamination was derived from only one of the sources: the BYBY. Thus, although leachate modeling was conducted for each of the sources to determine which sources may cause groundwater contamination, the combination of leachate modeling with groundwater transport and surface stream dilution was only conducted for BYBY (Fig. E.20).

E.4.2.2.1 Leachate modeling at Oil Landfarm – site-specific model parameters

Source Term. Analytical data for the OLF soil exposure concentrations were derived from soil samples collected from the area currently under the cap. Data correlating to subsequently excavated soils were not included in the analytical database. The exposure concentrations used in SESOIL and ODAST modeling represent the 95% UCL of the mean (Table E.21).

Hydrogeologic Parameters. An average depth to groundwater was determined using water level data from the Y-12 Plant well database (Jones, Thompson, and Field 1995). Averages of water levels using available temporal ranges from monitoring wells GW-005, -007, -010, and -013 were used to develop the average of 0.9 m (3 ft) bgs. This represents a range across the site of 0.09 to 1.5 m (0.28 to 5.0 ft) bgs. Analytical data for the area under the present cap represent soil from 0 to 0.46 m (0 to 1.5 ft) bgs and were simulated to migrate 0.46 m (1.5 ft) through the vadose zone to groundwater.

Geotechnical analyses of two undisturbed samples taken from the perimeter of the OLF were used to develop the following parameters: average moisture content of 15.75 weight %, average porosity of 0.34, average bulk density of 1.84 g/cm³, and average total organic content of 0.06% (Table E.18). These parameters were used as guidelines for calibration of the SESOIL model and, consequently, the ODAST model. The calibrated parameters used in this modeling are: intrinsic permeability of 2.66E-10 cm², soil moisture content of 25.1% corresponding to a percolation rate of 16.84 cm/year (6.7 in./year), and porosity of 35% (Table E.18).

SESOIL parameters were arranged in four layers for migration simulation from 0 to 0.9 m (0 to 3 ft) bgs. The first layer extended from 0 to 0.2 m (0 to 0.5 ft) bgs with no sublayers followed by the second layer from 0.2 to 0.5 m (0.5 to 1.5 ft) bgs with no sublayers. These top two layers received the contaminant loading and are in correlation with the intervals from which analytical samples were collected. The third layer extended from 0.5 to 0.6 m (1.5 to 2 ft) bgs and included five sublayers, and the fourth layer extended from 0.6 to 0.9 m (2 to 3 ft) bgs and included 10 sublayers. The third and fourth layers formed the leaching zone through which migration was simulated.

E.4.2.2.2 Leachate modeling for SL 1 – site-specific model parameters

Source Term. Analytical data for the SL 1 soil exposure concentrations were comprised of sample data from surface soil and subsurface soil samples collected outside of the capped area. The exposure concentrations used in SESOIL and ODAST modeling represent 95% UCL of the mean calculated using data from aggregates of 1.2-m (4-ft) interval beginning with the ground surface. Analytical data from time-composited surface water samples collected from NT-3 were used as leachate concentrations in ODAST modeling where available. NT-4 data were also evaluated but were not used due to drainage patterns suggesting little influence from SL 1. The source term characterizations for SL 1 are presented in Table E.22.

Hydrogeologic Parameters. An average depth to groundwater was determined using water level data from the Y-12 Plant well database (Jones, Thompson, and Field 1995). Averages of water levels using available temporal ranges from monitoring wells GW-097, -226, -227, and -229 and an interpolated value for the central region were used to develop the average of 3.7 m (12 ft). This represents a range across the site of 1.2 to 5.1 m (3.95 to 16.71 ft) bgs and is in agreement with the valley-wide model values.

Geotechnical analyses from two samples collected from the OLF were used to develop the following site-specific parameters due to lack of geotechnical data from the SL 1 and the close proximity of the OLF: average moisture content of 15.75 weight %, average porosity of 0.34, average bulk density of 1.84 g/cm³, and an average total organic content of 0.06% (Table E.18). These parameters were used as guidelines for calibration of the SESOIL model and, consequently, the ODAST model. The calibrated parameters used in this modeling are: intrinsic permeability of 1.54E-10 cm², soil moisture content of 24.9% corresponding to a percolation rate of 9.6 cm/year (3.8 in./year), and porosity of 36% (Table E.18).

SESOIL parameters were arranged in four layers from ground surface to 3.7 m (12 ft) bgs. The first and second layers are 1.2-m (4-ft) intervals each, with no sublayers. These layers are combined with the third layer, 2.4 to 3.0 m (8 to 10 ft) bgs with no sublayers, to define the contaminant loading zone for the SL 1. The fourth layer, 3.0 to 3.7 m (10 to 12 ft) bgs with eight sublayers, defines the contaminant leaching zone.

E.4.2.2.3 Modeling at BYBY

Component 1 - Leachate Modeling

Source Term. Analytical data for the BYBY soil exposure concentrations were comprised of sample data from surface soil and subsurface soil samples collected outside of the capped area. The exposure concentrations used in SESOIL and ODAST modeling represent 95% UCL of the mean calculated using data from aggregates of 1.2-m (4-ft) interval beginning with the ground surface. The maximum concentrations from OU 1 shallow groundwater aggregate analytical data (Table D.60 in Appendix D) were used as leachate concentrations in ODAST modeling where available. The source term characterizations for BYBY are presented in Table E.23.

Hydrogeologic Parameters. An average depth to groundwater was determined using water level data from the Y-12 Plant well database (Jones, Thompson, and Field 1995). Averages of water levels using available temporal ranges from monitoring wells GW-087, -067, and -084, and an interpolated value for the central region were used to develop the average of 2.1 m (7 ft). This represents a range across the site of 0.6 to 3.8 m (1.97 to 12.37 ft) bgs. Due to fluctuating groundwater levels and the vadose zone limit of the models used, contaminant loading was restricted to the 0- to 1.2-m (0- to 4-ft) interval. Leachate modeling, therefore, represents migration of the constituents through 0.9 m (3 ft) of leaching zone to the groundwater.

Geotechnical analyses from two samples taken from the BYBY were used to develop the following site-specific parameters: average moisture content of 26.1 weight %, average porosity of 0.41, average bulk density of 1.61 g/cm³, and average total organic content of 0.385% (Table E.18). These parameters were used as guidelines for calibration of the SESOIL model and, consequently, the ODAST model. The final calibration parameters used in the model were as follows: intrinsic permeability of 1.5E-10 cm² and soil moisture content of 30.10% corresponding to a percolation rate of 14.20 cm/year (5.7 in./year) (Table E.18).

SESOIL parameters were arranged in 4 layers for migration simulation from 0 to 2.1 m (0 to 7 ft) bgs. The first layer extended from 0 to 1.2 m (0 to 4 ft) bgs with no sublayers followed by the second layer from 1.2 to 1.5 m (4 to 5 ft) bgs with two sublayers. The first layer received the contaminant loading. The third layer extended from 1.5 to 1.8 m (5 to 6 ft) bgs and included five sublayers, and the fourth layer extended from 1.8 to 2.4 m (6 to 8 ft) bgs and included eight sublayers. The second, third, and fourth layers formed the leaching zone through which migration was simulated.

Component 2 - CRAFLUSH Modeling

There are two potential pathways for contaminant migration away from the source area at BYBY. These are by discharge to surface water at NT-3 or migration across strike in the Nolichucky Shale to discharge points either into Bear Creek or the Maynardville Limestone. Currently, only radionuclides and inorganic contaminants appear to migrate to NT-3, whereas, organic contaminants and unknown amounts of the inorganic contaminants migrate directly to Bear Creek. This effect is due, in part to the relative distributions of the plumes of organic and inorganic contaminants, where the centroid of the inorganic and radionuclide contaminant plume is located directly under NT-3; whereas, the centroid of the organic plume is located at the west edge of the Hazardous Chemical Disposal Area (HCDA) cap.

Two CRAFLUSH models were used to simulate these conceptual pathways. One was used to model the migration of COPCs from the HCDA cap to NT-3 in an along strike flow path. The second

was used to model migration of the COPCs across strike from the plume centroids to Bear Creek or the Maynardville Limestone. The source concentrations used by the CRAFLUSH model are summarized in Table E.24.

Component 3 - Surface Stream Dilution Factors

Component 3 of the BYBY model is a series of simple dilution calculations. Dilution of contaminant concentration occurs at the discharge point where contaminated groundwater discharge mixes with uncontaminated runoff derived from the headwaters of NT-3. An average dilution factor was calculated based on results of uranium concentrations. The maximum value from the OU 1 shallow samples (Table D.60 in Appendix D) was used to represent shallow groundwater at NT-3, and the maximum concentrations in the NT-3 aggregate (Table D.48) were used to derive the baseflow concentrations. However, based on recent groundwater and surface water sampling and analysis at NT-1, the dilution factor at NT-3 was revised. To be conservative, the calculated dilution factor at NT-1 was modified by comparing the water flux from NT-1 and NT-3. The modified dilution factor was used for all the COPCs from BYBY.

E.4.2.3 Modeling Approach for the Bear Creek Burial Grounds FA

At the BCBG FA, there are numerous potential sources for contamination in groundwater, where each trench is a potential individual source. For modeling purposes, these sources were grouped into four areas: BG-A North, BG-A South, Walk-in Pits (WIP), and BG-C East, -D East, and -C West (Fig. E.21). These groupings are based on similarities in the hydrogeological properties of the source area. Discharge points for contaminants from these source areas are NT-7, NT-8, the Maynardville Limestone or Bear Creek, and the Compliance Plane (Fig. E.21; refer to Sect. E.3).

E.4.2.3.1 Component 1

For component 1 in the BCBG model, leachate models were conducted for the WIP and BG-A North source groups where a vadose zone probably exists between the waste materials and the groundwater table (refer to Sect. D.8.1 in Appendix D for a discussion of BCBG site hydrology). Partition calculations were used in BG-A South where the waste is assumed to be submerged most of the time, and data from the seep 2 leachate collection system were assumed to represent shallow groundwater at the BG-C East group. For this last source group, no calculations were carried out because leachate data were available.

In addition, liquid disposals at BG-A South are known to have resulted in migration of DNAPL to the bedrock. This situation is also probably the case at the BG-A North and WIP source groups where concentration of dissolved VOCs in groundwater strongly indicates the presence of DNAPL. Therefore, for organics at these source areas, it was assumed that the source for maximum concentrations of contaminants in groundwater is the in-place DNAPL; therefore, leachate modeling was not carried out.

Leachate Modeling for the WIP Site - Site-specific Model Parameters

Source Term. Analytical data for the WIP were comprised of soil sample data from surface soil and subsurface soil samples collected from the perimeter of the capped areas. The exposure concentrations used for the modeling represent the 95% UCL of the mean calculated with data from the appropriate range of sample intervals. When applicable, estimated concentrations from BCBG inventory (Appendix A) were used as exposure concentrations. The source term characterizations for WIP site are presented in Table E.25.

Hydrogeologic Parameters. The WIP site includes both WIP North and WIP South, BG-B, and BG-D(S). An average depth to groundwater was determined using water level data from the Y-12 Plant well database (Jones, Thompson, and Field 1995). Averages of water levels using available temporal ranges from monitoring wells GW-250, -249, -257, -248, -258, -290, and -259 were used to develop the average of 6.1 m (20 ft) bgs. This represents a range across the site of 0.7 to 10.4 m (2.3 to 34.21 ft) bgs. Maximum concentrations for constituents were found in the vadose zone and in the groundwater requiring vadose zone modeling and partition modeling.

Geotechnical analyses of four undisturbed samples taken from characteristic areas of the BCBG were used to develop the following parameters: average moisture content of 22.35 weight %, average porosity of 0.45, average bulk density of 1.53 g/cm³, and average total organic content of 0.11%. These parameters were used as guidelines for calibration of the SESOIL model and, consequently, the ODAST model. The calibrated parameters used in this modeling are: intrinsic permeability of 1.54E-10 cm², soil moisture content of 31.05% corresponding to a percolation rate of 9.6 cm/year (3.8 in./year) and porosity of 45% (Table E.18). Additional parameters required for ODAST modeling included a seepage velocity of 0.0024 ft/d and a dispersion coefficient of 0.00082 ft²/d.

SESOIL model inputs were arranged in four layers from ground surface to 4.9 m (16 ft) bgs. The first layer [0 to 1.2 m (0 to 4 ft) bgs] incorporated most of the concentration maximums and did not include sublayers. The second layer extended from 1.2 to 3.7 m (4 to 12 ft) bgs and included two sublayers. The third layer included the 3.7- to 4.9-m (12- to 16-ft) interval with no sublayers. The fourth layer, 4.9 to 6.1 m (16 to 20 ft) bgs, represented the leaching zone through which contaminant migration was simulated.

Leachate Modeling for BG-A North - Site-specific Model Parameters

Source Term. Analytical data for the BG-A North site were comprised of soil sample data from surface soil and subsurface soil samples collected from the perimeter of the capped areas. The exposure concentrations used for the modeling represent the 95% UCL of the mean calculated with data from the appropriate range of sample intervals. When applicable, estimated concentrations from BCBG inventory (Appendix A) were used as exposure concentrations. The source term characterizations for BG-A North are presented in Table E.26.

Hydrogeologic Parameters. The BG-A North site also includes BG-A-16, -17, and -18, all of which were incorporated into vadose zone modeling and partition modeling for those constituents with maximum concentrations in the groundwater. An average depth to groundwater was determined using water level data from the Y-12 Plant well database (Jones, Thompson, and Field 1995). Averages of water levels using available temporal ranges from monitoring wells GW-027, -039, -089, and -040 were used to develop the average of 3 m (10 ft) bgs for the aggregate. This represents a range across the site of 0 to 8.6 m (0 to 28.11 ft) bgs. Maximum concentrations for constituents were found in the vadose zone and in the groundwater requiring vadose zone modeling and partition modeling.

Geotechnical analyses of four undisturbed samples taken from characteristic areas of the BCBG were used to develop the following parameters: average moisture content of 22.35 weight %, average porosity of 0.45, average bulk density of 1.53 g/cm³, and average total organic content of 0.11%. These parameters were used as guidelines for calibration of the SESOIL model and, consequently, the ODAST model. The calibrated parameters used in this modeling are: intrinsic permeability of 1.54E-10 cm², soil moisture content of 31.05% corresponding to a percolation rate of 9.6 cm/year (3.8 in./year) and porosity of 45% (Table E.18). Additional parameters required for ODAST modeling included a seepage velocity of 0.0024 ft/d and a dispersion coefficient of 0.00082 ft²/d.

SESOIL modeling was accomplished using four layers from ground surface to 3 m (10 ft) bgs. The first layer [0 to 1.2 m (0 to 4 ft) bgs] incorporated most of the concentration maximums and did not include sublayers. The second layer extended from 1.2 to 2.4 m (4 to 8 ft) bgs and included one sublayer. The third layer extended from 2.4 to 2.7 m (8 to 9 ft) bgs with one sublayer, and the deepest layer, 2.7 to 3 m (9 to 10 ft) bgs, contained five sublayers. The third and fourth layers represented the leaching zone through which contaminant migration was simulated.

Partition Modeling for BG-A South - Site-specific Model Parameters

Source Term. Analytical data for the BG-A South site were comprised of soil sample data from surface soil and subsurface soil samples collected from the perimeter of the capped area. The exposure concentrations used for the partitioning model represent the 95% UCL of the mean calculated with data from the entire range of sample intervals. When applicable, estimated concentrations from BCBG inventory (Appendix A) were used as exposure concentrations. Predicted concentration ranges were derived using the literature values of K_d ranges for inorganics and radionuclides, and variation of the fraction of organic content for the site and, consequently, the site-specific K_d . The source term characterizations for BG-A South are presented in Table E.27.

E.4.2.3.2 Component 2

There are three potential pathways for contaminant migration away from the source areas at BCBG. These are by discharge to surface water at NT-6, -7, or -8; by migration across strike in the Nolichucky Shale to discharge points either into Bear Creek or the Maynardville Limestone; or by migration along strike in the bedrock to the integrator plain.

Five CRAFLUSH models were used to simulate these conceptual pathways. These are shown in Fig E.21 and are as follows:

- shallow groundwater at BG-A North and -A South to NT-7,
- intermediate and deep groundwater at BG-A South and -A North to the integrator plane,
- shallow groundwater at WIP to NT-8,
- intermediate and deep groundwater at WIP to the integrator plane, and
- intermediate and deep groundwater at BG-C East, -C West, and -D East to the integrator plane.

Tables E.28, E.29, and E.30 present the source concentrations for the CRAFLUSH models from BG-A North and -A South; BG-WIP, and BG-C East, -C West, and -D East, respectively.

E.4.2.3.3 Component 3

Component 3 of the BCBG model is a series of simple dilution calculations. Dilution of contaminant concentration occurs at the discharge point where contaminated groundwater discharge mixes with uncontaminated runoff derived from the headwaters of NT-7 and NT-8. Because the dilution factors calculated are based on the maximum values from the BCBG, groundwater aggregate data (Table D.91 in Appendix D) used to represent groundwater at NT-7 and also at NT-8 cannot be realistic. Therefore, like NT-3, the dilution factor of nitrate at NT-1 was used after modifying by comparing their respective water fluxes.

E.4.3 MODELING RESULTS

The following is a presentation of the results of modeling future conditions at each of the FAs in BCV. In interpreting the modeling results, the following criteria must be taken into consideration:

- Although the modeling results are based on uncertainty analysis performed on key input parameters (both site-related and chemical-specific), the major source of uncertainty for the present study existed with the oversimplification of the flow and transport processes using CRAFLUSH, a one-dimensional transport model for a system of parallel fractures. The effects of heterogeneity, anisotropy, and spatial distribution of fractures upon retardation, advection, and dispersion are not addressed in the simulations using CRAFLUSH.
- A specific uncertainty is the magnitude, timing, and direction of flow and contaminant transport across geologic contacts associated with the strong heterogeneity at the present site. The present modeling study using CRAFLUSH does not address the effects of flow and contaminant transport across interfaces in a sharply varying heterogeneous media.
- The CRAFLUSH model was applied separately for shallow and deep flow conditions. The effects of interaction between deep and shallow flow conditions due to changes in vertical gradients and spatial variations associated with the heterogeneity and anisotropy were not accounted for in the simulations. The model results, based on the assumed system of parallel fractures with an average seepage flow, dispersion coefficient, retardation factor, and porosity do not truly represent the physical conditions that exist in BCV. As an example, contaminants migrating along strike from the S-3 deeper plume and discharging to NT-2 have been modeled. In reality, a portion of this contamination is also being discharged into NT-1, which could not be accounted for in this 1-D CRAFLUSH modeling. In this way, concentrations in NT-1 are underpredicted and those in NT-2 overpredicted.
- The potential impact of the pressure bulge beneath S-3 could not be addressed in these modeling results. Using a 1-D sharp interface model has indicated that the pressure bulge observed beneath the S-3 Site is almost at steady state. It may take thousands of years for natural dissipation of this pressure bulge. Therefore, it is expected that it will continue to feed contamination to the tributaries for this long period of time.
- In calculating the likely concentrations for VOCs in tributaries, volatilization is not accounted for in these models. The concentrations predicted are, therefore, overestimates of the likely concentrations. These values also represent the maximum concentration in a tributary that would occur only at the discharge point and do not represent concentrations downstream at the confluence with Bear Creek.
- The time frame for modeling at each FA has assumed that contamination of groundwater was initiated when operations at the waste site commenced. For the S-3 Site and the BCBG, 1950 was assumed as t_0 making 1995 $t=45$ years. For BYBY, 1945 should be assumed as t_0 making 1995 $t=50$.

E.4.3.1 S-3 Site

E.4.3.1.1 S-3 Site component 1

The results of the vadose zone modeling for S-3 Site are summarized in Table E.31. Presented in this table are the soil exposure concentrations (i.e., the 95% UCL values for the sludge

concentrations in the S-3 Ponds), the predicted range of peak concentrations in leachate before entering the water table, and the corresponding time for peak concentrations. In addition, this table presents for comparison the current maximum concentrations in the groundwater for the S-3 groundwater aggregate (Table D.30 in Appendix D), and drinking water MCLs or remedial goal objectives (RGOs) (if MCL is not available). In Table E.31, the high-end values for predicted concentrations represent predictions based on parameter values that are very conservative. The low-end values in the range represent predictions based on reasonable parameter values (i.e., site-specific, if available). Only those constituents, which are projected to reach the water table in 100 years (for organic compounds) or 500 years (for metals and radionuclides) from the existing S-3 sludge, are presented in this table. A >500-year range for the time range indicates that the constituent is expected to reach the aquifer within 500 years, however, the peak concentration is not expected to be reached within 500 years of simulation time.

Using SESOIL, predicted concentrations of all the organic compounds are relatively low compared to existing groundwater contamination, with the exception of 1,1,2-TCA. In addition, the concentrations of organic compounds have already peaked and are predicted to decline in the future. Figure E.22 presents plots of projected concentration of PCE with time due to loading from S-3 Site using SESOIL with less conservative (a) and very conservative (b) parameters, respectively.

Using ODAST to calculate contributions from inorganic compounds and radionuclides, the predicted concentrations of cadmium, chromium, cyanide, mercury, uranium, and ^{99}Tc , ^{238}Pu , $^{239/240}\text{Pu}$ are high compared to preliminary remedial goals (PRGs) but not when compared to current groundwater maximum concentrations. However, based on conservative parameters, concentrations of uranium and ^{99}Tc are predicted to exceed current groundwater concentrations in the future. Figure E.23 presents the modeling results for cadmium and uranium isotopes as representative of inorganic contaminants. These graphs show the arrival times, peak concentrations, and times of peak concentrations.

E.4.3.1.2 S-3 Site components 2 and 3

The summary of the simulated maximum groundwater and surface water concentration ranges at the receptors due to contaminant loading from the S-3 Site to NT-1 and -2 and Bear Creek are presented in Tables E.32, E.33, and E.34, respectively. Only the COPCs, which are predicted to produce groundwater concentrations at levels greater than their MCLs/PRGs, are presented in these tables. Also presented in these tables are predicted peak concentration ranges in the groundwater and in the surface water, and the corresponding time ranges for the peak concentrations in the groundwater. The predicted groundwater concentrations represent the concentrations in the shallow bedrock system near NT-1 (Table E.32), in the shallow water table system near Bear Creek upstream of BCK12.46 (Table E.33), and in the deep system near NT-2 (Table E.34). The predicted surface water concentrations at NT-1 (Table E.32) and NT-2 (Table E.33) represent the groundwater concentrations near NT-1 and NT-2, divided by the respective dilution factors. Figures E.24 through E.27 present plots of normalized groundwater concentrations versus time for nitrate, uranium, PCE, and ^{99}Tc , respectively, for the modeled pathway to NT-1 (shallow bedrock along strike to NT-1). Figures E.28 and E.29 present plots of normalized groundwater concentrations versus time for nitrate and uranium, respectively, for the modeled pathway to NT-2 (deep bedrock along strike to NT-2). Figures E.30 and E.31 present plots of normalized groundwater concentrations versus time for nitrate and uranium, respectively, for the modeled pathway to Bear Creek (water table interval to Bear Creek groundwater). These figures mainly show the effects of fracture velocity and fracture aperture on the model predictions for the three modeled pathways from S-3 Site for the contaminants as specified in the respective figures. As evident from these figures the predicted peak concentrations for all of these contaminants increase with the increase of both fracture velocity and aperture, while the time

required to reach the peak concentrations is significantly reduced with slight increases of these parameters.

Surface water concentrations at NT-1 are predicted to increase over time for all modeled constituents but manganese and strontium. When compared with observed surface water concentrations, it appears that the peak concentrations of manganese and strontium have already been reached and approximately steady state conditions have been attained. The predicted peak surface water concentration ranges for uranium, cadmium, manganese, mercury, nickel, nitrate, ^{99}Tc , and PCE exceeded the groundwater MCLs or RGOs. However, when compared with the analytical data from NT-1, the maximum concentration of only uranium does not lie within the predicted range, indicating that the concentrations of uranium may increase in the future over a period from 40 to 150 years before reaching steady state. For cadmium, mercury, nickel, nitrate, PCE and ^{99}Tc , it may be concluded that these constituents may be very close to reaching steady state or may take another 100 to 200 years to reach the steady state conditions although peak concentrations may increase only slightly.

Surface water concentrations at NT-2 are predicted to increase over time for all modeled constituents. The predicted peak surface water concentration ranges for uranium, manganese, and nitrate exceeded the groundwater MCLs or RGOs. When compared with the analytical data from NT-2, the maximum concentrations of uranium, barium, and nitrate do not lie within the predicted range, indicating that the concentrations of these constituents may increase in the future over a period from 100 to >1000 years for uranium (see Fig. E.29), 75 to 400 years for nitrate (Fig. E.28), and 40 to 100 years for barium, before reaching steady state.

Near Bear Creek upstream of BCK 12.46, like uranium and nitrate (as shown in Figs. E.30 and E.31), all the constituents are predicted to have already reached the peak concentrations, which occurred during operation of the S-3 Site. Concentrations of uranium and nitrate in this reach of Bear Creek are predicted to further decrease in the future. This situation is consistent with the conceptual model for contaminant distribution at the S-3 Site.

In general, the predicted concentrations of organics in groundwater are relatively low except for PCE because of its high concentration and the assumption of DNAPL at the source. As shown in Table E.32, predicted concentrations of PCE at NT-1 range from 4 to 58 ppb with an average of 31 ppb as compared to the observed 19 ppb (Table D.27), which lies within the predicted range. Therefore, it may be concluded that PCE either has already reached the peak or may continue to increase for another 30 years before reaching steady state.

E.4.3.2 Oil Landfarm FA

E.4.3.2.1 Oil Landfarm FA component 1

BYBY Leachate Modeling

The results of the vadose zone modeling for BYBY are summarized in Table E.35, which has the same format as the results table for the S-3 Site model (Table E.31). The soil exposure concentrations presented in this table represent the 95% UCL values for BYBY soil aggregates (Tables D.36 and D.37 in Appendix D). Table E.35 also presents for comparison the current maximum concentrations in the groundwater for the OLF OU 1 groundwater aggregate (Table D.60 in Appendix D) and drinking water MCLs or RGOs (if MCL is not available). As discussed under S-3 leachate modeling results (Sect. E.4.3.1), the high-end values for the predicted concentrations represent predictions based on parameter values that are very conservative.

From the results of soil sampling, it was determined that most VOC contamination in soils at BYBY is submerged by groundwater; *Crystal Ball* with partition modeling was used to make predictions for concentrations in groundwater for these compounds. Bis(2-ethylhexyl)phthalate, PCBs, antimony, beryllium, cyanide, manganese, nickel, selenium, silver, zinc, ^{99}Tc , and ^{232}Th are also submerged in groundwater; therefore, *Crystal Ball* with partition model was used to make the predictions for these compounds. Among the organics, acetone, TCE, PCE, and PCBs are expected to produce concentrations in groundwater that are higher than their PRGs. Only TCE and PCE are observed in groundwater at BYBY (Table D.60 in Appendix D) with concentrations higher than the PRGs and also higher than the predicted values.

Using SESOIL, the predicted concentrations of SVOCs in groundwater are relatively low compared to groundwater PRGs with the exception of carbazole (Table E.35). PAHs and the furans are highly adsorbing compounds and are not expected to reach the water table within 100 years.

Using ODAST, the predicted concentrations (high-end values) of arsenic, barium, cadmium, chromium, cobalt, copper, lead, and mercury are high compared to PRGs. However, only barium, cadmium, chromium, and copper are expected to exceed the PRGs when compared to the low-end values of the range. All the uranium isotopes have already exceeded the PRGs, and the concentrations are expected to increase in the future. Figure E.28 presents a plot of projected cadmium concentration versus time and the plot of uranium isotopes.

SL 1 Leachate Modeling

The results of the vadose zone modeling for SL 1 are summarized in Table E.36, which has the same format as the results table for the S-3 Site model (Table E.31). The soil exposure concentrations presented in this table represent the 95% UCL values for SL 1 soil aggregates (Tables D.43, D.44, and D.45 in Appendix D). This table also presents for comparison the current maximum concentrations in the groundwater for the OLF groundwater aggregate (Table D.56 in Appendix D) and drinking water MCLs or RGOs (if MCL is not available).

Figure E.32 presents a plot of projected concentration of cadmium versus time due to loading from SL 1 with site-specific values (less conservative parameters). The figure shows the arrival time (i.e., the time for the contaminant to migrate from the source to the water table with the percolating water) within 500 years of simulation; however, the concentration of cadmium is expected to rise after 500 years, and peak concentration was not attained.

Based on soil sampling results, the constituents that have the maximum soil concentrations below the water table are: 2-butanone, 2-hexanone, 4-methyl-2-pentanone, barium, beryllium, manganese, ^{137}Cs , and ^{208}Th . *Crystal Ball* with partition modeling was used to make predictions for these constituents. The concentration ranges for these constituents represent the 95% UCL. The LCL concentrations for each modeled chemical are below the groundwater PRGs, with the exception of 2-butanone and 4-methyl-2-pentanone. These two chemicals have very low K_d values; and the model, therefore, produces very high concentrations in groundwater for these two chemicals. These high concentrations are probably not reasonable because both 2-butanone and 4-methyl-2-pentanone usually have relatively high biodegradation rates, and their concentrations would be expected to be relatively low if biodegradation had been considered. Groundwater sampling results support this supposition, and it is assumed that these two chemicals are not expected to reach the peak values predicted by the model.

The predicted concentrations of organic compounds that are contaminants above the water table are relatively low compared to groundwater PRGs with the exception of carbazole. The PAHs and

the pesticides and PCBs remain adsorbed to the soil, and are not expected to reach the water table within 100 years. The predicted concentrations (high-end values) of cadmium, copper, mercury, silver, zinc, and uranium isotopes are high compared to PRGs. However, only cadmium and copper are expected to exceed the PRGs when compared to the low-end values of the range. Concentrations for all metals are expected to rise in the future.

OLF Leachate Modeling

The results of the vadose zone modeling for OLF are summarized in Table E.37. Based on what is known of soils in the source, leachate modeling was conducted for only PCBs and uranium. PCBs were modeled using SESOIL, indicating that because the PCBs remain adsorbed to the soil, they are not expected to reach the water table within 100 years of simulation; the results for PCBs are, therefore, excluded from the summary table. Uranium was modeled using ODAST, and the summary results are shown in this table. Both low- and high-end values exceed uranium groundwater PRG. Figure E.28 presents the plot of projected concentration of uranium versus time due to loading from OLF. The figure shows the arrival time to be around 30 years; concentration will peak in ~110 years. Based on this figure, the current (~45 years of simulation time) uranium concentrations in groundwater due to loading from OLF are expected to be 0.2 mg/L.

E.4.3.2.2 Oil Landfarm FA components 2 and 3

The summary of the simulated maximum groundwater and surface water concentrations at the receptors due to contaminant loading from BYBY to NT-3 and Bear Creek are presented in Tables E.38 and E.39, respectively. Only the COPCs, which are predicted to produce groundwater concentrations at levels greater than their MCLs/PRGs, are presented in these tables. Also presented in these tables are predicted peak concentration ranges in the groundwater and in the surface water, and the corresponding time ranges for the peak concentrations in the groundwater. The predicted groundwater concentrations represent the concentrations in the shallow system near NT-3 (Table E.38) and Bear Creek adjacent to BYBY (Table E.39). The predicted surface water concentrations at NT-3 (Table E.38) present the groundwater concentrations near NT-3 divided by the dilution factor. Figures E.33 and E.34 present plots of normalized groundwater concentrations versus time for uranium and PCE for the modeled pathway to NT-3 (shallow bedrock along strike to NT-3). Similar effects on model predictions as discussed under S-3 Site results are observed here. However, it can be seen from these figures that steady state conditions have nearly been reached for both of these contaminants for all the modeled velocities, and the peak concentrations are not expected to increase in the future.

Overall, the modeling results for BYBY indicate that groundwater concentrations near NT-3 and Bear Creek are not expected to increase over time for all modeled constituents, mainly because the source of contamination is very close to the receptors (NT-3 and Bear Creek). However, it should be noted here that a continuous steady-state source was used in the modeling, therefore, concentrations were not predicted to decrease in the future. Using a source that is steadily depleting would ultimately result in lower peak concentrations. Because the mass of contaminants in the source cannot be predicted with any certainty, a conservative approach using a constant source was used. At NT-3, the predicted maximum surface water concentrations of antimony, manganese, mercury, uranium, ⁹⁹Tc, methylene chloride, TCE, and PCE exceeded the groundwater MCLs or RGOs. Also, when compared with the analytical data from NT-3, the maximum observed concentrations of these constituents excluding uranium and manganese are shown to be lower than their predicted maximums, indicating that the model is overpredicting for these contaminants. Uranium and manganese, on the other hand, are predicted to be lower than the observed maximum, indicating that the model is underpredicting for these contaminants.

The predicted concentrations of organics in groundwater represent highly conservative values. Most of these organics are highly degradable; their concentrations are expected to be zero within the time interval presented in these tables. The predicted surface water concentrations are based on the dilution factor for nitrate; therefore, these results are conservative because volatilization is not accounted for in this calculation. In reality, the concentrations of organics in surface water will be significantly lower because they will be volatilized quickly after discharging to NT-3 or Bear Creek. This may be why the organic COPCs are not currently detected in the surface water at NT-3.

E.4.3.3 Bear Creek Burial Grounds FA

E.4.3.3.1 Bear Creek Burial Grounds FA component 1

BG-A North Leachate Modeling

The results of the vadose zone modeling for BG-A North are summarized in Table E.40, which has the same format as the results table for the S-3 Site model (Table E.31). The soil exposure concentrations presented in this table represent either the 95% UCL values for BG-A North (including A-16, -17, and -18) soil aggregates (Tables D.69, D.70, and D.71 in Appendix D) or approximate concentration based on contaminant inventory data (Appendix A). This table also presents, for comparison, the current maximum concentrations in the groundwater for the BCBG groundwater aggregate (Table D.91 in Appendix D) and drinking water MCLs or RGOs (if MCL is not available). As discussed under S-3 leachate modeling results, the high-end values for the predicted concentrations represent predictions based on parameter values that are very conservative, and low-end values in the range represent predictions based on reasonable parameter values (i.e., site-specific, if available).

Predicted concentrations of organic compounds are relatively low compared to groundwater PRGs. PAHs and the pesticides and PCBs are highly adsorbing compounds and are not expected to reach the water table within 100 years. Figure E.30 presents a plot of projected concentration of 1,1,1-TCA versus time due to loading from BG-A North using SESOIL. The figure shows the arrival time (i.e., the time for the contaminant to migrate from the source to the water table with the percolating water), the peak concentration, and the time to reach the peak concentration. Based on this figure, the maximum loading concentrations for 1,1,1-TCA are predicted to be ~0.022 mg/L, which is much less than the MCL (0.2 mg/L) or current BCBG groundwater aggregate maximum of 13 mg/L.

Predicted concentrations (high-end values) of barium, beryllium, uranium, and ^{99}Tc are high compared to PRGs. The low-end values (or calculations based on site-specific parameters when available) for these constituents are also higher than the PRGs. Figure E.35 presents the modeling results for uranium and ^{99}Tc as representative of inorganic compounds and radionuclides. Because of uranium abundance in BG-A North, a steady-state concentration is attained whereas ^{99}Tc is expected to be depleted in 60 years.

Based on soil sampling results at BG-A North, the constituents that have the maximum soil concentrations below the water table are: benzene, chloroform, methylene chloride, toluene, bis(2-ethylhexyl)phthalate, barium, beryllium, copper, cyanide, manganese, nickel, and silver. Crystal Ball with partition modeling was used to make predictions for these constituents. The concentration ranges for these constituents represent the 95% confidence limit. Most of these compounds are predicted to be in groundwater exceeding the groundwater PRGs. However, because volatility and biodegradation were not accounted for, concentrations of VOCs are probably over predictions.

BG-A South Leachate Modeling

The results of the leachate modeling for BG-A South are summarized in Table E.41. The soil exposure concentrations presented in this table represent either the 95% UCL values for BG-A South soil aggregates (Tables D.67 and D.68 in Appendix D) or approximate concentration based on contaminant inventory data (Appendix A). This table also presents for comparison the current maximum concentrations in the groundwater for the BCBG groundwater aggregate (Table D.91 in Appendix D) and drinking water MCLs or RGOs (if MCL is not available).

Based on soil sampling results, the maximum soil concentrations for all the constituents are below the water table (i.e., contamination is almost completely inundated with water). Therefore, only Crystal Ball with partition modeling was used to make predictions for this site. The concentration ranges represent the 95% confidence limit. In general, very high concentrations for organics have been observed. Many of these constituents are expected to reach close to their solubility indicating the presence of NAPL. Among the metals, only uranium is shown to be present in relatively high concentrations.

WIP Leachate Modeling

The results of the vadose zone modeling for BG-A North are summarized in Table E.42. The soil exposure concentrations presented in this table represent either the 95% UCL values for WIP (includes WIP North and South, BG-B, and BG-D South) soil aggregates (Tables D.73 and D.74 in Appendix D) or approximate concentration based on contaminant inventory data (Appendix A). This table also presents for comparison the current maximum concentrations in the groundwater for the BCBG groundwater aggregate (Table D.91 in Appendix D) and drinking water MCLs or RGOs (if MCL is not available).

Predicted high-end concentrations values of benzene, methylene chloride, 1,1,1-TCA, 1,4-dichlorobenzene, and phenol are quite high (i.e., >PRGs). The PAHs and the pesticides and PCBs remain adsorbed to the soil and are not expected to reach the water table within 100 years. Figure E.30 presents a plot of projected concentration of benzene versus time due to loading from WIP using SESOIL. As can be seen from this figure, benzene concentration may have already peaked due to loading from WIP and that the concentration is currently decreasing. Based on modeling results, the predicted benzene concentrations at the present time (i.e., 45 years of simulation time) are expected to be ~0.5 mg/L as compared to 0.42 mg/L observed in BCBG groundwater aggregate.

The predicted concentrations (conservative) of arsenic, barium, beryllium, cyanide, manganese, uranium, and ^{99}Tc are high compared to PRGs. However, the low-end values (or calculations based on site-specific parameters when available) for only cyanide, uranium, and ^{99}Tc are higher than the PRGs. Figure E.30 presents the modeling results for uranium as representative of inorganic compounds. Like BG-A North, because of uranium abundance in WIP, uranium is expected to reach its peak concentrations and attain steady-state condition.

Based on soil sampling results at WIP, the constituents that have the maximum soil concentrations below the water table are methylene chloride and manganese. Therefore, Crystal Ball with partition modeling was used to make predictions for these constituents. The concentration ranges for these constituents represent the 95% confidence limit. For methylene chloride, both LCLs and UCLs exceed its PRG; however, for manganese, only the UCL exceeds the manganese secondary MCL.

E.4.3.3.2 Bear Creek Burial Grounds FA components 2 and 3

The summary of the simulated maximum groundwater and surface water concentration ranges at the receptors due to contaminant loading from BG-A North and South to NT-7, and from WIP and BG-C (includes BG-C East and West, and BG-D East) to NT-8, are presented in Tables E.43, E.45 and E.47, respectively. The results of simulated maximum groundwater concentrations along strike to Picket A from these sources are presented in Tables E.44, E.46, E.48. In Table E.44 and E.46, predicted concentrations represent simulation results of individual sources, and the sum of the contributions from these sources are presented in Table E.48. Only the COPCs, which are predicted to produce groundwater concentrations greater than their MCLs/PRGs, are presented in these tables. Also presented in these tables are predicted peak concentration ranges in the groundwater and in the surface water, and the corresponding time ranges for the peak concentrations in the groundwater. The predicted groundwater concentrations represent the concentrations in the shallow system near NT-7 (Table E.43) and NT-8 (Table E.45 and Table E.47), and in the deeper system near Picket A (Tables E.44, E.46, E.48). The predicted surface water concentrations at NT-7 (Table E.43) and NT-8 (Tables E.45 and E.47) represent the groundwater concentrations near NT-7 and NT-8 divided by their respective dilution factors. Table E.49 presents predicted surface water concentrations at NT-8 based on contributions from both BG-WIP and BG-C. In general, the predicted range for a constituent is greater than the observed range, except for uranium and ^{40}K . Under prediction for these two contaminants may be due to the selection of source term concentrations.

The source term concentrations for BG-A North and South are based on results from component 1, currently observed maximum groundwater concentrations, or BG-A South Standpipe liquid samples (Tables E.26 and E.27). The source term concentrations for WIP are based on results from component 1, currently observed maximum groundwater concentrations or from chemical analysis of water from leachate collection systems in Seep 2, or BG-B Standpipe liquid samples (Table E.25). The source term concentrations for BG-C represent the maximum concentrations from chemical analysis of water from leachate collection systems in Seeps 3 and 4 and BG C-West Toe (Table D.10 in Appendix D), or from the 1983 to 1984 standpipe samples from BG-C East. These concentrations were used as initial concentrations for the CRAFLUSH modeling.

Figures E.36 and E.37 represent plots of normalized groundwater concentrations versus time for uranium and PCE, respectively, for the modeled pathway to NT-7 (shallow bedrock along strike to NT-7), and Figures E.38 and E.39 represent plots of normalized groundwater concentrations versus time for uranium and TCE for the modeled pathway to NT-8 (shallow bedrock along strike BG-WIP to NT-7). Similar effects on model predictions as discussed under S-3 Site results are observed here. However, it can be seen from these figures that steady state conditions may have been reached for all these contaminants at high-end velocities, and the peak concentrations are not expected to increase in the future for these scenarios. On the other hand, at lower velocities (Figs. E.36 and E.38) or higher retardation factors (Fig. E.39), the peak concentrations have not been reached yet, and the concentrations will continue to increase in the future before reaching steady state.

Groundwater concentrations near NT-7 and NT-8 are expected to increase over time for all modeled constituents. The predicted maximum peak concentrations at NT-7 (Table E.43) for antimony, beryllium, cyanide, lead, lithium, manganese, uranium, 1,1,1-TCA, 1,1,2-TCA, 1,1-DCE, benzene, carbon tetrachloride, chloroform, PCE, trans-1,2-DCE, TCE, vinyl chloride, and ^{40}K are expected to exceed the MCLs/RGOs. Similarly, the predicted maximum concentrations at NT-8 (Table E.45) for arsenic, beryllium, boron, cadmium, cyanide, lead, lithium, manganese, thallium, uranium, 1,1,1-TCA, 1,1,2-TCA, 1,1-DCE, 1,2-DCA, benzene, bis(2-ethylhexyl)phthalate, methylene chloride, PCBs, PCE, trans-1,2-DCE, TCE, vinyl chloride, ^{40}K , and ^{99}Tc are expected to exceed the MCLs/RGOs. Predicted groundwater concentrations near Picket A due to contaminant loading from

BG-A North and South, BG-WIP, and BG-C (Table E.48) indicate that all the COPCs except chloroform listed in the table are expected to be above the MCLs/PRGs. However, it should be noted that, like BYBY, a steady-state source was used in modeling BCBG. This is justified in this case by the known large mass of contaminants in the source trenches at this site that is unlikely to be depleted significantly in this time period under these conditions.

The predicted concentrations of organics and cyanide in groundwater represent highly conservative values. These organics and cyanide are degradable under most natural conditions. Predicted surface water concentrations are based on the dilution factor for nitrate, therefore, these results are conservative because volatilization is not accounted for in this calculation. In reality, the concentrations of organics in surface water will be significantly lower because they will be volatilized quickly after discharging to NT-7 and NT-8 before reaching Bear Creek and to BCK9.47.

E.4.3.4 Migration to BCK 9.47 – Component 4

Table E.50 presents the summary of combined modeling results from the S-3, OLF, and BCBG FAs. The estimated future maximum surface water concentrations at BCK 9.47 for BCV COPCs are presented in these tables. Table E.50 represents the mass balance calculations based on the predicted peak concentrations (both low and high) for all the COPCs from the different source areas at the BCV site. As discussed under Sect. E.4.2, Modeling Approach for Component 4, the surface water concentrations at BCK 9.47 were estimated by making valley-wide mass balance calculations around Bear Creek (i.e., the surface water concentration of a constituent at BCK 9.47 equals the total maximum mass of that constituent entering Bear Creek for a certain period of time divided by the volumetric water flow at BCK 9.47 at that same period of time). Although contaminants other than the COPCs at a particular site (e.g., S-3, BYBY, etc.) are not accounted for in the overall balance calculations, it was assumed that the peak of the contaminants in the Bear Creek and its tributaries reaches at BCK 9.47 at the same time, and the contaminants flow downstream without any attenuation. Mass balance calculations based on predicted maximums indicate that the concentrations of inorganic and radionuclides (antimony, beryllium, cadmium, cyanide, lithium, manganese, thallium, total uranium, nitrate, and ^{99}Tc), and organic compounds (1,1-DCE, 1,2-DCA, benzene, methylene chloride, PCE, TCE, trans-1,1,2-DCA, and vinyl chloride) are expected to exceed the MCLs or RGOs in the future. Recent data indicate that uranium, nitrate, and ^{99}Tc have already exceeded their MCLs or RGOs. Also, current surface water concentrations of these constituents are below the predicted maximum in the future. Therefore, it is expected that concentrations of all these inorganic, radionuclides, and organic constituents as mentioned above (including total uranium, nitrate, and ^{99}Tc) are expected to increase in the future.

The mass balance calculations for VOCs without considering volatilization are highly conservative. It is estimated that >80% of VOCs that are discharged from the tributary stream to Bear Creek volatilize before reaching BCK 9.47 (Sect. E.2). This situation is not expected to change in the foreseeable future; therefore, the results for VOCs presented in Table E.50 are highly conservative.

Table E.50 also shows a comparison between the predicted and the currently observed surface water concentrations at BCK 9.47 for the COPCs at the BCV site. In general, it can be seen from this table that the predicted concentrations are slightly higher than the currently observed concentrations, indicating that the peak concentrations for the COPCs might not have reached yet. However, for all the inorganic constituents, usually the observed maximum lies within the predicted range.

E.4.3.5 Migration in the Maynardville Limestone

Results of contaminant fate and transport modeling using CRAFLUSH for TCE in the deep Maynardville Limestone are presented in Table E.51 and in Supporting Information, Section E.8. It has been observed from this modeling study that concentration of TCE at the integrator plane may continue to increase in the future until reaching the peak (150 ppb) at ~ 500 years (Table E.51 and Fig. E.40). It was also predicted (see Supporting information, Section E.8) that it might take more than 1000 years before TCE concentration will be reduced to below its MCL at the integrator plane. It should be noted here, that the modeling was performed assuming no biodegradation of TCE supported by the current field observations, which indicate that concentrations within the TCE plume are fairly constant.

E.4.3.6 Dissipation of Pressure Bulge Beneath S-3 Site

The results of interface modeling to investigate dissipation of the pressure bulge beneath S-3 Site are presented in detail in Supporting Information, Section E.9. The results of this investigation indicated that the pressure bulge observed beneath S-3 Site is almost at steady state (Fig. E.41). It may take thousands of years for natural dissipation of this pressure bulge unless outside disturbance is created (pumping or increase the matrix hydraulic conductivity by hydraulic fracturing). Therefore, it is expected that with slow dissipation of pressure that the pressure bulge it will continue to feed contamination to the tributaries for thousands of years.

E.5 SUMMARY AND CONCLUSIONS

Section E.1 of this Appendix identified four questions that needed to be answered in order to provide input on contaminant releases in BCV:

- Where are the sources of contamination in the valley, and what sources have similar waste and hydrogeologic characteristics, and thus could be addressed with similar response actions?
- Which sources in the valley are currently contributing the most to releases?
- Which source releases are likely to contribute the most to releases in the future?

This section provides summarized answers to these questions based on the development of the conceptual model, evaluation of current releases, and modeling of future potential releases.

E.5.1 CONTAMINANT SOURCES

Based on the review of all types of data, the following conclusions were made about the contaminant sources in BCV:

- The total uranium inventory is estimated to be >15 million Kg, or ~16,800 tons. This estimate does not include the uranium that was disposed in the S-3 Ponds and is currently in the groundwater below the site. The primary sources of uranium in the Maynardville Limestone and Bear Creek appear to be BYBY and the secondary sources (soils and groundwater plumes) underlying the S-3 Site. The largest quantities of uranium are buried in the BCBG area; however, these sources are in solid forms and are probably immobile.
- Although the greatest mass of uranium is located in the BCBG, the highest releases occur at BYBY and the S-3 Site, where the form of uranium is more mobile and located closer to the exit pathway.
- Organic constituents appear to have been disposed of in most of the waste units in the valley, with the largest sources being BG-A South and North, S-3, and BYBY. Additional but lesser sources include BG-D, BG-E East, and SL 1. At three sites, BG-A North, BYBY, and to some extent, S-3, contaminants have migrated from the unit in a nonaqueous phase, resulting in DNAPL in the groundwater.
- There is no primary waste unit in BCV currently acting as a source of nitrate; however, past releases from the S-3 Ponds have resulted in a secondary source: neutralized waste water in the shallow and deep groundwater systems in the Nolichucky Shale at the S-3 Site.
- During a large part of the year, sources with current active releases are all in direct contact with the groundwater, including the S-3 secondary plumes, BYBY, BG-A South, and BG-C East and BG-D East. With the exception of BG-C East and BG-D East, these sites are located near Bear Creek and the Nolichucky Shale/Maynardville Limestone contact.

E.5.2 CURRENT RELEASES

- Uranium, nitrate, and several VOCs are the major contaminants released to surface water and groundwater. Of the three, uranium poses the greatest human health hazard, contributing 98% of the total risk resulting from contaminant flux leaving BCV at BCK 9.47 and 64% to total toxic effects.
- Most of the uranium migrating off site via surface water probably comes from NT-3 (~40%). Based on soil boring results and Ultra Sonic Ranging and Data System survey results, the source of the majority of the uranium at NT-3 is the BYBY. The second greatest identified source is BCK 12.36 and NT-1, which captures fluxes coming from the S-3 Site and the S-3 groundwater plume.
- The source of a significant percentage of the uranium flux measured at BCK 9.47 (~31%) is not easily identifiable. The source of the ungaged uranium is likely the shallow groundwater plumes from BYBY and S-3 Site, and runoff from the BYBY causing direct discharge to Bear Creek and the Maynardville Limestone.
- Nitrate, which has been the focus of many studies in BCV in the past, is detected in the upper portions of the valley at BCK 12.36, NT-1, and NT-2. No sources of nitrate are found downgradient of these areas. Nitrate, unlike other contaminants, may be moving off site via the intermediate/deep groundwater in the Maynardville Limestone.
- VOCs are detected in several of the tributaries in the valley, with the greatest amounts entering Bear Creek at NT-7 (27%) and NT-8 (71%). The primary VOCs in these tributaries are: 1,1-DCE (with concentrations ranging from 33 to 410 $\mu\text{g/L}$), PCE (16 to 120 $\mu\text{g/L}$), 1,1,1-TCA, 1,1-DCA, 1,2-DCE, TCE, and vinyl chloride. The primary waste sources for these VOCs appear to be BG-A South and BG-A North, based on shallow groundwater results, and BG-C East and BG-D East, based on seep and transect sampling results taken along NT-8. DNAPL underlying the BCBG is also an active source.

It is estimated that >80% (or 55 Kg) of the VOC mass detected in the tributaries during the 10-month study period volatilized prior to reaching BCK 9.47/SS-05.

E.5.3 FUTURE RELEASES

- Based on modeling results (leachate modeling and CRAFLUSH modeling), it appears that uranium will continue to be a major contaminant of concern both in groundwater and surface water. Leachate modeling indicates that uranium may be leaching from BYBY, S-3 Site, and BCBG at concentrations significantly higher than its drinking water MCL (i.e., 0.02 mg/L). Results of CRAFLUSH modeling combined with dilution and mass balance calculations indicate that the concentrations of uranium in NT-1, -2, -3, -7, and -8, and also in BCK 9.47, may either increase in the future or remain at current level.
- CRAFLUSH modeling results indicate that the concentrations of ^{99}Tc in BCK 9.47 may increase over a long period of time due to loading from the S-3 Site, BYBY, and BG-WIP.
- Some metals (e.g., antimony, beryllium, cadmium, lithium, and thallium) that are currently adsorbed to soil at the sources may eventually leach to the groundwater and may become both groundwater and surface water contaminants of concern in the future at the IP.

- Results of CRAFLUSH modeling combined with dilution and mass balance calculations show that the secondary source of nitrate migrating along strike in shallow and deep bedrock will continue to feed contamination for NT-1 and NT-2 and eventually to BCK 9.47 for approximately another 400 years.
- Because of the possible presence of DNAPL in BCBG and also in S-3 Site, the dissolved phase will continue to be a groundwater problem for a long time until the source is completely deleted or degraded. However, because of the high volatility of VOCs, they are not expected to occur in surface water at concentrations greater than those observed today.
- Based on contaminant fate and transport modeling using CRAFLUSH for TCE in the deep Maynardville Limestone, it can be concluded that degradation of TCE is minimal in the deep system, and the concentration of TCE at the integrator plane will increase in the future until reaching a peak at approximately 500 years.
- The results of interface modeling near S-3 indicated that the pressure bulge observed beneath S-3 Site is almost at steady state. It may take thousands of years for natural dissipation of this pressure bulge, and therefore, it is expected that with slow dissipation of the pressure bulge it will continue to feed contamination to the tributaries for thousands of years.

E.6 REFERENCES

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E.7 FIGURES

BEAR CREEK VALLEY KEY MAP

LEGEND:

- BEAR CREEK & TRIBUTARIES
- SUBWATERSHED BOUNDARY
- SOURCE AREAS
- NT-2..... SURFACE WATER GAGED STATION
- SS-1 SPRING

Fig. E.1. BCV waste areas and watershed.

Sub Watershed	Primary Source Units
Upper Bear Creek/NT-1	S-3
NT-2	
NT-3	Bonyard/Burnyard, Oil Landfarm, Sanitary Landfill 1
NT-4	Oil Landfarm, Sanitary Landfill 1
NT-5	
NT-6	BG_A South, BG-A North
NT-7	BG_A South, BG-A North, A-16, A-17, A-18, BG-B, WIP-South, WIP-North, BG-C East
NT-8	BG-B, WIP-South, WIP-North, BG-C East, BG-C West, BG-D East, BG-D South, BG-D West, BG-E, BG-J
Bear Creek Valley (BCK 9.4)	All Sources

BEAR CREEK
VALLEY
WATERSHED

Fig. E.2. Uranium inventory for the waste areas in BCV.

400 800
1" = 800'

LEGEND:

BEAR CREEK VALLEY URANIUM INVENTORY

Site	Uranium Inventory (Kg)
S-3 Site (1)	18,000
Boneyard/Burnyard (1)	250,000
Oil Landfarm (1)	3,600
Sanitary Landfill 1 (1)	13,000
BG-A South (2)	930,000
BG-A North (2)	930,000
A-16 (2)	27,000
A-17 (2)	42,000
A-18 (2)	21,000
BG-B (2)	6,100,000
BG-C East (2)	250,000
BG-C West (2)	680,000
BG-D East (2)	3,400,000
BG-D South (2)	30,000
BG-E (2)	1,200,000
BG-D West (2)	350,000
BG-J (2)	1,900,000
WJP-N (2)	1,670,000
WJP-S (2)	1,120,000

- (1) Estimated from analytical data and information on source volume
(2) Estimated from inventory records

Bear Creek Valley

Fig. E.4. Geological cross sections of BCV showing principal waste areas.

ORDOVICIAN					Predominantly Clastic	
Upper	Middle	Chickamauga Group (Och)	100 - 170		Omc	Moccasin Formation
			105 - 110		Owi	Written Formation
			5 - 10		Obw	Bowen Formation
			110 - 115		Obe	Benbolt / Wardell Formation
			80 - 85		Ork	Rockdell Formation
Lower	Knox Group (OCK)	75 - 80	OH		Hogskin Member Egmont Shale Member	I incl. in Fm
		70 - 80	Oe		Edison Member	
			Obl		Blackford Formation	
		75 - 150	Oma		Mascot Dolomite	
		90 - 150	OK	Kingsport Formation		
Upper	Conasauga Group (Cc)	40 - 60	OLV	Longview Dolomite		
		152 - 213	OC	Chepultepec Dolomite		
		244 - 335	CC	Copper Ridge Dolomite		
		100 - 110	CM	Maynardville Limestone		
		150 - 180	EN	Nolichucky Shale		
Middle		98 - 125	EDG	Maryville Limestone (Dismal Gap Formation)		
		25 - 34	ERG	Rogersville Shale		
		31 - 70	EI	Rutledge Limestone (Friendship Formation)		
		56 - 70	EPV	Pumpkin Valley Shale		
		122 - 183	EI	Rome Formation		
Lower						Predominantly Clastic

Fig. E.5. Geology of BCV. Picture of the Nolichucky Shale courtesy of P. Lemiski.

Fig. E.6. Schematic showing conceptual groundwater flow in BCV.

E7-11

Fig. E.7. Conceptual model for the shallow groundwater interval in BCV.

Fig. E.8. Particle tracking model output showing route and travel time (years) for subsurface particles to reach receiving surface water.

BYBY

Fig. E.9. Conceptual model for contaminant distribution and migration at BYBY.

Fig. E.10. Conceptual model for contaminant transport in Upper BCV.

um-contaminated groundwater

ek

reek

port pathway

port pathway

S-3 SITE

Historical Plumes act
as secondary source

Fig. E.11. Distribution of mass fluxes for radionuclides and VOCs in tributaries NT-1 to NT-8.

LEGEND:

BEAR CREEK &
TRIBUTARIES

SUBWATERSHED BOUNDARY

SOURCE AREAS

▽ NT-2.....SURFACE WATER SAMPLE (OU4)
SURFACE WATER SAMPLE

● SS-1 AT SPRINGS (OU4)

BEAR CREEK
VALLEY
WATERSHED

400 800
1" = 800'

Fig. E.12. Extent of groundwater contaminant plumes in Upper BCV.

LEGEND:

=====	ROADS	[White Box]	... ALPHA >15 pCi/L
-----	BEAR CREEK & TRIBUTARIES	[Dotted Box]	... NITRATE >10 ug/L
-----	10' CONTOUR	[Diagonal Lines Box]	... TCE >5 ug/L
○	SURFACE WATER	[Cross-hatched Box]	NITRATE/
ALPHA MIXTURE
○ SS-5	SAMPLE AT SPRINGS		

**BEAR CREEK
VALLEY
SHALLOW AND DEEP
GROUNDWATER PLUMES**

Fig. E.13. Conceptual view of BCV integrator point plane.

Percent Contribution to Total Risk for each Carcinogen at BCK 9.4

Percent Contribution to total Toxic Effects at BCK 9.4

Fig. E.14. Contribution to total risk and total toxic effects at the IP from contaminants of concern included in the IP assessment.

**Percent Relative Risks for each Site Contributing to Contaminant Migration
through BCK 9.4**

**Percent Relative Toxicity for each Site Contributing to Contaminant Migration
through BCK 9.4**

Fig. E.15. Percent relative risks and relative toxicity for contributing sites in the IP assessment.

E7-26

Fig. E.16. Relative contributions from BCV sources to BCK 9.47 and SS-5.

Fig. E.17. Generalized components of the conceptual model for contaminant fate and transport.

Develop Conceptual Model

Evaluate Existing Data to Determine

- Sources
- Flow Paths
- Exposure Points

Postulate Future Sources,
Flow Paths, and Exposure
Points

Develop list of Contaminants
to be EvaluatedDevelop Comprehensive list of Site Related Contaminants for
Groundwater

Site related contaminants that
have reached groundwater
determined from background
screen on existing data

Site related contaminants with
potential to leach from primary
sources evaluated using
SESOIL

No Further
Evaluation

No

Are
SRCS > SW
and/or GW
potential
ARARs?

No

Yes

Are
SRCS > SW
and/or GW
ecological
benchmarks?

No

Yes

Are
SRCS > SW
and/or GW
human
health risk
PRGs?

Yes

COPCs to be further evaluated

Conduct Evaluation¹

Fate and Transport Evaluation

Estimate dilution
factors from existing
data¹

1-D fracture flow
modeling using
CRAFLUSH

Geochemical
modeling to
estimate changes in
mobility

Bracket range of concentrations and arrival times of COPCs
at exposure points

¹NOTE: Further evaluation will not be conducted if dilution factors bring the maximum concentration below PRGs and/or potential ARARs at the exposure point.

Fig. E.18. Decision flowchart for evaluating COPCs for the fate and transport model.

E7-29

Fig. E.19. Conceptual model for fate and transport at the S-3 Site.

Fig. E.20. Conceptual model for fate and transport at the sites at OLF FA.

Fig. E.21. Conceptual model for fate and transport at the BCBG FA.

S-3: PCE (low)
Concentration Vs. Time at 609.6 cm Depth

S-3: PCE (high)
Concentration Vs. Time at 609.6 cm Depth

Fig. E.22. Predicted concentration of PCE in leachate at the S-3 Site using conservative and site-specific parameters.

Fig. E.23. Predicted cadmium and radionuclide concentrations in leachate at the S-3 Site.

EFFECT OF FRACTURE VELOCITY S-3 to NT-1 for Nitrate

Fig. E.24. Predicted normalized groundwater concentrations of nitrate near NT-1 for different fracture velocities.

EFFECT OF FRACTURE APERTURE S-3 to NT-1 For Uranium

Fig. E.25. Predicted normalized groundwater concentrations of uranium near NT-1 for different fracture apertures.

EFFECT OF FRACTURE VELOCITY S-3 TO NT-1 FOR PCE

Fig. E.26. Predicted normalized groundwater concentrations of PCE near NT-1 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY S-3 TO NT-1 FOR Tc-99

Fig. E.27. Predicted normalized groundwater concentrations of Tc-99 near NT-1 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY S-3 TO NT-2 FOR NITRATE

Fig. E-28. Predicted normalized groundwater concentrations of nitrate near NT-2 for different fracture velocities.

EFFECTS OF FRACTURE VELOCITY S-3 TO NT-2 FOR URANIUM

Fig. E.29. Predicted normalized groundwater concentrations of uranium near NT-2 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY S - 3 TO BEAR CREEK FOR NITRATE

Fig. E.30. Predicted normalized groundwater concentrations of nitrate near Bear Creek upstream of BCK 12.46 for different fracture velocities.

EFFECT OF FRACTURE APERTURE S-3 TO BEAR CREEK FOR TOTAL URANIUM

Fig. E.31. Predicted normalized groundwater concentrations of uranium near Bear Creek upstream of BCK 12.46 for different fracture velocities.

Fig. E.32. Predicted concentrations of metals and radionuclides in leachate from site in the OLF FA.

EFFECT OF FRACTURE VELOCITY BYBY TO NT-3 FOR TOTAL URANIUM

Fig. E.33. Predicted normalized groundwater concentrations of uranium near NT-3 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY BYBY TO NT-3 FOR PCE

Fig. E.34. Predicted normalized groundwater concentrations of PCE near NT-3 for different fracture velocities.

Fig. E.35. Predicted concentrations of radionuclides and VOCs in leachate at the BCBG FA.

EFFECT OF FRACTURE VELOCITY BG-A N & S TO NT-7 FOR TOTAL URANIUM

Fig. E.36. Predicted normalized groundwater concentrations of uranium near NT-7 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY BG-A N & S TO NT-7 FOR PCE

Fig. E.37. Predicted normalized groundwater concentrations of PCE near NT-7 for different fracture velocities.

EFFECT OF FRACTURE VELOCITY BG WIP TO NT-8 FOR TOTAL URANIUM

Fig. E.38. Predicted normalized groundwater concentrations of uranium near NT-8 for different fracture velocities.

EFFECT OF MATRIX RETARDATION BG WIP TO NT-8 FOR TCE

Fig. E.39. Predicted normalized groundwater concentrations of TCE near NT-8 for different matrix retardation factors.

Fig. E.40. Predicted normalized groundwater concentrations of TCE in the Maynardville Limestone near Picket A.

Predicted pressure bulge
using regional model K-field

Fig. E.41. Simulated pressure bulge beneath S-3 after 60 years.

E.8 TABLES

Table E.1. Contaminant characteristics of burial units in BCV

Waste unit	Waste characteristics		
	From inventory records	From soil sampling results	Detected in nearby shallow groundwater
S-3 Ponds	Nitrate, uranium, ^{137}Ce , 57 and ^{60}Co , ^{237}Np , ^{95}Nb , 238 and ^{239}Pu , ^{106}Ru , ^{90}Sr , 230,232,234 , and ^{238}Th , ^{90}Tc , ^{95}Zr , and isotopes of Cf, Am, I, and Ni.	Tc-99, Th, Uranium, other radionuclides; VOCs, other organics ^a , mercury	Nitrate, uranium, PCE, acetone, 1,1-DCE, Tc-99, metals
Boneyard/Burnyard	Not available	Uranium, mercury, other metals, PCBs, PAHs	Uranium, TCE, PCE, 1,2-DCE, mercury, lithium
Oil Landfarm	Not applicable	PCBs, Uranium ^b	1,2-DCE, 1,1,1-TCA, 1,1-DCE, 1,1-DCA, PCE, TCE
Sanitary Landfill 1	Not available	PCBs, mercury, uranium	1,1-DCA, 1,1,1-TCA, 1,2-DCA
BG-A South	Chemicals - >100,000 Kg: Uranium, >10,000 Kg: 1,1,1-TCA, PCE, Freon, >1000 Kg: benzene, TCE, MEK, PCBs <100 Kg: Be, Li Other - Alcohol, asbestos fuel-water, waste oils, mop water	Not available	Uranium, PCE, TCE, 1,2-DCE, vinyl chloride, Chloroethane
BG-A North	Chemicals - >100,000 Kg: Uranium, PCBs >100 Kg: Th <100 Kg: Be, Li, Tc Other - asbestos, waste oils, mop water	Not available	Uranium, PCE, TCE, 1,2-DCE, 1,1,1-TCA, 1,1-DCA, 1,2-DCA, vinyl chloride, chloroethane
A-16, A-17, A-18	>10,000 Kg: Uranium	Not available	limited groundwater coverage
BG-B	>1,000,000 Kg: Uranium >1,000 Kg: Th	Not available	Uranium, PCE

Table E.1 (continued)

Waste unit	Waste characteristics		
	From inventory records	From soil sampling results	Detected in nearby shallow groundwater
Walk-in Pits North	>1,000,000 Kg: Uranium >10,000 Kg: Th >1,000 Kg: Total Organics Other - Waste Oil	Not available	Uranium, PCE
Walk-in Pits South	>1,000,000 Kg: Uranium >1,000 Kg: mixed acids <1,000 Kg: Th, Hg	Not available	Uranium, PCE
BG-D South	>100,000 Kg: Uranium	Not available	1,2-DCE, 1,2-DCA, vinyl chloride, chloroethane
BG-C East	>100,000 Kg: Uranium >10,000 Kg: Li, Be, Th	Not available	1,2-DCE, 1,2-DCA, vinyl chloride, chloroethane
BG-D East	>1,000,000 Kg: Uranium	Not available	
BG-C West	>100,000 Kg: Uranium >10,000 Kg: Be, Th >1,000 Kg: Li <1,000 Kg: Tc	Not available	Uranium, Li, Be, Hg
BG-D West, BG-E, BG-J	>1,000,000 Kg: Uranium		Uranium, Li, Be, Hg

^aFrom post-treatment sampling data and Blue Lagoon sampling data.

^bFrom compliance sampling results collected during OLF soil excavation.

Table E.2. Hydrogeologic category of BCV waste units

Waste unit	Hydrogeologic category	Evidence
S-3 Ponds	Intermittent inundation	Nearby wells
Boneyard/Burnyard	Inundated during wet season; intermittent during dry season	Nearby wells
Oil Landfarm	"Dry"	Contamination in top 6 in. of soils
Sanitary Landfill 1	Inundated during wet season; intermittent during dry season	Nearby wells
BG-A South	Perennially inundated	Nearby wells and site photos
BG-A North	Northern trenches dry; southern trenches may be inundated	Nearby wells
A-17	Bathtubbing of stormflow	Recent leachate observed at base of soil cover
A-16 and A-18	"Dry," may bathtub	
BG-B	"Dry"	Capped; water table ~20 ft bgs
Walk-in Pits, North and South	"Dry"	Capped; water table ~20 ft bgs
BG-D South	"Dry," may bathtub	
BG-C East	Perennially inundated	Water close to ground surface year-round at Seep 2
BG-C West, BG-D East	Probably inundated only during wet season	Nearby wells
BG-D East, BG-E, BG-J	Intermittent during storms, may bathtub	Site photos

Table E.3. BCV water balance model

Water balance component	Annual water volume (liters)	Reference
Precipitation	4.8E+09	NOA
Evapotranspiration	2.8E+09	HELP Model
Gaged surface water flow	1.6E+09	Gaged flow at BCK 9.4
Gaged subsurface flow	3.2E+08	Gaged flow at SS-5
Ungaged subsurface flow	6.0E+07	Unknown in using water balance equation

Table. E.4. Appendix E definitions

Term	Definition
Contaminant mass flux	The mass of a contaminant that crosses an area over a specified time.
Gaged monitoring station	Contaminant releases to the surface water are gaged at several points throughout the valley, including at the point where each major tributary and spring enters Bear Creek. This information gathered at these stations, including continuous flow and systematic grab samples.
Gaged surface water	Water that flows through gaged monitoring stations on Bear Creek or the tributaries.
Gaged subsurface water	Water that flows through gage stations at springs entering Bear Creek.
Integration point	The point in the surface water (Bear Creek) where contaminant releases from all upstream sources come together. The Integration Point in BCV is the point where flows from BCK 9.47 and SS-5 mix.
Integration plane	The plane (represented by a subsurface cross section that includes the Integration Point at the top of the plane) where releases from all upgradient sources leave Upper BCV via the intermediate/deep Maynardville Limestone.
Integration point assessment	An assessment of the relative contribution from each upstream, upgradient source to the total contamination and contaminant risk detected at the integration point/integration plane.
Mass balance	The act of balancing the mass of something entering a system with the mass of it leaving the system. In this section, the mass of each contaminant entering the valley at gaged monitoring stations is compared to the total mass leaving the upper valley at two gaged monitoring stations, BCK 9.47 and SS-5.
Relative risk	The percent contribution from a single waste source to total risk at the integration point/integration plane. This relative risk is estimated by distributing the total estimated integration point risk to sources in proportion to the contaminant flux each is contributing to that point.
Ungaged intermediate/deep groundwater	Groundwater that passes the integration plane in the ungaged intermediate/deep Maynardville Limestone (~100 ft bgs).

Table E.5. Sources of existing surface water contamination

Watershed	Primary source units	Secondary sources	Most likely source(s) of detected contamination in tributary
Upper Bear Creek (BCK12.38)	Former S-3 Ponds	nitrate and uranium plumes in groundwater in the Nolichucky Shale	plumes in the Nolichucky Shale
NT-1			
NT-2		S-3 plumes	S-3 plumes
NT-3	BYBY, Oil Landfarm, SL-1, HCDA	BYBY uranium and organic plumes	BYBY source and plumes
NT-4	Oil Landfarm SL-1	Oil Landfarm plume	only low levels detected
NT-5			only low levels detected
NT-6	BG-A South, BG-A North	VOC plume in the Nolichucky below DGA	only low levels detected
NT-7	BG-A South, BG-A North, A-16, A-17, A-18, BG-B, WIP-South, WIP North, BG-C East	BG- A South and North organic plumes, WIP plumes	(1) BG-A South, (2) BG-A North
NT-8	BG-B, WIP North, BG-C East, BG-C West, BG-D East, BG-D West, BG-E, BG-J	BG-C West organic plume, BG-C West, D-East, and WIP-N shallow plume	BG-C East, BG-D East, BG-C West
SS-4		S-3 nitrate and uranium plume, BYBY uranium plume, BYBY overland flow; Bear Creek Road Site Debris Burial Area	S-3 and BYBY plumes
SS-5		Same as SS-4	S-3 and BYBY plumes

Table E.6. Sources of current groundwater contamination

Groundwater contaminant(s)	Primary source(s)
Nitrate	Former S-3 operations
Alpha (Uranium)	Former S-3 operations; BYBY; BG-B/WIP (minimal releases)
VOCs	Sources/operations in Upper East Fork Watershed; S-3; BYBY; Former Oil Landfarm materials; BG-A South; BG-A North; BG-C East; BG-D East; DNAPL underlying BCBG
Beta	Former S-3 operations
Metals	Former S-3 operations; BG

Table E.7. Contaminants detected at downgradient sampling locations in Upper BCV

Contaminant	Concentration at downgradient sampling location		
	Surface water BCK 9.47	Shallow groundwater SS-5	Groundwater GW-683
Aluminum (mg/L)	0.031 - 29.8	ND	0.026 - 0.22
Boron (mg/L)	0.1 - 4.1	0.18	0.05 - 0.66
Fluoride (mg/L)	0.12 - 0.4	0.1 - 0.44	0.1 - 0.2
Lithium (mg/L)	0.028 - 0.091	ND	
Nickel (mg/L)	0.0037 - 0.021	ND	ND
Nitrate (mg/L)	0 - 46.2	0.65 - 29	0.23 - 32
Strontium (mg/L)	0.079 - 0.22	0.025 - 2	0.05 - 0.16
Vanadium (mg/L)	0.005 - 0.057	ND	ND
Zinc (mg/L)	0.0029 - 0.223	ND	0.006 - 0.012
Gross Alpha (pCi/L)	18.9 - 138	10.6 - 75.8	12.6 - 35.8
Gross Beta (pCi/L)	18.7 - 119.8	12.5 - 81.75	12.7 - 93.2
Technetium-99 (pCi/L)	110	ND	
Thorium-228 (pCi/L)	0.0126 - 0.126	ND	
Thorium-230 (pCi/L)	0.2 - 0.2	0.213 - 0.123	
Uranium-233/234 (pCi/L)	7.6 - 29.2	5.9 - 26.6	
Uranium-235 (pCi/L)	1.16 - 1.69	1.1 - 2.98	
Uranium-238 (pCi/L)	18.7 - 64.5	9.9 - 58.4	
1,1-Dichloroethane (µg/L)	1 - 2	ND	ND
1,2-Dichloroethene (µg/L)	1 - 28	0.9 - 2	ND
2-Butanone (µg/L)	8 - 24	ND	ND
Acetone (µg/L)	6 - 23	2 - 6	3 - 11
Chloromethane (µg/L)	2 - 7	ND	ND
Methylene Chloride (µg/L)	3 - 4	3 - 4	1
Tetrachloroethane (µg/L)	0.5 - 4	ND	4 - 5
Trichloroethene (µg/L)	0.6 - 2	0.9 - 2	ND

**Table E.8. Comparison of water balance models,
BCV versus Melton Valley**

Model component	Percent flow	
	Bear Creek Valley	White Oak Creek Watershed
Gaged surface water flow	80.8	> 95
Gaged subsurface flow that resurfaces after integration point (SS-5)	16.2	<1
Ungaged intermediate/deep groundwater flow in the Maynardville Limestone	2.7	
Ungaged intermediate/deep groundwater flow in the Nolichucky Shale	0.3	<1 ^a

^aCombined value for Maynardville Limestone and Nolichucky Shale

Table E.9. Toxicity and ARAR information for chemicals detected at Integrator Point

Chemical	Oral cancer slope factor ^a (mg/kg/day); (risk/pCi)	Chemical toxicity oral reference dose ^b (mg/kg/day)	Federal MCL	
			Level (µg/L; pCi/L)	Basis
Aluminum				
Boron				
Fluoride				
Lithium				
Nickel				
Nitrate		1.6	10,000	Toxic effect
Strontium				
Uranium		0.003	20 (Proposed)	Toxic effect
Vanadium		0.007	NA	
Zinc		0.3	SMCL	
1,2-Dichloroethene		0.009	7	
1,1-Dichloroethane		0.1	7	
Acetone		0.1	NA	
Chloromethane	0.13			
Methylene Chloride	0.0075	0.06	5	
Tetrachloroethane	0.052	0.01	5	Cancer effect
Trichloroethene	0.011			Cancer effect
Radionuclides				
Gross Alpha			15 pCi/L	Cancer effect
Gross Beta			4 mrem/year	Cancer effect
Tc-99	1.4E-12			
Th-228	2.3E-10			
Th-230	3.7E-11			
U-233/234	4.4E-11		~ 30 pCi/L	toxic effect
U-235	4.7E-11		~ 30 pCi/L	toxic effect
U-238	6.2E-11		~ 30 pCi/L	toxic effect

^a The cancer slope factor reflects the 95% confidence level slope of the dose-response curve for the chemical. The greater the slope, the greater the cancer potency of the chemical or radionuclide.

^b The reference dose is the dose below which no toxic effect are expected to occur in humans. The lower the RfD, the more toxic the chemical.

Table E.10. Summary of flow-weighted average concentration and total flow volumes for the BCV watershed

	Units	Integrator Point			Contributing Sites								
		BCK 9.47											
				+								BCK 12.3	
		BCK 9.47	SS-05	SS-05	NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	(NT-1)	SS-01
Total Flow Volume^a	m ³	1.62E+06	3.23E+05	1.94E+06	1.56E+05	1.19E+05	1.17E+05	1.26E+05	8.92E+04	1.31E+05	1.39E+05	2.04E+05	1.66E+05
Chemical													
Aluminum	mg/L	1.77E+01		1.47E+01		1.83E+01							
Barium	mg/L						3.03E+01				1.07E-01	2.25E-01	
Beryllium	mg/L				3.02E-04								
Chloride	mg/L	8.95E+00	1.31E+01	9.64E+00	8.00E+00	6.27E+00		9.00E+00	4.51E+00	1.65E+00	1.84E+00	4.32E+02	4.50E+01
Cyanide	mg/L				1.31E-02				2.12E-05		4.86E-05		
Fluoride	mg/L	1.69E-01		1.41E-01	1.69E-01	1.19E-01		1.85E-01	6.60E-02	6.59E-01	4.17E-03	4.27E-01	
Lithium	mg/L	1.65E-03		1.38E-03	2.66E-02		7.46E-01			2.33E-03			
Manganese	mg/L												3.61E-02
Mercury	mg/L				8.38E-05	1.26E-06				4.58E-05		3.31E-05	6.25E-05
Nickel	mg/L	1.37E-02		1.14E-02		1.32E-02						2.80E-02	
Nitrate	mg/L	3.70E+00	9.15E+00	4.61E+00	2.92E-01	4.05E-01	1.56E-01	6.25E+00			1.08E+01	3.66E+01	2.41E+01
Sulfate	mg/L									2.36E+01		2.45E+01	4.49E+01
Uranium	mg/L	5.71E-02	5.24E-02	5.63E-02	6.21E-02	2.51E-02	8.90E-03	1.75E-03	1.04E-05	3.27E-01		7.10E-02	2.50E-02
Vanadium	mg/L	3.48E-02		2.90E-02		4.48E-02							3.21E-03
Zinc	mg/L	6.38E-02		5.31E-02		8.94E-02							
1,1,1-Trichloroethane	ug/L				6.41E+00	6.95E+00							
1,1,2-Trichloroethane	ug/L				5.67E-02								
1,1-Dichloroethane	ug/L	7.68E-02		6.40E-02	1.62E+01	6.19E+00							
1,1-Dichloroethene	ug/L				6.47E+00	3.64E+00							
1,2-Dichloroethane	ug/L	1.18E+01		9.84E+00	1.07E+00	7.37E+00				1.26E+01	9.71E+00	9.36E+00	
1,2-Dichloroethene	ug/L	5.75E+00	2.59E-01	4.84E+00	2.31E+02	7.30E+01		2.53E+00	9.14E-02				
2-Butanone	ug/L	3.34E-01		2.78E-01									
2-Hexanone	ug/L											3.38E-01	
4-Methyl-2-pentanone	ug/L											3.33E-01	
Acetone	ug/L	1.48E+01	2.49E-01	1.24E+01		9.74E+00				1.36E+01	9.88E+00	3.22E+00	1.45E-01

Table E.10 (continued)

	Units	Integrator Point			Contributing Sites								
		BCK 9.47			NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	BCK 12.3 (NT-1)	SS-01
		BCK 9.47	SS-05	SS-05									
Benzene	ug/L				1.15E+00	9.23E-02							
Carbon disulfide	ug/L												1.46E-01
Chloroform	ug/L				1.60E+00	1.48E+00							
Chloromethane	ug/L	2.41E+00		2.01E+00		3.30E+00				4.39E+00	2.90E+00	2.76E+00	
Methylene chloride	ug/L	3.93E-01	3.69E-01	3.89E-01	4.14E-02	3.41E-01		6.19E-02				8.97E-01	
Tetrachloroethene	ug/L	5.30E-01		4.41E-01	1.17E+01	2.99E+01						1.28E+00	5.65E-01
Toluene	ug/L							1.05E-01					
Trichloroethene	ug/L	1.10E-01	8.30E-02	1.06E-01	1.68E+01	1.83E+01		3.54E+00					2.07E-01
Trichlorofluoromethane	ug/L				2.34E-02	4.04E-02							
Vinyl chloride	ug/L				1.16E+01	1.09E+01							
GROSS ALPHA	pCi/L	3.33E+01	3.12E+01	3.29E+01	3.96E+01	1.86E+01	1.02E+00			1.57E+02		3.09E+01	1.76E+01
GROSS BETA	pCi/L	4.86E+01	2.92E+01	4.54E+01	5.00E+01	3.39E+01	2.88E+00	5.98E-01		1.12E+02	1.30E+01	9.66E+01	3.99E+01
Strontium-90	pCi/L									2.36E-01		2.52E-01	
Technetium-99	pCi/L	1.94E-01		1.61E-01							7.06E-01	6.04E+01	
Thorium-228	pCi/L	2.35E-04		1.96E-04	0.00E+00	7.89E-02				1.46E-01		6.07E-02	
Thorium-230	pCi/L	3.17E-04	1.07E-02	2.04E-03	5.36E-03	6.92E-02				1.17E+00		6.04E-02	
Thorium-232	pCi/L				0.00E+00	6.33E-02				8.78E-02		4.08E-02	
Uranium-233/234	pCi/L	1.05E+01	1.22E+01	1.08E+01	1.03E+01	5.52E+00	2.24E+00	3.70E-01	2.87E-03	6.56E+01		1.54E+01	8.45E+00
Uranium-235	pCi/L	1.09E-01	2.41E-01	1.31E-01	1.54E-01	6.38E-01	1.33E-03	5.16E-02		2.45E+00		6.07E-01	
Uranium-238	pCi/L	2.75E+01	2.25E+01	2.66E+01	3.10E+01	1.06E+01	3.69E+00	7.42E-01	4.07E-03	1.50E+02		3.13E+01	8.20E+00

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^a Total flow Volume is for 10 Months.

Table E.11. Summary of flux for the BCV watershed, including SS-05

Chemical	Units	Integrator Point			Contributing Sites									Ungaged source (+)/ sink (-)
		BCK 9.47	SS-05	BCK 9.47 + SS-05	NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	BCK 12.3 (NT-1)	SS-01	
Aluminum	kg	2.86E+04		2.86E+04		2.17E+03								2.64E+04
Barium	kg						3.55E+03				1.48E+01	4.58E+01		-3.61E+03
Beryllium	kg				4.73E-02									-4.73E-02
Chloride	kg	1.45E+04	4.24E+03	1.87E+04	1.25E+03	7.45E+02		1.13E+03	4.02E+02	2.16E+02	2.56E+02	8.80E+04	7.49E+03	-8.08E+04
Cyanide	kg				2.05E+00				1.89E-03		6.76E-03			-2.06E+00
Fluoride	kg	2.73E+02		2.73E+02	2.64E+01	1.41E+01		2.33E+01	5.88E+00	8.63E+01	5.80E-01	8.69E+01		2.98E+01
Lithium	kg	2.67E+00		2.67E+00	4.15E+00		8.74E+01			3.05E-01				-8.92E+01
Manganese	kg												6.01E+00	-6.01E+00
Mercury	kg				1.31E-02	1.50E-04				6.00E-03		6.74E-03	1.04E-02	-3.64E-02
Nickel	kg	2.22E+01		2.22E+01		1.56E+00						5.70E+00		1.49E+01
Nitrate	kg	5.98E+03	2.96E+03	8.94E+03	4.57E+01	4.81E+01	1.83E+01	7.85E+02			1.50E+03	7.44E+03	4.01E+03	-4.92E+03
Sulfate	kg									3.09E+03		4.99E+03	7.46E+03	-1.55E+04
Uranium	kg	9.23E+01	1.69E+01	1.09E+02	9.72E+00	2.98E+00	1.04E+00	2.19E-01	9.28E-04	4.29E+01		1.45E+01	4.15E+00	3.37E+01
Vanadium	kg	5.62E+01		5.62E+01		5.33E+00							5.34E-01	5.03E+01
Zinc	kg	1.03E+02		1.03E+02		1.06E+01								9.24E+01
1,1,1-Trichloroethane	g				1.00E+03	8.26E+02								-1.83E+03
1,1,2-Trichloroethane	g				8.87E+00									-8.87E+00
1,1-Dichloroethane	g	1.24E+02		1.24E+02	2.53E+03	7.36E+02								-3.15E+03
1,1-Dichloroethene	g				1.01E+03	4.33E+02								-1.45E+03
1,2-Dichloroethane	g	1.91E+04		1.91E+04	1.68E+02	8.76E+02				1.65E+03	1.35E+03	1.91E+03		1.31E+04
1,2-Dichloroethene	g	9.29E+03	8.38E+01	9.38E+03	3.62E+04	8.67E+03		3.18E+02	8.15E+00					-3.58E+04
2-Butanone	g	5.39E+02		5.39E+02										5.39E+02
2-Hexanone	g											6.89E+01		-6.89E+01
4-Methyl-2-pentanone	g											6.78E+01		-6.78E+01
Acetone	g	2.39E+04	8.05E+01	2.40E+04		1.16E+03				1.79E+03	1.37E+03	6.55E+02	2.41E+01	1.90E+04
Benzene	g				1.80E+02	1.10E+01								-1.91E+02
Carbon disulfide	g												2.43E+01	-2.43E+01
Chloroform	g				2.50E+02	1.76E+02								-4.27E+02
Chloromethane	g	3.89E+03		3.89E+03		3.92E+02				5.76E+02	4.04E+02	5.62E+02		1.96E+03
Methylene chloride	g	6.35E+02	1.19E+02	7.54E+02	6.48E+00	4.05E+01		7.78E+00				1.83E+02		5.17E+02
Tetrachloroethene	g	8.56E+02		8.56E+02	1.83E+03	3.55E+03						2.61E+02	9.39E+01	-4.87E+03

Table E.11 (continued)

Chemical	Units	Integrator Point			Contributing Sites										Ungaged source (+)/ sink (-)
		BCK 9.47	SS-05	BCK 9.47 + SS-05	NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	BCK 12.3 (NT-1)	SS-01		
Toluene	g							1.32E+01							-1.32E+01
Trichloroethene	g	1.78E+02	2.68E+01	2.05E+02	2.63E+03	2.18E+03		4.45E+02					3.45E+01		-5.09E+03
Trichlorofluoromethane	g				3.66E+00	4.80E+00									-8.46E+00
Vinyl chloride	g				1.82E+03	1.30E+03									-3.12E+03
GROSS ALPHA	ugCi	5.38E+04	1.01E+04	6.39E+04	6.20E+03	2.21E+03	1.19E+02			2.06E+04		6.28E+03	2.92E+03		2.56E+04
GROSS BETA	ugCi	7.86E+04	9.42E+03	8.80E+04	7.82E+03	4.03E+03	3.38E+02	7.52E+01		1.46E+04	1.81E+03	1.97E+04	6.64E+03		3.30E+04
Strontium-90	ugCi									3.09E+01		5.12E+01			-8.21E+01
Technetium-99	ugCi	3.13E+02		3.13E+02							9.82E+01	1.23E+04			-1.21E+04
Thorium-228	ugCi	3.80E-01		3.80E-01	0.00E+00	9.38E+00				1.91E+01		1.24E+01			-4.04E+01
Thorium-230	ugCi	5.12E-01	3.45E+00	3.96E+00	8.39E-01	8.22E+00				1.54E+02		1.23E+01			-1.71E+02
Thorium-232	ugCi				0.00E+00	7.52E+00				1.15E+01		8.30E+00			-2.73E+01
Uranium-233/234	ugCi	1.70E+04	3.94E+03	2.09E+04	1.61E+03	6.56E+02	2.63E+02	4.65E+01	2.56E-01	8.60E+03		3.13E+03	1.40E+03		5.21E+03
Uranium-235	ugCi	1.75E+02	7.79E+01	2.53E+02	2.41E+01	7.58E+01	1.56E-01	6.48E+00		3.21E+02		1.24E+02			-2.98E+02
Uranium-238	ugCi	4.44E+04	7.27E+03	5.16E+04	4.84E+03	1.25E+03	4.32E+02	9.32E+01	3.63E-01	1.97E+04		6.38E+03	1.36E+03		1.76E+04

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* Total flow Volume is for 10 Months.

Table E.12. Contaminant balance across flow paths in BCV

Flow path model component	Water balance		Contaminant mass balance		
	Percent of total rainfall	Percent of available water ^a	Nitrate balance	Uranium balance	VOC balance
Gaged Surface Water (BCK 9.47)	33.7 % (39.7)	80.5 %	61 % (5978 kg)	85 % ^b (62 Ci)	17 % (12 kg)
Gaged Shallow Subsurface Water (SS-5)	5.5 % (6.5 cm)	16.1 %	20 % (1988 kg)	15 % ^b (11 Ci)	< 1 % (0.2 kg)
Ungaged Subsurface Groundwater (Maynardville)	2.6 % (3.2 cm)	3.4 %	6 % (590 kg)	Unknown	< 1 %
Other (e.g., denitrification, evapotranspiration)	58 % (68.5 cm)		13 % (1250 kg)		83 % (55 kg)
Rainfall	100 % (117.8 cm)				

^a Available water is water available for either runoff to stream or infiltration to the groundwater, or available water = rainfall minus evapotranspiration.

^b Calculation of the percentage of uranium in these exit pathways does not include flux in intermediate and deep groundwater in the Maynardville Limestone

Table E.13. Chemical screening for integrator point assessment

Chemical	Included in IP assessment?	Human health hazard evaluated in IP assessment	Reason for exclusion from IP assessment
Aluminum	no	NA	No toxic effects at environmental levels
Boron	no	NA	Analyzed for only during NPDES sampling
Fluoride	yes	toxicity	NA
Lithium	no	NA	No toxicity data
Nickel	no	NA	< PRG
Nitrate	yes	toxicity	NA
Strontium	no	NA	Analyzed for only during NPDES sampling.
Uranium	yes	toxicity	NA
Vanadium	yes	toxicity	NA
Zinc	no	NA	< PRG
1,2-DCE	no	NA	< PRG
1,1-DCA	no	NA	< PRG
Acetone	no	NA	< PRG
Methylene chloride	no	NA	< PRG
PCE	yes	toxicity and carcinogenicity	NA
TCE	yes	carcinogenicity	NA
Tc-99	yes	carcinogenicity	NA
Th-228	no	NA	< PRG
Th-230	no	NA	< PRG
U-233/234	yes	carcinogenicity	NA
U-235	yes	carcinogenicity	NA
U-238	yes	carcinogenicity	NA

Table E.14. Summary of relative risk for the BCV watershed, including SS-05

	Integrator Point	Contributing Sites									
Chemical	BCK 9.47/SS-05	NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	BCK 12.3 (NT-1)	SS-01	Ungaged
	ILCR	ILCR _{BCK 9.4} * (Flux _{site} / Flux _{BCK 9.4 + SS-05})									
Tetrachloroethene	5.63E-07	1.20E-06	2.33E-06						1.72E-07	6.18E-08	-3.21E-06
Trichloroethene	5.43E-08	6.99E-07	5.78E-07		1.18E-07					9.15E-09	-1.35E-06
Technetium-99	4.74E-09							1.49E-09	1.86E-07		-1.83E-07
Uranium-233/234	1.01E-05	7.75E-07	3.16E-07	1.27E-07	2.24E-08	1.23E-10	4.13E-06		1.51E-06	6.76E-07	2.50E-06
Uranium-235	1.29E-07	1.23E-08	3.86E-08	7.93E-11	3.30E-09		1.64E-07		6.29E-08		-1.52E-07
Uranium-238	3.47E-05	3.25E-06	8.42E-07	2.90E-07	6.26E-08	2.44E-10	1.32E-05		4.28E-06	9.15E-07	1.18E-05
Total Risk at BCK 9.47	4.55E-05										
Sum of Flux-weighted Risks		5.94E-06	4.11E-06	4.17E-07	2.07E-07	3.67E-10	1.75E-05	1.49E-09	6.21E-06	1.66E-06	9.41E-06
Relative Percent Risk for each Site		13.06	9.03	0.92	0.45	0.0008059	38.52	0.00	13.66	3.65	20.70

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Table E.15. Summary of relative toxicity for the BCV watershed, including SS-05

Chemical	Integrator Point	Contributing Sites									
	BCK 9.47/SS-5	NT-8	NT-7	NT-6	NT-5	NT-4	NT-3	NT-2	BCK 12.3 (NT-1)	SS-01	Ungaged
	HQ	HQ _{BCK 9.4} * (Flux _{site} / Flux _{BCK 9.4 + SS-05})									
Fluoride	6.45E-02	6.23E-03	3.33E-03		5.50E-03	1.39E-03	2.04E-02	1.37E-04	2.05E-02		7.03E-03
Nitrate	7.93E-02	4.06E-04	4.27E-04	1.62E-04	6.97E-03			1.33E-02	6.61E-02	3.56E-02	-4.36E-02
Uranium	5.16E-01	4.59E-02	1.41E-02	4.93E-03	1.04E-03	4.38E-06	2.03E-01		6.83E-02	1.96E-02	1.59E-01
Vanadium	1.41E-01		1.34E-02							1.34E-03	1.26E-01
Tetrachloroethene	2.29E-03	4.89E-03	9.51E-03						7.01E-04	2.52E-04	-1.31E-02
Total HI for BCK 9.47	8.03E-01										
Sum of Flux-weighted HIs		5.74E-02	4.07E-02	5.09E-03	1.35E-02	1.39E-03	2.23E-01	1.34E-02	1.56E-01	5.68E-02	2.36E-01
Relative Toxicity		7.15	5.07	0.63	1.68	0.1735443	27.78	1.67	19.38	7.08	29.38

Table E.16. Integrator point assessment results

Subwatershed	Major sources	Cancer effects		Toxic effects	
		Relative risk (percent)	Contaminants contributing the majority to risk at BCK 9.47/SS-05	Relative toxicity (percent)	Contaminants contributing the most to toxic effects BCK 9.47/SS-05
BCK 12.38/ NT-1/SS-1	S-3, S-3 plumes	17.4	uranium	26.5	uranium, nitrate
NT-2	S-3 plumes	<0.1	-	1.7	nitrate
NT-3	BYBY	38.5	uranium	27.7	uranium
NT-4	-	<0.1	-	0.2	-
NT-5	-	0.45	-	1.7	-
NT-6	-	0.92	-	0.6	-
NT-7	BG	9.1	uranium, PCE, TCE	5.1	uranium, vanadium
NT-8	BG	13.0	uranium, PCE, TCE	7.1	uranium
Ungaged	S-3 and BYBY subsurface plumes, ungaged runoff from BYBY	20.7	uranium	29.4	uranium, vanadium
BCK 9.47/SS-05		100		100	uranium, vanadium, nitrate

Table E.17. Source characterization for the S-3 Site

Constituents	Source term concentrations ^a
<i>Volatile Organic Compounds</i>	
1,1,2-TCA	7.5E+01
1,1,2,2-TCA	3.8E+02
1,1,2-Trichloro-1,2,2-trifluoroethane	4.35E+00
1(2-Butoxyethoxy)ethanol	1.0E+03
2(2-Butoxyethoxy)ethanol	1.9E+03
2-Butoxyethanol	2.3E+03
2-Hexanol	3.0E+02
3(1,1-Dimethyl)phenol	6.0E+03
Acetone	2.3E+01
PCE	7.9E+02
Toluene	2.7E-01
TCE	2.8E-01
Methylene chloride	4.9E-01
<i>Semivolatile Organic Compounds</i>	
Phenol	7.3E+03
Phosphoric Acid	7.7E+02
Trichlorofluoromethane	3.8E-01
Diethylphthalate	5.2E+02
<i>Pesticides and PCBs</i>	
Aroclor-1248	5.7E+03
<i>Inorganics</i>	
Beryllium	2.7E+00
Boron	3.8E+01
Cadmium	4.9E+00
Chromium	1.3E+02
Cyanide	5.95E+00
Lithium	7.6E+01

Table E.17 (continued)

Constituents	Source term concentrations ^a
Mercury	2.3E+00
Molybdenum	1.5E+01
Nickel	5.5E+02
Nitrate	6.1E+03
Strontium	3.5E+01
Uranium	9.9E+02
Zirconium	4.8E+02
<i>Radionuclides</i>	
¹³⁷ Cs	4.8E+00
²³⁷ Np	9.9E+00
²³⁸ Pu	2.5E+01
^{239/240} Pu	2.5E+00
¹⁰⁶ Ru	3.3E+01
⁹⁰ Sr	1.3E+01
⁹⁹ Tc	7.5E+03
²²⁸ Th	2.7E+02
²³⁰ Th	5.4E+02
²³² Th	8.7E+01
²³⁴ U	1.2E+02
²³⁵ U	8.1E+00
²³⁶ U	7.7E+00
²³⁸ U	3.3E+02

^a Concentrations for organics are reported in µg/kg.
 Concentrations for inorganics are reported in mg/kg.
 Concentrations for radionuclides are reported in pCi/g.

Table E.18. Soil parameters for vadose zone modeling

	S-3	BYBY	OLF	SL-1	BCBG	
					WIP ^a	BG-A (N) ^b BG-A (S) ^c
Bulk density (g/cm ³)	1.63	1.61	1.84	1.84	1.53	1.53
Intrinsic permeability (cm ²)	6.10E-10	1.5E-10	2.66E-10	1.54E-10	1.54E-10	1.54E-10
Disconnect- edness index	12	10	11	10	10	10
Porosity	0.42	0.42	0.35	0.36	0.45	0.45
Organic carbon content (%)	0.164	0.39	0.06	0.06	0.11	0.11
Moisture content (%)	31.0	30.1	25.1	24.9	31.0	31.1
Percolation rate (cm/year)	4.4	14.2	16.8	9.6	9.6	9.0

^a WIP includes both WIP North and South, and BG-B.

^b BG-A (N) also include A-16, A-17, and A-18.

^c Waste area BG-A South is inundated (i.e., leaching zone for this source is absent, therefore, vadose zone parameters are not applicable).

Table E.19. Source concentrations used by the CRAFLUSH model for transporting contaminants from S-3 to NT-1

Constituents	Concentrations ^d	Source	Comments
<i>Inorganics^a</i>			
Barium	7.1	GW-243	
Beryllium	0.07	GW-243	
Cadmium	2.3	GW-243	
Cyanide	27.0	Leachate Modeling Results	
Manganese	210.0	GW-243	
Mercury	0.08	GW-243	
Nickel	18.5	GW-243	
Strontium	12.0	GW-243	
Total uranium	33.4	GW-243	
<i>Common Anions^a</i>			
Nitrate	6,403	GW-243	
<i>Organics^b</i>			
1,1,2-Trichloroethane	250.0	Leachate Modeling Results	
Bis(2-ethylhexyl)phthalate	32.0	GW-243	
Chloroform	69.0	GW-243	
Methylene chloride	560.0	GW-243	
Tetrachloroethene	9,000.0	GW-243	
<i>Radioactivity^c</i>			
⁹⁹ Tc	57,900	Leachate Modeling Results	

^a Concentrations of inorganics are reported as mg/l.

^b Concentrations of organics are reported as ug/l.

^c Concentrations of radioactivity are reported as pCi/l.

^d Concentrations reported in this table represent maximum values

Table E.20. Source concentrations used by the CRAFLUSH model for transporting contaminants from S-3 deep plume to NT-2

Constituents	Concentrations ^a (mg/L)	Source	Comments
<i>Inorganics</i>			
Barium	340.0	GW-615	
Manganese	20.0	GW-615	
Strontium	310.0	GW-615	
Total uranium	0.43	GW-615	
<i>Common Anions</i>			
Nitrate	10,747	GW-615	

^a Concentrations reported in this table represent maximum values

Table E.21. Source characterization for the OLF Site

Constituents	Source term concentrations ^a
<i>PCBs</i>	
Arochlor-1254	6.02
Arochlor-1260	7.37
<i>Inorganics</i>	
Uranium (total)	77.3

^a All concentrations are reported as ppm (mg/kg).

Table E.22. Source characterization for the SL 1 Site

Constituents	Source term concentrations ^a
<i>Volatile Organic Compounds</i>	
Acetone	1100
Carbon disulfide	12
Chlorobenzene	2
Chloroform	1
Dimethylbenzene	27
Ethylbenzene	3
Toluene	110
2-Butanone	1000
2-Hexanone	140
<i>Semivolatile Organic Compounds</i>	
Acenaphthalene	49
Acenaphthene	310
Anthracene	1100
Benzo(a)anthracene	5700
Benzo(a)pyrene	4200
Benzo(b)fluoranthene	5800
Benzo(g,h,i)perylene	1700
Benzo(k)fluoranthene	3300
Bis(2-ethylhexyl)phthalate	3200
Carbazole	310
2,4-Dimethylphenol	730
Chrysene	5300
Di-n-butylphthalate	110
Di-n-octylphthalate	220
Dibenzo(a,h)anthracene	875
Dibenzofuran	130
Diethylphthalate	61
Fluoranthene	11000
Fluorene	410
Indeno(1,2,3-cd)pyrene	1500
Phenanthrene	4900
Phenol	230
Pyrene	9000

Table E.22 (continued)

Constituents	Source term concentrations ^a
<i>Pesticides and PCBs</i>	
4,4-DDE	13
Aldrin	19
Arochlor-1232	1090
Arochlor-1254	3000
Arochlor-1260	660
Endosulfan	27
Endosulfan sulfate	5.5
<i>Inorganic Compounds</i>	
Barium	486
Beryllium	2.2
Cadmium	2.71
Copper	252
Lead	201
Manganese	3150
Mercury	41.5
Nickel	67.9
Silver	7.6
Tin	4.8
Zinc	470
<i>Radionuclides</i>	
Cesium 137	1.2
Cobalt 60	1.3
Thallium 128	2.9
Uranium 234	14
Uranium 238	22

^a Concentrations for organics are reported in µg/kg.
 Concentrations for inorganics are reported in mg/kg.
 Concentrations for radionuclides are reported in pCi/g.

Table E.23. Source characterization for the BYBY Site

Constituents	Source term concentrations ^a
<i>Volatile Organic Compounds</i>	
1,2-Dichloroethene	3.34
2,3,7,8-TCDD	7.72
2-Butanone	7.8
Acetone	90.4
Tetrachloroethene	4.02
Trichloroethene	3.3
Toluene	257.0
<i>Semivolatile Organic Compounds</i>	
2-Methylnapthalene	1,240.0
Acenaphthene	4,380.0
Acenaphthylene	336
Anthracene	37,000.0
Benzo(a)anthracene	109,000.0
Benzo(a)pyrene	76,000.0
Benzo(b)fluoranthene	86,000.0
Benzo(g,h,i)perylene	30,000.0
Benzo(k)fluoranthene	77,800.0
Bis(2-ethylhexyl) phthalate	880
Butylbenzylphthalate	87
Carbazole	18,300.0
Chrysene	112,000.0
Di-n-butylphthalate	872.0
Dibenzo(a,h)anthracene	12,000.0
Dibenzofuran	7,870.0
Diethylphthalate	65.0
Fluoranthene	270,000.0
Fluorene	12,500.0
Indeno(1,2,3-cd)pyrene	31,000.0
Napthalene	3,060.0
Phenanthrene	149,000.0
Phenol	200.0
Pyrene	180,000.0

Table E.23 (continued)

Constituents	Source term concentrations ^a
<i>PCBs</i>	
Arochlor-1254	1,170.0
Arochlor-1260	1,260.0
<i>Inorganics</i>	
Antimony	423.0
Arsenic	28.8
Barium	577.0
Beryllium	1.6
Cadmium	19.7
Chromium	88.0
Cobalt	48.2
Copper	6,220.0
Cyanide	3.9
Lead	1,870.0
Manganese	1,470.0
Mercury	50.8
Molybdenum	41.9
Nickel	1,020.0
Selenium	12.5
Silver	13.4
Tin	62.0
Zinc	698.0
<i>Radionuclides</i>	
⁹⁹ Tc	24.1
²³² Th	4.3
²³⁴ U	260.0
²³⁵ U	17.0
²³⁸ U	541.0

^a Concentrations of organics are reported as µg/kg. Concentrations of inorganics are reported as mg/kg. Concentrations of radionuclides are reported in pCi/g.

Table E.24. Source concentrations used by the CRAFLUSH model for transporting contaminants from BYBY to NT-3 and Bear Creek

Constituents	Concentrations ^c	Source ^a	Comments
<i>Inorganics^b</i>			
Antimony	1.1	M	
Cadmium	0.07	M	
Lead	0.64	GW	Appendix D, Table D.60
Manganese	7.6	GW	Appendix D, Table D.60
Mercury	0.08	GW	Appendix D, Table D.60
Nickel	2.4	M	
Total uranium	5.4	GW	Mass conc. converted from isotopes
<i>Organics^c</i>			
1,1,2,2-Trichloroethane	41.0	GW	Appendix D, Table D.60
1,1-Dichloroethene	620.0	GW	Appendix D, Table D.60
1,2-Dichloroethane	27.0	GW	Appendix D, Table D.60
1,2-Dichloroethene	1,100.0	GW	Appendix D, Table D.60
Benzene	53.0	GW	Appendix D, Table D.60
Chloroform	140.0	GW	Appendix D, Table D.60
Methylene chloride	3,400.0	GW	Appendix D, Table D.60
Tetrachloroethene	1,600.0	GW	Appendix D, Table D.60
Trichloroethene	2,000	GW	Appendix D, Table D.60
Vinyl chloride	73.0	GW	Appendix D, Table D.60
<i>Radioactivity^d</i>			
⁹⁹ Tc	7,944	M	
²³⁴ U	1,300	GW	Appendix D, Table D.60
²³⁵ U	53	GW	Appendix D, Table D.60
²³⁸ U	1,800	GW	Appendix D, Table D.60

^a M indicates concentrations from leachate modeling results.

GW indicates maximum concentrations from OLF groundwater aggregate.

^b Concentrations of inorganics are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e Concentrations reported in this table represent maximum values

Table E.25. Source characterization for the WIP sites

Constituents	Source term concentrations ^a
<i>Volatile Organic Compounds</i>	
Acetone	180.0
Methylene Chloride	86.0
Toluene	250.0
1,1,1-Trichloroethane	7,700.0
<i>Semivolatile Organic Compounds</i>	
1,4-dichlorobenzene	200
Benzene	130,000.0
Benzidine	31,000.0
Bis(2-ethylhexyl)phthalate	8700.0
Di-n-octylphthalate	200.0
Phenanthrene	200.0
Phenol	47,000.0
Pyrene	240.0
<i>Pesticides and PCBs</i>	
4,4'-DDT	4,900.0
Aroclor-1254	10,000.0
Aroclor-1260	36,000.0
Epoxy	95,000.0
<i>Inorganics</i>	
Arsenic	19.0
Barium	220.0
Beryllium	26.0
Cyanide	45.7
Manganese	5550.0
Thorium	580.0
Tin	2.63
Uranium	72000.0
<i>Radionuclides</i>	
⁹⁹ Tc	11.8
²³⁸ U	4.15

^a Concentrations for organics are given in parts per billion (µg/kg).
Concentrations for inorganics are given in parts per million (mg/kg).
Concentrations for radionuclides are given in pCi/g.

Table E.26. Source characterization for the BG-A North site

Constituents	Source term concentrations ^a
<i>Volatile Organic Compounds</i>	
Benzene	180.0
2-Butanone	42.0
Chloroethane	170.0
Chloroform	15.0
1,1-DCA	72.0
1,1-DCE	5.0
Methylene chloride	7.0
Toluene	200.0
1,1,1-TCA	19.0
Vinyl chloride	6.0
<i>Semivolatile Organic Compounds</i>	
Benzo(a)anthracene	289.0
Benzo(b)fluoranthene	287.0
Benzo(k)fluoranthene	285.0
Bis(2-ethylhexyl)phthalate	2400.0
Chrysene	285.0
Fluoranthene	238.0
Phenanthrene	215.0
Pyrene	226.0
<i>Pesticides and PCBs</i>	
Aroclor-1254	89.0
Aroclor-1260	37.0
4,4'-DDE	2.9
4,4'-DDT	2.9
<i>Inorganics</i>	
Barium	376
Beryllium	1.5
Copper	46.7
Cyanide	44.2
Manganese	2330
Nickel	61.9

Table E.26 (continued)

Constituents	Source term concentrations ^a
Selenium	2.1
Silver	3.8
Tin	6.4
Uranium	11,000.0
<i>Radionuclides</i>	
⁹⁹ Tc	8.6

^a All concentrations of organics is in parts per billion (µg/kg).
 All concentrations of inorganics is in parts per million (mg/kg).
 All concentrations for radionuclides are reported in pCi/g.

Table E.27. Source characterization for the BG-A South site

Constituents	Source term concentration ^a
<i>Volatile Organic Compounds</i>	
1,1-DCA	3.65
1,1,1-TCA	960000
1,2-DCE	23.4
Acetone	36.8
Benzene	140000
Freon	480000
Methanol	380000
Methyl Ethyl Ketone	62000
PCE	890000
TCE	85000
Toluene	3.54
<i>PCBs and Pesticides</i>	
PCB (total)	21000
Methoxychlor	9.3
<i>Inorganics</i>	
Barium	191
Beryllium	2.5
Cobalt	20.3
Copper	34.7
Lead	14.3
Lithium	1.1
Manganese	1360
Nickel	41.5
Silver	2.23
Tin	2.71
Uranium	15000

^a All concentrations of organics are given in parts per billion (µg/kg). All concentrations of inorganics are given in parts per million (mg/kg).

Table E.28. Source concentrations used by the CRAFLUSH model for transporting contaminants from BG-A North and South sites to NT-7

Constituents	Concentrations ^c	Source ^a	Comments
<i>Inorganics^b</i>			
Antimony	0.2	GW	Table D.91
Beryllium	5.0	BG-A South standpipe liquid samples	Appendix B
Boron	31	GW	Table D.91
Cadmium	0.05	GW	Table D.91
Copper	6.6	GW	Table D.91
Cyanide	2,140.0	M	
Lead	0.7	GW	Table D.91
Lithium	5.8	BG-A South standpipe liquid samples	Appendix B
Manganese	19	GW	Table D.91
Nickel	1.7	GW	Table D.91
Total uranium	3.5	M	
<i>Organics^c</i>			
1,1,1-Trichloroethane	27,000.0	BG-A South standpipe liquid samples	Appendix B
1,1,2-Trichloroethane	300.0	GW	Table D.91
1,1-Dichloroethane	23,300.0	BG-A South standpipe liquid samples	Appendix B
1,1-Dichloroethene	4,800.0	BG-A South standpipe liquid samples	Appendix B
1,2-Dichloroethane	300.0	GW	Table D.91
1,2-Dichloroethene	5,400.0	GW	Table D.91
2-Butanone	4,300.0	BG-A South standpipe liquid samples	Appendix B
Acetone	590,000.0	BG-A South standpipe liquid samples	Appendix B
Benzene	1,300.0	BG-A South standpipe liquid samples	Appendix B
Carbon tetrachloride	15,300.0	BG-A South standpipe liquid samples	Appendix B
Chloroethane	740.0	GW	Table D.91
Chloroform	10,600.0	GW	Table D.91
Methylene chloride	760.0	GW	Table D.91
PCB (total)	18.2	M	
Tetrachloroethene	63,000.0	GW	Table D.91
Trans-1,2-Dichloroethene	50,000.0	GW	Table D.91
Trichloroethene	24,000.0	GW	Table D.91
Trichlorotrifluoromethane	1,600.0	GW	Table D.91
Vinyl chloride	3,400.0	GW	Table D.91
<i>Radioactivity^d</i>			
⁴⁰ K	160.0	GW	Table D.91

^a M indicates concentrations from leachate modeling results.

GW indicates maximum concentrations from BCBG groundwater aggregate.

^b Concentrations of inorganics are reported as mg/l.

^c Concentrations of organics are reported as µg/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e Concentrations reported in this table represent maximum values

Table E.29. Source concentrations used by the CRAFLUSH model for transporting contaminants from BG-WIP sites to NT-8

Constituents	Concentrations ^c	Source ^a	Comments
<i>Inorganics^b</i>			
Arsenic	0.8	BG Seep 2	Table D.89
Beryllium	1.1	BG Seep 2	Table D.89
Boron	17.5	BG Seep 2	Table D.89
Cadmium	0.02	BG Seep 2	Table D.89
Chromium	0.3	BG Seep 2	Table D.89
Copper	0.6	BG Seep 2	Table D.89
Cyanide	100	Leachate Modeling Results	
Lead	0.8	BG Seep 2	Table D.89
Manganese	18.7	BG Seep 2	Table D.89
Nickel	0.4	BG Seep 2	Table D.89
Total uranium	4.3	Leachate Modeling Results	
<i>Organics^c</i>			
1,1,1-Trichloroethane	8,000.0	BG-B Standpipe liquid samples	Appendix B
1,1,2-Trichloroethane	300.0	GW	Appendix D Table
1,1-Dichloroethane	10,600.0	BG-B Standpipe liquid samples	Appendix B
1,1-Dichloroethene	13,000.0	GW	Appendix D Table
1,2-Dichloroethane	300.0	GW	Appendix D Table
1,2-Dichloroethene	5,400.0	GW	Appendix D Table
Benzene	85,000.0	Leachate Modeling Results	
Carbon tetrachloride	190.0	GW	Appendix D Table
Chloroform	1,700.0	GW	Appendix D Table
Methylene chloride	8,400.0	BG-B Standpipe liquid samples	Appendix B
PCB -1248	220.0	BG-B Standpipe liquid samples	Appendix B
Tetrachloroethene	8,400.0	BG-B Standpipe liquid samples	Appendix B
Trans-1,2-Dichloroethene	50,000.0	GW	Appendix D Table
Trichloroethene	800.0	BG-B Standpipe liquid samples	Appendix B
Vinyl chloride	3,400.0	GW	Appendix D Table
<i>Radioactivity^d</i>			
⁴⁰ K	160.0	GW	Appendix D Table
⁹⁹ Tc	7,110.0	Leachate Modeling Results	

^a GW indicates concentrations from BCBG groundwater Aaggregate.

^b Concentrations of inorganics are reported as mg/l.

^c Concentrations of organics are reported as µg/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e Concentrations reported in this table represent maximum values

Table E.30. Source concentrations used by the CRAFLUSH model for transporting contaminants from BG-C West to Picket A

Constituents	Concentrations ^d	Source	Comments
<i>Inorganics^a</i>			
Arsenic	0.2	BG C-West Toe Seep Data	Table D.89
Barium	2.2	BG Seeps 3 and 4	Table D.89
Beryllium	0.03	BG Seeps 3 and 4	Table D.89
Boron	126	BG Seeps 3 and 4	Table D.89
Cadmium	0.02	BG C-West Toe Seep Data	Table D.89
Chromium	0.4	BG C-East Standpipe liquid samples	Appendix B
Lead	0.1	BG Seeps 3 and 4	Table D.89
Lithium	32.4	BG Seeps 3 and 4	Table D.89
Manganese	13.5	BG Seeps 3 and 4	Table D.89
Nickel	0.05	BG Seeps 3 and 4	Table D.89
Selenium	0.5	BG Seeps 3 and 4	Table D.89
Thallium	0.2	BG Seeps 3 and 4	Table D.89
Total uranium	1.1	BG C-East Standpipe liquid samples	Appendix B
<i>Organics^b</i>			
1,1,1-Trichloroethane	4,200.0	BG C-East Standpipe liquid samples	Appendix B
1,1-Dichloroethane	800.0	BG C-East Standpipe liquid samples	Appendix B
1,2-Dichloroethane	2,800.0	BG C-East Standpipe liquid samples	Appendix B
Benzene	53.0	BG Seeps 3 and 4	Table D.89
Bis (ethylhexyl)phthalate	123.0	BG C-East Standpipe liquid samples	Appendix B
Chloroethane	2,700.0	BG C-East Standpipe liquid samples	Appendix B
Methylene Chloride	47.0	BG C-West Toe Seep Data	Table D.89
PCB(Total)	130.0	BG C-East Standpipe liquid samples	Appendix B
Tetrachloroethene	14.0	BG C-East Standpipe liquid samples	Appendix B
Trans-1,2-Dichloroethene	1,800.0	BG C-East Standpipe liquid samples	Appendix B
Trichloroethene	150.0	BG C-East Standpipe liquid samples	Appendix B
Vinyl chloride	2,300.0	BG C-East Standpipe liquid samples	Appendix B
<i>Radioactivity^c</i>			
^{233/234} U	225.0	BG C-East Standpipe liquid samples	Appendix B
²³⁵ U	9.8	BG C-East Standpipe liquid samples	Appendix B
²³⁸ U	363.0	BG C-East Standpipe liquid samples	Appendix B

^a Concentrations of inorganics are reported as mg/l.

^b Concentrations of organics are reported as µg/l.

^c Concentrations of radioactivity are reported as pCi/l.

^d Concentrations reported in this table represent maximum values

Table E.31. Summary of vadose zone modeling results from S-3 Ponds

Constituents	Soil Exposure conc	Range of time for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
<i>Volatile Organic Compounds^c</i>					
1,1,2-Trichloroethane	75	7 - 11	18 - 250	1	5 (M)
1,1,2,2-Tetrachloroethane	380	22 - 60	0 - 12.0		0.43 (R)
1,1,2-Trichloro-1,2,2-trifluoroethane	4.35	7 - 12	0 - 5.8		1,100,000 (R)
1(2-Butoxyethoxy)ethanol	1000	9 - 14	0.0004 - 1.3		
2(2-Butoxyethoxy)ethanol	1900	9 - 14	0.0008 - 2.4		
2-Butoxyethanol	2300	9 - 14	0.001 - 3.0		
2-Hexanol	300	4 - 9	750 - 1700		
Acetone	23	1 - 2	45 - 200	6,000	3700 (R)
Methylene chloride	0.49	1 - 3	0.027 - 6.8		5 (M)
Tetrachloroethene	790	9 - 22	0.0004 - 4.0	9,000	5 (M)
Toluene	0.27	11 - 28	0 - 0.6	35	1000 (M)
Trichloroethene	0.28	8 - 20	0.00004 - 0.2	16	5 (M)
<i>Semivolatile Organic Compounds^c</i>					
Diethylphthalate	520	17 - 18	0 - 21.0		29000 (R)
Phenol	7300	3 - 4	0 - 65,000		22000 (R)
Trichlorofluoromethane	0.38	12 - 25	0 - 0.0003		11000 (R)
<i>Inorganics^b</i>					
Boron	7.6	75 - 500	0 - 0.7	4.4	3.3 (R)
Cadmium	4.9	75 - 500	0.002 - 0.65	4	0.005 (M)
Chromium	133.2	45 - 500	0 - 14.3	0.31	0.1 (M)
Cyanide	6	2 - 3	27 - 40		0.2 (M)

Table E.31 (continued)

Constituents	Soil Exposure conc	Range of time for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
Mercury	2.3	250 - 500	0.0 - 0.09	0.11	0.002(M)
Molybdenum	15.2	350 - 500	0.0 - 0.08	0.023	0.18(R)
Nickel	550.3	> 500	0.0 - 0.2	20	0.73 (R) ^d
Strontium	35.5	310 - 500	0.006 - 0.8	340	22 (R)
Uranium	991.7	60 - 220	45.1 - 163.8	44	0.02 (M) ^e
Radionuclides^c					
²³⁸ Pu	25	210 - >500	0 - 255		0.16 (R)
^{239/240} Pu	2.5	250 - >500	0 - 97.7		0.15 (R)
⁹⁰ Sr	13	220 - >500	0.0001 - 3	254	1.2 (R)
⁹⁹ Tc	7500	35 - 85	18600- 57,900	80,400	34 (R)
²³⁴ U	120	160 - 170	40.3 - 114.9	4,650	1.1 (R)
²³⁵ U	8.1	140 - 160	5.4 - 15.9	547	1.1 (R)
²³⁶ U	7.7	140 - 160	40.3 - 60		1.1 (R)
²³⁸ U	330	140 - 160	21.6 - 43.1	13,600	1.1 (R)

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to loading from the S-3 site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c All concentrations of organics is in parts per billion (µg/l). All concentrations of inorganics is in parts per million (mg/l). All concentrations for radionuclides are reported in pCi/L.

^d The Environmental Protection Agency has deleted from the *CFR* the MCL and MCLG for nickel, which have been vacated by a court ruling, effective June 29, 1995 (60 *FR* 33926, June 29, 1995). The risk-based value used is for soluble nickel salts.

^e Proposed MCL for natural uranium, approximately equal to 30 pCi/l.

**Table E.32. Summary of predicted future groundwater and surface water concentrations
at NT-1 due to contaminant loading from S-3 Site**

Constituents	<i>Predicted Maximum Groundwater Conc. Range^a</i>	<i>Predicted Time Range for Peak Conc. (Years from Start)</i>	<i>Predicted Maximum Surface Water Conc. Range^a</i>	<i>Observed Surface Water Conc. Range</i>	<i>Groundwater RGOs^e</i>	
<i>Inorganics^b</i>						
Beryllium	0.01 to 0.03	40 to 200	0.00 to 0.001	0.0003 to 0.0007	0.005	M
Cadmium	0.27 to 0.90	40 to 200	0.01 to 0.05	0.017 to 0.038	0.005	M
Manganese	28.91 to 95.69	steady state	1.74 to 5.76	0.10 to 6.93	0.05	M ²
Mercury	0.01 to 0.03	40 to 100	0.00 to 0.004	0.0002 to 0.0002	0.002	M
Nickel	2.10 to 7.26	40 to 100	0.10 to 0.33	0.048 to 0.15	0.1	M
Strontium	1.27 to 4.49	steady state	0.25 to 0.87	0.33 to 0.81	22	R
Total uranium	6.78 to 16.58	40 to 150	0.81 to 1.99	0.031 to 0.075	0.02	M
<i>Common Anions^b</i>						
Nitrate	2,093 to 4,518	33 to 100	251 to 541	230 to 230	10	M
<i>Organics^c</i>						
Tetrachloroethene	39.9 to 581.4	33 to 75	3.99 to 58.1	1.0 to 19.0	5	M
<i>Radioactivity^d</i>						
⁹⁹ Tc	7,023 to 23,176	33 to 100	465 to 1,538	890 to 1,110	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

Table E.33. Summary of predicted groundwater and surface water concentrations at NT-2 due to contaminant loading from the S-3 Site

Constituents	Predicted Maximum Groundwater Conc. Range	Predicted Time Range for Peak Conc. (Years from start)	Predicted Maximum Surface Water Conc. Range	Observed Surface Water Conc. Range	Groundwater RGOs ^c
<i>Inorganics^b</i>					
Barium	25.22 to 94.96	40 to 100	2.43 to 9.13	0.060 to 0.682	2 M
Manganese	1.97 to 7.24	50 to 200	0.19 to 0.70	0.021 to 0.392	0.05 M ²
Strontium	23.00 to 86.58	100 to 200	2.21 to 8.33		22 R
Total uranium	0.20 to 0.35	100 to >1000	0.019 to 0.034	0.148 to 0.148	0.02 M
<i>Common Anions^b</i>					
Nitrate	5,026 to 8,221	75 to 400	483 to 791	2.90 to 211.0	10 M

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

**Table E.34. Summary of predicted future groundwater concentrations
near Bear Creek due to contaminant loading from S-3 Site**

Constituents	<i>Predicted Maximum Groundwater Concentration Range^a</i>	<i>Predicted Time Range for Peak Concentration (years from start)</i>	<i>Groundwater RGOs^e</i>	
<i>Inorganics^b</i>				
Beryllium	0.002 to 0.01	<45	0.005	M
Cadmium	0.08 to 0.25	<45	0.005	M
Manganese	7.00 to 21.00	<45	0.05	M ²
Mercury	0.003 to 0.01	<45	0.002	M
Nickel	0.75 to 2.24	<45	0.1	M
Strontium	0.51 to 1.53	<45	22	R
Total uranium	1.22 to 3.49	<45	0.02	M
<i>Common Anions^b</i>				
Nitrate	151.4 to 583	<45	10	M
<i>Organics^c</i>				
1,1,2-Trichloroethane	1.42 to 5.09	<45	5	M
Tetrachloroethene	82.36 to 210	<45	5	M
<i>Radioactivity^d</i>				
⁹⁹ Tc	2109.00 to 6,752	<45	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, R = Risk-based

Table E.35. Summary of vadose zone modeling results from BYBY

Constituents	Soil exposure conc.	Range of time ^h for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
<i>Volatile Organic^c</i>					
1,2-Dichloroethene	3.34	NA	7.1 - 23.8	1100	100 (M)
2-Butanone	7.8	NA	1310.3 - 4403.7	91	22000 (R)
Acetone	90.4	NA	6958.2 - 89613.7	86	3700 (R)
Tetrachloroethene	4.02	NA	3.5 - 16.6	1600	5.0 (M)
Trichloroethene	3.3	NA	2.7 - 8.2	2000	5.0 (M)
Toluene	257	NA	9.4 - 143.5	3	1000 (M)
<i>Semivolatile Organic Compounds^c</i>					
Bis(2-ethylhexyl)phthalate	880	NA	0.1 - 1.2	17	6.1 (R)
Carbazole	18300	45 - 90	0.2 - 35	0.0	4.3 (R)
Diethylphthalate	65	12 - 25	0.0 - 21	0.0	29000 (R)
Phenol	200	3 - 4	0.0 - 700	2	22000 (R)
<i>PCBs^c</i>					
Aroclor 1254	1170	NA	0.2 - 2.2	0.0	0.5 (M)
Aroclor 1260	1260	NA	0.05 - 0.8	0.0	0.5 (M)
<i>Inorganics^d</i>					
Antimony	423.0	NA	1.08 - 17.8	0.03	0.006 (R)
Arsenic	28.8	35 - >500	0 - 3.8	0.01	0.05 (M)
Barium	577.0	300 - >500	2.5 - 4.5	1.2	2.0 (M)

Table E.35 (continued)

Constituents	Soil exposure conc.	Range of time ^h for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
Beryllium	1.6	NA	0.001 - 0.006	0.003	0.004 (M)
Cadmium	19.7	45 - >500	0.07 - 2.7	0.03	0.005 (M)
Chromium	88.0	25 - >500	0.0 - 4.9	0.41	0.1 (M)
Cobalt	48.2	>500	0.0 - 0.01	0.09	
Copper	6220	300 - >500	1.5 - 180.7	0.1	1.3 (M) ^f
Cyanide	3.87	NA	121.4 - 1287.4	0.03	0.2 (M)
Lead	1,870	>500	0.0 - 0.5	0.64	0.015 (M) ^f
Manganese	1470	NA	0.0 - 0.2	7.6	0.05 (M)
Mercury	50.8	150 - >500	0.0 - 2.9	0.08	0.002 (M)
Molybdenum	41.9	300 - >500	0.002 - 1.2	0.13	0.18 (R)
Nickel	1020	NA	2.4 - 69.5	0.21	0.73 (R) ^g
Selenium	12.5	NA	0.07 - 5.0	0.007	0.05 (M)
Silver	13.4	NA	0.03 - 0.5	0.0	0.1 (M)
Tin	62.0	>500	0 - 0.02	0.0	22 (R)
Zinc	698.0	NA	0.05 - 2.3	1.2	5.0 (M)
<i>Radionuclides^c</i>					
⁹⁹ Tc	24.1	NA	7944.2 - 82935.6	2800 ⁱ	34 (R)
²³² Th	4.3	NA	0.5 - 8.0	1.2	1.5 (R)
²³⁴ U	260.0	35 - 80	216 - 1276.6	1300	1.1 (R)

Table E.35 (continued)

Constituents	Soil exposure conc.	Range of time ^h for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
²³⁵ U	17.0	35 - 80	17.6 - 52.3	53	1.1 (R)
²³⁸ U	541	35 - 80	540 - 1777.0	1800	1.1 (R)

NA indicates not applicable, and a blank space indicates data not available.

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to loading from the BYBY site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c Concentrations for Organics are given in parts per billion (µg/l or µg/kg).

^d Concentrations for inorganics are given in parts per million (mg/l or mg/kg).

^e Concentrations for radionuclides are given in pCi/L.

^f The 1995 MCL values for copper and lead are listed as "treatment technology" and the "action levels" are 1300 µg/l (1.3 mg/l) for copper (also the MCLG value for copper) and 15 µg/l (0.015 mg/l) for lead.

^g The Environmental Protection Agency has deleted from the *CFR* the MCL and MCLG for nickel, which have been vacated by a court ruling, effective June 29, 1995 (60 *FR* 33926, June 29, 1995). Risk-based value used is for soluble nickel salts.

^h All constituents with maximum concentration below the vadose zone were modeled using Crystal Ball with partition model, therefore a range of time for maximum concentration are not applicable and indicated by an "NA".

ⁱ The value represents β activity.

Table E.36. Summary of vadose zone modeling results from SL 1

Constituents	Soil exposure conc.	Range of time ^h for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health risk based ^b
<i>Volatile Organic Compounds^c</i>					
Acetone	1100	1 - 3	0 - 3500	86	3700 (R)
Toluene	110	7 - 8	0.0 - 100	3	1000 (M)
2-Butanone	1000	NA	133,254.1 - 1,154,409.9	91	22000 (R)
2-Hexanone	140	NA	1785.3 - 13353		
<i>Semivolatile Organic Compounds^c</i>					
4-Methyl-2-pentanone	10.7	NA	3226.5 - 6937.4		
Acenaphthene	310	33-99	0.0 - 10.0		2200 (R)
Carbazole	310	18 - 51	4.8 - 6.0		4.3 (R)
Diethylphthalate	61	4 - 13	0.0 - 20.0		29000 (R)
Phenol	230	2 - 3	0.04 - 800	2	22000 (R)
<i>Inorganics^d</i>					
Barium	486	NA	1.4 - 8.2	1.2	2.0 (M)
Beryllium	2.2	NA	0.003 - 0.008	0.003	0.004 (M)
Cadmium	2.71	45 - 500	0.02 - 0.5	0.03	0.005 (M)
Copper	252	300 - 500	9.4 - 14.1	0.1	1.3 (M) ^f
Manganese	3150	NA	0.02 - 0.6	6.9	0.05 (M)
Mercury	41.5	150 - 500	0.0 - 3.08	0.0006	0.002 (M)
Nickel	231	>500	0.0 - 0.3	0.21	0.73 (R) ^g

Table D.36 (continued)

Constituents	Soil exposure conc.	Range of time ^h for C _{max} (years)	Predicted range of C _{max} ^a beneath the source	Currently observed C _{max} in groundwater	PRG human health risk based ^b
Silver	7.6	400 - 500	0.003 - 0.2	0.0	0.1 (M)
Tin	4.8	>500	0.0 - 0.006		22 (R)
Zinc	470	55 - 500	0 - 96.8	1.2	5.0 (R)
Radionuclides^e					
Cesium 137	1.2	NA	0.1 - 1.9		1.5 (R)
Thallium 208	2.9	NA	1.8 - 2.1		2700 (R)
Uranium 234	14	75 - 350	1.6 - 211		1.1 (R)
Uranium 238	940	70 - 350	2.6 - 523		1.1 (R)

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose zone aquifer interface due to loading from the SL1 site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c All organic concentrations are reported in parts per billion (µg/l or µg/Kg).

^d Inorganic concentrations are reported in parts per million (mg/l or mg/kg).

^e All concentrations for radionuclides are reported in pCi/L.

^f The 1995 MCL value for copper is listed as "treatment technology" and the "action level" is 1300 µg/l (1.3 mg/l) which is also the MCLG for copper.

^g The Environmental Protection Agency has deleted from the CFR the MCL and MCLG for nickel, which have been vacated by a court ruling, effective June 29, 1995 (60 FR 33926, June 29, 1995). The risk-based value used is for soluble nickel salts.

^h All constituents with maximum concentration below the vadose zone were modeled using Crystal Ball with partition model, therefore a range of time for maximum concentration are not applicable and indicated by an "NA".

Table E.37. Summary of vadose zone modeling results from OLF

Constituents	Soil exposure conc.	Range of time for C_{max} (years)	Predicted range of C_{max} beneath the source ^a	Currently observed C_{max} in groundwater	PRG human health ^b
<i>Inorganics^c</i>					
Uranium	77.3	30-110	0 - 3.5	0.52	0.02 (M) ^d

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to loading from the BYBY site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c Concentrations for inorganics are given in parts per million (mg/l).

^d Proposed MCL for natural uranium, approximately equal to 30 pCi/l.

**Table E.38. Summary of predicted future groundwater and surface water concentrations
at NT-3 due to contaminant loading from BYBY**

Constituents	Predicted Maximum Groundwater Conc. Range ^a	Predicted Time Range for Peak Conc. (years from start)	Predicted Maximum Surface Water Conc. Range ^a	Observed Surface Water Conc. Range	Groundwater RGOs ^e	
<i>Inorganics^b</i>						
Antimony	0.26 to 0.63	Steady-state	0.03 to 0.08	0.0017 to 0.0049	0.006	M
Cadmium	0.02 to 0.04	Steady-state	0.002 to 0.005		0.005	M
Manganese	1.89 to 4.45	Steady-state	0.230 to 0.530	0.021 to 1.2	0.05	M
Mercury	0.03 to 0.06	Steady-state	0.00 to 0.01	0.0002 to 0.00053	0.002	M
Nickel	0.46 to 1.27	Steady-state	0.06 to 0.15	0.0042 to 0.0086	0.1	M
Total uranium	3.07 to 4.65	Steady-state	0.37 to 0.56	0.19 to 1.63	0.02	M
<i>Organics^b</i>						
1,1,2,2-Tetrachloroethane	0.00 to 1.27	<45	0.00 to 0.15		0.43	R
1,1-Dichloroethene	0.00 to 25.7	<45	0.00 to 3.08		7	M
1,2-Dichloroethene	160.95 to 413.16	<45	19.28 to 49.48		330	R
Methylene chloride	0.00 to 122.6	<45	0.00 to 14.7		5	M
Tetrachloroethene	162.4 to 480	<45	19.4 to 57.4		5	M
Trichloroethene	110.6 to 423	<45	13.25 to 50.6		5	M
Vinyl Chloride	9.6 to 26	<45	1.15 to 3.1		2	M
<i>Radioactivity^c</i>						
⁹⁹ Tc	5,911 to 7,694	steady-state	708 to 921	55.8 ^f to 603 ^f	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics are reported as mg/l.

^c Concentrations of organics are reported as µg/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, R = Risk-based

**Table E.39. Summary of predicted future groundwater concentrations
near Bear Creek due to contaminant loading from BYBY**

Constituents	Predicted Maximum Groundwater Concentration Range ^a	Predicted Time Range for Peak Conc. (years from start)	Groundwater RGOs ^c	
<i>Inorganics^b</i>				
Antimony	#REF! to #REF!	steady-state	0.006	M
Cadmium	#REF! to #REF!	steady-state	0.005	M
Manganese	2.7 to 5.2	steady-state	0.05	M ²
Mercury	#REF! to #REF!	steady-state	0.002	M
Nickel	#REF! to #REF!	steady-state	0.1	M
Total uranium	#REF! to #REF!	steady-state	0.02	M
<i>Organics^c</i>				
1,1,2,2-Tetrachloroethane	#REF! to #REF!	<45	0.43	R
1,1-Dichloroethene	#REF! to #REF!	<45	7	M
1,2-Dichloroethene	#REF! to #REF!	<45	330	R
Benzene	#REF! to #REF!	<45	5	M
Methylene chloride	#REF! to #REF!	<45	5	M
Tetrachloroethene	#REF! to #REF!	<45	5	M
Trichloroethene	#REF! to #REF!	<45	5	M
Vinyl Chloride	#REF! to #REF!	<45	2	M
<i>Radioactivity^d</i>				
⁹⁹ Tc	#REF! to #REF!	steady-state	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years

^b Concentrations of inorganics are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, R = Risk-based

Table E.40. Summary of vadose zone modeling results from BG-A North site

Constituents	Soil exposure conc.	Range of time ⁱ for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
<i>Volatile Organic Compounds^c</i>					
Benzene	180	NA	109.4 - 1496.2	420.0	5.0 (M)
2-Butanone	42	2 - 8	0.0 - 250	3,600.0	22000 (R)
Chloroethane	170	3 - 5	8 - 65	740.0	
Chloroform	15	NA	132.5 - 317.3	1,700.0	100 (M) ^d
1,1-Dichloroethane	72	3 - 4.5	65 - 90	7,800.0	3700 (R)
1,1-Dichloroethene	5	2.5 - 3.5	0.9 - 4.9	13,000.0	7.0 (M)
Methylene chloride	7	NA	175.5 - 409.7	490.0	5.0 (M)
Toluene	200	NA	17.7 - 169.0	670.0	1000 (M)
1,1,1-Trichloroethane	19	7.5 - 10	13 - 22	13,000.0	200.0 (M)
Vinyl chloride	6	3 - 5	0.2 - 5.8	3,400.0	2.0 (M)
<i>Semivolatile Organic Compounds^c</i>					
Bis(2-ethylhexyl)phthalate	2400	NA	5 - 46.9		6.1 (R)
<i>Inorganics^c</i>					
Barium	376	NA	3.3 - 6.09	1.6	2.0 (M)
Beryllium	1.5	NA	0.006 - 0.007	0.004	0.004 (M)
Copper	46.7	NA	0.3 - 1.3	6.6	1.3 (M) ^e
Cyanide	44.2	NA	2,143.1 - 5,223.2		0.2 (M)
Manganese	2330	NA	0.1 - 0.4	19.0	0.05 (M)
Nickel	61.9	NA	0.2 - 0.7	1.7	0.73 (R) ^f

Table E.40 (continued)

Constituents	Soil exposure conc.	Range of time ⁱ for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
Selenium	2.1	55 - >500	0.0007 - 0.5	0.0	0.05 (M)
Silver	3.8	NA	0.01 - 0.05	0.0	0.1 (M) ^g
Tin	6.4	>500	0.0000003 - 0.01		22.0 (R)
Uranium	11,000.0	80 - 290	1.5	0.17	0.02 (M) ^h
<i>Radionuclides^c</i>					
⁹⁹ Tc	8.6	10 - 25	0.0008 - 71.02		34 (R)

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to contaminant loading from BG-A North.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c All concentrations of organics are in parts per billion (µg/l for water and µg/kg for soil). All concentrations of inorganics is in parts per million (mg/l for water and mg/kg for soil). All concentrations for radionuclides are reported in pCi/L for water matrix or pCi/g for soil matrix.

^d Total allowable concentration of trihalomethanes (the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane and bromoform).

^e The 1995 MCL for copper is listed as "treatment technology" and the "action level" of 1300 µg/l (1.3 mg/l) for copper is also the MCLG for copper.

^f The Environmental Protection Agency has deleted from the CFR the MCL and MCLG for nickel, which have been vacated by a court ruling, effective June 29, 1995 (60 FR 33926, June 29, 1995). The risk-based value used is for soluble nickel salts.

^g Federal Secondary drinking water MCL.

^h Proposed MCL for natural uranium, approximately equal to 30 pCi/l.

ⁱ All constituents with maximum concentration below the vadose zone were modeled using Crystal Ball with partition model, therefore a range of time for maximum concentration are not applicable and indicated by an "NA".

Blanks indicate data not available; NA indicates "not applicable".

Table E.41. Summary of vadose zone modeling results from BG-A South site

Constituents	Soil exposure conc.	Range of time ^g for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
<i>Volatile Organic Compounds^c</i>					
1,1-Dichloroethane	3.65	NA	61.0 - 369.6	7800	3700 (R)
1,1,1-trichloroethane	960000	NA	44000 - 220000	13000	200 (M)
1,2-Dichloroethene	23.4	NA	255.9 - 4433.3	5400	100 (M)
Acetone	36.8	NA	44009.4 - 324974.9	850	3700 (R)
Benzene	140000	NA	17800 - 89000	420	5.0 (M)
Freon	480000	NA	1700 - 8500		1,100,000 (R)
Methanol	380000	NA	5,000,000.0		18000 (R)
2-Butanone	62000	NA	13,750,000.0	3600	22000 (R)
Tetrachloroethene	890000	NA	1500 - 7500	63000	5 (M)
Trichloroethene	85000	NA	11499.3 - 55000	24,000	5 (M)
Toluene	3.54	NA	5.69 - 40.6	670	1000(M)
<i>PCBs/Pesticides^c</i>					
PCB (total)	21000	NA	18.2 - 311.7		0.5 (M)
Methoxychlor	9.3	NA	0.1 - 0.4		180 (R)
<i>Inorganics^c</i>					
Barium	191	NA	2.9 - 4.2	1.6	2.0 (M)
Beryllium	2.5	NA	0.0 - 0.01	0.0038	0.004 (M)
Cobalt	20.3	NA	0.0 - 0.06	0.099	
Copper	34.7	NA	0.5 - 3.2	6.60	1.3 (M) ^d

Table E.41 (continued)

Constituents	Soil exposure conc.	Range of time ^g for C _{max} (years)	Predicted range of C _{max} beneath the source ^a	Currently observed C _{max} in groundwater	PRG human health ^b
Lead	14.3	NA	0.0 - 0.01	0.70	0.015 (M) ^d
Lithium	1.1	NA	0.0 - 0.01	0.99	
Manganese	1360	NA	0.02 - 0.3	19.00	0.05 (M)
Nickel	41.5	NA	0.09 - 0.8	1.70	0.73 (R) ^e
Silver	2.23	NA	0.0 - 0.05	0.0	0.1 (M)
Tin	2.71	NA	0.01 - 0.07		22 (M)
Uranium	15000	NA	3.5 - 44.9	0.17	0.02 (M) ^f

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to loading from the S-3 site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c All concentrations of organics is in parts per billion (µg/l or µg/kg). All concentrations of inorganics is in parts per million (mg/l or mg/kg).

^d The 1995 MCL values for copper and lead are listed as "treatment technology" and the "action levels" are 1300 µg/l (1.3 mg/l) for copper (also the MCLG for copper) and 15 µg/l (0.015 mg/l) for lead.

^e The Environmental Protection Agency has deleted from the *CFR* the MCL and MCLG for nickel, which have been vacated by a court ruling, effective June 29, 1995 (60 *FR* 33926, June 29, 1995). The risk-based value used is for soluble nickel salts.

^f Proposed MCL for natural uranium, approximately equal to 30 pCi/l.

^g All constituents with maximum concentration below the vadose zone were modeled using Crystal Ball with partition model, therefore a range of time for maximum concentration are not applicable and indicated by an "NA".

Blanks indicate data is not available; NA indicates data are not available.

Table E.42. Summary of vadose zone modeling results from WIP sites

Constituents	Soil exposure conc.	Range of time for $C_{\max}^g$ (years)	Predicted range of $C_{\max}$ beneath the source ^a	Currently observed $C_{\max}$ in groundwater	PRG human health ^b
<i>Volatile Organic Compounds^c</i>					
Acetone	180	5 - 6	0.02 - 1000	850	3700 (R)
Benzene	130,000.0	6 - 7	85,000.0 - 130,000.0	420	5.0 (M)
Methylene Chloride	86	NA	615.3 - 7162.5	490	5.0 (M)
Toluene	250	20 - 44	0.0 - 35.0	670	1000 (M)
1,1,1-Trichloroethane	7,700.0	6 - 7	2,600.0 - 27,000.0	13,000.0	200 (M)
<i>Semivolatile Organic Compounds^c</i>					
1,4-dichlorobenzene	200	65 - >100	0.0 - 25		3.5 (R)
Phenol	47,000.0	4 - 5	0.0 - 160,000.0	0.2	22,000 (R)
<i>Inorganics^d</i>					
Arsenic	19.0	95 - >500	0.0 - 5.0	0.01	0.05 (M)
Barium	220	310 - 500	1.8 - 2.3	1.6	2.0 (M)
Beryllium	26.0	10 - 500	0.0 - 0.03	0.004	0.004 (M)
Cyanide	45.7	4 - 8	100 - 470		0.2 (M)
Manganese	5550	NA	0.03 - 0.7	19	0.05 (M)
Tin	2.63	>500	0.0 - 0.00003		22 (R)
Uranium	72000	130 - 450	0.5 - 4.3	0.17	0.02 (M) ^f

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Table E.42 (continued)

Constituents	Soil exposure conc.	Range of time for $C_{\max}^g$ (years)	Predicted range of $C_{\max}$ beneath the source ^a	Currently observed $C_{\max}$ in groundwater	PRG human health ^b
<i>Radionuclides^e</i>					
⁹⁹ Tc	11.8	20 - 45	7110 - 17500		34 (R)
²³⁸ U	4.15	75 - 250	389 - 1430		1.1 (R)

^a Maximum groundwater concentration represents the predicted maximum concentration at the vadose aquifer interface due to loading from the WIPs site.

^b The basis for establishing groundwater PRG is indicated next to the value: M = MCL and R = risk based concentrations associated with an ILCR of 1E-6 or an HQ of 1 from drinking water ingestion.

^c Concentrations for organics are given in parts per billion (µg/l).

^d Concentrations for inorganics are given in parts per million (mg/l).

^e Concentrations for radionuclides are given in pCi/L.

^f Proposed MCL for natural uranium, approximately equal to 30 pCi/l.

^g All constituents with maximum concentration below the vadose zone were modeled using Crystal Ball with partition model, therefore a range of time for maximum concentration are not applicable and indicated by an "NA".

Blanks indicate no data available; NA indicates "not applicable".

Table E.43. Summary of predicted future groundwater and surface water concentrations at NT-7 due to contaminant loading from BG A-North and A-South

Constituents	Predicted Max. Groundwater Conc. Range ^a	Predicted Time Range for Peak Conc. (years from start)	Predicted Max. Surface Water Conc. Range ^a	Observed Surface Water Concentration Range	Groundwater RGOs ^c
Inorganics^b					
Antimony	0.04 to 0.11	>1000 ^f	0.004 to 0.012	0.0023 to 0.003	0.006 M
Beryllium	0.27 to 1.62	>1000 ^f	0.03 to 0.18	0.0004 to 0.0013	0.005 M
Boron	15.3 to 25.0	>1000 ^f	1.73 to 2.82		3.3 R
Cadmium	0.02 to 0.04	>1000 ^f	0.003 to 0.005		0.005 M
Copper	1.8 to 4.1	>1000 ^f	0.20 to 0.46	0.0306 to 0.0306	1 M
Cyanide	22.0 to 214.0	10 to 100	2.5 to 24.1	0.0139 to 0.0139	0.2 M
Lead	0.07 to 0.30	>1000 ^f	0.008 to 0.034		0.015 M ³
Lithium	0.29 to 1.87	>1000 ^f	0.03 to 0.21	0.0283 to 0.057	0.073 R
Manganese	3.73 to 10.3	>1000 ^f	0.4 to 1.2	0.0085 to 1.01	0.05 M ²
Nickel	0.25 to 0.83	>1000 ^f	0.03 to 0.09	0.0031 to 0.022	0.1 M
Total uranium	1.79 to 2.88	>1000 ^f	0.20 to 0.32	0.0114 to 0.1524	0.02 M
Organics^c					
1,1,1-Trichloroethane	576.2 to 3,861.7	20 to 150	65.0 to 435.9	3 to 35	200 M
1,1,2-Trichloroethane	14.2 to 59.3	20 to 250	1.6 to 6.7		5 M
1,1-Dichloroethene	0.00 to 144.7	20 to 55	0.00 to 16.3	2 to 16	7 M
1,2-Dichloroethane	5.97 to 40.5	20 to 130	0.67 to 4.6	1 to 19	5 M
1,2-Dichloroethene	506.6 to 1,587.8	20 to 300	57 to 179	33 to 290	330 R
Benzene	18.4 to 158.4	20 to 150	2.1 to 17.9	1 to 2	5 M
Carbon tetrachloride	0.00 to 796.6	20 to 100	0.00 to 89.9		5 M
Chloroform	366.0 to 1,789.3	20 to 325	41.3 to 202.0	1 to 8	100 M
Methylene chloride	0.00 to 20.1	10 to 45	0.00 to 2.26	1 to 4	5 M
Tetrachloroethene	1,920.1 to 10,417.8	20 to 200	216.7 to 1,175.8	16 to 120	5 M
Trans-1,2-Dichloroethene	4,801.4 to 14,341.8	20 to 225	542 to 1,619		100 M
Trichloroethene	651.9 to 3,758.2	20 to 200	73.6 to 424.2	8 to 82	5 M
Vinyl chloride	305.9 to 990.8	20 to 170	34.5 to 111.8	6 to 33	2 M
Radioactivity^d					
⁴⁰ K	70.9 to 122.2	>1000 ^f	8.0 to 13.8		3.8 R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

^f Because of unlimited source of contaminant inventory, concentration will continue to rise for a long period of time, however modeling results indicate that currently, the concentrations are very close to steady state condition.

Table E.44. Summary of predicted future groundwater concentrations at Picket A due to contaminant loading from BG A-North and A-South

Constituents	Predicted Maximum Groundwater Con Range ^a	Predicted Time Range for Peak Conc. (years from start)	Groundwater RGOs ^e	
<i>Inorganics^b</i>				
Antimony	0.00 to 0.02	>1000	0.006	M
Beryllium	0.00 to 0.06	>1000	0.005	M
Boron	3.0 to 13.0	>1000	3.3	R
Cadmium	0.00 to 0.02	>1000	0.005	M
Cyanide	0.00 to 0.79	<500	0.2	M
Lead	0.00 to 0.04	>1000	0.015	M ³
Lithium	0.00 to 0.05	>1000	0.073	R
Manganese	0.00 to 2.41	>1000	0.05	M ²
Total uranium	0.34 to 1.50	>1000	0.02	M
<i>Organics^c</i>				
1,2-Dichloroethene	0.00 to 86	<800	330	R
Tetrachloroethene	0.00 to 205	>1000	5	M
Trans-1,2-Dichloroethene	0.00 to 696	<825	100	M
Trichloroethene	0.00 to 63	>1000	5	M
Vinyl chloride	0.00 to 65	<775	2	M
<i>Radioactivity^d</i>				
⁴⁰ K	8.4 to 53.7	>1000	3.8	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

Table E.45. Summary of predicted future groundwater and surface water concentrations at NT-8 due to contaminant loading from WIP

Constituents	Predicted Maximum Groundwater Conc. Range ^a	Predicted Time Range for Peak Conc. (years from start)	Predicted Maximum Surface Water Conc. Range ^a	Observed Surface Water Conc. Range	Groundwater RGOs ^e 5	
Inorganics^b						
Arsenic	0.52 to 0.73	>1000 ^f	0.05 to 0.07	0.0024 to 0.0143	0.05	M
Beryllium	0.17 to 0.54	>1000 ^f	0.02 to 0.06	0.0004 to 0.0086	0.005	M
Boron	11.4 to 15.9	>1000 ^f	1.16 to 1.63		3.3	R
Cadmium	0.013 to 0.02	>1000 ^f	0.001 to 0.002		0.005	M
Chromium	0.20 to 0.28	>1000 ^f	0.02 to 0.03		0.1	M
Cyanide	6.53 to 23.29	10 to 100	0.67 to 2.38	0.0215 to 0.0215	0.2	M
Lead	0.20 to 0.48	>1000 ^f	0.02 to 0.05		0.015	M ³
Manganese	7.32 to 13.35	>1000 ^f	0.75 to 1.37	0.0259 to 0.425	0.05	M ²
Nickel	0.13 to 0.27	>1000 ^f	0.01 to 0.03	0.0046 to 0.0046	0.1	M
Total uranium	2.90 to 3.96	>1000 ^f	0.30 to 0.41	0.06 to 1.32	0.02	M
Organics^c						
1,1,1-Trichloroethane	776.0 to 2,334	20 to 180	79.4 to 238.9	2 to 11	200	M
1,1,2-Trichloroethane	43.5 to 110	20 to 180	4.46 to 11.24	1 to 2	5	M
1,1-Dichloroethene	113.5 to 1345	10 to 40	11.6 to 137.6	5 to 11	7	M
1,2-Dichloroethane	27.2 to 84.53	10 to 100	2.78 to 8.65	2 to 4	5	M
1,2-Dichloroethene	1075.0 to 2,479	20 to 200	110.0 to 253.7	4 to 410	330	R
Benzene	6,659 to 22,208	20 to 130	682 to 2,273	1 to 3	5	M
Carbon tetrachloride	4.34 to 27.8	20 to 100	0.44 to 2.85		5	M
Chloroform	198 to 557	20 to 200	20.3 to 57.0	1 to 3	100	M
Methylene chloride	55 to 801	10 to 45	5.58 to 82.0	1 to 3	5	M
Tetrachloroethene	989.2 to 2,713	30 to 225	101.2 to 277.7	26 to 58	5	M
Trans-1,2-Dichloroethene	10,758 to 23,390	20 to 160	1101 to 2,394		100	M
Trichloroethene	99 to 268	30 to 225	10.2 to 27.4	13 to 29	5	M
Vinyl chloride	522.79 to 1,303	20 to 140	53.5 to 133.4	3 to 21	2	M
Radioactivity^d						
⁴⁰ K	96.3 to 141.4	>1000 ^f	9.9 to 14.5	130 to 130	3.8	R
⁹⁹ Tc	6,067 to 7,030	>1000 ^f	621 to 720		34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

^f Because of unlimited source of contaminant inventory concentration will continue to rise for a long period of time, however modeling results indicate that currently, the concentrations are very close to steady state condition.

Table E.46. Summary of predicted future groundwater concentrations at Picket A due to contaminant loading from WIP

Constituents	Predicted Max. Groundwater Concentration Range ^a	Predicted Time Range for Peak Conc. (years from start)	Groundwater RGOs ^c	
<i>Inorganics^b</i>				
Arsenic	0.12 to 0.42	>1000	0.05	M
Beryllium	0.000 to 0.073	>1000	0.005	M
Boron	2.7 to 9.1	>1000	3.3	R
Cadmium	0.003 to 0.011	>1000	0.005	M
Chromium	0.05 to 0.17	>1000	0.1	M
Cyanide	0.00 to 0.51	<300	0.2	M
Lead	0.00 to 0.11	>1000	0.015	M ²
Manganese	0.3 to 4.4	>1000	0.05	M ²
Nickel	0.00 to 0.08	>1000	0.1	M
Total uranium	0.75 to 2.36	>1000	0.02	M
<i>Organics^c</i>				
Benzene	0.00 to 793	<350	5	M
Tetrachloroethene	0.00 to 161.1	<500	5	M
Trans-1,2-Dichloroethene	8.6 to 2,520	<425	100	M
Trichloroethene	0.00 to 16.90	<500	5	M
Vinyl chloride	0.00 to 94.6	<350	2	M
<i>Radioactivity^d</i>				
⁴⁰ K	18.4 to 73.4	>1000	3.8	R
⁹⁹ Tc	2,963 to 5,503	>1000	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

Table E.47. Summary of predicted future groundwater concentrations at Picket A and surface water concentrations at NT-8 due to contaminant loading from BG-C West

Constituents	Predicted Maximum Groundwater Conc. Range ^a	Predicted Time Range for Peak Conc. (years from start)	Predicted Maximum Surface Water Conc. Range ^a at NT-8	Observed Surface Water Conc. Range at NT-8	Groundwater RGOs ^c
<i>Inorganics^b</i>					
Arsenic	0.05 to 0.13	>1000	0.02 to 0.04	0.0024 to 0.0143	0.05 M
Boron	34.24 to 79.81	>1000	11.45 to 25.20		3.3 R
Cadmium	0.01 to 0.01	>1000	0.002 to 0.004		0.005 M
Chromium	0.12 to 0.27	>1000	0.04 to 0.08		0.1 M
Manganese	0.95 to 4.87	>1000	1.23 to 2.70	0.0259 to 0.425	0.05 M ²
Selenium	0.03 to 0.18	>1000	0.05 to 0.10		0.05 M
Thallium	0.00 to 0.00	>1000	0.02 to 0.04		0.002 M
Total uranium	0.33 to 0.73	>1000	0.10 to 0.22	0.06 to 1.32	0.02 M
<i>Organics^c</i>					
1,1,1-Trichloroethane	0.00 to 174.44	<350	381.8 to 840.0	2 to 11	200 M
1,2-Dichloroethane	0.00 to 103.37	<200	254.5 to 560.0	2 to 4	5 M
Benzene	0.00 to 1.61	<225	4.8 to 10.6	1 to 3	5 M
Bis (ethylhexyl)phthalate	0.00 to 0.00	>1000	11.2 to 24.6		6.1 R
Methylene Chloride	0.00 to 0.0793	<50	4.3 to 9.4	1 to 3	5 M
PCB(Total)	0.00 to 0.0358	>1000	11.8 to 26.0		5 M
Trans-1,2-Dichloroethene	32.6 to 201.8	<300	163.6 to 360.0		100 M
Trichloroethene	0.00 to 6.93	<375	13.6 to 30.0	13 to 29	5 M
Vinyl chloride	61.37 to 314.32	<275	209.1 to 460.0	3 to 21	2 M

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

Table E.48. Summary of predicted peak groundwater concentrations at Picket A due to contaminant loading from BG A-North and South, BG WIP, and BGC West

<i>Constituents</i>	<i>Groundwater Concentrations^a Range at Picket A Range</i>	<i>Groundwater RGOs^c</i>
<i>Inorganics^b</i>		
Antimony	0.18 to 0.57	0.006 M ³
Beryllium	0.00 to 0.14	0.005 M
Boron	39.92 to 101.96	3.3 R
Cadmium	0.01 to 0.04	0.005 M
Chromium	0.18 to 0.43	0.1 M
Copper	0.05 to 1.48	1 M ²
Cyanide	0.00 to 1.30	0.2 M
Lead	0.00 to 0.18	0.015 M ³
Manganese	1.25 to 11.70	0.05 M ²
Nickel	0.00 to 0.25	0.1 M
Selenium	0.03 to 0.18	0.05 M
Total uranium	1.42 to 4.59	0.02 M
<i>Organics^c</i>		
1,1,1-Trichloroethane	0.00 to 335.55	200 M
1,1,2-Trichloroethane	0.00 to 9.68	5 M
1,2-Dichloroethane	0.00 to 107.25	5 M
1,2-Dichloroethene	0.00 to 378.12	330 R
Benzene	0.00 to 795.85	5 M
Chloroform	0.00 to 64.68	100 M
Tetrachloroethene	0.00 to 366.61	5 M
Trans-1,2-Dichloroethene	41.20 to 3417.87	100 M
Trichloroethene	0.00 to 86.70	5 M
Vinyl chloride	61.37 to 473.93	2 M
<i>Radioactivity^d</i>		
40K	26.75 to 127.17	3.4 R
Tc99	2962.99 to 5502.93	38 R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M² = Secondary MCL, M³ = MCLG, R = Risk-based

Table E.49. Summary of predicted future surface water concentration at NT-8 due to combined contaminant loading from BG-WIP and BG-C West

Constituents	Surface Water Concentratonsa	Observed Surface Water		Groundwater	
	at NT-8 Range ^a	Concentration Range at NT-8		RGOs ^o	
<i>Inorganics^b</i>					
Arsenic	0.07 to 0.11	0.0024 to	0.0143	0.05	M
Beryllium	0.02 to 0.07	0.0004 to	0.0086	0.005	M
Boron	12.62 to 26.83			3.3	R
Cadmium	0.00 to 0.01			0.005	M
Chromium	0.06 to 0.11			0.1	M
Cyanide	0.67 to 2.38	0.0215 to	0.0215	0.2	M
Lead	0.03 to 0.07			0.015	M ³
Lithium	2.95 to 6.48	0.134 to	0.188	0.073	R
Manganese	1.98 to 4.07	0.0259 to	0.425	0.05	M ²
Selenium	0.05 to 0.10			0.05	M
Thallium	0.02 to 0.04			0.002	M
Total uranium	0.40 to 0.63	0.06 to	1.32	0.02	M
<i>Organics^c</i>					
1,1,1-Trichloroethane	461.24 to 1078.87	2 to	11	200	M
1,1,2-Trichloroethane	4.46 to 11.24	1 to	2	5	M
1,1-Dichloroethene	11.61 to 137.64	5 to	11	7	M
1,2-Dichloroethane	257.33 to 568.65	2 to	4	5	M
Benzene	686.40 to 2283.72	1 to	3	5	M
Bis (ethylhexyl)phthalate	11.18 to 24.60			4.8	R
Carbon tetrachloride	0.44 to 2.85			5	M
Methylene Chloride	9.86 to 91.36	1 to	3	5	M
PCB(Total)	11.82 to 26.16			5	M
Tetrachloroethene	102.52 to 280.53	26 to	58	5	M
Trans-1,2-Dichloroethene	1264.79 to 2754.05			100	M
Trichloroethene	23.81 to 57.43	13 to	29	5	M
Vinyl chloride	262.60 to 593.38	3 to	21	2	M

Table E.49 (continued)

Constituents	Surface Water Concentrations ^a at NT-8 Range ^a	Observed Surface Water Concentration Range at NT-8	Groundwater RGOs ^c	
	<i>Radioactivity^d</i>			
⁴⁰ K	9.86 to 14.47	130 to 130	3.8	R
⁹⁹ Tc	621.01 to 719.55	20.3 ^f to 66 ^f	34	R

^a These concentrations represent predicted peak concentrations over a simulation period of 1000 years.

^b Concentrations of inorganics and common anions are reported as mg/l.

^c Concentrations of organics are reported as ug/l.

^d Concentrations of radioactivity are reported as pCi/l.

^e M = MCL, M^2 = Secondary MCL, M^3 = MCLG, R = Risk-based

^f Concentrations represent gross beta activity

Table E.50. Comparison of model predicted future concentrations with analytical measurements for surface water concentrations at BCK 9.47

Constituents	Overall Predicted Range	Predicted Range excluding contribution from NT-8	Observed Range	Groundwater RGOs ^d
<i>Inorganics^a</i>				
Antimony	0.004 to 0.009	0.004 to 0.009	0.002 to 0.003	0.006 M
Beryllium	0.004 to 0.020	0.002 to 0.014	0.002 to 0.002	0.005 M
Cadmium	0.002 to 0.006	0.002 to 0.005		0.005 M
Cyanide	0.247 to 2.01	0.180 to 1.80		0.2 M
Lithium	0.29 to 0.64	0.002 to 0.02	0.028 to 0.091	0.073 R
Manganese	0.42 to 1.12	0.23 to 0.73	0.025 to 0.708	0.05 M ²
Thallium	0.002 to 0.004	0.000 to 0.000		0.002 M
Total Uranium	0.16 to 0.31	0.12 to 0.25	0.005 to 0.152	0.02 M
<i>Common Anions^a</i>				
Nitrate	62.17 to 113.2	62.17 to 113.2	0 to 46.2	10 M
<i>Organics^b</i>				
1,1-Dichloroethene	1.1 to 14.9	0.01 to 1.6		7 M
1,2-Dichloroethane	25.0 to 55.4	0.06 to 0.4	12 to 20	5 M
Benzene	66.59 to 222.8	0.16 to 1.4		5 M
Carbon tetrachloride	0.04 to 6.89	0.00 to 6.60		5 M
Methylene chloride	0.98 to 10.91	0.03 to 2.10	3 to 4	5 M
Tetrachloroethene	28.6 to 125	18.7 to 98	0.5 to 4	5 M
Trans-1,2-Dichloroethene	162 to 386	39.8 to 119		100 M
Trichloroethene	9.3 to 42.3	7.0 to 36.7	0.6 to 2	5 M
Vinyl chloride	28.08 to 65.98	2.70 to 8.50		2 M
<i>Radioactivity^c</i>				
⁴⁰ K	1.54 to 2.41	0.59 to 1.01		3.8 R
⁹⁹ Tc	171.7 to 293.0	111.6 to 223.1	110 to 110	34 R

^a Concentrations of inorganics and common anions are reported as mg/l.

^b Concentrations of organics are reported as µg/l.

^c Concentrations of radioactivity are reported as pCi/l.

^d M = MCL, M² = Secondary MCL, R = Risk-based

Table E.51. Summary of predicted groundwater concentrations of trichloroethene (TCE) in the Maynardville Limestone using uncertainty analysis

Location of Prediction	Distance^a from the source (ft)	Predicted Max. Groundwater Concentration Range $\mu\text{g/l}$	Predicted Time Range for Peak Conc. (years)
SS-4	3,400	44.16 to 121.4	100 to 300
Picket A (SS-5)	6,300	18.4 to 92.0	130 to 500
Picket W	11,000	7.36 to 69.9	200 to 800

^a Distances were taken from the center of the TCE plume.

^b The source term concentration used in this calculation represent the concentration at the center of the plume.

**E.9 SUPPORTING INFORMATION
FOR APPENDIX E**

- **MODELING APPROACHES AND APPLICATIONS**
- **MODELING OF TCE IN THE MAYNARDVILLE LIMESTONE**
- **DISSIPATION OF PRESSURE BULGE BENEATH S-3 SITE
IN THE NOLICHUCKY SHALE**

E.9.1 MODELING APPROACHES AND APPLICATIONS

E.9.1.1 Source Term Leachate Models

ODAST. ODAST, a one-dimensional analytical solution (Javandel, Doughty, and Tsang 1984), was used for determining fate and transport of the inorganic compounds and radionuclides in the unsaturated zone. This computer code is based on the solution originally developed by Ogata and Banks (1961), and calculates the normalized concentrations of a given constituent in a uniform flow field from a source having a constant or varying concentration in the initial layer. ODAST evaluates the basic one-dimensional analytical solute transport equation as a function of seepage velocity, dispersion coefficient, source decay, retardation factor, depletion time, and source rate. ODAST has been extensively verified against STRIP1B (Batu 1989). ODAST was used to provide the final leachate concentrations for all the inorganic compounds and radionuclides before reaching the water table.

SESOIL. The SESOIL computer model (Bonazountas and Wagner 1984) was selected to simulate the vertical transport of organic contaminants from the source areas down through the vadose zone to the aquifer. SESOIL is an acronym for Seasonal Soil compartment model and is a one-dimensional, vertical transport code for the unsaturated soil zone. It is an integrated soil compartment model and is designed to simultaneously model water transport, sediment transport, and pollutant fate. The program was developed for the Environmental Protection Agency's (EPA's) Office of Water and the Office of Toxic Substances in 1981 by Arthur D. Little, Inc., which updated the SESOIL model in 1984 to include a fourth soil compartment (the original model included up to three layers) and the soil erosion algorithms (Bonazountas, Wagner, and Goodwin 1982; Bonazountas and Wagner 1984). SESOIL was modified to enhance its capabilities (Hetrick et al. 1989; Hetrick et al. 1986; Hetrick and Travis 1988) to perform "long-term" simulations of chemical transport and transformations in soil.

The SESOIL model estimates pollutant concentrations in the soil profile following introduction via direct application and/or interaction with other media. The model defines the soil compartment as a soil column extending from the ground surface through the unsaturated zone and to the upper level of the saturated soil zone. A simplified generic vadose zone conceptual model used by SESOIL for the source areas at BCV is shown in Fig. E.42. Processes simulated in SESOIL are categorized in three cycles—the hydrologic cycle, sediment cycle, and pollutant cycle. Each cycle is a separate submodule in the SESOIL code. The hydrologic cycle includes rainfall, surface runoff, infiltration, soil-water content, evapotranspiration, and groundwater recharge. The pollutant cycle includes convective transport, volatilization, adsorption/desorption, and degradation/decay. A contaminant in SESOIL can partition in up to four phases (liquid, adsorbed, air, and pure).

Data requirements for SESOIL are not extensive, utilizing a minimum of soil and chemical parameters and monthly or seasonal meteorological values as input. Output of the SESOIL model includes pollutant concentrations at various soil depths and pollutant loss from the unsaturated soil zone in terms of surface runoff, percolation to groundwater, volatilization, and degradation.

The mathematical representations used at the BCV generally consider the rate at which the modeled processes occur, the interaction of different processes with each other, and the initial conditions of both the waste area and the surrounding geohydrologic formations. Some of the major steps involved in constructing mathematical representations of the conceptual models used at the BCV include:

- Quantification of the concentrations of constituents in the waste area and the hydrologic processes previously identified.
- Use of measured leachate data or alternative methods to determine the chemical composition in the leachate projected to result from the reactions of infiltrating water with the waste materials and the residuum.
- Estimation of the rate constants describing the cationic retardation of the predicted contaminants. These rate constants are based on partitioning coefficients selected during an extensive literature search.
- Estimation of the rate constants describing contaminant retardation attributable to interactions with organic carbon in the geological formation. These constants are based upon the constituents' organic carbon partitioning coefficients and organic carbon content of the residuum and/or the waste matrix.
- Estimation of the rate constants describing the decay rates of the modeled contaminants. These first-order rate constants are based upon radioactive half-lives and biodegradation half-lives in groundwater for radionuclides and organic chemicals, respectively.

Fate and transport models are used to simulate the vertical transport of contaminants from the waste source through the vadose zone to the saturated zone.

E.9.1.2 Groundwater Model

CRAFLUSH is an analytical contaminant transport model developed by Sudicky and Frind (1982) that simulates flushing of the contaminated matrix with a system of parallel fractures. The model considers decay of contaminants, matrix diffusion, retardation of contaminants in matrix, advective and dispersive transport with retardation of contaminants in the fracture.

The analytical solution of the model is based on applying Laplace transform to the one-dimensional contaminant transport equation in a single fracture including flux related to matrix diffusion along the dimension perpendicular to the longitudinal direction of the fracture. The transformed solution in Laplace space is inverted numerically to obtain solution of the concentration of the contaminant in real time and space.

CRAFLUSH is used to estimate the lateral migration of the contaminants from the source to individual site receptors. It is to predict the lateral migration time along with the concentration for a contaminant that it will take to reach its maximum concentrations at the receptor.

E.9.1.3 Model Input Parameters

E.9.1.3.1 SESOIL input parameters

The input data for SESOIL can be grouped into four types: climatic data, chemical data, soil data, and application data. There are a total of 61 separate parameters contained in these four data groups as presented in Table E.52.

Wherever possible, site-specific parameter values were used for the modeling. Certain parameters, however, were not available for all of the waste areas, and were estimated based on pertinent scientific literature search, geochemical investigations, and checks for consistency between

model results and historical data. Conservative estimates were used when a range of values was indicated or parameter values were not available. Uncertainty in the selection of model parameter values is addressed by performing sensitivity analyses. Sensitivity analyses were performed by varying parameters within reasonable ranges. Additional information regarding the sensitivity is presented in Sect. E1.4.1.

Climate Data. The climatic data file of SESOIL consists of an array of mean monthly temperature, mean monthly cloud cover fraction, average monthly relative humidity, average monthly shortwave albedo, average daily evapotranspiration, monthly precipitation, mean number of storm events per month, mean duration of rainfall, and mean length of rainy season. SESOIL climatic data file is presented in Table E.53. These data were taken from the GSC Climatic Database for Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge.

Chemical Data. The pollutant fate cycle of SESOIL focuses on the various chemical transport and transformation processes that may occur in the soil zone. These processes include volatilization/diffusion, adsorption/desorption, and cation exchange, biodegradation and hydrolysis, and metal complexation. Solubility in water, air diffusion coefficient, Henry's law constant, and organic carbon partition coefficient are chemical-specific parameters and were obtained from literature (EPA 1987; EPA 1988; EPA 1991; EPA 1993; Shen, Schmidt, and Card 1993; Perry, Chilton, and Kirkpatrick 1969). The remaining input parameters listed above are both chemical and site-specific (e.g., soil adsorption coefficient, biodegradation rates, etc.). Values found for these parameters in literature were screened to select those values that were derived under conditions that approximate those at BCV. Literature values for K_d were used for inorganic COPCs and were taken from Sheppard and Thibault (1990) or Baes et al. (1984). K_d values for organics were estimated using organic carbon content. An empirical formula (Mills et al. 1985) was used to correlate the octanol-water partitioning coefficient (K_{ow}) to the octanol-carbon partitioning coefficient (K_{oc}). The K_{ow} s for the organic compounds were taken from EPA Risk Reduction Engineering Laboratory Treatability Database (EPA 1993) and EPA Soil Transport and Fate Database (EPA 1991).

The process of hydrolysis was ignored in this study because of the large uncertainty in the hydrolysis rates; e.g., the rates of hydrolysis for various organic chemicals vary over more than 14 orders of magnitude. Due to this large uncertainty, SESOIL model results would become highly uncertain. Therefore, hydrolysis parameters were set to zero for this analysis, which results in conservative output.

The biodegradation rates for the organic compounds were taken from the *Handbook of Environmental Degradation Rates* (Howard et al. 1991). The lowest biodegradation rates (highest half-life) were used in this analysis. This approach was adopted to be conservative in estimating contaminant loss through degradation/decay. The biodegradation rate was set to zero if none could be found in literature.

The Air Diffusion Coefficient is used to calculate losses of the pollutant due to the volatilization/diffusion process. Further, to determine the concentration of pollutant in the soil air (gaseous phase), Henry's Constant is required in the chemical input file. These parameters are summarized in Table E.54. For a compound for which the air diffusion coefficient cannot be found directly from literature, a reasonable estimate was made from a known compound using the following equation:

$$D^* = D (M/M^*)^{1/2} \text{ (Shen, Schmidt, and Card 1993),}$$

where:

- D^* = air diffusion coefficient for the unknown compound,
- D = air diffusion coefficient for the known compound,
- M = molecular weight of the known compound,
- M^* = molecular weight of the unknown compound.

“Known” compound refers to the chemical for which the air diffusion coefficient is known from the literature. “Unknown” compound refers to the chemical for which the air diffusion coefficient is sought. This can be applied only to an unknown compound having a molecular weight and a molecular structure close to that of the known compound (i.e., furan to dibenzofuran, etc.).

Inorganic COPCs for BCV site include metals and cyanide. Partitioning of inorganics between solids/ and liquids is generally based on the retardation factor (R_d). The R_d describes numerically the extent to which the velocity of the contaminant is slowed and is largely derived from the partitioning coefficient (K_d). Table E.55 presents the range of K_d s for the soil type prevalent at the site. These K_d values are used to calculate the R_d s of the inorganic COPCs this site based.

In addition to geochemical transformation processes, radionuclides undergo spontaneous decay to stable elements. The decay time is accounted for in the modeling with half lives ($t_{1/2}$), radioactive decay constants (λ) [Table E.56 presents the half-lives ($t_{1/2}$)], radioactive decay constants (λ), and the range of K_d s for the radionuclides of potential concern at the BCV sites. Since most of the radionuclides of concern at these sites are long (thousands to billions of years; see Table E.56), the persistence of radionuclide contaminants on BCV sites is related largely to their geochemical mobility in the environment.

Multimedia partitioning and decay properties must also be accounted for in modeling organics, except in this case, decay occurs through biological processes. Decay half-lives of organic compounds in various media can vary from minutes to years, depending on the chemical and environmental conditions. Environmental half-lives for organic COPCs are presented in Table E.54.

Retardation of organic chemicals can be described by the octanol-water partition coefficient (K_{ow}). The K_{ow} is used to estimate the tendency for a chemical to partition between environmental phase of different polarity. Organic compounds with $\log K_{ow}$ values <1 are highly hydrophilic, while organic compounds with $\log K_{ow}$ values >4 are nearly insoluble in water and will partition to soil particles. Detected SVOCs, and pesticides and PCBs have $\log K_{ow}$ values >4 indicating preferential partitioning to soil. The organic carbon based water partition coefficient (K_{oc}) is used to estimate the degree to which a compound will adsorb to soil. The formula (Mills et al. 1985) used to relate K_{ow} to K_{oc} is:

$$K_{oc} = 0.63 K_{ow} .$$

The sorption coefficient/distribution coefficient (K_d) of an organic compound is related to K_{oc} by:

$$K_d = f_{oc} \cdot K_{oc} ,$$

where:

f_{oc} = soil organic carbon content as mass fraction.

Table E.54 presents the solubility, Henry's Law constant (K_H), air diffusion coefficients, and biodegradation rate constants for the organic compounds that are of potential concern at the source/exposure units. K_{ow} and K_{oc} s are also presented in this table.

Soil Data. The soil data file of SESOIL contains input parameters describing the physical characteristics of the subsurface soil. The parameters include soil bulk density, intrinsic permeability, soil disconnectedness index, soil porosity, organic carbon content, and cation exchange capacity. Most of these data were collected during the RI and average values were used. There is, however, no measurement method for the soil disconnectedness index or a measured value of the Freundlich exponent. Soil disconnectedness index is a parameter that relates the soil permeability to the moisture content. Thus, SESOIL default values were used for these two parameters. The soil parameters presented in Table E.18 are used by SESOIL in this modeling effort.

The intrinsic permeability for the vadose zone was calibrated using the soil moisture content as the calibration target. The soil porosity was set to the site average value. The intrinsic permeability was adjusted until the predictions for the average volumetric soil moisture content for the vadose zone matched as closely as possible with the site average values based on RI sampling results. The calibrated intrinsic permeabilities are presented in Table E.18. These values lie within the range of values observed at Oak Ridge Reservation in the shallow soil zone and corresponds to silty clay (Freeze and Cherry 1979). These values, however, are very close to the maximum permeability ($7.8E-05$ cm/s) measured at this site. By using an average of the measured permeability values, a groundwater recharge rate of <1 cm/year was obtained, which does not agree with the groundwater recharge rate estimated for the BCV sites. However, by using the calibrated intrinsic permeabilities, the model produced recharge rates 5 to 17 cm, which compare favorably with 12 to 20 cm based on water balance calculations.

Soil disconnectedness index replaces the moisture retention curves (or characteristic curves) used by other unsaturated zone leaching models. SESOIL User's Guide (Hetrick and Scott 1993) defines this parameter to be the exponent relating the "wetting" and "drying" time-dependent permeability of soil to its saturated permeability. This "one" variable approach of using soil disconnectedness index in SESOIL simplifies the data estimation process and reduces computational time. In addition, this parameter was calibrated for four different soil types ranging from sandy loam to clay (Hetrick et al. 1986) and the calibrated values fell within the default range specified in the SESOIL User's Guide.

E.9.1.3.2 ODAST input parameters

The estimates of the vertical seepage velocities used in the vadose zone transport model ODAST were based on the steady state moisture contents and the recharge rates. The longitudinal dispersion coefficients (D_L), a function of dispersivity, interstitial seepage velocity and molecular diffusion coefficient were estimated by the methods presented by Biggar and Nielsen (1976), and Mills et al. (1985). The BCV sites flow parameters for the vadose zone modeling are presented in Table E.57.

E.9.1.3.3 CRAFLUSH input parameters

The input parameters for CRAFLUSH include fracture spacing, velocity in the fracture, fracture effective porosity, matrix porosity, fracture aperture, matrix diffusion, fracture dispersivity, tortuosity, degradation or radioactive half life, fracture retardation factor, and matrix retardation factor. Sensitivity analysis was performed on these parameters to identify the most sensitive parameters. The sensitivity test was conducted by simulating nitrate, uranium, and trichloroethene from the S-3 site to NT-1 and NT-2. Based on this analysis, the most sensitive parameters were

selected for calibrating the S-3 Site conditions. These parameters include matrix diffusion, fracture velocity, matrix retardation factor, biodegradation, matrix porosity, fracture aperture, and fracture retardation factor. Among them the fracture retardation factor was found to be less sensitive than others. However, matrix diffusion is chemical specific and was obtained from literature. Fracture velocity, matrix porosity, and fracture aperture were refined through calibration by simulating nitrate at the S-3 Site. All other constituents at the S-3 Site were simulated using the parameters refined for nitrate. The predicted groundwaters near NT-1 and NT-2 were compared with the observed groundwater, and an agreeable match was obtained by calibrating matrix and fracture retardation factors. Table E.58 presents the calibrated values of input parameters used by CRAFLUSH.

The calibrated values of matrix and fracture retardation factors at the S-3 Site were used as baseline values for simulating constituents at the Burial Grounds and BYBY. Formulation using octanol water partition coefficient and organic carbon content was used to compute distribution coefficient for some of the organic constituents for which calibration was not performed at the S-3 Site. Retardation factors were computed using distribution coefficients for some of the inorganics, radionuclides, and organic constituents at the Burial Grounds and BYBY sites due to the lack of calibrated values.

E.9.1.4 Model Application

Figure E.43 presents a conceptual diagram for application of various models (SESOL, ODAST, Crystal Ball, and CRAFLUSH) used at this site. Their applications are discussed below.

E.9.1.4.1 SESOIL application

The SESOIL model was applied to leaching of organic compounds from contaminated wastes and soils and their migration through the vadose zone to groundwater. SESOIL was run for each of the site-related organic contaminants listed in Table E.59 using the average initial concentrations at different depth intervals obtained from the RI sampling. These input soil concentrations at different depth intervals represent the 95% UCL of the mean (or the maximum if it is less than the UCL) for the soil samples in that particular depth interval for a particular source area. If a modeled chemical was not detected in a particular depth interval based on RI sampling, the SESOIL input concentration was set to zero in that depth interval.

The simulations using SESOIL were continued until the maximum concentration in groundwater was attained. However, due to the voluminous amount of output per run and the computing time it takes to complete a long-term simulation, the SESOIL model was run for only 100 years for this analysis. Because SESOIL is only applied to the organic compounds, it may be expected that the organic compounds which do not peak in 100 years may be eventually degraded within that time frame.

The application data file of SESOIL contains the general information describing the specifics of the chemical releases or application to the soil column. The information required includes the dimensions of the soil column, the definition of soil layers (e.g., depths), and several additional soil properties already discussed in the previous section.

Sensitivity Analysis using SESOIL. The discrepancy between the contaminant concentrations measured in the field and the values predicted by the model were investigated by performing sensitivity analysis on the model input parameters that have the most influence on the model predictions. These parameters are: (1) biodegradation rate constants, (2) saturated hydraulic conductivity of the unsaturated zone (which relates to percolation rates), (3) the soil disconnectedness

index, (4) soil porosity, (5) f_{oc} (fraction of soil organic carbon-content) in the case of organic compounds, and (6) K_d in the case of radionuclides and inorganic compounds. Latin Hypercube sampling was used to generate sets of independently random parameter values for input to the model (Hetrick, Luxmoore, and Tharp 1993). A range of values was used to generate these sets of random parameter values. For f_{oc} and porosity, the range was obtained from the field measurements discussed in Appendix C; for disconnectedness index, a range of 10 to 12 (i.e., loam to clay type soil) was used. Hydraulic conductivity was not used in generating these sets of random parameters. Instead, a range of 3.5 to 20 cm/year for the percolation rate was used. The hydraulic conductivity values were then generated by calibrating to the randomly generated percolation rates. The biodegradation rate constant, which is the most sensitive parameter, was also excluded from the generation of sets of random input variables because of the large uncertainty in the biodegradation rates and the lack of site-specific values.

Because of very high concentrations of PCE in S-3 Site groundwater it was selected for the sensitivity analysis. SESOIL was run separately with the parameter sets generated by the Latin Hypercube sampling for the selected chemical for sensitivity analysis. The results of these runs were analyzed to provide a normal distribution for the groundwater concentrations. The results of this analysis are presented in Table E.59. This table presents the parameter sets, time of arrival, time of peak concentration, and projected peak concentrations in groundwater for all the SESOIL model runs. These results are further summarized to provide the minimum and maximum peak concentrations as well as the mean, standard deviation, and the 95 % UCL of the predicted peak concentrations within 100 years of simulation time.

To determine the uncertainty in the model prediction with respect to biodegradation, SESOIL was run for all organic COPCs using the most conservative biodegradation rates (i.e., the maximum half-life) obtained from the literature. Two sets of parameters were used to run with biodegradation: the set of parameters that produced the highest concentration, and the set of parameters that produced the lowest peak concentration in the sensitivity runs. The results of these runs are summarized in the summary result tables for the individual sites.

The calculated groundwater concentrations using ODAST were generally sensitive to changes in the leach rate of the waste, the thickness of the vadose zone, the dispersion coefficient, the interstitial water velocity, the retardation factor, the radioactive decay constant, and the depletion time of the source.

E.9.1.4.2 ODAST application

The ODAST model was used to model the migration of inorganic substances and radionuclides through the vadose zone to groundwater. ODAST was run for 500 model years for each inorganic and radionuclide COPCs that are present in the waste area and not inundated by the water table. A range of retardation factors was evaluated using the seepage velocities and dispersion coefficients for the vadose zone. ODAST was used to calculate the normalized concentration at the bottom of the vadose zone. For the 500-year scenario, the projected concentration of the leachate entering the aquifer beneath the waste area was calculated by multiplying the normalized concentration at the base of waste area by the source term (initial contaminant concentration at the source). The plots of concentration versus time were then produced for the constituents, which were projected to reach the aquifer within 500 years. The peak values in these plots were considered as the maximum concentration to be expected in the aquifer beneath the source for the contaminants over 500 years. The loading rates can also be calculated by multiplying the projected concentration beneath the waste area by the recharge rate from the source.

For ODAST a source term input was developed prior to running the model. Source term concentrations for analytes were developed in one of three ways depending on the availability of information concerning the source:

- When available analytical results from in situ leachate composition is the best method of estimating source terms at the waste areas. In situ leachate reflects the complex chemical interactions that take place between the waste solids and contact solution in the physical disposal environment.
- Samples from nearby seeps were used as an approximation for the leachate concentration.
- Geochemical modeling using thermodynamic data on mineral solubilities or using adsorption isotherms to calculate partitioning of chemical species between the solution (leachate) and sorbet (solid) phases. The most commonly applied equilibrium adsorption isotherm in groundwater contamination problems is the Freundlich's linear equilibrium adsorption isotherm:

$$C_s = K_d C_L,$$

or

$$K_d = \frac{C_s}{C_L},$$

where:

K_d is called the distribution coefficient,

C_s is the concentration of the constituent in the solid phase,

C_L the concentration of the constituent in solution phase (leachate).

For BCV waste areas, C_s is known from analytical data on the waste or based on contaminant inventory data, K_d is estimated based on literature search. Therefore, C_L can be calculated by applying the above equation. This method is most commonly used. The major uncertainty with this approach is that the estimated K_d values may not represent the site condition and may be off by orders of magnitudes.

E.9.1.4.3 Application of Crystal Ball

If the maximum soil contamination based on RI sampling data was observed below the water table, neither ODAST nor SESOIL modeling was performed. For these constituents the maximum concentrations in the groundwater were projected using a simple partitioning model. To evaluate the uncertainty, the partition model was incorporated into a Microsoft EXCEL spreadsheet model that links with Crystal Ball, a forecasting software which used Monte Carlo simulation technique.

E.9.1.4.4 Application of CRAFLUSH

The CRAFLUSH model was applied to the COPCs in groundwater to predict their lateral migration (along strike and across strike) from the source areas to respective receptor locations. The source term concentrations (or initial concentrations) for CRAFLUSH for individual areas were developed by comparing the results of leachate modeling with current groundwater concentrations. If the current groundwater concentration exceeded the maximum concentration predicted by leachate modeling, the groundwater concentrations were used as the source concentrations, otherwise the

maximum concentrations from the leachate modeling were used as source term concentrations for CRAFLUSH modeling.

The input at the boundary is given as a source of dissolved contaminant with time-varying concentration entering the fracture. The initial condition is described by the strength of dissolved contaminant that exists in the matrix and in the fracture prior to the onset of simulation. The simulations using CRAFLUSH were continued for 1000 years or until the maximum concentrations at the receptor were attained.

Sensitivity Analysis

Initial sensitivity analysis was performed for three representative contaminants: nitrate, ^{238}U , and PCE using CRAFLUSH. Two hypothetical scenarios, contaminant transport from S-3 to NT-1 and contaminant transport from S-3 to NT-2 were selected for this analysis. It was assumed that contaminant loadings from S-3 were started ~40 years from today.

Model baseline parameters were selected to transport the most mobile contaminant nitrate to NT-1 (traveling a distance of 1740 feet from S-3) and to NT-2 (traveling a distance of 3060 feet from S-3). Multiple jobs were run for these two scenarios varying the individual parameters from the baseline values. The selected baseline parameter values are shown in Table E.60. The simulation results for nitrate at baseline conditions are depicted in Fig. E.44.

Variations in the values of flow and transport parameters have unequal effects on the transport of contaminants at far field away from the source. Some of the parameters have greater effects than the others. The effects due to change in the values of the parameters from the baseline values for nitrate after 40 years are shown in Figs. E.47 through E.51. The time-varying changes in the simulation results for nitrate due to changes in the flow and transport parameters from the baseline values are shown in Figs. E.52 through E.55. Also presented are Figs. E.56 and E.57 showing the time varying changes in the simulation results for uranium due to changes in matrix and fracture retardation factor, respectively, from the baseline value of 1.0. Figure E.58 shows the change of concentration versus time for PCE due to changes in the biodegradation half life.

From the above analysis it can be concluded that matrix diffusion, fracture velocity, matrix retardation factor, and biodegradation are the most sensitive parameters, and matrix porosity, fracture aperture, and fracture retardation factor are moderately sensitive. Fracture spacing is sensitive at low spacing (i.e., <3 ft) and becomes completely insensitive at higher spacings (i.e., >3 ft). Dispersivity within the range of 10 to 150 did not produce any significant variation in the predictions.

Uncertainty

The sensitivity analysis and simulations using CRAFLUSH for the present study helped determine important parameters and identify constituents of potential concern at the S-3, BYBY, and BCBG sites that are or will be migrating to different receptor locations. It was also possible to study all constituents of concern for RI, by simulating their transport from source to different receptors using CRAFLUSH in a short time.

To address some of these uncertainties, an uncertainty analysis was performed. A plausible range was selected (Tables E.61 through E.67) at each site for the parameters that are variable in nature or could not be estimated with a reasonable accuracy. Calibrated values of these parameters were systematically changed within the range, and a set of model results was obtained. Model results from uncertainty analysis are expected to reflect reality better with a range of the predicted

contaminant concentration at the receptors and the most probable time of occurrence. To select the parameters for uncertainty analysis, initial sensitivity analysis results for S-3 Site were utilized. A new sensitivity analysis was done at all sites for the parameter deemed to be sensitive in the initial sensitivity analysis for S-3 Site. Fracture velocity, fracture aperture, matrix retardation factor, half-life of the organics were selected for uncertainty analysis. All the parameters used in uncertainty analysis are site-specific. Ranges of the parameters for the uncertainty analysis were estimated using the measured soil properties, geological characteristics of the sites, and the related properties of the contaminants. Five values were selected for uncertainty analysis from the range of each parameter, except for velocity. Seven values were selected for the velocity as it varies within a wide range. Model runs were accomplished changing each parameter within the selected range keeping all other parameters to the base value. Descriptive statistical analyses were performed on the predicted normalized peak concentrations obtained for each COPC at each site to calculate the 95% confidence limits (i.e., both UCLs and LCLs) to represent the range of uncertainty in the predicted concentrations at the Bear Creek or its tributaries.

Despite successful uncertainty analysis and simulations for COPCs, the major source of uncertainty for the present study existed with the oversimplification of the flow and transport processes using CRAFLUSH, a one-dimensional transport model in a single fracture. The effects of heterogeneity, anisotropy, and spatial distribution of fracture upon retardation, advection, and dispersion are not addressed in the simulations using CRAFLUSH.

A specific problem is the expected change in the magnitude, timing, and direction of flow and contaminant transport across geologic contacts associated with the strong heterogeneity at the present site. The present modeling study using CRAFLUSH does not address the effects of flow and contaminant transport across interface in a sharply varying heterogeneous media. It is important to investigate flow and transport processes associated with the discontinuity of properties in a strongly heterogeneous porous media. Bear (1972) described methodologies to deal with these types of discontinuity of the properties in the subsurface. It would be appropriate to investigate the effects of sharply varying geologic profiles on flow and contaminant transport that exists at the present site.

The CRAFLUSH model was applied separately for shallow and deep flow conditions. The effects of interaction between deep and shallow flow conditions due to changes in vertical gradients and spatial variations associated with the heterogeneity and anisotropy were not accounted for in the simulations using CRAFLUSH. The results based on the assumed single fracture with an average seepage flow, dispersion coefficient, retardation factor, and porosity does not represent the real physical conditions that exists at the Bear Creek Valley site.

It would be appropriate to perform modeling study for selected COCs using FRAC3DVS in a three-dimensional space extending both horizontally and vertically from the sources to the boundaries including the receptors. The FRAC3DVS model was organized by ECE with pre- and post-processors for the present site. By using FRAC3DVS, the behavior of the plumes associated with the selected COCs can be simulated by realistically representing the fractured porous media at the present site in three-dimensional space.

E.9.1.5 References

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E.9.2 MODELING OF TCE IN THE MAYNARDVILLE LIMESTONE

Contaminant fate and transport modeling of trichloroethene (TCE) from S-3 site through the Maynardville Limestone was performed. Currently, the center of the TCE plume in the Maynardville Limestone is estimated to be located near BYBY at a depth of ~ 31 to 152 m (100 to 500 ft) below ground surface.

E.9.2.1 Source Concentration and Decay Factor

Maximum observed concentration (368 $\mu\text{g/l}$) in the center of the plume near BYBY was taken as the source concentration for TCE. The depletion rate for the source was estimated performing a mass balance on the current plume. Total mass of plume was calculated by using the concentration contours and the extent of the plume along stratigraphic thickness of Maynardville Limestone and by using an average Maynardville porosity of 2.1%. Groundwater flux along strike in the Maynardville was calculated using Darcy velocities from the BCV Sitewide Flow Model (DOE 1996b) for Layers 2, 3, and 4 [i.e., from 31 to 152 m (100 to 500 ft) below ground surface]. The depletion factor for TCE was calculated to be 0.0051/year (an exponential decay was assumed for this calculation).

E.9.2.2 Calibration of Parameters

Site-specific parameters for the CRAFLUSH modeling were obtained by calibrating the nitrate plume in the Maynardville. It was assumed that the currently observed nitrate concentration near BYBY is in steady state condition. Therefore, the average concentration (48.7 mg/L) in this plume was taken as the source concentration, and the concentration of nitrate at a distance 1219 m (4000 ft) along strike in the Maynardville Limestone near SS-4 (21.5 mg/L) was used as the target concentration for calibration of nitrate. It was assumed that ~20 years were necessary for reaching the current steady state concentration of nitrate near BYBY since the contamination of S-3 Site. The result of this calibration was further verified by predicting the nitrate concentration near Picket A that

matched the recently observed nitrate data near Picket A. Contaminant-specific parameters were obtained from the properties of TCE and the related properties of the site. A conservative approach was used in the parameter selection process. No biodegradation was assumed for the base run. Current field observations indicate that the concentration of the TCE plume is constant, which supports little or no biodegradation. Input model parameters, including the calibrated values used for TCE simulation in the Maynardville Limestone, are presented below:

<u>Parameter</u>	<u>Base Value</u>
Source concentration at infinite time	1.0
Source decay constant (1/year)	0.0051
Initial concentration in matrix and fracture at the point of interest	0.0
Biodegradation	None
Velocity in fracture (ft/d)	28.0
Fracture dispersivity (ft)	50.0
Fracture aperture (ft)	0.54E-03

<u>Parameter</u>	<u>Base Value</u>
Fracture spacing (ft)	7.0
Matrix porosity	0.02
Matrix tortuosity	1.00
Diffusion coefficient in water (ft ² /d)	3.394E-02
Fracture retardation factor	1.0
Matrix retardation factor	2.5

E.9.2.3 Model Applications

Simulations were performed using the above mentioned parameter values for TCE for three different scenarios: Scenario 1 represents TCE transport to SS-4, Scenario 2 represents TCE transport to Picket A (or SS-5), and Scenario 3 represents TCE transport to Picket W. Figures E.59, E.60, and E.61 present plots of predicted TCE concentration versus time at SS-4, Picket A, and Picket W, respectively. Concentrations at all these locations are expected to increase for another 300 to 800 years (assuming no biodegradation). Table E.68 presents the predicted normalized peak concentrations and the corresponding TCE concentrations for the three scenarios. The expected time of the peak concentrations is also presented in this table. The results indicate that concentration of TCE at these locations will exceed the MCL in the future.

E.9.2.4 Uncertainty Analysis

The CRAFLUSH model was applied to evaluate the uncertainty in the modeling results by performing sensitivity analysis on the most sensitive parameters. The uncertainty analysis was performed to get a better reflection of the reality. A reasonable range of values was selected for the most sensitive parameters that were either not available from field measurements or could not be estimated with a reasonable accuracy. These parameters were systematically changed one at a time and a set of model results was obtained. Presented below are the parameters selected for the uncertainty analysis and their ranges used in the analysis:

<u>Parameter</u>	<u>Range</u>
Biodegradation rate (1/d)	0 to 0.0002
Velocity in fracture (ft/d)	1.7 to 28
Fracture aperture (ft)	0.00004 to 0.0009
Matrix retardation factor	2.5 to 25

Descriptive statistics were performed on simulated results (peak concentrations) to predict the TCE concentrations with a 95% confidence limit. Table E.69 presents the summary of predicted peak concentrations for the three modeled scenarios.

E.9.3 DISSIPATION OF PRESSURE BULGE BENEATH S-3 SITE IN THE NOLICHUCKY SHALE

E.9.3.1 Introduction

The pressure measurement using a multiport system in the borehole GW-134, west of S-3 Ponds, indicated a pressure bulge in the central portion of the well at a depth of about 137 m (450 ft); the sample analysis indicated a maximum nitrate concentration near the crest of the pressure bulge (Interra 1995). A sharp variation of hydraulic conductivity in the subsurface beneath the S-3 Ponds may have contributed to the existence of the pressure bulge. Slow dissipation of the pressure bulge may result in a continuous flow of contamination for a long period of time.

The purpose of this modeling study is to simulate the pressure bulge that is consistent with the observed data for GW-134, and to study the natural dissipation (if any) of this pressure bulge. The study will also focus on the effects of groundwater extraction on the pressure bulge.

At the BCV site, flow and transport along and across low hydraulic conductivity Nolichucky Shale encounters an interface (i.e., the region of geologic contact between Nolichucky Shale and Maynardville Limestone) and the sharp variation of hydraulic conductivity. The sharp variations of properties cause discontinuity in the domain. These effects can be studied by the methodologies described by Bear (1972) that deal with flow in a strongly heterogeneous medium with discontinuities in properties. Some specific and special conditions are required to deal with such a system. The model developed in this study will account for these sharp variation of properties.

E.9.3.2 A Brief Description of the Model

The partial differential equation describing the density dependent flow in a porous medium in two-dimension format can be written as:

$$\frac{\partial}{\partial x}(\rho_f K_x h \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(\rho_f K_y h \frac{\partial h}{\partial y}) + \rho_s R = \rho_f (S_y + S_x h) \frac{\partial h}{\partial t} ,$$

For a one-dimensional case, the equation can be written as:

$$\frac{\partial}{\partial x}(\rho_f K_x h \frac{\partial h}{\partial x}) + \rho_s R = \rho_f (S_y + S_x h) \frac{\partial h}{\partial t} ,$$

For a strongly heterogeneous medium, the governing equation can be written for each geologic unit (Bear 1972; Liggett and Liu 1983; and Taigbenu 1985). In this approach, the original domain is divided into subdomains. Each subdomain is homogeneous but anisotropic. Therefore, the mathematical problem is decomposed into subproblems corresponding to each subdomain. The governing equation for any homogeneous subdomain can be written as:

$$\frac{\rho_f g}{\nu} k_x \frac{\partial}{\partial x} \left(h \frac{\partial h}{\partial x} \right) + \rho_f R = \rho_f (S_y + S_i h) \frac{\partial h}{\partial t},$$

where

k_x = permeability of a medium, and

g = acceleration due to gravity.

According to Bear (1972) and Liggett and Liu (1983), a compatibility and continuity criteria at the interface between adjacent subdomains should be utilized. The compatibility criterion allows a unique solution of the hydraulic head at the interface, and the continuity criterion allows inflow/outflow between adjacent subdomains. These criteria are as follows:

Compatibility:

$$h_i^j = h_i^{j+1},$$

where

h_i^j = hydraulic head at the point of discontinuity 'i' corresponding to the subdomain 'j', and 'j', and
 h_i^{j+1} = hydraulic head at the point of discontinuity 'i' corresponding to the subdomain 'j+1', and 'j'.

Continuity:

$$q_i^j = q_i^{j+1}$$

where

q_i^j = flux at the point of discontinuity 'i' corresponding to the subdomain 'j', and

q_i^{j+1} = flux at the point of discontinuity 'i' corresponding to the subdomain 'j+1'.

The aforementioned conditions at the points of discontinuities and the governing equation for each subdomain are combined to obtain the solution for the whole heterogeneous domain. Finite difference numerical solution technique is applied to solve for groundwater flow in a heterogeneous domain with abrupt changes in properties. The inclusion of the special conditions of compatibility and continuity ensures stability, convergence, and consistency in the numerical solution for sharply varying aquifer characteristics in a domain.

E.9.3.3 Comparison with Analytical Solution

To gain confidence in the numerical solutions, it is required to compare the numerical model results with the analytical solutions. It is difficult to obtain an analytical solution for a heterogeneous

domain. However, simplified analytical solutions can be obtained for an incompressible and homogeneous medium.

A simplified form of the governing equation for a one-dimensional homogeneous problem can be written as (Ahmed 1992):

$$\alpha \frac{\partial^2 h}{\partial x^2} + \beta h - \bar{P} = \frac{\partial h}{\partial t},$$

where

$$= \frac{T}{n_e},$$

$$T = K_x b,$$

where

b = a known saturated thickness,

n_e = effective porosity,

$$\beta = \frac{-K_c}{n_e d},$$

$$\bar{P} = \frac{-R + K_c}{n_e},$$

K_c = hydraulic conductivity of the underlying aquitard , and

d = thickness of the underlying aquitard.

For the above simplified governing equation, the analytical solutions for two sets of boundary conditions are as follows:

Dirichlet problem:

For the Dirichlet problem, both ends of the one-dimensional domain are described using Dirichlet conditions as follows:

$$h(x = 0) = h_o$$

$$h(x = L) = h_L$$

The solution for hydraulic head in space and time for the above boundary conditions is as follows:

$$h(x,t) = a_n e^{-\frac{\pi^2 t}{\lambda}} + \frac{2\bar{P}\lambda}{n^3 \pi} (\cos n\pi - 1)(1 - e^{-\frac{\pi^2 t}{\lambda}}) + \frac{X}{L} h_L + (1 - \frac{X}{L}) h_o,$$

where

$$\lambda = \frac{L^2 n^2}{\pi^2 T},$$

$$a_n = \frac{2}{n\pi} [(h_i - h_o)(1 - \cos n\pi) + (h_o - h_L)(-1)^{n+1}], \text{ and}$$

$$n = 1, 2, \dots, \infty.$$

The above solution was obtained using the method of the separation of variables by Hildebrand (1976).

Dirichlet-Neumann problem:

In the Dirichlet-Neumann problem, one end of the domain is described using Dirichlet boundary condition and the other end of the domain is described using Neumann condition as follows:

$$h(x=0) = h_o$$

$$\frac{\partial h}{\partial x}(x=L) = i_L$$

The solution for hydraulic head in space and time for the above conditions is as follows:

$$h(x,t) = \sum_{n=0}^{\infty} C_n(t) \sin(\gamma x) + h_o + i_L \frac{x^2}{2L}$$

where

$$C_n(t) = a_n e^{-\alpha t} + \frac{i_L}{\alpha} (1 - e^{-\alpha t})$$

$$\alpha = \alpha \lambda^2 - \beta$$

$$a_n = \frac{2}{L} (h_i - h_o) \int_0^L \sin(\gamma x) dx - \frac{\alpha i_L}{L^2} \int_0^L x^2 \sin(\gamma x) dx$$

$$\hat{i}_n = \frac{2}{L} \left(\frac{\alpha i_L}{L} + \beta h_o - \bar{P} \right) \int_0^L \sin(\lambda x) dx - \frac{\beta i_L}{L^2} \int_0^L x^2 \sin(\gamma x) dx,$$

$$\gamma = \frac{(2n+1)\pi}{2L}, \text{ and}$$

$$n = 1, 2, \dots, \infty.$$

E.9.3.4 Model Verification

For the purpose of verification of the model, it was necessary to compare the numerical model results with the analytical solutions. Analytical solutions were obtained for a specific set of boundary conditions on both ends of a simple homogeneous domain. In the present comparison, two different analytical solutions were obtained. In one solution, both ends of the domain were assigned Dirichlet boundary conditions. In the other solution, the left end was assigned Dirichlet and the right end was assigned Neumann boundary condition. The former problem was defined as a Dirichlet problem, and the latter problem was defined as a Dirichlet-Neumann problem.

The comparison between numerical and analytical solutions in a 4.6-m (15-ft) long domain is shown in Figs. E.62 to E.65. The numerical and analytical solutions have similar trends with time. However, there are some discrepancies between numerical and analytical solutions between 5 and 20 d in the computational period, as shown in Fig. E.63. The domain used for comparison was relatively small. The results would be more agreeable if the domain were larger and the comparisons were made at a considerable distance away from the boundary. To investigate the results in a relatively long domain, both numerical and analytical models were applied to a 32-m (105-ft) long block. More agreeable results are observed, as shown in Figs. E.64 and E.65. Some discrepancies are observed after the onset of the simulations. These discrepancies are due to the errors introduced by the initial conditions. Also, some time intervals were required for the solutions to become consistent with respect to the initial conditions.

E.9.3.5 Model Application and Results

To simulate the pressure bulge in the nolicucky shale beneath the S-3 Ponds, hydraulic conductivity data were taken from the sitewide model (DOE 1996). In the first run, a horizontal to vertical anisotropy ratio of 10:1 was used to convert horizontal hydraulic conductivity to vertical hydraulic conductivity (that were used in this model). The model was simulated for 60 years using the pressure data from GW-134 to represent the initial conditions of the model. The model results at the end of 60 years of simulations are presented in Fig.E.66, which shows no natural dissipation of the pressure bulge.

In the second run, a horizontal to vertical anisotropy ratio of 100 was used, all other data were kept the same as the first run. The result of the second run is presented in Fig. E.67, which shows no dissipation of the pressure bulge in 60 years.

In the third run, hydraulic conductivity data were taken from a previous study (INTERA 1995) with a horizontal to vertical hydraulic conductivity ratio of 10. Same GW-134 pressure data were used to construct the pressure bulge. The model results for 60 year simulation are shown in Fig. E.68. Dissipation of pressure bulge was not observed.

Natural dissipation of the pressure bulge was not predicted in the simulations. To observe the effect of withdrawal, different withdrawal rates were used in three more simulations. Simulations were run for 60 years. Conductivity data were taken from the regional sitewide model, and pressure data of GW-134 were used in these simulations. The plot of observed and simulated pressure data, and the results of simulations with withdrawals are presented in Fig. E.69. The results indicate that after 60 years of simulation, pressure bulge may be reduced with high withdrawal (e.g., $2.99\text{E-}02$ gal/ft³/d) but does not disappear completely.

The results indicate that natural dissipation of this bulge may take thousands of years. Outside disturbance (pumping or increasing the matrix hydraulic conductivity by hydraulic fracturing) may accelerate the dissipation of the bulge. Therefore, it is expected that with slow dissipation of the pressure bulge, under present condition, contaminants will continuously be fed to the tributaries for thousands of years.

E.9.3.6 References

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**E.10 SUPPORTING INFORMATION
FOR APPENDIX E—FIGURES**

Fig. E.42. Conceptual vadose zone model used by SESOIL.

Fig. E.43. Conceptual diagram for source leachate modeling.

Fig. E.44. Concentration vs time for nitrate at baseline conditions at 1740 ft and 3060 ft from source.

Fig. E.45. Concentration vs diffusion coefficient for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.46. Concentration vs matrix tortuosity for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.47. Concentration vs matrix porosity for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.48. Concentration vs fracture spacing for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.49. Concentration vs fracture aperture for nitrate at 40 years at 1740 ft and 3060 ft from source.

E10-8

Fig. E.50. Concentration vs dispersivity for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.51. Concentration vs velocity in fracture for nitrate at 40 years at 1740 ft and 3060 ft from source.

Fig. E.52. Normalized concentrations of nitrate vs time at 1740 ft from source for different values of diffusion coefficient (ft^2/d).

Fig. E.53. Normalized concentrations of nitrate vs time at 1740 ft from source for different values of matrix porosity.

E10-10

Fig. E.54. Normalized concentrations of nitrate vs time at 1740 ft from source for different values for fracture aperture.

Fig. E.55. Normalized concentrations of nitrate vs time at 1740 ft from source for different values of velocity in fracture.

E10-11

Fig. E.56. Normalized concentrations of ^{238}U vs time at 1740 ft from source for different fracture retardation values (R_f).

Fig. E.57. Normalized concentrations of ^{238}U vs time at 1740 ft from source for different values of matrix retardation (R_d).

Fig. E.58. Normalized concentrations of PCE vs time at 1740 ft from source for different half-lives (days).

Predicted TCE at SS-4

Fig. E. 59. Predicted TCE at SS-4.

Predicted TCE at Picket A

Fig. E.60. Predicted normalized groundwater concentrations of TCE in the Maynardville Limestone near Picket A.

Predicted TCE at Picket W

Fig. E.61. Predicted normalized groundwater concentrations of TCE in the Maynardville Limestone near Picket W.

Fig. E.62. Comparison between numerical model results with analytical solution for a Dirichlet-Neumann problem in a 15-ft block.

Fig. E.63. Comparison between numerical model results with analytical solution for a Dirichlet problem in a 15-ft block.

Fig. E.64. Comparison between numerical model results with analytical solution for a Dirichlet problem in a 105-ft block.

Fig. E.65. Comparison between numerical model results with analytical solution for a Dirichlet-Neumann problem in a 105-ft block.

Predicted pressure bulge using regional model K-field

Fig. E.66. Predicted pressure bulge using regional model K-field.

Predicted pressure bulge using modified regional K-field

Fig. E.67. Predicted pressure bulge using modified regional K-field.

Predicted pressure bulge using K-field (Interra, Inc.)

Fig. E.68. Predicted pressure bulge using K-field (Interra, Inc.).

Predicted pressure bulge using regional model K-field and different withdrawal rates

Fig. E.69. Predicted pressure bulge using regional model K-field and different withdrawal rates.

**E.11 SUPPORTING INFORMATION
FOR APPENDIX E—TABLES**

Table E.52. Input data accepted by SESOIL

<u>SOIL DATA</u>	<u>CHEMICAL DATA</u>
Description of Soil Type Soil Bulk Density Soil Intrinsic Permeability (Unsaturated Zone) Soil Disconnectedness Index Soil Porosity Saturated Hydraulic Conductivity (Saturated Zone) Hydraulic Gradient (Saturated Zone) Organic Carbon Content of the Soil Cation Exchange Capacity of the Soil Freundlich Exponent Aquifer thickness <u>CLIMATE DATA</u> Average Monthly Temperature Average Monthly Fraction of Cloud Cover Average Monthly Relative Humidity Average Monthly Shortwave Albedo Average Daily Evapotranspiration Monthly Precipitation Depth Mean Time of Rainfall Mean Number of Storm Events/Month Mean Length of Rainy Season	Description of the Compound Solubility in Water Diffusion Coefficient in Air Henry's Law Constant Adsorption Coefficient on Organic Carbon Adsorption Coefficient of the Soil Molecular Weight of the Compound Valence of the Compound Neutral Hydrolysis Constant Base Catalyzed Hydrolysis Constant Acid Catalyzed Hydrolysis Constant Biodegradation Rate in the Liquid Phase Biodegradation Rate in the Solid phase Stability Constant of the Ligand Complex Moles of Ligand/Mole Complexed Molecular Weight of Ligand
<u>APPLICATION DATA</u> Number of Soil Layers Number of Years of Data included in the Data Set Surface Area of the Compartment Depth of Each Layer (Unsaturated Zone) pH of Each Layer Intrinsic Permeability of Each Layer Layer Ratios for Biodegradation in the Liquid Phase Layer Ratios for Biodegradation in the Solid Phase Layer Ratios for Organic Carbon Content of the Soil Layer Ratios for Cation Exchange Capacity in the Soil Layer Ratios for Freundlich Exponent Layer Ratios for Adsorption Coefficient Monthly Pollutant Load (Mass/Unit Area) entering Each Zone Monthly Mass of Pollutant Transformed in Each Sublayer by Some Other Process Monthly Mass of Pollutant Removed from Each Sublayer by Some Other Process Monthly Ligand Mass Input to Each Sublayer Index of Volatilization/Diffusion Occurrence from Each Soil Index of Surface Pollutant Runoff	

Table E.53. Climatology data used by SESOIL

Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
TA	14.30	8.70	4.10	2.20	3.90	9.00	14.20	18.60	22.70	24.80	24.30	20.90
NN	.50	.60	.65	.70	.65	.65	.60	.60	.60	.60	.55	.50
S	.70	.70	.70	.70	.70	.65	.65	.70	.70	.70	.75	.75
A	.16	.16	.17	.19	.19	.17	.16	.16	.16	.16	.16	.16
REP	.15	.21	.25	.21	.21	.25	.19	.21	.20	.24	.17	.19
MPM	8.10	11.60	14.20	11.60	10.70	14.10	10.20	11.80	10.50	13.20	9.50	10.00
MTR	.46	.49	.60	.61	.57	.52	.46	.41	.33	.30	.28	.44
MN	4.51	5.80	6.38	6.67	6.54	7.35	6.58	6.93	6.58	7.67	6.22	5.00
MT	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40

TA = monthly mean temperature (°C)
 NN = monthly mean cloud cover fraction
 S = monthly mean relative humidity
 A = short wave albedo fraction for each month of the year
 REP = monthly mean evapotranspiration rate (cm/day)
 MPM = monthly precipitation (cm/month)
 MTR = mean duration of individual storm events (days)
 MN = number of storm events per month
 MT = length of the rainy season (days)

Table E.54. Physical and chemical properties of organic constituents at BCV

Constituents	Mol. Wt.	Solubility Sw (mg/L)	Sw @ Temp. C.	KOW (ml/ml)	Henry's Constant (Kh) atm.m ³ /mol	Kh @ Temp. C.	Air Diff. Coeff. cm ² /s		KOC ml/g	BDR1 1/day	Biodeg. half-life (day)	Log (KOW)
1,1 Dichloroethane	99.0	5.50E+03	20	6.17E+01	5.45E-03	25	0.091		3.88E+01	1.13E-03	616	1.79
1,1 Dichloroethene	96.9	2.10E+02	25	3.02E+01	1.49E-02	25	0.114	s	1.90E+01	3.85E-03	180	1.48
1,1,1 Trichloroethane	133.4	4.40E+03	20	2.95E+02	4.08E-03	25	0.019	s	1.86E+02	6.35E-04	1092	2.47
1,1,2 Trichloroethane	133.4	4.50E+03	20	1.48E+02	2.94E-05	25#	0.079	#	9.32E+01	4.75E-04	1458.33	2.17
1,1,2-Trichloro-1,2,2-trifluoroethane	187.4	1.70E+02	25	1.04E+03	3.96E-01	25*	0.078	t	6.57E+02	4.81E-04	1440	3.02*
1,1,2,2 Tetrachloroethane	167.9	2.00E+02	20	1.10E+03	1.10E-02		0.073	t	6.91E+02	9.62E-04	720.83	3.04
1,2 Dichloroethene	96.9	8.00E+02	#	1.23E+02	6.60E-03	ssc	0.114		7.75E+01	2.41E-04	2875	2.09*
1,4-Dichlorobenzene	147.0	7.90E+01	25	2.45E+03	2.72E-03	25	0.069	t	1.55E+03	9.63E-04	720	3.39
2-Butanone	72.1	2.75E+05		1.82E+00	6.61E-07	25#	0.092	s	1.15E+00	2.48E-02	28	0.26
2-Butoxyethanol												
2-Hexanone	100.2	3.50E+04	20	2.40E+01	7.53E-06	20	0.078		1.51E+01			1.38
2-Hexanol	102.2	5.90E+03		1.07E+02	1.80E-05		0.059		6.75E+01			2.03
2-Methylnaphthalene	142.2	2.60E+01	25	7.24E+03	2.20E-02		0.056		4.56E+03			3.86
1-(2-Butoxyethoxy)-ethanol												
2-(2-Butoxyethoxy)-ethanol	162.2	Miscible		1.59E+02	8.11E-02	25	0.041		9.99E+01			2.20
2,3,7,8-TCDD												
2,4-Dimethylphenol	122.2	5.90E+02	#	2.63E+02	1.70E-05	25	0.074		1.66E+02	2.48E-02	28	2.42
3-(1,1-Demethylethyl)-phenol												
4,4'-DDE	318.0	4.00E-02	20	4.90E+05	5.72E-07	25#	0.041		3.09E+05	6.16E-05	11250	5.69

Table E.54 (continued)

Constituents	Mol. Wt.	Solubility Sw (mg/L)	Sw @ Temp. C.	KOW (ml/ml)	Henry's Constant (Kh) atm.m ³ /mol	Kh @ Temp. C.	Air Diff. Coeff. cm ² /s	KOC ml/g	BDRl 1/day	Biodeg. half-life (day)	Log (KOW)
4,4'-DDT	354.5	3.10E-03	25	1.55E+06	3.89E-05	25	0.039	9.76E+05	6.16E-05	11250	6.19
Acenaphthene	154.2	3.42E+00	25	8.32E+03	2.41E-04	25	0.062	5.24E+03	1.70E-03	408	3.92
Acenaphthylene	152.2	3.93E+00	25	1.17E+04	1.14E-04	25	0.062	7.40E+03	2.92E-03	237.5	4.07
Acetone	58.1	1.00E+06		5.75E-01	5.14E-07	25#	0.110	s 3.63E-01	2.48E-02	28	-0.24
Aldrin	364.9	1.70E-02	25	1.29E+05	4.90E-04	25	0.013	w 8.12E+04	1.17E-03	591.67	5.11
Anthracene	178.2	1.29E+00	25	2.82E+04	8.60E-05	25	0.042	1.78E+04	3.77E-04	1840	4.45
Aroclor-1232	232.2	1.45E+00		3.47E+04	6.11E-01	25*	0.049	2.18E+04			4.54
Aroclor-1242	266.5	1.00E-01	24	1.29E+04	3.43E-04	25	0.045	8.12E+03			4.11
Aroclor-1248	299.5	5.40E-02		5.62E+05	4.40E-04	25	0.043	3.54E+05			5.75
Aroclor-1254	328.4	5.70E-02	24	1.07E+06	8.37E-03	25	0.041	6.75E+05	4.72E-03	147	6.03
Aroclor-1260	375.7	8.00E-02	24	1.29E+06	3.36E-04	25	0.038	8.12E+05			6.11
Benzene	78.1	1.78E+03	20	1.35E+02	5.55E-03	25	0.093	s 8.50E+01	9.63E-04	720	2.13
Benzidine	184.2	4.00E+02	12	6.46E+01	7.00E-09		0.003	4.07E+01	2.20E-02	32	1.81
Benzo (a) anthracene	228.3	1.00E-02	24	4.07E+05	2.94E-08	25#	0.051	2.57E+05	2.55E-04	2720	5.61
Benzo (a) pyrene	252.3	3.80E-03	25	9.55E+05	4.90E-07	25	0.043	6.02E+05	3.27E-04	2120	5.98
Benzo (b) fluoranthene	252.3	1.00E-03	#	3.72E+06	2.94E-07	25#	0.044	# 2.34E+06	2.84E-04	2440	6.57
Benzo (g,h,i) perylene	276.3	2.60E-04	25	1.70E+07	1.40E-07		0.042	1.07E+07	2.67E-04	2600	7.23
Benzo (k) fluoranthene	252.3	3.00E-04	#	6.92E+06	2.54E-05	25#	0.044	4.36E+06	8.10E-05	8560	6.84
Bis-(2-Ethylhexyl)phthalate	390.6	1.30E+00	25	2.00E+05	3.00E-07	20	0.032	s 1.26E+05	1.78E-03	389	5.30
Butylbenzylphthalate	312.4	2.90E+00		6.03E+04	3.18E-08	25#	0.040	3.80E+04	3.85E-03	180	4.78

Table E.54 (continued)

Constituents	Mol. Wt.	Solubility Sw (mg/L)	Sw @ Temp. C.	KOW (ml/ml)	Henry's Constant (Kh) atm.m ³ /mol	Kh @ Temp. C.	Air Diff. Coeff. cm ² /s		KOC ml/g	BDR1 1/day	Biodeg. half-life (day)	Log (KOW)
Carbazole	167.2	2.00E+00	w	3.24E+03	1.10E-01	25*	0.039	w	2.04E+03			3.51**
Carbon disulfide	76.1	2.90E+03	20	1.45E+02	2.94E-04	25#	0.105	s	9.11E+01			2.16
Chlorobenzene	112.6	4.88E+02	25	6.92E+02	3.93E-03	25	0.073	s	4.36E+02	1.16E-03	600	2.84
Chloroethane	64.5	5.74E+03	20	2.69E+01	1.11E-02	24.8	0.107	s	1.70E+01	6.19E-03	112	1.43
Chloroform	119.4	9.30E+03	25	9.33E+01	3.39E-03	25	0.091	s	5.88E+01	3.85E-04	1800	1.97
Chrysene	228.3	6.00E-03	25	4.07E+05	1.05E-06	25	0.046		2.57E+05	1.73E-04	4000	5.61
Dibenzofuran	168.2	1.00E+01		1.32E+04			0.068		8.31E+03	6.19E-03	112	4.12
Dibenzo(a,h)anthracene	278.4	5.00E-04	25	9.33E+05	7.30E-08	25	0.042		5.88E+05	1.84E-04	3760	5.97
Diethylphthalate	222.2	2.10E-02	#	9.12E+02	1.17E-08	25#	0.053		5.75E+02	3.09E-03	224	2.96
Dimethylbenzene												
Di-n-butylphthalate	278.4	4.00E+02	25	1.58E+05	2.80E-07	25	0.042		9.98E+04	3.01E-02	23	5.20
Di-n-octylphthalate	390.6	3.00E+00	25	1.58E+09	3.45E-14		0.035		9.98E+08	1.90E-03	365	9.20
Endosulfan I	407.0	3.20E-01	22	3.55E+03	1.67E-05	25*	0.012	w	2.24E+03	1.24E-02	56	3.55
Endosulfan sulfate	422.9	2.20E-01		4.57E+03	2.53E+01	?	0.011	w	2.88E+03			3.66
Ethylbenzene	106.2	1.52E+02	20	1.41E+03	6.44E-03	25	0.075	t	8.90E+02	3.04E-03	228	3.15
Fluoranthene	202.3	2.65E-01	25	2.14E+05	6.50E-06	25	0.069	s	1.35E+05	3.94E-04	1760	5.33
Fluorene	166.2	1.90E+00	25	1.51E+04	1.17E-04	25	0.055		9.54E+03	2.89E-03	240	4.18
Heptachlor epoxide	389.2	3.50E-01	25	1.07E+05	3.16E-05	25	0.012	w	6.76E+04			5.03*
Ideno (1,2,3-cd) pyrene	276.3	1.40E-04	#	4.57E+07	6.95E-08	25	0.044		2.88E+07	2.37E-04	2920	7.66
Methanol	32.0	1.00E+06		2.19E-01	4.66E-06		0.157		1.38E-01	9.90E-02	7	-0.66

Table E.54 (continued)

Constituents	Mol. Wt.	Solubility Sw (mg/L)	Sw @ Temp. C.	KOW (ml/ml)	Henry's Constant (Kh) atm.m ³ /mol	Kh @ Temp. C.	Air Diff. Coeff. cm ² /s		KOC ml/g	BDR1 1/day	Biodeg. half-life (day)	Log (KOW)
Methylene chloride	84.9	1.67E+04	25	1.78E+01	3.19E-03	25	0.104	s	1.12E+01	6.19E-03	112	1.25
Naphthalene	128.2	3.00E+01	25	2.34E+03	4.83E-04	25	0.059		1.48E+03	2.69E-03	258	3.37
Phenanthrene	178.2	8.16E-01	21	2.88E+04	3.93E-05	25	0.054		1.82E+04	8.66E-04	800	4.46
Phenol	94.1	8.00E+04	25	2.88E+01	1.30E-06	25	0.087	s	1.82E+01	2.48E-02	28	1.46
Phosphoric acid	98.0	soluble										
Pyrene	202.3	1.60E-01	26	1.51E+05	5.10E-06	25	0.051		9.54E+04	9.12E-05	7600	5.18
p,p'-Methoxychlor	345.7	4.00E-02	24	4.79E+04	6.12E-10	25#	0.039		3.02E+04	1.90E-03	365	4.68
Tetrachloroethene	165.8	1.50E+02	25	3.39E+02	2.87E-02	25	0.077	s	2.13E+02	4.19E-04	1653	2.53
Toluene	92.1	5.15E+02	20	4.90E+02	5.92E-03	25	0.087	t	3.09E+02	3.30E-03	210	2.69
Trichloroethene	131.4	1.10E+03	25	3.39E+02	1.17E-02	25	0.088	s	2.13E+02	4.19E-04	1653	2.53
Trichlorofluoromethane	137.5	1.10E+03	25	3.39E+02	5.83E-02	25	0.087	s	2.13E+02	4.81E-04	1440	2.53
Vinyl Chloride	62.5	1.10E+00	25	3.98E+00	2.78E-02	25	0.106	s	2.51E+00	2.41E-04	2875	0.60

Solubilities, Henry's Constant, and Log (Kow) have been taken from RREL Treatability Data Base (EPA 1993) except otherwise indicated.

Biodegradation half-lives are taken from Hand Book of Environmental Degradation Rates (Howard et. al. 1991) except otherwise indicated.

Air diffusion coefficients are obtained from EPA 1987, except otherwise indicated.

[*] Represents calculated values, [**] indicates the source of Lyman et al. 1990, [#] indicates STF Data Base (EPA 1992) as the source, and [s] indicates Shen, Schmidt, and Card 1993 as the source, [w]-EPA WATER7 database November 1990, [t] indicates

Table E.55. References for constituents

Constituents	K _d Range (L/kg)	Reference
Antimony	45-150	Sheppard and Thibault, 1990
Arsenic	3-200	Baes and Sharp, 1984
Barium	50-60	Baes and Sharp, 1984
Boron	3-	Baes and Sharp, 1984
Beryllium	250-800	Sheppard and Thibault, 1990
Cadmium	2.9-57.6	Batch Sorption test, 1995
Cesium	93.9-10000	ORNL/TM-10634, 1987
Chromium	2.2-1000	Sheppard and Thibault, 1990
Cobalt	100-9700	Sheppard and Thibault, 1990
Copper	20-100	Looney, et al., 1987
Lithium	300	Baes and Sharp, 1984
Lead	100-59000	Sheppard and Thibault, 1990
Manganese	40-77000	Sheppard and Thibault, 1990
Mercury	10-104	Baes and Sharp, 1984
Molybdenum	125	Sheppard and Thibault, 1990
Neptunium	33.2-472	ORNL/TM-10634, 1987
Nickel	60-300	Sheppard and Thibault, 1990
Silver	28-333	Sheppard and Thibault, 1990
Selenium	3-150	Sheppard and Thibault, 1990
Strontium	14.8-64.5	Batch Sorption Test, 1995
Technetium	0.5-1.3	ORNL/TM-10634
Tin	100-450	Sheppard and Thibault, 1990
Thallium	1500	Baes and Sharp, 1984
Thorium	3300-5800	Sheppard and Thibault, 1990
Uranium	2.3-8.6	ORNL/TM-10634
Vanadium	1000	Baes and Sharp, 1984
Zinc	3.6-11000	Sheppard and Thibault, 1990
Zirconium	2200-3000 ^c	Sheppard and Thibault, 1990

Table E.56. Radioactive half lives, decay constants, and range of Kd for radionuclides at BCV

Radionuclide	Half Life (Year)	Decay Constant	Kd Range (L/Kg)	Reference
²⁴¹ Am	4.32E+02	4.39E-06	4.0E+02 - 4.8E+05	Sheppard and Thebault, 1990
¹³⁷ Cs			9.39E+01 - 1.0E+04	ORNL/TM-10634, 1987
⁶⁰ Co	5.26E+00	3.61E-04	1.0E+02 - 9.7E+03	Sheppard and Thebault, 1990
²³⁷ Np	2.14E+06	8.87E-10	3.3E+01 - 4.72E+02	ORNL/TM-10634, 1987
²³⁸ Pu	8.78E+01	2.16E-05	1.0E+01 - 5.9E+03	Sheppard and Thebault, 1990
^{239/240} Pu	2.41E+04	7.87E-08	1.0E+01 - 5.9E+03	Sheppard and Thebault, 1990
¹⁰⁶ Ru	1.01E+00	1.88E-03	1.0E+02 - 1.0E+03	ORNL/TM-10634, 1987
⁹⁰ Sr	2.86E+01	6.64E-05	1.48E+01 - 6.45E+01	Batch Sorption Test, 1995
⁹⁹ Tc	2.13E+05	8.92E-09	5.0E-01 - 1.3E+00	ORNL/TM-10634, 1987
²²⁸ Th	1.91E+00	9.93E-04	3.3E+03 - 5.8E+03	Sheppard and Thebault, 1990
²³⁰ Th	7.70E+04	2.47E-08	3.3E+03 - 5.8E+03	Sheppard and Thebault, 1990
²³² Th	1.41E+10	1.35E-13	3.3E+03 - 5.8E+03	Sheppard and Thebault, 1990
²⁰⁸ Tl	5.90E-06	3.22E+02	1.50E+03	Baes and Sharp, 1984
²³⁴ U	2.45E+05	7.77E-09	2.3E+00 - 8.6E+00	ORNL/TM-10634, 1987
²³⁵ U	7.04E+08	2.70E-12	2.3E+00 - 8.6E+00	ORNL/TM-10634, 1987
²³⁸ U	4.47E+09	4.25E-13	2.3E+00 - 8.6E+00	ORNL/TM-10634, 1987

Table E.57. Flow parameters for vadose zone modeling using ODAST

Waste Area	Recharge (q) (ft/day)	Seepage Velocity (Vs) (ft/day)	Dispersion Coeff (Dx) (ft ² /day)	Volumetric Percolation (Qp) (L/day)	Total Mass of Waste (M _T) (kg)
S-3	0.00093	0.0031	0.00088	1.54E+07	1.86E+07
BYBY	0.0128	0.0043	0.00098	1.065E+07	1.47E+08
SL-1	0.0128	0.0048	0.0010	6.30E+06	1.99E+08
OLF	0.0015	0.006	0.0011	9.21E+06	4.65E+07
BG-A North ^a	0.00081	0.0024	0.00082	3.76E+06	1.99E+08
WIP ^b	0.00081	0.0024	0.00082	7.47E+05	6.21E+07

^a BG-A South was inundated with groundwater, therefore vadose zone modeling was not required.

^b WIP includes WIP North, WIP South, BG-B, and BG-D South.

Table E.58. Calibrated parameter values used by CRAFLUSH for model application at the BCV Sites^a

Parameter description	Parameter value
Source concentration at infinite time	Variable or 1.0
Initial concentration in matrix and fractures	0.0
Velocity in fractures (ft/d)	15.0, 28.0, 131.2 ^b
Fracture dispersivity (ft)	10.0
Fracture aperture (ft)	3.94E-04
Fracture spacing (ft)	7.0
Matrix porosity	0.04
Matrix tortuosity	1.0
Diffusion coefficient in water (ft ² /d)	9.30E-05
Fracture retardation factor	1.0
Matrix retardation factor	1.0

^a Assumption: non-decaying solute.

^b Shallow, deep, and across strike, respectively.

**Table E.59. Sensitivity analysis for PCE from the S-3 Site
using SESOIL with Latin Hypercube sampling**

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
1	0.08017	40.6	8.19	10	1.36	7.86	2.35E-10	4	5	0.0027
2	0.182	44	27.6	10	1.68	8.03	2.20E-10	8	9	0.0055
3	0.07731	48.8	22.4	10	1.76	5.45	1.58E-10	5	7	0.0023
4	0.333	41.6	16.6	10	1.66	9.78	2.60E-10	10	12	0.0065
5	0.06873	37.7	19.7	11	1.6	11.1	4.80E-10	2	5	0.011
6	0.166	38.6	13.6	12	1.63	9.13	5.98E-10	6	8	0.0005
7	0.104	44.2	30.7	11	1.82	8.92	3.85E-10	5	8	0.003
8	0.406	43.6	24	11	1.59	8.73	3.85E-10	12	14	0.001
9	0.372	37.2	18.8	12	1.65	6.21	5.40E-10	13	156	0.000009
10	0.03866	43	32.6	10	1.49	9.08	2.40E-10	3	5	0.013
11	0.489	39.8	24.5	10	1.72	8.17	2.37E-10	15	18	0.0016
12	0.281	35.3	26.4	11	1.66	9.96	4.60E-10	9	11	0.0012
13	0.391	44.1	27.8	10	1.46	8.52	2.30E-10	10	13	0.004
14	0.07458	35.5	31.8	10	1.42	12.1	3.45E-10	3	4	0.017
15	0.247	44.6	20.5	10	1.97	7.73	2.10E-10	10	12	0.004
16	0.02887	51.5	20.8	10	1.6	5.92	1.65E-10	4	6	0.0045
17	0.141	36.5	26.6	12	2	8.36	5.95E-10	7	8	0.00018
18	0.05575	39.1	15.3	11	1.74	10.9	4.75E-10	3	5	0.012

Table E.59 (continued)

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content Θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
19	0.07665	46.8	25.1	10	1.37	4.06	1.45E-10	5	7	0.0004
20	0.06248	41.8	21.6	11	1.71	9.31	4.10E-10	4	6	0.0035
21	0.04038	43.3	31	11	1.64	7.36	3.63E-10	4	5	0.001
22	0.168	40	28.8	11	1.67	9.27	4.23E-10	6	8	0.0022
23	0.112	51.7	28.3	12	1.7	11.2	5.95E-10	6	7	0.004
24	0.204	47.1	22.1	12	1.6	8.32	5.45E-10	8	10	0.00045
25	0.09721	33	28.5	10	1.88	4.89	2.20E-10	5	7	0.0003
26	0.119	29.6	19.9	11	1.68	7.71	4.50E-10	5	6	0.00023
27	0.0429	39.5	22.8	11	1.17	9.22	4.30E-10	3	4	0.003
28	0.196	30.6	23.1	10	1.57	7.42	2.80E-10	6	8	0.0012
29	0.472	43.5	27.3	12	1.71	8.71	5.60E-10	15	18	0.00018
30	0.235	39	14.9	12	1.4	8.08	5.70E-10	8	10	0.0001
31	0.176	37.3	26	12	1.72	9.73	6.20E-10	7	8	0.0006
32	0.02585	33.4	21.2	12	1.56	8.6	6.10E-10	3	4	0.0005
33	0.103	58.9	19.9	10	1.41	9.51	1.90E-10	5	7	0.016
34	0.05692	27.6	21.7	12	1.73	7.14	6.30E-10	3	5	0.0004
35	0.06727	39.4	18.6	12	1.77	6.08	5.30E-10	5	6	0.00004
36	0.675	32.8	25.6	12	1.65	7.28	5.80E-10	20	23	0.000008

Table E.59 (continued)

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content Θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
37	0.532	36.8	12.1	11	1.78	11.5	4.95E-10	14	18	0.0026
38	0.151	42.3	17.2	10	1.45	6.58	1.95E-10	6	8	0.002
39	0.09428	44.7	16.7	12	1.5	12.8	6.60E-10	4	6	0.009
40	0.22	43.8	14	10	1.63	10.2	2.60E-10	7	9	0.013
41	0.03464	38	25.2	10	1.64	9.4	2.80E-10	3	4	0.016
42	0.24	38.3	26.8	12	1.69	7.96	5.70E-10	9	11	0.0001
43	0.124	46.6	20.3	12	1.58	9.48	5.73E-10	6	8	0.0011
44	0.223	31.2	20.6	11	1.56	8.58	4.55E-10	7	9	0.00045
45	0.07294	47.4	21.5	11	1.27	10.7	4.10E-10	4	6	0.006
46	0.107	45.8	22.6	12	1.34	8.44	5.50E-10	5	7	0.0006
47	0.173	47.6	22.4	12	1.86	6.76	5.10E-10	9	10	0.00013
48	0.02061	41.9	19.3	10	1.49	10.3	2.77E-10	3	4	0.03
49	0.301	48.1	23.2	10	1.91	7.05	1.90E-10	11	14	0.003
50	0.03769	44.5	21.4	12	1.85	7.88	5.40E-10	4	5	0.0005
51	0.135	41.2	24	12	1.64	10.4	6.10E-10	6	7	0.0013
52	0.102	49.6	21	12	1.51	9.54	5.60E-10	5	7	0.0017
53	0.03243	48.6	23.8	11	1.93	9.35	3.90E-10	4	5	0.01
54	0.348	34.9	22.8	10	1.55	10.3	3.15E-10	9	11	0.006

Table E.59 (continued)

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content Θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
55	0.09064	34.3	24.7	11	1.53	10.7	5.00E-10	7	9	0.0004
56	0.145	43.1	15.5	11	2.03	6.66	3.50E-10	3	5	0.0017
57	0.05134	37.9	16.1	12	1.48	9.84	6.20E-10	7	9	0.00005
58	0.194	35.7	18	12	1.47	7.48	5.75E-10	6	9	0.00005
59	0.128	45.2	18.4	11	1.78	8.23	3.80E-10	6	8	0.0026
60	0.08617	50.9	26.1	12	1.66	6.48	4.90E-10	6	8	0.00018
61	0.131	40.2	19	10	1.69	7	2.20E-10	6	8	0.0025
62	0.07053	38.8	16.9	10	1.76	8.41	2.50E-10	4	6	0.007
63	0.09926	34.2	23.5	10	1.58	11.4	3.43E-10	3	5	0.025
64	0.05353	41	21.9	11	1.54	9.68	4.20E-10	4	5	0.0045
65	0.02955	42.1	33.7	12	1.62	8.22	5.60E-10	4	5	0.007
66	0.148	40.9	23.3	10	1.8	12.6	3.25E-10	5	7	0.03
67	0.09304	40.7	24.2	11	1.86	7.95	3.90E-10	5	7	0.0015
68	0.207	52.6	29.4	11	1.75	10.8	4.00E-10	8	10	0.007
69	1.15	45.6	23.6	10	1.61	9.04	2.35E-10	28	31	0.0022
70	0.267	54.4	25	12	1.54	9.62	5.50E-10	9	11	0.0015
71	0.06601	46.2	23.7	11	1.46	7.21	3.50E-10	5	6	0.0014
72	0.213	39.7	22	12	1.43	8.48	5.80E-10	7	9	0.0003

Table E.59 (continued)

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
73	0.124	49.3	25.3	12	1.57	8.77	5.40E-10	6	7	0.001
74	0.268	40.5	27.2	10	1.51	6.31	2.10E-10	9	11	0.0014
75	0.08421	45.8	17.8	11	1.5	7.6	3.50E-10	5	7	0.0009
76	0.04458	34.9	30.2	11	1.67	6.51	3.90E-10	4	5	0.00035
77	0.138	41.5	28.1	12	1.47	7.81	5.50E-10	6	8	0.00018
78	0.135	39.2	29.5	12	1.38	7.63	5.60E-10	6	8	0.00012
79	0.257	45.4	21.3	12	1.76	8.68	5.60E-10	10	12	0.0005
80	0.04696	35.9	24.8	11	1.62	10	4.60E-10	3	4	0.0035
81	0.11	32.5	20.8	11	1.59	7.52	4.30E-10	5	6	0.0004
82	0.161	48.5	18.5	11	1.74	9.18	3.70E-10	7	9	0.003
83	0.295	45	19.4	10	1.3	7.35	2.10E-10	8	10	0.032
84	0.06001	41.4	18.1	10	1.56	5.59	1.90E-10	4	6	0.017
85	0.08537	42.6	22.2	12	1.83	8.82	5.80E-10	5	7	0.001
86	0.115	46.1	26.3	11	1.54	10.1	4.10E-10	5	7	0.006
87	0.155	36.4	14.6	11	1.44	8.12	4.10E-10	6	7	0.00045
88	0.117	50.3	13	12	1.55	7.07	5.10E-10	6	8	0.00035
89	0.08114	38.4	19.6	12	1.81	8.97	5.90E-10	5	6	0.0005
90	0.0587	36.9	17.6	12	1.79	9.89	6.20E-10	4	5	0.0013

Table E.59 (continued)

Run No.	Organic Carbon Content (%)	Porosity η (%)	Moisture Content Θ (%)	Discon Index C	Bulk Density P_b (g/cc)	Percolation Rate v (cm/yr)	Calibrated Intrinsic Permeability (cm ²)	Time of Arrival (year)	Time of Maximum Conc (year)	Maximum Conc (mg/L)
91	0.06332	40.3	25.5	12	1.31	4.72	5.00E-10	5	6	0.000009
92	0.01	42.5	20.2	10	1.83	8.86	2.40E-10	3	4	0.017
93	0.12	47.7	17.3	12	1.52	5.83	4.90E-10	7	8	0.00006
94	0.184	24.4	27	12	1.39	6.87	1.03E-10	5	6	0.0035
95	0.189	31.8	25.8	11	1.53	10.4	1.94E-10	6	7	0.0015
96	0.04884	33.9	20.4	11	1.8	6.9	1.26E-10	4	5	0.00035
97	0.157	37.5	24.4	12	1.61	11.8	1.93E-10	5	7	0.004
98	0.08984	36.3	19.1	10	1.7	5.36	1.69E-10	5	7	0.0005
99	0.315	42.9	23	12	1.73	6.37	1.18E-10	12	14	0.00003
100	0.05008	42.2	15.9	12	1.9	10.6	2.04E-10	4	5	0.0017
Maximum								28	156	0.032
Minimum								2	4	0.000008
Mean								6.5	9.6	0.004
Std Deviation								3.7	15.3	0.007
95% UCL								7.2	12.6	0.006

Table E.60. Baseline parameter values used by CRAFLUSH for initial sensitivity analysis at S-3 Site^a

Parameter description	Parameter value
Source concentration at infinite time	1.0
Initial concentration in matrix and fractures	0.0
Velocity in fractures (ft/d)	32.8
Fracture dispersivity (ft)	100.0
Fracture aperture (ft)	3.94E-04
Fracture spacing (ft)	7.0
Matrix porosity	0.05
Matrix tortuosity	0.75
Diffusion coefficient in water (ft ² /d)	8.60E-03
Fracture retardation factor	1.0
Matrix retardation factor	1.0

^a Assumption: non-decaying solute and constant source.

Table E.61. Range of the parameters for organics used in CRAFLUSH for S-3 Site

Velocity in fracture	1.82E+03~4.74E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Tortuosity	1.00E+00	unitless
Fracture retardation*		unitless

COPCs	Diffusion Coefficient ft ² /y	Simulation Range R _m unitless	Simulation Range Half-life year
<i>Organics</i>			
1,1,2-Trichloroethane (TCA)	2.99E-01	1.25 to 3.0	4 to 40
Bis(2-ethylhexyl) phthalate	1.24E-01	4 to 200	1.06 to 10
Chloroform	3.39E-01	1.1 to 5	5 to 50
Methylene Chloride	4.38E-01	1 to 2.3	0.33 to 3.33
Tetrachloroethene	2.78E-01	1 to 8	4.53 to 45

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.62. Range of the parameters for organics used in CRAFLUSH for BYBY

Velocity in fracture	1.825E+03~3.65E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Tortuosity	1.00E+00	unitless
Fracture retardation*	1.00E+00	unitless

COPCs	Diffusion Coefficient ft ² /y	Simulation Range R _m unitless	Simulation Range Half-life year
<i>Organics</i>			
1,1,2,2-Tetrachloroethane	2.68E-01	11.53 to 20	1.97 to 20
1,1-Dichloroethene	3.87E-01	1.1 to 3	0.5 to 5
1,2-Dichloroethane	3.84E-01	1 to 3	2 to 20
1,2-Dichloroethene	7.75E+01	1.01 to 2	7.91 to 80
Benzene	3.33E-01	1.32 to 7	2 to 20
Chloroform	3.39E-01	2 to 12	5 to 50
Methylene Chloride	4.38E-01	1 to 3	0.33 to 3.33
Tetrachloroethene	2.78E-01	1 to 10	4.53 to 45
Trichloroethene	3.09E-01	1.8 to 10	4.53 to 46
Vinyl Chloride	4.18E-01	1.05 to 2	7.91 to 80

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.63. Range of the parameters for organics used in CRAFLUSH for BG-A North and -A South

Velocity in fracture	1.82E02~3.65E04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Tortuosity	1.00E+00	unitless
Fracture retardation*	1.00E+00	unitless

COPCs	Diffusion Coefficient ft ² /year	Simulation Range R _m unitless	Simulation Range Half-life Year
<i>Organics</i>			
1,1,1-Trichloroethane	2.99E-01	1.2 TO 5	3 to 30
1,1,2-Trichloroethane	2.99E-01	1.35 to 4	4 to 40
1,1-Dichloroethane	3.36E-01	1.14 TO 3	1.73 to 17.
1,1-Dichloroethene	3.87E-01	1.14 TO 2.5	0.49 to 5
1,2-Dichloroethane	3.84E-01	1.1 TO 2.5	2 to 20
1,2-Dichloroethene	3.39E-01	1.29 TO 5	7.92 to 80
2-Butanone (Methyl ethyl ketone)	3.36E-01	1 TO 3	0.07 to 0.8
Acetone	3.87E-01	1 TO 2	0.08 to 0.8
Benzene	3.33E-01	1.32 TO 5	2 to 20
Carbon Tetrachloride	2.99E-01	2.26 TO 10	1 to 10
Chloroethane	3.90E-01	1.06 TO 2.5	0.33 to 3.3
Chloroform	3.39E-01	2 TO 10	5 to 50
Methylene Chloride	4.38E-01	1 TO 2.5	0.33 to 3.3
PCB (total)	3.39E-02	10 TO 70	0.4 to 4
Tetrachloroethene (PCE)	2.78E-01	1 TO 8	4.53 to 45.0
Trans-1,2-Dichloroethene	3.87E-01	1.1 TO 2.5	7.92 to 80
Trichloroethene (TCE)	3.09E-01	1 TO 8	4.53 to 45.0
Trichlorotrifluoromethane	3.29E-01	1 TO 8	4 to 40
Vinyl Chloride	4.18E-01	1.01 TO 2	7.92 to 80

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.64. Range of the parameters for organics used in CRAFLUSH for WIP

Velocity in fracture	1.82E+02~3.65E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Fracture retardation*	1.00E+00	unitless

COPCs	Diffusion Coefficient ft ² /year	Simulation Range R _m unitless	Simulation Range Half-life Year
<i>Organics</i>			
1,1,1-Trichloroethane	2.99E-01	1.2 to 5	3 to 30
1,1,2-Trichloroethane (TCA)	2.99E-01	1 to 4	4 to 40
1,1 Dichloroethane	3.36E-01	1.145 to 3	1.73 to 17
1,1-Dichloroethene	3.87E-01	1.1 to 2.5	0.49 to 5
1,2-Dichloroethane	3.84E-01	1 to 3	2 to 20
1,2-Dichloroethene	3.39E-01	1.29 to 5	7.92 to 80
Benzene	3.33E-01	1.32 to 5	2 to 20
Carbon Tetrachloride	2.99E-01	2.26 to 10	1 to 10
Chloroform	3.39E-01	2 to 10	5 to 50
Methylene Chloride	4.38E+00	1 to 2.5	0.33 to 4
PCB-1248	3.39E-02	100 to 500	0.4 to 4
Tetrachloroethene (PCE)	2.78E-01	1 to 8	4.53 to 45
Trans-1,2-Dichloroethene	3.87E-01	1.1 to 2.5	7.92 to 80
Trichloroethene (TCE)	3.09E-01	1 to 8	4.53 to 45
Vinyl Chloride	4.18E-01	1.01 to 2	4 to 40

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.65. Range of parameters for organics used in CRAFLUSH for BG-C West

Velocity in fracture	1.82E+03~3.65E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Fracture retardation*	1.00E+00	unitless

COPCs	Diffusion Coefficient ft ² /year	Simulation Range R _m unitless	Simulation Range Half-life Year
<i>Organics</i>			
1,1,1-Trichloroethane	2.99E-01	1.2 to 5	3 to 30
1,1-Dichloroethane	3.36E-01	1.145 to 3	1.73 to 17.3
1,2-Dichloroethane	3.84E-01	1 to 2.5	2 to 20
Benzene	3.33E-01	1.32 to 5	2 to 20
Chloroethane	3.73E-01	1 to 2.5	0.31 to 3
Methylene Chloride	4.38E-01	1 to 2.5	0.33 to 3.3
PCB (total)	3.39E-02	10 to 70	0.4 to 4
Tetrachloroethene (PCE)	2.78E-01	1 to 8	4.53 to 45.3
Trans-1,2-Dichloroethene	3.87E-01	1.1 to 2.5	7.91 to 80
Trichloroethene (TCE)	3.09E-01	1 to 8	4.53 to 45
Vinyl Chloride	4.18E-01	1.01 to 2	7.92 to 80

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.66. Range of the parameters for inorganics used CRAFLUSH for BYBY

Velocity in fracture	1.82E+03~3.65E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Diffusion Coefficient	3.39E-02	ft ² /year
Fracture retardation*	1.00E+00	unitless
<hr/>		
COPCs	Simulation	
	Range	
	R _m	
<hr/>		
unitless		
<hr/>		
<i>Inorganics</i>		
Antimony	223.0 - 300	
Cadmium	15.3 - 50	
Copper	50 - 200	
Chromium	12.8 - 40	
Lead	500 - 1000	
Manganese	200 - 300	
Mercury	50-150	
Nickel	300 - 500	
Total Uranium	12.4 - 40	
 Radionuclides		
⁹⁹ Tc	3-7	
^{233/234} U	12.4 - 40	
²³⁵ U	12.4 - 40	
²³⁸ U	12.4 - 40	

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

Table E.67. Range of the parameters for inorganics used in CRAFLUSH for BCBG

Velocity in fracture	1.82E+03~3.65E+04	ft/year
Dispersivity (alpha)	1.00E+01	ft
Fracture aperture	0.4E-04~1.6E-03	ft
Fracture spacing	7.00E+00	ft
Matrix porosity	4.00E-02	unitless
Diffusion coefficient	3.39E-02	ft ² /year
Fracture retardation*	1.00E+00	unitless

	Simulation Range R _m unitless
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Inorganics

Antimony	223.0 - 300
Arsenic	15.8 - 50
Barium	100 -200
Beryllium	1234 - 2000
Boron	15.8 - 50
Cadmium	15.3 - 50
Chromium	11.9 - 40
Copper	100 - 200
Cyanide	1.01 - 2
Lead	500 - 1000
Lithium	1481 - 2,200
Manganese	200 - 300
Nickel	300 - 500
Selenium	175 - 250
Total Uranium	12.4 - 40

Radionuclides

⁴⁰ K	28 - 60
⁹⁹ Tc	3-7
^{233/234} U	12.4 - 40
²³⁵ U	12.4 - 40
²³⁸ U	12.4 - 40

*Fracture retardation was not varied from the base values as the model is not sensitive to the changes in fracture retardation.

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