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UCOR-5095/R2

Composite Analysis for the Environmental Management Waste Management Facility and the Environmental Management Disposal Facility, Oak Ridge, Tennessee

This document is approved for public release per review by:

Peter Kortman (signature on file)	04-16-2020
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UCOR-5095/R2

Composite Analysis for the Environmental Management Waste Management Facility and the Environmental Management Disposal Facility, Oak Ridge, Tennessee

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Prepared for the
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Office of Environmental Management

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APPROVALS

Composite Analysis for the Environmental Management Waste Management Facility and the Environmental Management Disposal Facility, Oak Ridge, Tennessee	**UCOR-5095/R2** April 2020

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REVISION LOG

Revision Number	Description of Changes	Pages Affected
0	Draft transmitted to OREM for comment.	All
1	Initial issue of document incorporating OREM comments.	All
2	Addressed comments from Low-Level Waste Disposal Facility Federal Review Group review held September 2018.	All

CONTENTS

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TABLES

FIGURES

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ACRONYMS

BCBG	Bear Creek Burial Grounds
BCK	Bear Creek kilometer
BCV	Bear Creek Valley
BJC	Bechtel Jacobs Company LLC
BYBY	Boneyard/Burnyard
CBCV	Central Bear Creek Valley
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CRM	Clinch River Mile Marker
DAS	Disposal Authorization Statement
DMC	Document Management Center
DNAPL	dense, non-aqueous phase liquid
DOE	U.S. Department of Energy
DOE M	DOE Manual
DOE O	DOE Order
DQO	data quality objective
EFPC	East Fork Poplar Creek
ELCR	excess lifetime cancer risk
EMDF	Environmental Management Disposal Facility
EMWMF	Environmental Management Waste Management Facility
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
FFA	Federal Facility Agreement
FFS	Focused Feasibility Study
FS	Feasibility Study
GDP	gaseous diffusion plant
HCDA	Hazardous Chemicals Disposal Area
IWMF	Interim Waste Management Facility
LLW	low-level (radioactive) waste
LFRG	Low-level Waste Disposal Facility Federal Review Group
NT	North Tributary
OLF	Oil Landfarm
OREM	Oak Ridge Office of Environmental Management
ORNL	Oak Ridge National Laboratory
ORP	Oil Retention Pond
ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
POA	point of assessment
QA	quality assurance
RCRA	Resource Conservation and Recovery Act of 1976
RDR	Remedial Design Report
RESRAD	RESidual RADioactivity
RER	Remediation Effectiveness Report
RI	Remedial Investigation
ROD	Record of Decision
SAMOA	Server Asset Management and Official Application
SL-1	Sanitary Landfill 1
SNS	Spallation Neutron Source

SR	State Route
SS	Surface Spring
SWSA	Solid Waste Storage Area
TMR	telescopic mesh refinement
TSCA	Toxic Substances Control Act of 1976
TSCOM	technical steering committee
TVA	Tennessee Valley Authority
UBCV	Upper Bear Creek Valley
UEFPC	Upper East Fork Poplar Creek
USGS	U.S. Geological Survey
VOC	volatile organic compound
WAC	waste acceptance criteria
Y-12	Y-12 National Security Complex

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) operates the Environmental Management Waste Management Facility (EMWMF) in the Bear Creek Valley (BCV) on the Oak Ridge Reservation (ORR). This low-level (radioactive) waste (LLW) disposal facility for ORR waste generated by response actions conducted under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) is expected to reach its disposal capacity in the mid-2020s. DOE has proposed the construction and operation of another LLW disposal facility for ORR waste generated by response actions conducted under CERCLA. The proposed location for this disposal facility, the Environmental Management Disposal Facility (EMDF), is also in BCV. For this reason, a single Composite Analysis has been prepared to account for the sources of radioactive material that may interact with these disposal facilities. This Composite Analysis satisfies the DOE Manual (M) 435.1-1 requirement for a Composite Analysis to support authorization for the proposed EMDF and continued disposal authorization for the EMWMF. The original EMWMF composite analysis was written in 1999. The proposed EMDF represents an additional source term in BCV, contributing to the cumulative dose projected to a hypothetical member of the public.

The DOE Order (O) 435.1, *Radioactive Waste Management* (DOE 2001a), and implementing the DOE M 435.1-1, *Radioactive Waste Management Manual* (DOE 2011a), requires that a Composite Analysis be prepared to account for all sources of radioactive material that may be left at the DOE site and may interact with the LLW disposal facility, contributing to the dose projected to a hypothetical member of the public from the existing or future disposal facilities.

This Composite Analysis incorporates minor differences in the remediation of BCV assumed in the 1999 Composite Analysis and the remediation and future land uses codified in a 2000 CERCLA Record of Decision (ROD) for BCV. This Composite Analysis provides a status of remediation that has been completed in BCV and uses measured concentrations of contamination in the surface water and groundwater to define dose estimates.

This Composite Analysis considers all potential buried radioactive material sources on the ORR that might contribute to radiation doses to members of the public at the same location or locations where doses might be received from radionuclides released from both EMWMF and the proposed EMDF. Investigations conducted to support remedial actions on the ORR under CERCLA have concluded that groundwater and surface water flow are the principal contaminant transport mechanisms, and that the long northeast-southwest trending valleys and ridges on the ORR define essentially isolated hydrologic systems (watersheds) with very little exchange of water or contamination from one valley to another. Furthermore, airborne movement of radioactive contaminants is not expected to be a major contributor to doses to the public from disposal sites at the ORR and significant airborne migration of contaminants from valley to valley is unlikely (UCOR, an Amentum-led partnership with Jacobs, 2020a, Sect. 3.2.2; DOE 1999a, pages A-7 and A-8). Therefore, a hypothetical public receptor would only be exposed to contaminants released from sources within the watershed inhabited by the receptor, or via groundwater or surface water entering the disposal facility's watershed from another, hydrologically connected watershed. Therefore, this Composite Analysis considers only those sources of potential radiological contaminant releases located in the BCV watershed, which is the location of EMWMF and the proposed location of EMDF.

Introductory material and background information are presented in Sects. 1 and 2 of this Composite Analysis. The three source terms defined in Sect. 2.5 include the following:

- Other existing BCV sources
- EMWMF
- EMDF.

"Other existing BCV sources" originated from the disposal of radioactive waste from various operations at the Y-12 National Security Complex. These disposal sites were in use during the Manhattan Project, beginning in the 1940s, and were all closed by the mid- to late-1980s. Measurements of contaminant levels in the groundwater, Bear Creek, nearby springs and seeps, and tributaries to Bear Creek from 2001 to 2017 indicate that some of these sites are releasing radioactive contaminants, principally uranium. These sources were the subject of *Record of Decision for the Phase I Activities in Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (Phase I BCV ROD) (DOE 2000a) and were characterized in *Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (DOE 1997a). Future remedial actions are expected to meet the goals described in the Phase I BCV ROD.

The second potential source of radioactive contamination is the operating EMWMF and the third source considered is the proposed EMDF. It is important to note that these same three source terms would be developed and evaluated if two stand-alone composite analyses were being prepared for EMWMF and the proposed EMDF, rather than this single Composite Analysis that encompasses both LLW disposal facilities.

The other existing BCV sources were evaluated using the CERCLA process. This process included the Remedial Investigation (RI) of BCV (DOE 1997a) and the *Feasibility Study for Bear Creek Valley at the Y-12 Plant, Oak Ridge, Tennessee* (DOE 1997b), and codified a risk goal as an excess lifetime cancer risk (ELCR) of 1×10^{-5} at Bear Creek kilometer (BCK) 9.2 in the Phase I BCV ROD (DOE 2000a). The status of the actions selected in the ROD are documented in *2018 Remediation Effectiveness Report for the U.S. Department of Energy Oak Ridge Site Oak Ridge, Tennessee – Data and Evaluations* (DOE 2018a), as are the data and information used to determine the effectiveness of the remedial actions conducted in BCV. The 2018 Remediation Effectiveness Report (RER) concludes that additional remedial actions will be required to achieve the commitments in the Phase I BCV ROD. The RER also presents 17 years of uranium and Tc-99 concentrations in Bear Creek (DOE 2018a, Table 4.5 and Fig. 4.4). These concentrations were used to predict a dose following future remedial actions in BCV required to comply with the ROD. The post-remediation dose for other existing BCV sources at BCK 9.2 was calculated to be 0.98 mrem/year. This dose is based on a regulatory commitment in the ROD and is an estimate of the maximum dose that DOE must comply with or revise the ROD.

The estimates of potential risks to the public from EMWMF were embedded in the CERCLA risk assessments conducted as part of *Remedial Investigation/Feasibility Study for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Waste* (EMWMF RI/Feasibility Study [FS]) (DOE 1998a) and codified in *Record of Decision for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response Compensation, and Liability Act of 1980 Waste* (DOE 1999b). Those risk assessments were used in conjunction with CERCLA risk goals of an ELCR of 1×10^{-5} during the first 1000 years after facility closure and an ELCR of 1×10^{-4} thereafter to determine the concentrations of contaminants that could be accepted at the facility. The use of such risk-based waste acceptance criteria ensures that potential maximum doses to human receptors at the East BCV site (at the confluence of North Tributary [NT]-5 and Bear Creek) from potential releases from the closed EMWMF would be within prescribed bounds (DOE 2001b, Sect. 1.2).

EMWMF is filled to approximately 80 percent of capacity (UCOR 2019a). Therefore, actual waste disposal information was used to estimate an EMWMF radiological inventory at closure, assuming the current radiological composition remains unchanged. This radiological inventory was used to calculate radiological concentrations at the confluence of NT-5 and Bear Creek (BCK 10.5). The concentrations at this location were predicted using the PATHRAE-RAD model and modeling scenario as discussed in the EMWMF RI/FS for disposal of ORR CERCLA waste and its addendum (DOE 1998a, DOE 1998b). The predicted concentrations for the primary radionuclides at EMWMF closure were used to calculate the resulting maximum dose inside the 1000-year compliance period for the all pathways exposure scenario in DOE 1998a and 1998b. The resulting dose from EMWMF, with the current inventory assumed at closure at BCK 10.5, is 0.09 mrem/year. This dose is primarily from H-3, C-14, I-129, and Tc-99 from the consumption of water from Bear Creek.

The estimates of potential doses to the public from EMDF were calculated in *Performance Assessment for the Environmental Management Disposal Facility, Oak Ridge, Tennessee* (UCOR 2020a). This Composite Analysis uses the results of the performance modeling in the Performance Assessment and develops a dose estimate for EMDF at the confluence of NT-11 and Bear Creek using the same model used in the Performance Assessment (RESidual RADioactivity-OFFSITE). This dose, predicted to be 0.25 mrem/year, is primarily from exposure to C-14 by ingesting fish.

The point of assessment (POA) selected for this Composite Analysis is also at the confluence of NT-11 and Bear Creek (at BCK 7.73). The receptor is assumed to be a resident farmer immediately southwest (downstream) of the proposed EMDF. The resident farmer receptor is assumed to use Bear Creek water for all domestic and agricultural purposes. At this location, the receptor is likely to receive the maximum exposure from contaminant release from all three source terms. This receptor at this location is consistent with the land use for this portion of BCV (Zone 2) currently designated in the Phase I BCV ROD (DOE 2000a).

Seventeen years of flow rate data in Bear Creek were evaluated and a surface area analysis was conducted to determine the mixing ratios in Bear Creek between the confluence of NT-5 (at BCK 10.5) and BCK 9.2 and from BCK 9.2 to BCK 7.73. The dose from EMWMF then was extrapolated to BCK 7.73 using these mixing factors. The dose from the other existing BCV sources was extrapolated using the mixing ratio from BCK 9.2 to BCK 7.73. Figure ES.1 shows the locations of three source terms considered in this Composite Analysis with each point of compliance and the POA. These two extrapolated doses then were totaled at the POA (BCK 7.73) with the dose from the proposed EMDF. Table ES.1 summarizes this assessment for the DOE O 435.1 1000-year post-closure compliance period (referred to as the “base case assessment”).

A total annual dose of 0.98 mrem/year is projected at the POA (BCK 7.73), which is significantly less than the 100 mrem/year limit in the performance measures discussed in Sect. 1.2.1. This annual dose is also significantly less than the administratively limited dose constraint of 30 mrem, which would require an options analysis. For this reason, an options analysis has not been performed in this Composite Analysis.

This composite dose includes a predicted contribution of 0.25 mrem/year from the EMDF and a predicted contribution of 0.09 mrem/year from the EMWMF. At these predicted doses, neither of these disposal facilities is a significant contributor to a receptor dose in the context of the performance measure of 100 mrem/year. Also, neither of these doses exceeds the general screening value of 1 mrem/year in the DOE Standard *Disposal Authorization Statement and Tank Closure Documentation* (DOE 2017a). Additionally, at these predicted doses, the EMWMF and the proposed EMDF cannot lead to the need for future corrective or remedial actions (see Sect. 6).

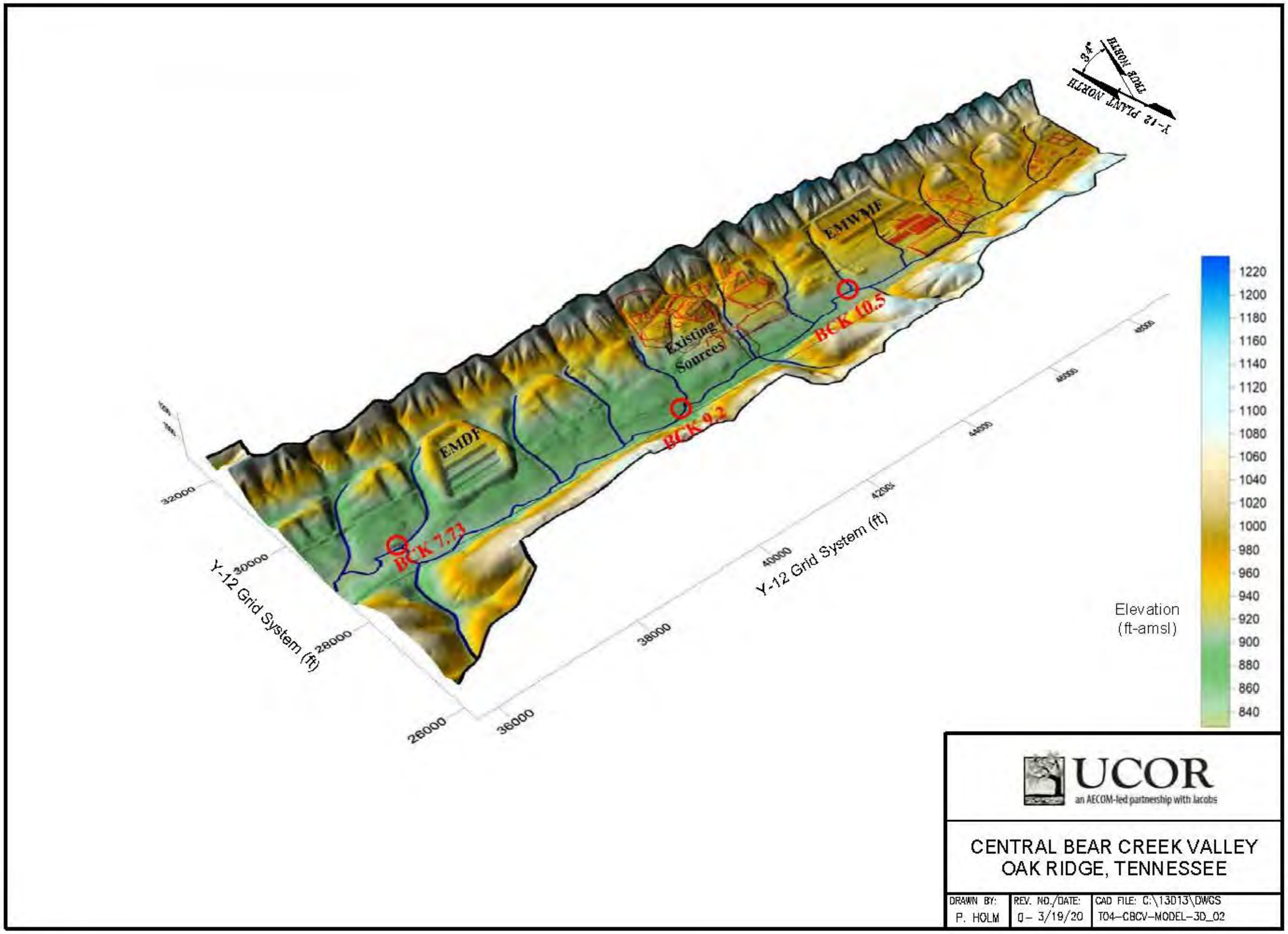

Fig. ES. 1. Other existing BCV sources, EMWMF, and the proposed EMDF with points of compliance and Composite Analysis point of assessment (also BCK 7.73)

Table ES.1. Base case assessment summary

Source term	Dose basis at each point of compliance	Dose at each point of compliance (mrem/year)	Bear Creek mixing ratio	Dose at Composite Analysis POA (mrem/year)
Other existing BCV sources	Post-remediation dose assuming compliance with Phase I BCV ROD (at BCK 9.2)	0.98	1.43	0.69
EMWMF	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5	0.09	2.36	0.04
Proposed EMDF	Dose in Bear Creek at BCK 7.73 from RESRAD modeling of EMDF source term	0.25	1.00	0.25
			Total dose	**0.98**

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
POA = point of assessment
RESRAD = RESidual RADioactivity
ROD = Record of Decision

Sensitivities to uncertainties in the Composite Analysis were also evaluated. The major sensitivities evaluated include land use, the post-1000-year maximum dose, Bear Creek flow rates, a groundwater/surface water user at the POA, and the dose for the other existing BCV sources considering no further remediation. Table ES.2 summarizes the results of the sensitivity analyses.

Table ES.2. Summary of sensitivity/uncertainty analyses

Sensitivity/uncertainty	Source term	Dose at POA (mrem/year)	Method of analysis (for all pathways dose)
Sect. 5.2 Sensitivity to Remedial Actions on Other Existing BCV Sources	Other existing BCV sources	3.10	Seventeen-year average uranium and Tc-99 concentrations in Bear Creek, conversion from concentrations to dose
	EMWMF	0.04	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment
	Proposed EMDF	0.25	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment
		3.39	**Total dose**
Sect. 5.3 Post-1000-year Maximum Dose (within 10,000 years)	Other existing BCV sources	0.69	Post-remediation dose assuming compliance with Phase I BCV ROD
	EMWMF	0.34	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5
	Proposed EMDF	0.13	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term
		1.16	**Total dose**

Table ES.2. Summary of sensitivity/uncertainty analyses (cont.)

Sensitivity/uncertainty	Source term	Dose at POA (mrem/year)	Method of analysis (for all pathways dose)
Sect. 5.4 Sensitivity to Bear Creek Flow Rates at Confluence of NT-11	Other existing BCV sources	0.98	Post-remediation dose assuming compliance with Phase I BCV ROD, no mixing in Bear Creek from BCK 9.2 to POA
	EMWMF	0.05	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5, no mixing in Bear Creek from BCK 9.2 to POA
	Proposed EMDF	0.35	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment (considering reduced Bear Creek flow)
		1.38	**Total dose**
Sect. 5.5 Sensitivity to Groundwater and Surface Water Usage Pathway in Base Case Assessment	Other existing BCV sources	0.69	Post-remediation dose assuming compliance with Phase I BCV ROD from base case assessment
	EMWMF	0.04	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment
	Proposed EMDF	1.28	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term plus dose from 100-m well in Performance Assessment
		2.01	**Total dose**
Sect. 5.6 Sensitivity to Percent Contaminant Mass Discharge from EMDF	Other existing BCV sources	0.49	Post-remediation dose assuming compliance with Phase I BCV ROD from base case assessment, mixing in Bear Creek to NT-14
	EMWMF	0.03	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment, mixing in Bear Creek to NT-14
	Proposed EMDF	0.18	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term, mixing in Bear Creek to NT-14
		0.70	**Total dose**
Sect. 5.7 Sensitivity to Risk Agreements in BCV and EMWMF CERCLA RODs	Other existing BCV sources	0.27	Risk (1E-05) to dose conversion at BCK 9.2
	EMWMF	0.17	Risk to dose conversion at BCK 10.5
	Proposed EMDF	0.25	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment
		0.69	**Total dose**

Table ES.2. Summary of sensitivity/uncertainty analyses (cont.)

Sensitivity/uncertainty	Source term	Dose at POA (mrem/year)	Method of analysis (for all pathways dose)
Sect. 5.8 Sensitivity to an Alternate Conceptual Site Model	Other existing BCV sources (domestic water)	0.98	Post-remediation dose assuming compliance with Phase I BCV ROD in shallow groundwater well in BCK 9.2 area
	EMWMF (domestic water)	0.05	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5, mixing in Bear Creek to shallow groundwater well in BCK 9.2 area
	Proposed EMDF (domestic and agricultural water)	2.01	Dose in 100-m well in Performance Assessment assumed in shallow groundwater well in BCK 9.2 area, plus total base case assessment dose in Bear Creek at BCK 7.73
		3. 04	**Total dose**

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
NT = North Tributary
POA = point of assessment
ROD = Record of Decision
RER = Remediation Effectiveness Report
RESRAD = RESidual RADioactivity

Sensitivity analyses show that the highest projected annual dose from all potential sources of radioactive contamination in BCV occurs if no further remediation is performed in BCV. A composite dose of 3.39 mrem/year is predicted at the POA. This is not considered realistic because the dose predicted from the other existing BCV sources in this sensitivity analysis does not comply with the Phase I BCV ROD. All other sensitivity analyses performed for times in the 1000-year compliance period resulted in predicted doses of less than 3.39 mrem/year. The post-1000-year maximum composite dose, 1.16 mrem/year, is slightly higher than the dose from the base case assessment, but is lower than the dose if no further remediation is performed in BCV.

While there is uncertainty in the parameters used for estimating the projected doses, there is considerable conservatism built into those estimates. Conservatisms include future land use, assuming radionuclides peak simultaneously, and an all-pathways exposure scenario based on a local agricultural subsistence lifestyle that is uncommon in present day Eastern Tennessee. Therefore, it is unlikely that any of the uncertainties in the parameters used to estimate the doses will cause actual future doses to exceed 30 mrem/year; the conclusion that the dose constraint will be met is robust.

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1. INTRODUCTION

1.1 BASIS FOR THE COMPOSITE ANALYSIS

The U.S. Department of Energy (DOE) operates the Environmental Management Waste Management Facility (EMWMF) in the Bear Creek Valley (BCV) on the Oak Ridge Reservation (ORR) (see Fig. 1). This LLW disposal facility for ORR waste, generated by response actions conducted under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), is expected to reach its disposal capacity in the mid-2020s. DOE has proposed the construction and operation of another low-level (radioactive) waste (LLW) disposal facility for ORR waste generated by response actions conducted under CERCLA. The proposed location for this disposal facility, the Environmental Management Disposal Facility (EMDF), also is in BCV (see Fig. 1). For this reason, a single Composite Analysis has been prepared to account for the sources of radioactive material that may interact with these disposal facilities.

The DOE Order (O) 435.1, Radioactive Waste Management (DOE 2001a), and implementing the DOE Manual (M) 435.1-1, Radioactive Waste Management Manual (DOE 2011a), requires that a Composite Analysis be prepared to account for all sources of radioactive material that may be left at the DOE site and that may interact with the low-level (radioactive) waste (LLW) disposal facility, contributing to the dose projected to a hypothetical member of the public from the existing or future disposal facilities.

This Composite Analysis satisfies the DOE O 435.1/DOE M 435.1-1 requirement for a Composite Analysis to support authorization for the proposed EMDF and continued disposal authorization for the EMWMF. The original EMWMF composite analysis was written in 1999 (DOE 1999a, Appendix A). The proposed EMDF represents an additional source term in BCV, contributing to the cumulative dose projected to a hypothetical member of the public. Research, field studies, monitoring, and actions taken since the issuance of the 1999 EMWMF Composite Analysis to address uncertainties or gaps in existing data were evaluated and the results were incorporated into this revision. Examples of this information include engineering and performance of groundwater suppression (Bechtel Jacobs Company LLC [BJC 2003]), analyses of the performance of EMWMF Cells 1-6 (BJC 2010), and the results of performance and operations monitoring of EMWMF that verify no unauthorized releases to the environment.

This Composite Analysis incorporates minor differences in the remediation of BCV assumed in the 1999 Composite Analysis and the remediation and future land uses codified in the Record of Decision for the Phase I Activities in Bear Creek Valley at the Oak Ridge Y-12 Plant (Phase I BCV Record of Decision [ROD] [DOE 2000a]) (Table 1). Finally, this Composite Analysis takes into consideration remediation completed in BCV and uses measured concentrations of contamination in the surface water and groundwater to define dose estimates.

This Composite Analysis considers all potential buried radioactive material sources on the ORR that might contribute to radiation doses to members of the public at the same location or locations where doses might be received from radionuclides released from EMWMF and the proposed EMDF. Investigations conducted to support remedial actions on the ORR under CERCLA have concluded that groundwater and surface water are the principal contaminant transport mechanisms and that the long northeast-southwest trending valleys and ridges on the ORR define essentially isolated hydrologic systems (watersheds) with very little exchange of water from one valley to another. Furthermore, airborne movement of radioactive contaminants is not expected to be a major contributor to doses to the public from disposal sites on the ORR and significant airborne migration of contaminants from valley to valley is unlikely (UCOR, an Amentum-led partnership with Jacobs, 2020a, Sect. 3.2.2; DOE 1999a, pages A-7 and A-8).

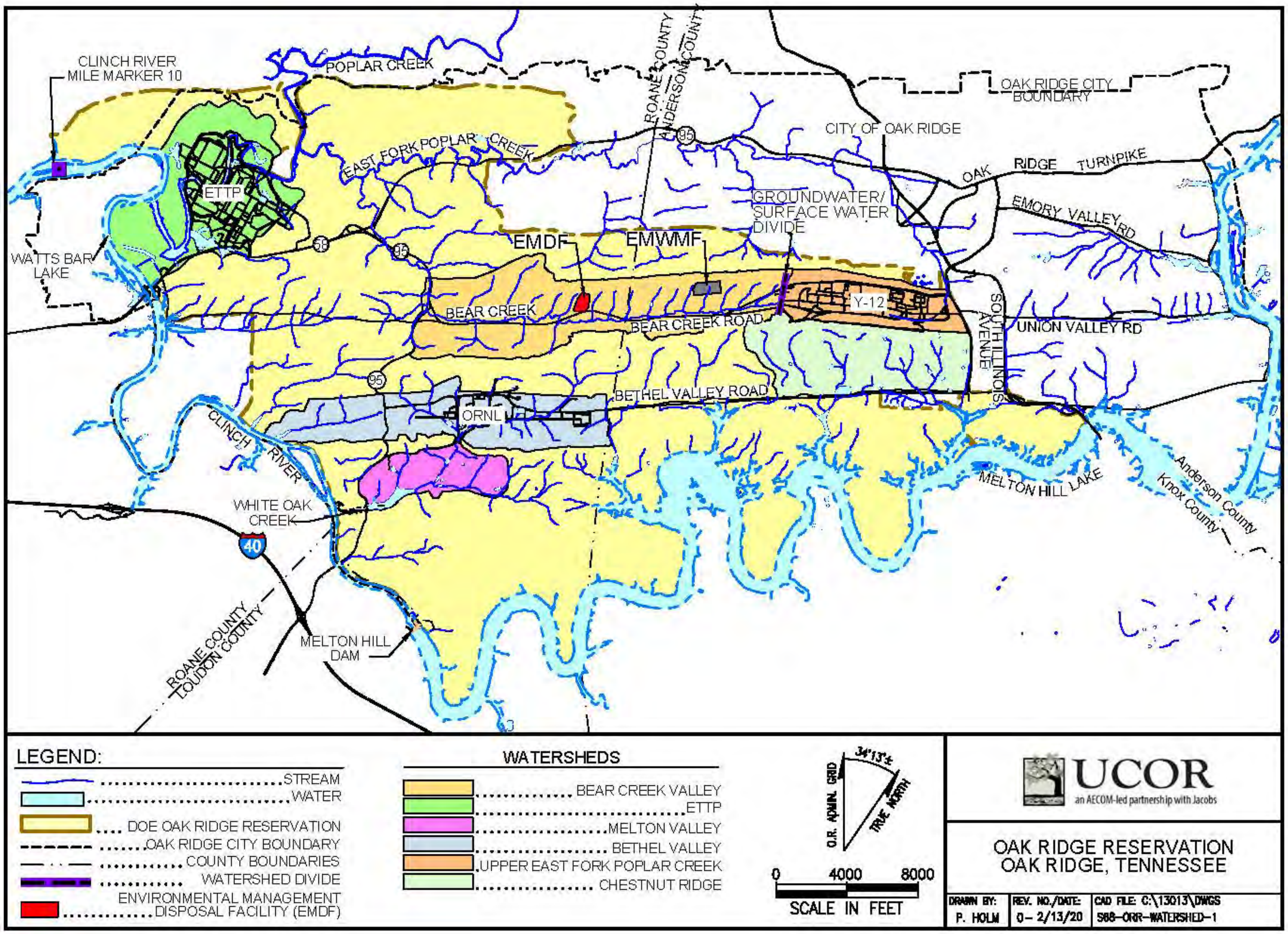


Fig. 1. Bear Creek Valley watershed on the Oak Ridge Reservation

Therefore, a hypothetical public receptor would only be exposed to contaminants released from sources within the watershed inhabited by the receptor, or via groundwater or surface water entering the disposal facility's watershed from another, hydrologically connected watershed. Therefore, this Composite Analysis considers only sources of potential contaminant releases located in the BCV watershed, which is the location of EMWMF and the proposed location of EMDF.

Table 1. Summary of changes from 1999 EMWMF Composite Analysis in this 2020 EMWMF and EMDF Composite Analysis

1999 EMWMF Composite Analysis	2020 EMWMF and EMDF Composite Analysis
EMWMF and other BCV sites	Includes additional source term from the planned EMDF
EMWMF inventory estimated based on WAC	Inventory based on 80 percent utilization of the EMWMF and EMDF estimated inventory
POA located at BCK 9.2	POA located at BCK 7.73
N/A[a]	Incorporates monitoring data from 17 years of EMWMF operations
	Incorporates the approved Phase I BCV ROD and 17 years of uranium and Tc-99 concentrations from Bear Creek
	Minor differences in remediation as part of the Phase I BCV ROD

[a] There were no corresponding items in the 1999 EMWMF Composite Analysis.

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
EMWMF = Environmental Management Waste Management Facility
EMDF = Environmental Management Disposal Facility
N/A = not applicable
POA = point of assessment
ROD = Record of Decision
WAC = waste acceptance criteria

The three source terms to be defined in this Composite Analysis (Sect. 2.5) include the following:

- Other existing BCV sources
- EMWMF
- EMDF.

"Other existing BCV sources" originated from the disposal of radioactive waste from various operations at the Y-12 National Security Complex (Y-12). These disposal sites were in use during the Manhattan Project, beginning in the 1940s, and were all closed by the mid- to late-1980s. Measurements of contaminant levels in the groundwater, Bear Creek, nearby springs and seeps, and tributaries to Bear Creek from 2001 to 2017 indicate that some of these sites are releasing radioactive contaminants, principally uranium (*2018 Remediation Effectiveness Report for the U.S. Department of Energy Oak Ridge Site Oak Ridge, Tennessee – Data and Evaluations* [DOE 2018a]). These sources were the subject of the Phase I BCV ROD (DOE 2000a) and were characterized in *Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (DOE 1997a). Some remedial actions have been implemented; other future remedial actions are expected to meet goals described in the Phase I BCV ROD.

The second potential source of radioactive contamination is the operating EMWMF and the third potential source of contamination is the proposed EMDF. It should be noted that these same three source terms would be developed and evaluated if two stand-alone composite analyses were being prepared for EMWMF and the proposed EMDF, rather than this single Composite Analysis that encompasses both LLW disposal facilities.

To confirm the potential long-term contaminant migration pathways from the other existing BCV sources, EMWMF, and the proposed EMDF and their cumulative impacts, three-dimensional groundwater flow models for BCV were developed to support the Performance Assessment for EMDF and this Composite Analysis (Sect. 3.4 and Appendix A). These groundwater flow models are based on the regional BCV watershed model, developed to support the BCV watershed Remedial Investigation (RI) and Feasibility Study (FS), and detailed site-specific models developed for EMWMF. These models were used to predict the ultimate flow path and plume migration within BCV. Model simulation, consistent with the conceptual site model detailed in Sect. 3.2 and the contaminant fate and transport information presented in Sect. 2.4.4.1, indicates that all predicted contamination from the other existing BCV sources and EMWMF would discharge from shallow groundwater to Bear Creek prior to reaching the location of the hypothetical receptor (i.e., the point of assessment [POA]), and that significant mixing of the contamination would be expected in Bear Creek before reaching the POA. Model simulation also predicts that a radiologically contaminated groundwater plume at the POA would originate from the proposed EMDF.

The EMWMF is filled to approximately 80 percent of capacity (UCOR 2019a). Actual waste disposal information was used to estimate an EMWMF radiological inventory at closure, assuming the current radiological composition remains unchanged. The dose was predicted using the PATHRAE-RAD model and modeling scenario as discussed in the RI/FS for disposal of ORR CERCLA waste (referred to herein as the EMWMF RI/FS) and its addendum (DOE 1998a, DOE 1998b). The predicted concentrations for the primary radionuclides at EMWMF closure were used to calculate the resulting maximum dose inside the 1000-year compliance period for the all pathways exposure scenario in DOE 1998a and 1998b. The resulting dose from EMWMF, with the current inventory assumed at closure at Bear Creek kilometer (BCK) 10.5, is 0.09 mrem/year (see Table B.7 in Appendix B). This dose is predicted from primarily H-3, C-14, I-129, and Tc-99.

This point of compliance for the EMWMF is at the confluence of North Tributary (NT)-5 and Bear Creek (BCK 10.5). (Positions along Bear Creek are denoted by locators termed “creek kilometers.” These locators are designated by BCK, plus the distance measured in kilometers from the confluence with East Fork Poplar Creek [EFPC] [e.g., BCK 9.2 is just west of the confluence of Bear Creek and NT-8 and BCK 12.36 is at the confluence of Bear Creek and NT-1].)

Estimates of potential doses to the public from EMDF were calculated in *Performance Assessment for the Environmental Management Disposal Facility, Oak Ridge, Tennessee* (UCOR 2020a). This Composite Analysis develops a surface water-based dose for EMDF in Bear Creek at the confluence of NT-11 and Bear Creek using the same model used in the Performance Assessment (RESidual RADioactivity-Offsite [RESRAD-OFFSITE] version 3.2) (Yu et al. 2007, Gnanapragasam and Yu 2015). This dose, predicted to be 0.25 mrem/year, is primarily from exposure to C-14 by ingesting fish.

The post-remediation goal of an excess lifetime cancer risk (ELCR) of 1×10^{-5} at BCK 9.2 for the other existing BCV sources was codified in the Phase I BCV ROD (DOE 2000a, pages 1-7 and 2-61). This location, the Integration Point, was subsequently defined as the point of compliance for the ROD based on future land use zones defined in the ROD and sampling/monitoring considerations discussed in the *Bear Creek Valley Watershed Remedial Action Report Comprehensive Monitoring Plan* (DOE 2012a, pages 1 and 6) and the 2015 Remediation Effectiveness Report (RER) (DOE 2015, page 4-21). Significant input from the stakeholders and the End-Use Working Group went into the delineation of the land use scenarios defined in the ROD. This location is just downstream from the future boundary of the zone of DOE perpetually controlled, industrial use land assumed in the Phase I BCV ROD. The 2018 RER concludes that additional remedial actions will be required to achieve the commitments in the Phase I BCV ROD. The 2018 RER also presents 17 years of uranium and Tc-99 concentrations in Bear Creek (DOE 2018a, Table 4.5 and Fig. 4.4). These concentrations were used to predict a dose following future remedial actions in BCV required to comply with the ROD. The post-remediation dose for other existing BCV sources at BCK 9.2 was calculated to be 0.98 mrem/year (see Appendix C). This dose is based on a regulatory commitment in the ROD and is an estimate of the maximum dose that DOE must comply with or revise the ROD.

The confluence of NT-11 and Bear Creek (BCK 7.73) was selected as the POA in this Composite Analysis. All existing sources of potential radioactive contamination in BCV, including EMWMF and the proposed EMDF, are upstream of this location (see Sect. 1.2.2). There is no location closer to the proposed EMDF in which a member of the public could receive a potential radiological dose with a combined contribution from EMDF, EMWMF, and the other existing BCV sources.

Seventeen years of flow rate data in Bear Creek were evaluated and a surface area analysis was conducted to determine mixing ratios in Bear Creek between the confluence of NT-5 (at BCK 10.5) and BCK 9.2 and from BCK 9.2 to BCK 7.73. The dose for EMWMF then was extrapolated to BCK 7.73 using these mixing factors. The dose for the other existing BCV sources was extrapolated using the mixing ratio from BCK 9.2 to BCK 7.73. These two extrapolated doses then were totaled at the POA (BCK 7.73) with the dose from the proposed EMDF and compared to the performance measures in DOE O 458.1 for a primary limit of 100 mrem/year total effective dose to the representative person or maximally exposed individual, excluding contributions from radon and its decay products.

1.2 REGULATORY CONTEXT

DOE is responsible for sitewide waste management and environmental restoration activities on the ORR under its Office of Environmental Management Program at the national level. Locally the Oak Ridge Office of Environmental Management (OREM) is responsible for minimizing potential hazards to human health and the environment associated with contamination from past DOE practices and addressing the waste management and disposal needs of the ORR. Under the requirements of a Federal Facility Agreement (FFA) (DOE 1992) established by DOE, the U.S. Environmental Protection Agency (EPA), and the Tennessee Department of Environment and Conservation, all environmental restoration activities on the ORR are performed in accordance with CERCLA.

The OREM Program’s major focus has been remediation of facilities within the installations that are contaminated by historical Manhattan Project and Cold War activities. This cleanup mission is projected to take approximately three decades to complete and will result in large volumes of radioactive, hazardous, and mixed waste requiring disposal. The focus of CERCLA cleanup since the early 1990s has been on the remediation of existing waste disposal sites and deactivation and decommissioning of excess facilities at the former K-25 site (now referred to as the East Tennessee Technology Park [ETTP]), Y-12, and Oak Ridge National Laboratory (ORNL). Timely and effective ORR cleanup is essential to facilitate reindustrialization of the ETTP site, and to ensure worker safety and the success of DOE missions at Y-12 and ORNL.

A ROD for the disposal of ORR CERCLA waste (referred to herein as the EMWMF ROD) (DOE 1999b) was prepared that authorized construction of a facility located in BCV on the ORR to provide permanent disposal for radioactive, hazardous, and mixed wastes that present unacceptable risks to human health and the environment in their current setting at ORR and associated sites. This facility, EMWMF, has been constructed and is accepting CERCLA cleanup wastes. The capacity of EMWMF is 2.2 million cy (BJC 2010).

The scope of the OREM cleanup effort has expanded since the original waste estimates were made in the EMWMF RI/FS (DOE 1998a). Extensive, new cleanup actions were identified in the Integrated Facility Disposition Program and were added to the FFA in 2009. These added cleanup actions significantly increased the volume of CERCLA waste projected to be generated. Approximately 1.6 million cy of additional CERCLA waste will be generated and will require disposal after EMWMF has reached maximum capacity.

The DOE O 435.1, *Radioactive Waste Management*, also provides regulatory context for the EMWMF. The original Disposal Authorization Statement (DAS) authorizing low-level waste disposal was issued in 1999 as the EMWMF ROD (DOE 1999b). An Operating DAS was issued in December 2018 following closure of conditions resulting from a Low-level Waste Disposal Facility Federal Review Group (LFRG) review of the design modification to add Cell 6 and increase the capacity of the EMWMF (DOE 2018b).

Much of the regulatory context for the proposed EMDF at this time is set by DOE M 435.1-1 (DOE 2011a) performance requirements. Also, regulatory requirements that could influence future iterations of the EMDF Performance Assessment and Composite Analysis may be included in future documents required for authorization of EMDF operations under the FFA, including, but not limited to, the EMDF ROD, remedial design documentation, and waste acceptance criteria (WAC) development and compliance documentation. The EMDF RI/FS (DOE 2017b) includes remedial action objectives for the disposal facility, but final FFA determination of applicable or relevant and appropriate requirements for EMDF and a general framework for WAC development will not be available until the EMDF ROD is approved. The Resource Conservation and Recovery Act of 1976 (RCRA) and the Toxic Substances Control Act of 1976 (TSCA) will be applicable to the proposed EMDF.

1.2.1 Performance Measures

This BCV Composite Analysis provides an estimate of potential future radiation dose rates to members of the public from all sources of radioactive contaminants within BCV watershed for a period up to and beyond 1000 years after site closure (assumed closure of EMWMF and EMDF and completion of required remedial actions for the other existing BCV sources). Analysis of radionuclide impacts after 1000 years also is useful to identify source and pathway sensitivities within the compliance period of 1000 years. DOE guidance on the development of composite analyses (*Disposal Authorization Statement and Tank Closure Documentation* [DOE 2017a], page 3-8) contains the following requirements:

> The composite analysis should provide reasonable expectation that public exposures will not exceed the DOE O 458.1, primary limit of 100 mrem/year (1 mSv/year) total effective dose to the representative person or maximally exposed individual, excluding contributions from radon and its decay products. Note that the primary limit excludes dose received by patients from medical sources of radiation, and by volunteers in medical research programs; dose from background radiation; and dose from occupational exposure under Nuclear Regulatory Commission or Agreement State license or to general employees regulated under 10 *CFR* Part 835, *Occupational Radiation Protection*.
>
> A composite analysis-specific administrative limit for public exposures of 30 mrem/year (0.3 mSv/year) total effective dose from DOE sources to the representative person or maximally exposed individual is also applied (excluding contributions from radon and its decay products). If doses associated with DOE sources are above the administrative dose limit, an options analysis should be prepared to consider actions that could be taken to reduce the calculated dose and to consider the cost of those actions. Furthermore, if the composite analysis dose exceeds 25 mrem/year total effective dose for DOE sources, potential interacting non-DOE sources (excluding dose from radon and its decay products, medical exposures, background radiation, and occupational exposures) that could significantly contribute to doses at a receptor also should be considered. Additionally, any other performance measures deemed pertinent to the composite analysis due to any site-specific institutional relationships, agreements, or commitments should be identified.

This Composite Analysis demonstrates that these requirements are met. Section 6 provides the interpretation of the results of this Composite Analysis.

1.2.2 Point of Assessment and Compliance Period

The confluence of NT-11 and Bear Creek (BCK 7.73) was selected as the POA in this Composite Analysis. NT-11 is a stream containing water flow most or all of the year immediately southwest of the proposed EMDF. Groundwater modeling predicts that potential radiological contamination from EMDF will enter NT-11 and flow downstream into Bear Creek. A much smaller portion of the potential radiological contamination from the proposed EMDF is also predicted to enter Bear Creek just upstream of this confluence. The EMWMF and all of the other existing BCV sources of potential radioactive contamination are upstream of this confluence. There is no location closer to the proposed EMDF in which a member of the public could receive a potential radiological dose with a combined contribution from EMDF, EMWMF, and the other existing BCV sources.

This Composite Analysis determines compliance with performance measures listed in Sect. 1.2.1 from the period of facility closure to 1000 years post-closure. Note that the performance modeling assumes that the two LLW disposal facilities are closed and remediation of the other existing BCV sources in accordance with the Phase I BCV ROD is completed. A post-1000-year maximum composite dose has also been provided in this Composite Analysis (see Sect. 5.3).

1.3 OTHER RELATED ANALYSES

The Proposed Plan for disposal of ORR CERCLA waste (DOE 1999a) summarized the information discussed in the EMWMF RI/FS (DOE 1998a) and its addendum (DOE 1998b), and proposed an onsite disposal facility on ORR that became EMWMF. The 1999 Composite Analysis for an onsite disposal facility in BCV (i.e., EMWMF) was the appendix to that Proposed Plan. The EMWMF ROD for disposal of CERCLA waste (DOE 1999b) served as the CERCLA authorization for construction and operation of EMWMF. This ROD also codified the compliance standards for EMWMF and the point of compliance for those standards.

The BCV RI and FS provide the conceptual site model for BCV; evaluations of the existing waste sources; descriptions of contaminant fate and transport, environmental contamination, and ecology within BCV; a baseline risk assessment; and development and analyses of remedial action alternatives. The Phase I BCV ROD (DOE 2000a) documents the selected remedy for remediating the existing waste disposal sites in BCV and the primary goal for the selected remedy, details the remedial actions designed to attain that goal, and updates some information reported in the RI and FS. This ROD also defines the future land use scenarios in BCV that are assumed in this Composite Analysis. The 2018 RER (DOE 2018a, Sect. 4) documents the status of the actions selected in the ROD and presents data and information used to determine the effectiveness of the remedial actions conducted in BCV.

The BCV RI (DOE 1997a) and FS (DOE 1997b), Phase I BCV ROD (DOE 2000a), 2018 RER (DOE 2018a), Focused Feasibility Study (FFS) for the Bear Creek Burial Grounds (BCBG) (DOE 2008); and the 1999 EMWMF Proposed Plan/Composite Analysis (DOE 1999a) were used to define and delineate the existing sources of potential radiological contamination in the contaminant transport model. Information from these documents included waste forms buried, contaminants and contamination levels, scope and status of any remediation, and current contributions to surface and groundwater water contamination.

Table 2. Documents summary

Document	Document number	Historical use	Primary purpose(s) in Composite Analysis (location in document)
Proposed Plan for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Waste (EMWMF Composite Analysis)	DOE/OR/01-1761&D3	Includes EMWMF Composite Analysis	Provided approval approach, approvable level of detail, and initial DQOs for an EMWMF Composite Analysis (Appendix A)
Remedial Investigation/Feasibility Study for Comprehensive Environmental Response, Compensation, and Liability Act Oak Ridge Reservation Waste Disposal Oak Ridge, Tennessee (EMDF RI/FS)	DOE/OR/01-2535&D5	Evaluated feasibility of proposed EMDF	Provided information for DOE site characteristics (Appendix E) and information on proposed EMDF (Sect. 6)
Performance Assessment for the Environmental Management Disposal Facility, Oak Ridge, Tennessee (EMDF PA)	UCOR-5094/R2	Evaluated performance of proposed EMDF under DOE O 435.1	Provided information for EMDF preliminary design (Sects. 1.2, 1.3, 1.4), regulatory context (Sect. 1.5), land use and institutional controls (Sect. 1.6), RESRAD-OFFSITE model description (Sect. 3.3.4), base case dose (Sect. 4.5), and basis for EMDF source term (Sect. 2.3)
Remedial Investigation/Feasibility Study for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, Liability Act of 1980 Waste (EMWMF RI/FS)	DOE/OR/02-1637&D2	Evaluated feasibility of EMWMF, CERCLA equivalent performance assessment for EMWMF with the addendum below	Provided performance modeling information on EMWMF (supported sensitivity analysis) (RI/FS Appendix E, Addendum Sect. 2) and conceptual design information (Sect. 7.2)
Addendum to Remedial Investigation/Feasibility Study for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, Liability Act of 1980 Waste (EMWMF RI/FS addendum)	DOE/OR/02-1637&D2/A1		
Record of Decision for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Waste (EMWMF ROD)	DOE/OR/01-1791&D3	Authorized EMWMF construction through CERCLA	Provided Composite Analysis Sect. 5.7 goal-based source term for EMWMF (pp. 2-20 and B-4, with *Attainment Plan for Risk/Toxicity-Based Waste Acceptance Criteria at the Oak Ridge Reservation, Oak Ridge, Tennessee*, DOE/OR/01-1909&D3, Sect. 1.2)

Table 2. Documents summary (cont.)

Document	Document number	Historical use	Primary purpose(s) in Composite Analysis
Record of Decision for the Phase I Activities in Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee (Phase I BCV ROD)	DOE/OR/01-1750&D4	Codified remedial actions for existing sources in BCV	Provided remedial actions required for other existing BCV sources (Table 2.8), provided information for exclusion of waste areas for analysis (p. 2-7), provided Sect. 5.7 risk-based source term for the other existing BCV sources (p. 1-7), documented regulatory acceptance of BCV conceptual hydrogeological model for contaminant flow (Fig. 2.4), and provided future land use definition in BCV (p. 2-10, Fig. 2.3)
Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee (BCV RI) *Feasibility Study for Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (BCV FS)	DOE/OR/01-1455/V1-V6&D2 DOE/OR/02-1525/V1-V2&D2	Characterized BCV and the waste areas in BCV; presented conceptual site model for BCV; presented description of contaminant fate and transport for BCV sources; developed and evaluated alternatives for remediation	Provided characterization information for the other existing BCV sources of radioactive contamination (RI Appendix A, FS Sect. 1.2), provided general description of BCV conceptual site model (FS Sect. 1.2.1.8). provided contaminant fate and transport information (RI, Vol. 4, Appendix E), provided conceptual modeling information for contaminant transport in BCV (RI Appendix C, FS Sect. 1.2.4), and provided some information on BCV for DOE site characterization (FS Sect. 1.2.1)
2018 Remediation Effectiveness Report for the U.S. Department of Energy, Oak Ridge Site, Oak Ridge, Tennessee – Data and Evaluations (2018 RER)	DOE/OR/01-2757&D2	Provided status of ORR remedial actions and results of sampling and monitoring; documented that some existing sources are releasing radioactive contamination	Provided status of Phase I BCV ROD-required remedial actions (Table F.3), provided surface water and groundwater monitoring data used in contaminant modeling (Tables 4.3, 4.5, and Fig. 4.13), supported the Composite Analysis conclusion that additional remediation was required in BCV to achieve compliance with the ROD requirements (Sect. 4.2.1, Tables 4.5 and 4.6) and provided uranium concentrations in Bear Creek used to calculate dose for other existing BCV sources of radioactive contamination (Table 4.5)

Table 2. Documents summary (cont.)

Document	Document number	Historical use	Primary purpose(s) in Composite Analysis (location in document)
Focused Feasibility Study for the Bear Creek Burial Grounds at the Y-12 National Security Complex, Oak Ridge, Tennessee (BCBG FFS)	DOE/OR/01-2382&D1	Developed and evaluated alternatives for remediation of BCBG	Used to update and detail the BCBG area in three dimensional UBCV groundwater flow model in Sect. 3.2.3 (Sect. 2)

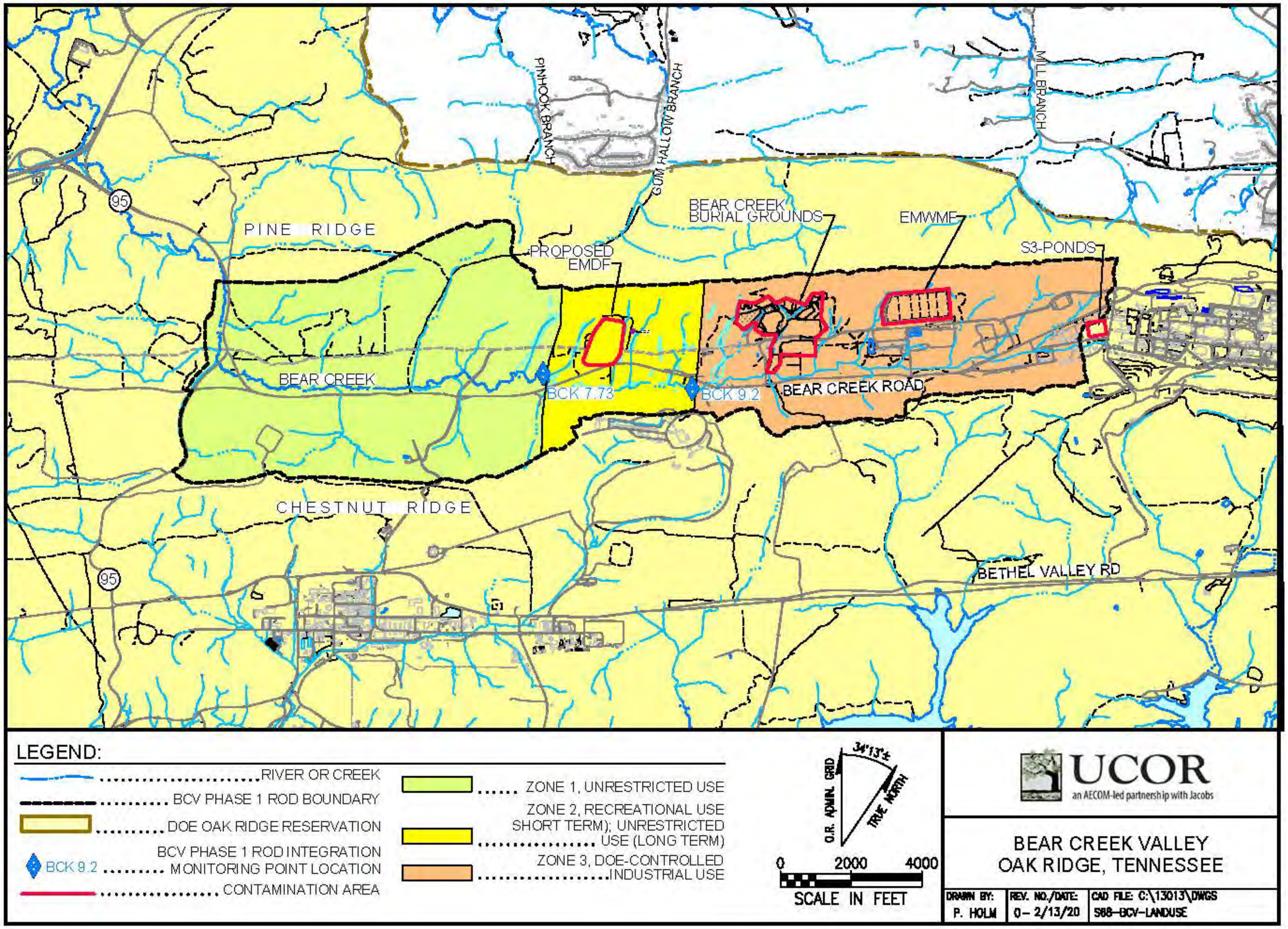
BCBG = Bear Creek Burial Grounds
BCV = Bear Creek Valley
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
DOE = U.S. Department of Energy
DOE O = DOE Order
DQO = data quality objective
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
FFS = Focused Feasibility Study
FS = Feasibility Study
ORR = Oak Ridge Reservation
PA = Performance Assessment
RER = Remediation Effectiveness Report
RESRAD = RESidual RADioactivity
RI = Remedial Investigation
ROD = Record of Decision
UBCV = Upper Bear Creek Valley

1.4 LAND USE AND INSTITUTIONAL CONTROLS

Future land uses to set cleanup levels in BCV are codified in the Phase I BCV ROD (DOE 2000a, page 2-10). BCV is divided into three zones (see Fig. 2). Zone 3, at the eastern end of the valley, is to be managed under restricted use by DOE. All of the other existing BCV sources and EMWMF are in Zone 3. Remediation in Zone 3 must reduce the migration of contamination sufficient to bring contaminants in Zone 2 (central BCV) to within acceptable levels for unrestricted use and protect Zone 1, at the lower end of the valley, for unrestricted use in perpetuity (DOE 2000a, Fig. 2.3). The RER has subsequently defined a remedial action goal for Zone 2 to protect a passive recreational user from unacceptable surface water and sediment contamination. In other words, land use that serves as the basis of cleanup levels in Zone 2 is currently defined as recreational but will eventually become unrestricted (Fig. 2). The proposed EMDF is located in Zone 2. However, the EMDF ROD will establish land use controls such as are in Zone 3.

The EMDF site is near existing DOE waste disposal facilities and mission-critical operational facilities at Y-12 and ORNL. BCV will remain under DOE control and within DOE ORR boundaries for the foreseeable future. Post-closure land use and other institutional controls are included in RODs for cleanup actions on the ORR. These controls include property record restrictions, property record notices, and access controls to limit physical access to the EMDF site. These future land use designations in the ROD are defined solely for the purpose of setting target cleanup levels and do not reflect DOE future land use plans. Additionally, DOE is required to maintain control over land containing radionuclide sources until the land can be safely released pursuant to DOE O 458.1, *Radiation Protection of the Public and the Environment* and CERCLA. The EMDF Proposed Plan (DOE 2018c) included discussion of land use controls for the BCV that would apply to the EMDF. Land use at the EMDF Central Bear Creek Valley (CBCV) site will be changed upon approval of the EMDF ROD.

This Composite Analysis assumes that a receptor can reside and farm land immediately downstream of EMDF. The POA for this Composite Analysis does not take credit for the existence of land use or other institutional controls beyond 100 years post-closure. As such, the likelihood that DOE or successor federal agencies will maintain control of a closed EMDF is considered as an aspect of defense in depth for the proposed EMDF disposal system.



Source*:* Modified from DOE 2015, Fig. 4.2

Fig. 2. Bear Creek Valley Phase I Record of Decision designated end-use and interim controls requiring long-term surveillance

1.5 SUMMARY OF KEY ASSUMPTIONS

This section presents the key assumptions, and presents the working assumptions guidance used in the Composite Analysis modeling.

1.5.1 Key Assumptions

The key assumptions used in this Composite Analysis that are of critical importance to its conclusions are as follows:

1. The contamination levels in Bear Creek following closure of the EMWMF, EMDF, and remediation sites in BCV will not exceed the values modeled. This assumption considers that the remediation goals in the Phase I BCV ROD are unchanged.
2. Hydrogeologic input parameters used for the Composite Analysis model are no less conservative than modeled. (In general, input parameters and assumptions were selected to deliberately bias projected doses to be higher than expected.)
3. The conclusions of the EMDF Performance Assessment and EMWMF Post-Closure Performance Assessment remain valid and future versions' conclusions of those performance assessments are no less conservative than those modeled in this Composite Analysis. This assumption considers that the EMDF is located at the CBCV site.

Land use is not a key assumption. As an additional conservatism, land use was modeled as unrestricted use even though the land is expected to remain under DOE institutional controls (see Sect. 1.4).

1.5.2 Additional Working Assumptions and Guidance

The following working assumptions and guidance was used for the modeling are presented below.

- This Composite Analysis prepared using the guidance provided in *2017 Disposal Authorization Statement and Tank Closure Documentation* (DOE 2017a).
- EMWMF is closed and active institutional controls are discontinued after 100 years. The engineered barriers in the cover and liner systems perform as modeled in the EMWMF RI/FS and its addendum (DOE 1998a, DOE 1998b) and EMWMF meets the compliance standards (an ELCR of 1×10^{-5} for the first 1000 years after closure and an ELCR of 1×10^{-4} after 1000 years) at the point of compliance as codified in the EMWMF ROD (DOE 1999b, pages 2-20 and B-4).
- EMDF is closed with active institutional controls discontinued after 100 years. The engineered barriers in the cover and liner systems perform as modeled in the EMDF Performance Assessment (UCOR 2020a, Appendix C).
- Remediation of BCV has been completed and contaminants begin migrating from the two closed disposal facilities (EMWMF and EMDF) at the same time.
- All exposure pathways were considered in the BCV RI and FS (DOE 1997a, DOE 1997b) and the EMDF Performance Assessment (UCOR 2020a), and groundwater and surface water were identified as the major contaminant transport media for producing exposures to the public in unrestricted areas. This is consistent with the 1999 Composite Analysis for EMWMF (DOE 1999a) and is documented in Sect. 8.1 of this Composite Analysis.
- Surface water and groundwater pathways for ingestion of contamination from the BCV sources are the only credible exposure pathways.

- Future exposures to direct radiation would be negligible because all sources of potential radiological contamination will be capped. Perpetual institutional controls and site maintenance were included in the selected remedial action alternative in the Phase I BCV ROD (DOE 2000a) and the EMWMF ROD (DOE 1999b). This would prevent long-term, unrestricted public access to the capped EMWMF and other waste sources in BCV and preserve the integrity of the caps over the waste areas.

- Airborne movement of radioactive contaminants is not expected to be a major contributor to doses to the public from disposal sites at the ORR, and significant airborne migration of contaminants from valley to valley is unlikely (UCOR 2020a, Sect. 3.2.2; DOE 1999a, pages A-7 and A-8). Therefore, a hypothetical public receptor would only be exposed to contaminants released from sources within the watershed inhabited by the receptor, or via groundwater or surface water entering the disposal facility's watershed from another, hydrologically connected watershed. Additionally, this area of the country is characterized by one of the calmest wind regimes in the country (DOE 1998a, page 3-8 and Sect. 2.3).

- The key contaminants modeled are Tc-99 and uranium isotopes, H-3, C-14, and I-129.

- The BCV RI and the Phase I BCV ROD (DOE 1997a, DOE 2000a) identified the primary radionuclide contaminants of concern as Tc-99 and uranium isotopes. The primary radionuclides of uranium are regularly monitored at BCK 9.2 to determine if surface water and groundwater complies with the uranium flux goals in the Phase I BCV ROD. These contaminants are observed in groundwater and surface water due to either high mobility (Tc-99) or significant source inventories having been disposed just above or in groundwater – attributes that are expected to persist into the future. Some source inventories and historical operations at Y-12 clearly support the inclusion of Tc-99 and uranium, where Tc-99 is a fission product impurity contained in uranium metal produced from the extraction of uranium from spent nuclear fuel. Technetium-99 is regularly monitored in Bear Creek at BCK 7.78. The monitoring results are presented in the RERs.

- Waste acceptance information was used for actual radionuclides disposed in EMWMF. This inventory confirmed that the primary radionuclides predicted to peak during the compliance period are H-3, C-14, I-129, and Tc-99. Primarily, uranium radionuclides were predicted to peak after the compliance period. Other fission product inventories are expected to be depleted through radioactive decay.

2. SITE AND FACILITY CHARACTERISTICS

2.1 PERFORMANCE ASSESSMENT FACILITIES

The two performance assessment facilities in this Composite Analysis are EMWMF and the proposed EMDF.

2.1.1 Environmental Management Waste Management Facility

EMWMF is an above-grade waste disposal facility located in East BCV (see Fig. 2). A plan view of the disposal facility and supporting facilities is presented in Fig. 3. The disposal cell is underlain by a leachate collection/detection system and a multilayer liner system designed to prevent leachate from entering the environment. The waste cell will be covered with an engineered, multilayer cap to minimize infiltration of precipitation into the waste; prevent erosion of the cover; and deter human, plant, and animal intrusion. The cell contains LLW, hazardous waste defined under RCRA, polychlorinated biphenyl (PCB) waste defined under TSCA, and mixed waste removed from contaminated sites as part of the ORR restoration activities under CERCLA. It is estimated that a volume of 2.3 million cy of waste (composed of approximately 41 percent soil and 59 percent debris) will be in EMWMF when it is closed. Most of this waste will have been generated by the demolition of facilities at ETTP. The waste disposed in the facility is constrained through the use of WAC such that risk from future combined radiological and non-radiological contaminant releases will not exceed specified limits (DOE 1999b, pages 1–5).

The EMWMF ROD limits radionuclide concentrations in waste such that a hypothetical receptor is limited to an ELCR of 1×10^{-5} for the first 1000 years after closure and an ELCR of 1×10^{-4} after 1000 years (DOE 1999b, pages 2-20 and B-4; DOE 2001b, Sect. 1.2) at the convergence of NT-5 and Bear Creek (BCK 10.5) (DOE 1998b, Fig. 4). Several re-evaluations of the performance of EMWMF have been conducted since operations began. These were performed following conceptual design when the location of the cell was adjusted to avoid the Oil Landfarm (OLF) and improve the cut-to-fill ratio during construction, during the design of cell expansions, and during the design of the underdrain to lower a rising water table beneath the cell (BJC 2003, BJC 2010, DOE 2001c, DOE 2001d, DOE 2010, DOE 2018b). These re-evaluations upheld the risk-based performance standards listed in the ROD.

The closed EMWMF is expected to occupy about 30 acres. Additional land adjacent to the disposal cell currently supports operations and will support closure. The design for EMWMF is available in the Remedial Design Report (DOE 2001c) and its addenda (DOE 2001d, DOE 2010).

2.1.2 Environmental Management Disposal Facility

The proposed EMDF also is an above-grade waste disposal facility planned to be located in CBCV between NT-10 and NT-11 (see Fig. 2). A preliminary plan view of the disposal facility and supporting facilities is presented in Fig. 4 although this is expected to change during the design process. The disposal cell will be underlain by a leachate collection/detection system and multilayer liner system designed to prevent leachate from entering the environment. The waste cell will be designed with an engineered, multilayer cap that will meet the same objectives as the EMWMF cap. The cell will contain LLW, hazardous waste defined under RCRA, PCB waste defined under TSCA, and mixed waste removed from contaminated sites as part of the ORR restoration activities under CERCLA (primarily at Y-12 and ORNL).

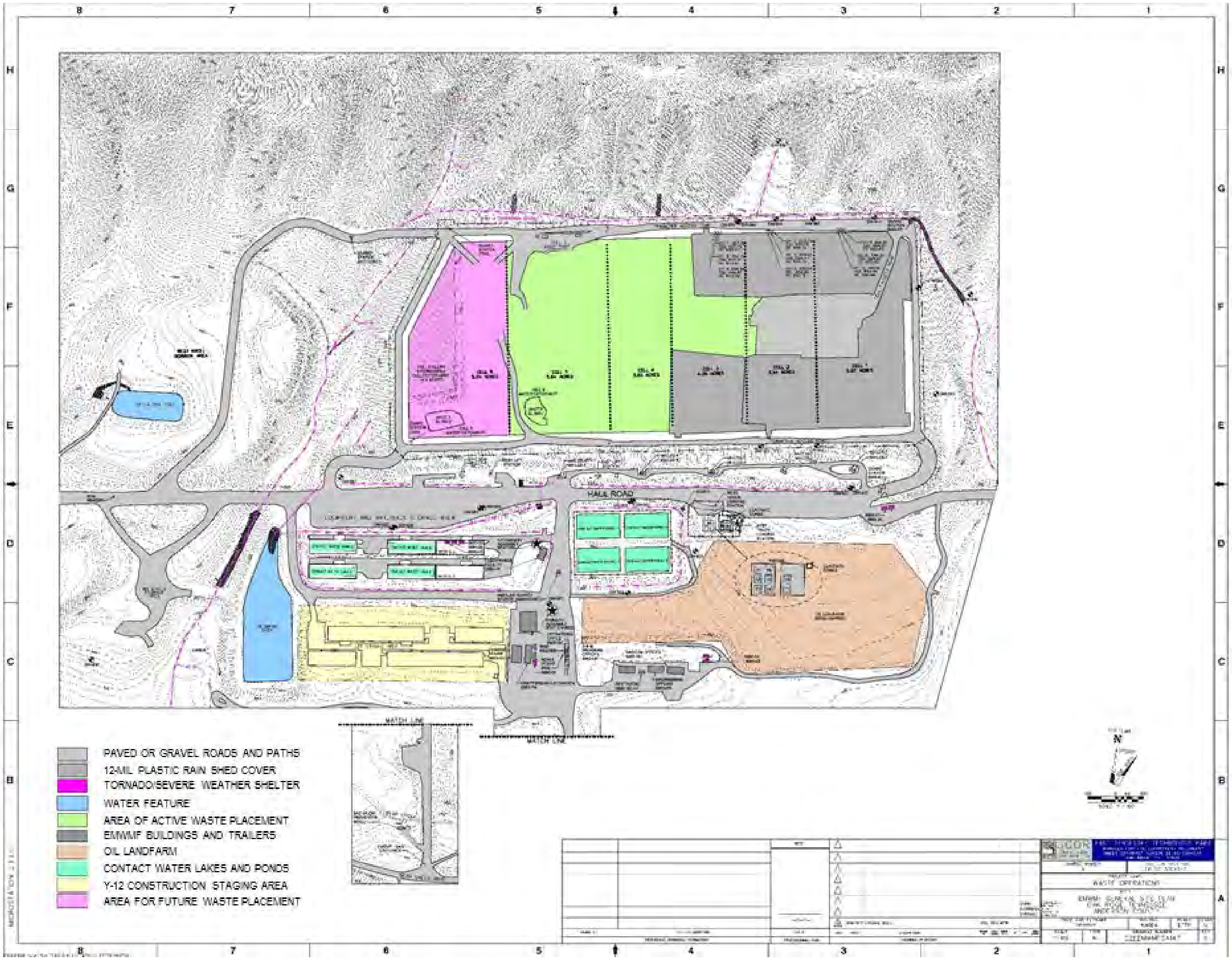


Fig. 3. EMWMF with support facilities

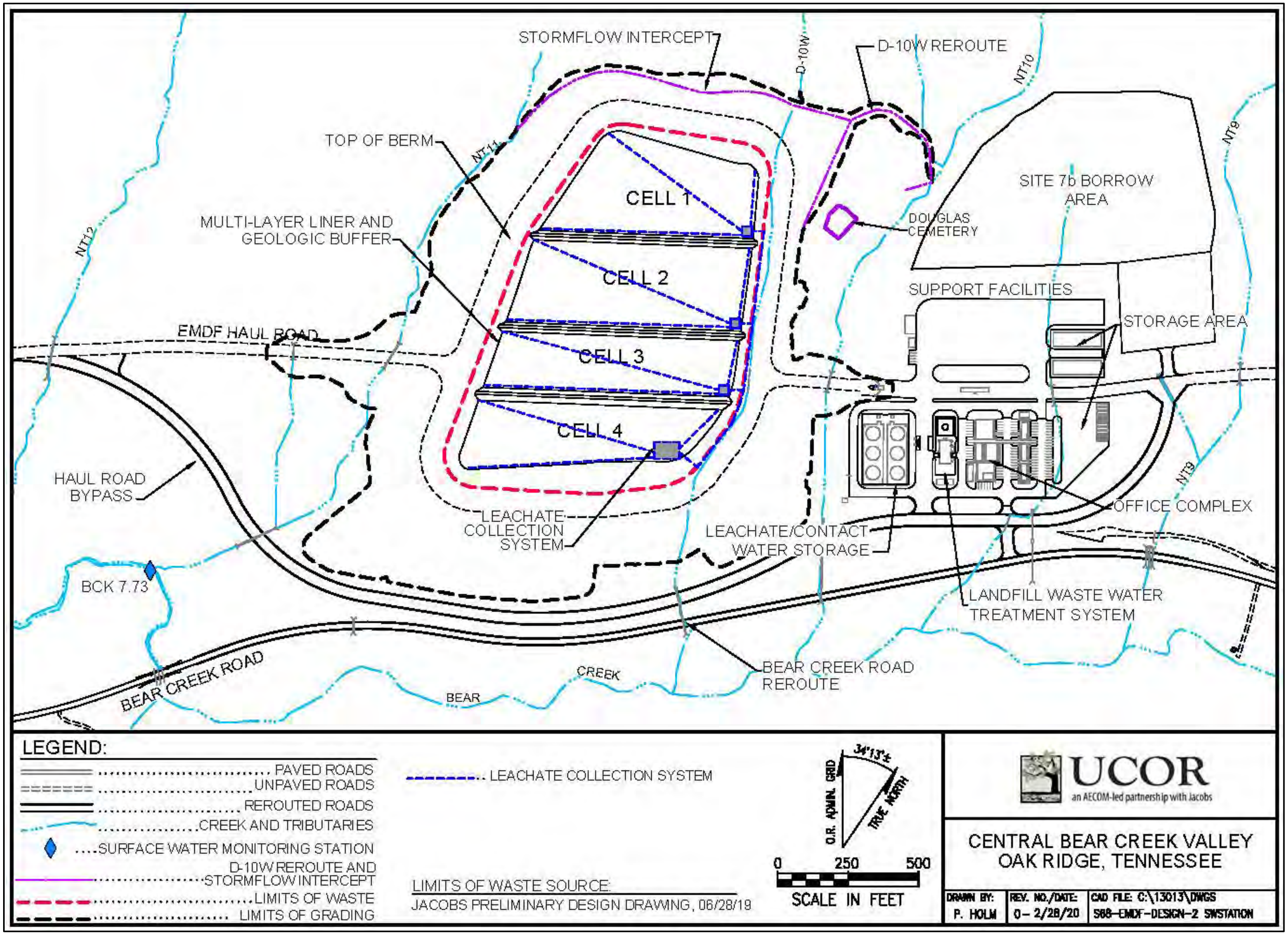


Fig. 4. Proposed layout for EMDF at CBCV site

Approximately 1.6 M cy of additional CERCLA waste is expected to be generated and require disposal after EMWMF has reached maximum capacity in the mid-2020s. The total design capacity, including a 25 percent contingency, clean fill (used to minimize voids in the waste and facilitate waste compaction), and interim covers, is 2.2 million cy (DOE 2017b, Sect. 2.2.2).

Waste disposed in the facility will be constrained similar as to what is in place for the EMWMF. An expected radiological inventory for the EMDF was assembled in Appendix B of the Performance Assessment. The UCOR waste generation forecast predicts waste streams that will be eligible for onsite disposal and waste streams that will require offsite disposal based on the EMWMF WAC. The waste was not constrained further than this in this Composite Analysis.

The facility will occupy approximately 70 acres based on the full 2.2-million-cy capacity. Some land adjacent to the disposal cell will be needed during construction, operation, and closure. A total operating time of about 20 years is anticipated (DOE 2017b, Sect. 7.2.2.5). No long-term interim storage of waste is anticipated. The closed EMDF is expected to occupy about 48 acres. Additional details on the preliminary EMDF design are available in the EMDF Performance Assessment (UCOR 2020a, Sects. 1.2, 1.3, 1.4).

2.2 DOE SITE OPERATIONAL DESCRIPTION, HISTORY, AND FUTURE

Additional end state sources with potential or existing residual radioactivity are identified in this section. Information also is presented to justify that all end state radionuclide sources that could potentially interact with radionuclide migration from EMWMF and the proposed EMDF at the POA during the compliance period, and significantly affect the projected dose relative to the performance measures, are appropriately considered in this Composite Analysis. Information is presented in this section on whether or not there are non-DOE sources (e.g., commercial nuclear facilities) that may result in radionuclide migration in the environment on the ORR.

Sources of potential or existing residual radioactivity in BCV have been identified for this Composite Analysis. The identification and documentation were accomplished using the CERCLA process. The BCV RI and FS (DOE 1997a, DOE 1997b) provide evaluations of the existing waste sources in BCV. That information is summarized in Sect. 2.3. The residual risk from the other existing BCV sources is limited to an ELCR of 1×10^{-5} at an Integration Point (BCK 9.2) by an approved ROD under CERCLA (DOE 200a). As noted in Sect. 2.5, the selection of this codified risk at the Integration Point is independent of the specific sources of potential radioactive contamination in BCV (i.e., the identification of an additional existing source of contamination in BCV would not change the commitment in the ROD [or the basis for the source term for the other existing BCV sources in this Composite Analysis]). That ROD also defines the assumed future land uses in BCV (see Fig. 2). These CERCLA documents were reviewed and approved by the FFA parties.

The remedial actions and agreements codified in these RODs are subjected to regulatory reviews every 5 years and any revisions to these RODs will require approval by the FFA parties.

All of the land in BCV east of Tennessee State Route (SR) 95 is currently owed by DOE and is completely surrounded by DOE-owned property (see Fig. 1). There are no adjacent commercial nuclear operations that will contribute to the cumulative impact at the POA for this Composite Analysis. There are several commercial nuclear facilities (such as Energy*Solutions*) on Bear Creek Road west of Tennessee SR 95. These facilities are located in another watershed that drains southwest, directly to the Clinch River, rather than to Bear Creek (DOE 2014, Fig. B-2) and therefore are not included in this Composite Analysis.

2.3 DOE SITE CHARACTERISTICS

The ORR occupies 33,542 acres in Anderson and Roane counties (Fig. 1) and is located within the Great Valley of Tennessee within the Valley and Ridge physiographic province. This area is characterized by steep-sided parallel ridges, oriented northeast-southwest, with broad intervening valleys.

The land on the ORR is used for multiple purposes to meet DOE's mission goals and objectives. Approximately one-third of the land (11,300 acres) is intensively developed as ETTP, ORNL, and Y-12.

2.3.1 Geography of the ORR

The ORR area is characterized by long linear northeast-southwest stream valleys between roughly parallel ridges. These define essentially isolated hydrologic systems (watersheds) with little exchange of water from one watershed to another.

The geographical boundary for this Composite Analysis is the BCV watershed, the location of EMWMF and the proposed location for EMDF. The BCV watershed delineation of ORR and the locations of EMWMF and the proposed EMDF are shown on Fig. 1. The figure also shows a groundwater/surface water divide in BCV west of Y-12. This divide separates the BCV watershed from the Upper East Fork Poplar Creek (UEFPC) watershed, which drains most of Y-12. Because EMWMF and the proposed EMDF locations are west of this divide, this Composite Analysis only considers hypothetical members of the public who could potentially reside in the Bear Creek watershed (no residents currently) or the downstream-connected Poplar Creek watershed and who receive potential doses from contaminated water flowing west of the groundwater divide.

BCV is approximately 10 miles long and trends northeast to southwest along the center of ORR. BCV is bordered by Pine Ridge on the northwest and Chestnut Ridge on the southeast. The width of the valley between these ridges varies between approximately 1980 ft in the vicinity of the S-3 Ponds to 2573 ft in the vicinity of BCBG (see Fig. 2). The average northeast to southwest gradient of the valley is 30 ft/mile. Topographic relief from the crest of Pine Ridge to the floor of BCV ranges from 260 to 300 ft; relief from the crest of Chestnut Ridge to the floor of BCV ranges from 280 to 400 ft (DOE 1997a).

The groundwater divide in the vicinity of the S-3 Ponds at the west end of Y-12 delineates the east end of the Bear Creek watershed (Fig. 2). Bear Creek originates near this groundwater divide and flows roughly westward through the valley. It turns northward through a gap in Pine Ridge just west of SR 95 and flows into EFPC about 0.6 mile north of the intersection of SR 95 and SR 58 (see Fig. 1 and DOE 1997a).

2.3.2 Land Use and Demography

The ORR has restricted access. Outside and adjacent to the ORR, land use is predominately rural (with agricultural and forest land dominating) and urban (mainly represented by the city of Oak Ridge). The residential areas of the city of Oak Ridge that abut ORR are primarily along the northern and eastern boundaries of the reservation, with some Roane county residents having homes adjacent to the western boundary of ORR. The Clinch River forms a boundary between Knox County, Loudon County, and portions of Roane County (DOE 2017b).

Oak Ridge has a population of approximately 29,330. In addition, several small towns (with a total population of 31,000) are within 10 miles of the ORR. Knoxville, located approximately 18 miles southeast of ORR, is the largest municipality, with a population exceeding 300,000 (DOE 2017b, DOE 1997a). The nearest Oak Ridge communities include Country Club Estates (0.8 mile away on the north side of Pine Ridge) and the historic Scarboro community as well as isolated homes located across the more rural intervening area. Pine Ridge separates these residential areas from Y-12 and BCV. Neither of these is in the BCV watershed (DOE 2017b). Additional detailed information on the demography and use of adjacent lands can be found in the EMDF Performance Assessment (UCOR 2020a, Sects. 2.1.1.2 and 2.1.1.3).

2.3.3 Ecology

Ecological surveys were completed for the EMWMF and the CBCV site. Results are documented in the EMDF RI/FS (DOE 2017b) and in reports generated since the RI/FS, including the *Natural Resource Assessment for the Proposed Environmental Management Disposal Facility (EMDF), Oak Ridge, Tennessee* (ORNL 2018). Wetlands have been delineated for both sites. The EMWMF is a developed site dominated by the waste disposal cells, Haul Road and the support facilities.

The CBCV site is characterized as a nearly completely closed canopy forest. The upland area between NT-11 and D-10W is an established mature forest dominated by white oak, chestnut oak, and various hickories with some yellow-poplar occupying the slopes. This upland area appears as mature forest in 1942 aerial photography. The bottomland forest is composed of yellow-poplar, sweetgum, red maple, and beech regeneration. The upper watershed of D-10W features this mix, but as residual species following the loss of the dominant yellow pine component due to southern pine beetles circa 2001 (heavy residual dead and down debris is apparent). This area, along with the bottoms of both aforementioned streams and the saddle between them, and the lowermost portions of the upland area, were maintained as open field per the 1942 aerial photography, and clearly now hosts a comparatively younger forest.

Several trees (mainly white oaks) were identified as potential roosting trees for the federally listed Indiana bat (endangered) and/or northern long-eared bat (threatened) (ORNL 2018). Bird species include red-shouldered hawk, white-breasted nuthatch, and yellow-bellied sapsucker (sign). A barred owl was noted north of the site. Chorus frogs were noted calling from a wetland along the haul road on the southern boundary of the site (Giffen 2017).

2.3.4 Geology and Soils

The geology of BCV is summarized from information presented in the BCV FS (DOE 1997b) and the EMDF RI/FS (DOE 2017b). The stratigraphic section exposed in BCV includes rocks ranging in age from Early Cambrian to Early Mississippian. The three rock sequences in the BCV (Rome Formation, Conasauga Group, and Knox Group) comprise a complex stratigraphic assemblage of shales, limestones, dolomites, siltstones, and sandstones.

The early Cambrian Rome Formation, which is the oldest unit exposed in the site area, outcrops on the ridge top of Pine Ridge and dips to the southeast beneath BCV. The Rome Formation consists of variegated shale, interbedded with siltstone, sandstone, and minor amounts of dolomite. Overlying the Rome Formation, and underlying the southern slope of Pine Ridge, is the middle- to late-Cambrian Conasauga Group, a sequence of primarily shales with some interbedded limestones and dolomites. Within the BCV, the Conasauga Group is subdivided into six formations: Pumpkin Valley, Rutledge, Rogersville, Maryville, Nolichucky, and Maynardville (DOE 1997a). The Maynardville Limestone, composed mostly of limestone, underlies the valley floor. The Knox Group of late-Cambrian is composed primarily of massive, siliceous dolomite that forms the Chestnut Ridge on the south side of BCV.

Small-scale geologic features, such as fractures and solution features, are a major factor in groundwater movement through the formations underlying BCV (see Sects. 2.4.4.1 and 3.2). These bedrock features provide pathways for groundwater flow through geologic formations such as shales and limestones, which typically have little intrinsic permeability. Fractures are well developed in all stratigraphic units as a result of tectonic activity and geostatic relief and are the most pervasive groundwater-transmitting feature on ORR

(ORNL 1992a). The most prominent and well-developed fracture sets are oriented parallel to geologic strike and result in hydraulic and dominant strike-parallel groundwater flow paths. Fracture aperture width and frequency generally decrease with depth in all formations and thus restrict the depth of active groundwater circulation.

The geologic units in BCV display an inclined stratigraphy, with a dip angle of 35 to 50 degrees in the southeastern direction. The stratigraphy of this valley creates an anisotropy of permeability and hydraulic conductivity that, especially in the predominantly clastic formations, exerts a strong influence on groundwater flow directions. In general, the rock units can be grouped into low-permeability clastic formations and higher-permeability carbonate formations (DOE 1997b, DOE 2017b).

Bedrock on the ORR is overlain by unconsolidated material that consists of weathered bedrock (or residuum), man-made fill, alluvium, and colluvium. Residuum comprises most of the unconsolidated material in this area. The depths to unweathered bedrock differ throughout BCV because of the different thicknesses of unconsolidated materials and the particular weathering characteristics of the bedrock units. The total thickness of these materials typically ranges from 10 to 50 ft (DOE 1997b, DOE 2017b).

2.3.5 Seismology and Volcanology

There is no evidence of active, seismically capable faults in the Valley and Ridge physiographic province or within the rocks under the ORR. The nearest capable faults are approximately 300 miles west-northwest of ORR in the New Madrid Seismic Zone. Historical earthquakes occurring in the Valley and Ridge are not attributable to fault structures in underlying sedimentary rocks, but rather at depth in basement rock. ORR lies within the East Tennessee Seismic Zone, a seismically active area roughly halfway between the New Madrid Seismic Zone and the Charleston, South Carolina Seismic Zone. Historic earthquakes in the East Tennessee Seismic Zone typically are of small magnitude and go unfelt to people. The largest recent seismic event was a moment magnitude 4.7 event earthquake in 1973 that had an epicenter near Alcoa, Tennessee, 21.6 miles southeast of Oak Ridge. The intensity of this earthquake felt in Oak Ridge was estimated to be light (UCOR 2020a, Sect. 2.1.3.6).

Field evidence of earthquake-related features, such as fracturing, co-seismic faulting, and liquefaction, suggests that earthquakes with magnitudes exceeding 6.5 have occurred in the region within the late Quaternary Period, possibly as late as 73,000 to 100,000 years ago (UCOR 2020a, Sect. 2.1.3.6).

Active volcanoes, lava flows, and other features of geologically recent volcanic activity do not occur in the southeastern United States anywhere near BCV. Based on current plate tectonic theory and the great distance of the site from any hot spots or plate subduction zones, volcanic activity would not be expected to occur within any future timeframes of concern relevant to this Composite Analysis (UCOR 2020a, Sect. 2.1.3.7).

2.3.6 Meteorology and Climatology

The climate of the region surrounding Oak Ridge is broadly classified as humid subtropical. The annual mean air temperature is 58.5°F, with the 30-year maximum daily temperatures ranging from 46.9°F in January to 88.5°F in July. The 30-year minimum daily temperatures range from 28°F in January to 67.5°F in July (DOE 2017b).

The annual average precipitation is 52.6 in., including about 10.4 in. of snowfall. Precipitation in the region is greatest in the winter and spring months (January to April) and least during the fall months (September to November) when high-pressure systems are most frequent (DOE 2017b, DOE 1997b).

The local ridge-and-valley terrain reduces average wind speeds within the valleys, resulting in frequent calm or near calm conditions. As measured at ORNL Tower C/D (MT2), the average wind speed in 2017 was 2.2 mph (DOE 2018d).

2.3.7 Hydrology

Annually, approximately 60 percent of precipitation in BCV exits the valley through evapotranspiration. Evapotranspiration is less pronounced during winter and early spring when the water demand from plants is low. Consequently, base flow in surface streams peaks during the winter. During the plant growing season, a high proportion of precipitation exits the hydrologic system through evapotranspiration, and flow in surface streams is reduced, with streams sometimes drying completely (DOE 1997b).

Within BCV, the majority of groundwater flow occurs primarily within the upper 100 ft of the aquifer system (ORNL 1992b). The occurrence and movement of groundwater in the bedrock is closely related to the presence of bedding planes, joints, fractures, and solution cavities. In general, groundwater in the bedrock occurs under water-table conditions, but becomes increasingly confined with depth. Downward recharge to the groundwater system occurs along the flanks of Pine Ridge and Chestnut Ridge.

The hydrogeologic units of BCV behave as a hydraulically anisotropic system, evidenced by the elongated drawdown along strike direction observed during pumping tests and the spatial distribution of contaminant plumes. The anisotropic nature of hydraulic conductivity associated with the bedrock underlying BCV is apparently caused by the orientation and intersection of fractures, joints, and/or bedding planes. Due to this anisotropy, groundwater flow is primarily along strike (i.e., northeast to southwest). Due to the along-strike flow directions, a large portion of the shallow groundwater discharges into the tributaries and eventually flows into Bear Creek.

Surface Water. The city of Oak Ridge relies on surface water for its municipal water supply, but the intakes on Melton Hill Lake are miles upstream of the surface water exiting Bear Creek, which ultimately drains into EFPC and the Clinch River several miles downstream of Melton Hill Dam (DOE 2017b).

Tributaries and major springs in the watershed are numbered consecutively from the headwaters of Bear Creek. Tributaries and springs near existing sources and the proposed locations of EMWMF and the proposed EMDF include NT-3 through NT-11 and Surface Spring (SS)-1 through SS-5.

Surface water plays the major role in the hydrogeology of BCV. Bear Creek displays losing and gaining reaches where groundwater is recharged and discharged to the surface, respectively. Major gaining reaches along strike are associated with large springs in the Bear Creek floodplain, which may be sites of upwelling groundwater from deep flow paths in the Maynardville Limestone. The locations of these springs may be controlled by large-scale geologic structures, such as across-strike faults or thinning of the Maynardville Limestone from facies change or faulting (DOE 1997b). Because of the karst conduit system in bedrock underlying Bear Creek, stream flow disappears along stretches of the channel between NT-3 and NT-8 during low flow periods. Downstream from NT-8 and BCK 9.47, flow in the Bear Creek channel is gaining and perennial, even in low flow periods. A comparison of long-term monitoring data collected at locations BCK 9.2 and BCK 11.54 (two points upstream of BCK 7.73) between January 2003 and December 2014 indicate the continuous flow and gaining nature of the stream (flow in Bear Creek is not measured at BCK 7.73). Flow at the downstream location (BCK 9.2) is continuous and much greater (typically four to five times greater) than flow at the upstream location indicating a gaining stream.

Note that there are depictions of Bear Creek in some publications, such as Fig. 4.1 in several of the RERs (DOE 2018a), which can be misinterpreted to conclude that significant portions of it and some of its tributaries are dry a significant portion of the year. A conversation with the originator of the figure in the RERs revealed the blue lines representing the streams should have been continuous and the figure was not intended to represent the nature (gaining/losing sections) or show the segments of streams that periodically contain no water flow.

As seen in Fig. 2, the surface water system in BCV comprises Bear Creek and its tributaries. Headwaters of Bear Creek are at the west end of Y-12 near the S-3 Ponds. Creek flow is supplemented by small tributaries originating on the southern slope of Pine Ridge and by springs emanating mainly from the base of Chestnut Ridge. The tributaries convey storm flow and shallow groundwater that has discharged to the surface. The drainage area of the Bear Creek watershed covers 7.1 square miles (DOE 1997b).

In its upper reaches, Bear Creek follows a relatively straight course along strike that lies close to the contact between the Maynardville Limestone and Nolichucky Shale. The original channel on the west side of the S-3 Ponds was filled with rubble during pond construction and rerouted to its present location. Approximately 4.5 miles downstream of its headwaters, Bear Creek turns northward through a gap in Pine Ridge and empties into EFPC approximately 6 miles upstream of the Clinch River.

The conceptual hydrologic model described in the BCV FS shows that although groundwater is the principal pathway for contaminants leaving the waste units, the largest mass of water (and the largest mass of contaminants) exits the valley via surface water. 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. The BCV FS also estimated that 97 percent of water available for leaching contaminants (precipitation minus evapotranspiration) exited the upper section of the valley as surface water flow (the BCV FS estimated that Bear Creek flow at BCK 9.47 is comprised of 81 percent surface water from the upper section of BCV and 16 percent groundwater discharged to surface water at SS-5). In addition, of water available for flow in the predominantly clastic formations outcropping on Pine Ridge, 94 percent exited these formations via surface water in tributaries and 6 percent exited via subsurface flow (note that this is not water loss from Bear Creek to the underlying Maynardville Limestone). Slightly less than 3 percent of the total water is estimated to continue along strike as groundwater in the Maynardville Limestone. Hydraulic monitoring data show that overland flow and soil interflow are only important during storm events and that recharge followed by groundwater flow to tributaries constitutes the main water flux pathway (DOE 1997b, Sect. 1.2.1.8). More than 99 percent of the available water from the upper portion of the valley passes through the BCK 9.47/SS-5 location as either surface water or groundwater (DOE 1997a, Sect. C.4.1).

Groundwater. The location of BCV on DOE property and DOE property ownership and controls for areas downgradient of EMDF preclude any domestic use of groundwater in the foreseeable future. There are no water supply wells in BCV anywhere near the current downgradient margins of contaminant plumes originating from sources in BCV. Groundwater flow at and downgradient of the EMDF site is constrained within the groundwater divides below Pine Ridge and Chestnut Ridge (DOE 2017b).

Depth to groundwater in BCV varies spatially and temporally. The water table is generally configured as a subdued replica of the surface topography, with higher elevations beneath hills and lower elevations in the valley bottoms. In general, water table elevations are lowest from October to December and highest from January to March.

The primary permeability of the rocks underlying BCV is generally very low. However, diagenesis, fracturing, and solution weathering of bedrock have resulted in secondary porosity and increased permeability through which most fluid movement occurs. The formations are extensively fractured and, in the case of carbonate formations, karstified, thereby enhancing their permeability. Cavity systems in the Maynardville Limestone 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 (DOE 1997b).

The orientations of well-connected fractures or solution conduits are predominantly along strike and enhance the effect of anisotropy caused by layering, resulting in dominance of a long-strike (down-valley) groundwater flow paths. Fracture aperture width generally decreases with depth in all formations, which restricts the depth of active groundwater circulation hydrology. Active (or open) fractures occur at greater depths in the carbonate-dominated Knox Group and Maynardville Limestone than in the clastic-rich members of the Conasauga Group, and active groundwater circulation is deeper in these formations.

The surface water and groundwater regime is well-defined for the upper BCV (upstream of BCK 9.2). There is no reason to expect the regime to change in the 1.74 km between BCK 7.73 at the EMDF and BCK 9.2 because this area of BCV has the same characteristics as upper BCV in terms of geologic units (it is along geologic strike), weathering characteristics (the climate is identical), topography, vegetation, and surface water features.

Water Quality. Water quality in Bear Creek and its tributaries has been studied extensively. Each of the documents in Sect. 1.3 contains information on water quality in Bear Creek or sections of Bear Creek. Water quality in East Bear Creek is affected by waste disposal facilities, construction, and the Y-12 site, which are locations upstream of the proposed EMDF site or in proximity to EMWMF. Many of these disposal facilities, including the S-3 Ponds, the former Boneyard/Burnyard (BYBY), the OLF, and BCBG, have contributed to the contamination of groundwater and surface water. These facilities were or are located in the Nolichucky Shale where most of the groundwater flow is shallow (less than 50 ft). Flow is primarily along strike and discharge is to tributaries of Bear Creek after short flow paths (DOE 1997a; DOE 1998a, Appendix D, Sect. 1.2).

The surface water in Bear Creek downstream of the S-3 Ponds exhibits concentrations of nitrate, cadmium, uranium, and Tc-99 above background levels, with shallow groundwater discharging into NT-1 and NT-2 as the primary source. Surface water downstream of BCBG show levels of beryllium, organic contaminants, and uranium isotopes above background where groundwater discharges into NT-7 and NT-8 (DOE 1997a, DOE 1998a, DOE 2017b). It is noted that U-234 and U-238 are at concentrations above the goal established in the Phase I BCV ROD. Groundwater in the BCBG area contains nitrates and uranium at concentrations less than surface water concentrations and, with the exception of U-238, are below the goals established in the Phase I BCV ROD. It also is noted that levels of contaminants entering NT-3 from the former BYBY have been reduced since that area was remediated in the early 2000s (DOE 2018a, Tables 4.5, 4.6, and Fig. 4.13).

2.3.8 Natural Resources

No geological resources (e.g., ores, fossil fuel sources, industrial mineral deposits, geothermal resources, etc.) are known to be present at or near the EMDF site that would affect the performance of the proposed disposal facility. The Maynardville Limestone is a source of limestone aggregate in the local area and is mined from an open face quarry located about 5 miles northeast of and along geologic strike with EMDF. However, DOE property controls preclude any use of the Maynardville near EMDF in the foreseeable future, and other local outcrop areas ensure the availability of ample source locations elsewhere over the long term. Additionally, no economically valuable natural resource exploitation is expected for BCV (UCOR 2020a, Sects. 2.1.8 and 2.1.9).

2.3.9 Natural Background and Anthropogenic Sources of Radiation

BCV has been impacted by activities on the ORR, including activities at Y-12 at the headwaters of Bear Creek. The primary sources of radioactivity in this area are described in the Phase I BCV ROD (DOE 2000a, Table 2.18) west of the groundwater divide as follows:

- S-3 Ponds (S-3 Site)
- OLF
- BYBY
- Sanitary Landfill 1 (SL-1)
- BCBG
- Miscellaneous disposal sites.

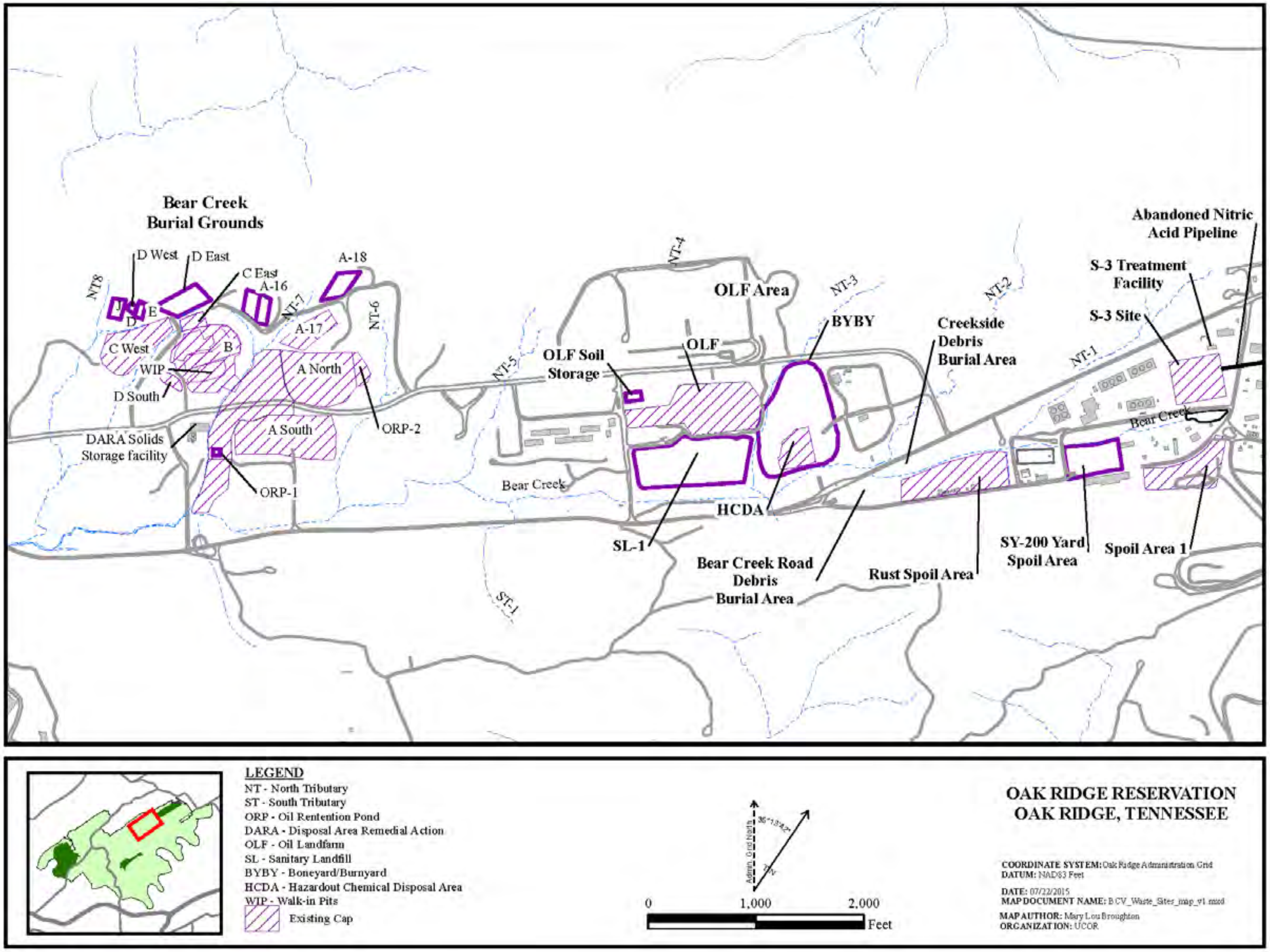
These sources originated from disposal of radioactive waste from operations at Y-12. The disposal sites were in use during the Manhattan Project, beginning in the 1940s, and were all closed by the mid-1990s. It is noted that many of these sites are potential sources of chemical contamination. However, the evaluation of chemical contamination is not in the scope of this Composite Analysis.

The locations of these sites are shown on Fig. 5. Extensive details concerning the history of these sites, their current status, and the alternatives for reducing contaminant releases from existing potential sources can be found in the BCV RI (DOE 1997a) and BCV FS (DOE 1997b). Information from these documents is summarized below and is analyzed relative to development of a source term for the other existing BCV sources in this section.

2.3.9.1 S-3 Site

The S-3 Site source area consists of four previously unlined ponds located adjacent to the west end of the Y-12 site. These ponds were used for industrial waste treatment and were filled and capped during closure in 1988. Constructed in 1951, these impoundments were approximately 400 ft × 400 ft and were part of the former S-3 Waste Management Area (see Fig. 5). The original pond excavations penetrated residual soil and fill materials, but based on the depth of bedrock in wells surrounding the site, did not extend down to the bedrock. While in operation, the ponds were approximately 17 ft deep and had a storage capacity of 2.5 million gal each (DOE 1997b, page 1-20).

There are no accurate records of the types and amounts of waste disposed of in the S-3 Ponds. However, three different waste types from four different sources are known to have been disposed there: (1) liquid wastes generated by Y-12 site operations and other facilities, (2) operational sludges generated from the treatment of acid raffinate (a mixture of 20 percent aluminum nitrate in 1 to 4 percent nitric acid aqueous solution), (3) contaminated sediments from two lagoons in upper Bear Creek (also known as the Blue Lagoons), and (4) sludges generated by remediation activities entailing in situ neutralization and biodenitrification of the pond waters. In addition, uranyl nitrate solutions containing small amounts of plutonium were discharged into the ponds. Depleted uranium in nitric acid solutions and technetium contained in raffinate and condensate also were released into the ponds. A now-abandoned nitric acid pipeline also transported Y-12 site nitric acid to the ponds, along with some liquid wastes that originated from sources outside the Y-12 site, including raffinate from the Savannah River Site and the Idaho National Engineering and Environmental Laboratory and waste streams from ETTP and ORNL. Influent discharge rates varied throughout the period of operation, but the amount of waste was significantly reduced when a nitric acid recovery system became operational in 1976 (although volumes of liquid disposal remained approximately the same because floor cleaning solutions [e.g., mop waters] were then discharged). In 1983, the annual quantity of liquid waste entering the ponds was approximately 2.7 million gal. Liquid waste discharges into the ponds were terminated in 1983 (DOE 1997b, page 1-21).



Source*:* DOE 1999a Fig. A.2 and DOE 2000a Fig. 2.2

Fig. 5. Existing sources of potential contamination in Bear Creek Valley

In situ treatment of wastewater in the S-3 Ponds consisted of neutralization and in situ biodenitrification processes that began in 1983 and continued until September 1984. After biodenitrification, the ponds' contents were allowed to settle and form a sludge layer ranging from 2 to 5 ft thick. The supernatant was pumped to the S-3 Ponds Treatment Facility for removal of trace metals and organics. Treated effluent was discharged to UEFPC in accordance with a National Pollutant Discharge Elimination System permit. The S-3 Site, which contained concentrated waste sludge, was closed under RCRA in 1988 by neutralizing sediment within the ponds, stabilizing the ponds with aggregate, and installing a multilayer cap covered with asphalt to create a parking lot (DOE 1997b, page 1-21; DOE 2014, page B-37).

2.3.9.2 Oil Landfarm

OLF is approximately 1.5 miles west of the Y-12 site, north of SL-1 and Bear Creek Road (see Fig. 5). OLF consists of a former land farming plot used for biodegradation of industrial waste oil and machine coolants between 1973 and 1982. Wastes disposed at OLF included waste oils, beryllium-contaminated soils, coolants, mop waters, tanker oils from ETTP, wastes from cooling towers and the Oil Retention Ponds (ORPs) at the BCBG, and unidentified miscellaneous liquid wastes. The oils and coolants applied at OLF were contaminated with beryllium compounds, depleted uranium, PCBs, tetrachloroethene (PCE), and 1,1,1-trichloroethane. Because operating instructions called for different types of oils to be applied to different plots, the composition and volume of liquid waste applied varied from plot to plot (DOE 1997b, page 1-22).

Land farming activities at OLF, in which approximately 1 million gal of liquid wastes were disposed, ended in 1982. Before OLF was closed in 1990 by covering with a multilayer RCRA cap, soil with PCBs > 25 ppm was excavated and placed in the OLF Soil Storage Facility (DOE 1997b, page 1-22). This waste was subsequently disposed at Envirocare of Utah (now Energy*Solutions)* (DOE 2001e, page ix).

2.3.9.3 Boneyard/Burnyard

BYBY, located west of the S-3 Ponds and adjacent to OLF, consists of three sites: the Boneyard, the Burnyard, and the Hazardous Chemicals Disposal Area (HCDA), built over part of BYBY (see Fig. 5). BYBY was one of the first areas established in BCV for the disposal of wastes generated at the Y-12 site.

The Boneyard, a series of unlined earthen trenches located east of OLF, was an active waste disposal site from 1943 to 1970. Wastes were characterized by properties ranging from ignitable and radioactive to inert, including organics, metals, debris, acids, and beryllium. The total quantity of material disposed is unknown. Magnesium chips were disposed of in the southwest corner of BYBY by placing them in burn pans in unlined earthen trenches and using ignitable solvents to initiate burning. The residue remaining in the trenches was covered with soil and compacted until the trenches were filled. The trenches were then covered with topsoil and seeded with grass. The remaining land in BYBY was used to dispose construction spoil material, such as concrete and rebar. Observations made during field activities indicated the presence of contaminated debris at the surface (DOE 1997b, pages 1-22 and 1-23).

The Burnyard consisted of two trenches approximately 300 ft long and 40 ft wide. It functioned as an active waste site from 1943 to 1968. The site received approximately 350 cy/month (4000 cy/year) of sanitary waste from site operations, including solids, liquids, and sludges. Waste materials may have included empty pesticide containers, metal shavings, solvents, oils, and laboratory chemicals. Wastes were placed in unlined earthen trenches and burned. Oils and other flammable liquids, possibly transformer oils containing PCBs, were used to start and sustain combustion. When filled, the trenches were covered with soil. Other than burning, no collection or treatment systems were used onsite (DOE 1997b, page 1-23).

HCDA received solid, liquid, and gaseous waste materials from 1975 to 1981. According to estimates, the site received less than 5 cy of waste annually. The material was broadly characterized as ignitable, reactive, corrosive, toxic, highly flammable, or, in some instances, inert. Generally, HCDA received wastes that posed safety hazards within the Y-12 site. The material consisted of gas cylinders with leaking or damaged valves and laboratory chemicals considered to be reactive or explosive. The laboratory chemicals included acids, bases, organics, water-reactive compounds, and explosive compounds such as picric acid, benzoyl peroxide, and ether. Bottles of chemicals were broken under water spray in a concrete vessel that was open to the atmosphere. After the explosion or chemical reaction, the effluent was discharged into a small, unlined surface impoundment and allowed to percolate through the soil. The chemical residue remaining in the concrete vessel was removed periodically and transported to BCBG. In 1989, a RCRA-type multilayer cap was installed over all of HCDA, including the contaminated soil (DOE 1997b, page 1-23).

In 2002, visual contamination was removed from the BYBY area. Residual soils were pushed into the Unit 6 landfill and covered with soil.

2.3.9.4 Sanitary Landfill 1

SL-1 is approximately 0.8 mile west of the Y-12 site, just north of Bear Creek and immediately south of OLF (see Fig. 5). It was used between 1968 and 1980 for the disposal of combustible and decomposable solid wastes. The landfill received materials such as paper and cardboard, plastics, rubber, wood, brush, animal bedding, organic garbage, textile products, and asphalt roofing materials. Although administrative controls were used to exclude the disposal of toxic chemicals and other contaminated materials, it is possible that some of these materials were disposed of in the landfill (DOE 1997b, page 1-23).

Trenches at SL-1 were excavated to depths of approximately 20 ft and were backfilled to approximately 15 ft above grade. Approximately 105,000 cy of refuse were disposed at the landfill. In 1985, the landfill was closed by grading to promote drainage, capping with 2 ft of clay and topsoil, and establishing a vegetative cover (DOE 1997b, page 1-23).

2.3.9.5 Bear Creek Burial Grounds

BCBG is approximately 2 miles west of the Y-12 site at the western border of the BVC waste storage area (see Fig. 5). BCBG operated from approximately 1955 to 1993. Its primary purpose was the disposal of uranium turnings and industrial wastes composed of, or contaminated with, uranium from the nuclear weapons production operations at the Y-12 site. The BCBG site consists of several principal waste disposal units designated as BCBG Areas A, B, C, D, E, and J; the Walk-in Pits; and the Uranium Vaults. Each waste disposal unit consists of a series of trenches used for disposal of liquid and solid wastes. The trenches are reportedly between 14 and 25 ft deep. BCBG contains what may be the most heterogeneous solid wastes of any of the BCV disposal sites.

Initially, BCBG was used for the disposal of solid waste materials. By 1959, the Y-12 site also began disposing of certain types of liquid industrial wastes, mop waters, waste oils, and machine coolant liquids at BCBG. The area received a diverse mixture of waste materials under a variety of waste disposal practices. Wastes included metals, oils, coolants, solvents, acids, caustics, salts, shop waste, debris, asbestos, PCBs, cleaning solutions, paints, pyrophoric materials, and chemical or biological laboratory wastes, all or most of which contained varying amounts of radioisotopic contamination. However, uranium wastes are the largest quantity of materials disposed of at BCBG, including uranium-contaminated waste, large pieces of uranium metal, uranium turnings, and uranium saw fines from fabrication methods used at the Y-12 site. The disposal locations of these waste forms are discussed in Appendix A of the BCV RI (DOE 1997a). Contaminated material and turnings were generally placed in the A trenches. Areas E and J received large uranium parts/pieces and saw fines. Some turnings were placed in 1-B area trenches and the C-J area trenches. In addition, general compounds, such as picric acid, ether, and chromic acid, were deposited in the Walk-in Pit locations because they were old, partially crystallized, or radioactively contaminated reagents, constituting an explosive hazard.

Unpublished reports and photographs indicate that after disposal uranium turnings exposed to air often oxidized rapidly, causing uranium fires. Saw fines, the most pyrophoric form of uranium disposed in BCBG, were placed in Walk-in Pits and stabilized with waste oils and coolants to prevent rapid oxidation and subsequent fires. These liquids were composed of varying amounts of PCB-containing organic compounds.

Disposal activities at BCBG ended in 1993. Since 1989, when RCRA closure activities at BCBG began, several sites have been closed under RCRA. BCBG Areas A and C West were closed in-place as a landfill and covered with a RCRA-approved cap in 1989. BCBG Area B, Walk-in Pit North and South, and part of BCBG Area C East were covered with a RCRA cap in 1994. Both ORPs were closed and capped under RCRA in 1989. During closure operations, 1282 cy of sludge, sediment, and soil were excavated from ORP-1, ORP-2, and NT-7 (DOE 1997a). This waste was placed in the Disposal Area Remedial Action Solids Storage Unit Facility located west of ORP-1. The ponds and the section of NT-7 north of ORP-1 were covered with an engineered multilayer cap, and a clay cap was installed over the portion of NT-7 below ORP-1. A new channel was constructed for NT-7 and this tributary was rerouted approximately 50 ft to the west of its original course.

Seepage zones from several locations in the burial areas have been observed on all three tributaries that drain the area. In 1989, a seepage collection system was installed in the NT-7 catchment. The seepage collection system was installed northeast of ORP-1 to intercept seepage from BCBG Area A North. The collection system consists of a gravity drain that leads to a pump station. This system collects an average of 0.5 gpm from Seep 1. A second leachate collection system was installed in the NT-8 catchment in 1993. This system collects water from Seeps 2, 3, and 4. Flow in this system is variable and may reach 20 gpm in rainy weather (DOE 1997b, pages 1-24 and 1-25).

2.3.9.6 Miscellaneous disposal sites

Before the disposal areas were established, some debris disposal activities were conducted in BCV between the Y-12 site boundary and the area just east of what is now the BYBY (see Fig. 5). Little information is available on two of these sites, the Bear Creek Road Debris Burial Area and the Creekside Debris Burial Area, both which contained radiologically contaminated debris (DOE 1997b, page 1-26).

Rust Engineering, formerly a DOE prime contractor, conducted various renovation, maintenance, and construction operations at Y-12. Solid waste (spoil material) generated during these operations was disposed in an area known as the Rust Spoil Area west of Y-12 on Old Bear Creek Valley Road near the junction with Bear Creek Road (see Fig. 5). The Rust Spoil Area was operated from 1975 to 1983. It was originally operated as a disposal area with periodic grading (typically once a month) to promote positive drainage. Disposal progressed northward from Old Bear Creek Valley Road. As dumping occurred, the natural topography was elevated and a portion of the Bear Creek channel was filled. Eventually, the stream channel course was relocated to the north to compensate for the outslope progression. Based on a review of maps depicting topography before and after disposal operations. It is estimated that less than 100,000 cy of construction debris and spoil were disposed at the site. The Rust Spoil Area underwent site closure activities during 1983 to 1984. The site was coved with a minimum of 2 ft of soil, and vegetative growth was established over disturbed areas. The site is segregated into lots for storage.

There are no detailed disposal records available for the Rust Spoil Area. The bulk of the waste is reported to consist of demolition debris, including soil, masonry materials (brick and concrete), and metal (steel rebar in concrete). A portion of the demolition debris was packaged and disposed in open-top metal containers, which were determined by the Y-12 Health Physics Department to be non-radioactively contaminated. Historical evaluation and remediation planning documents indicated the possibility that minor amounts of solvent-contaminated material, and material containing asbestos, mercury, and uranium, may have been disposed in this area. Both the RI work plan and the RI revealed the presence of additional contaminants of concern. The 5.4-acre site measures approximately 300 ft by 90 ft.

The BCV OU2 RI concluded that contaminant fate and transport over the next 100 years may provide contamination or will impact groundwater in the future such that the maximum concentration level for trichloroethene is currently exceeded and may be exceeded in the future (DOE 1995a, pages 3-15 and 8-6). For this reason, the Rust Spoil Area was not included in the BCV OU2 ROD (DOE 1996).

There are two primary conclusions from the information presented in this section that are relevant to this Composite Analysis. First, the quantification of a defensible, inventory-based source term for the other existing BCV sources of radiological contamination is not possible because of the lack of detailed records of the waste disposed, particularly in the S-3 Ponds and the BCBG, which are the primary contributors to the existing surface water contamination in the valley (DOE 2015, Sect. 4.2.1.3, first bullet). Second, additional characterization of the BCBG is not considered feasible because of safety risks from the disposal of pyrophoric and explosive wastes. Regardless, waste characterization for the definition of a source term would be difficult due to the heterogeneity of the waste forms disposed.

2.4 SOURCE TERMS AND RADIONUCLIDE INVENTORIES

2.4.1 EMWMF

EMWMF is filled to approximately 80 percent of its design capacity (approximately 1.725 million cy). Most of this waste originated at ETTP. The primary radiological contaminants in waste from ETTP are uranium radionuclides and Tc-99. Additional waste streams were generated from off-ORR cleanup activities, such as Atomic City Auto Parts and the David Witherspoon sites, were disposed in EMWMF. Several waste streams were generated from cleanup activities conducted at ORNL and Y-12 as a part of the American Recovery and Reinvestment Act of 2009 initiatives. Other ORNL and Y-12 waste streams have been disposed in EMWMF. Percentages of soil and debris waste forms disposed are about the same as predicted in the waste estimate (DOE 1998a). However, a significant amount of clean fill has been used in the cell to minimize voids in the debris waste and facilitate waste compaction when soil-like remediation waste was not available. A radionuclide waste inventory for the closed EMWMF was predicted based on actual waste disposed to-date (UCOR 2019a) and was modeled using PATHRAE-RAD to calculate a dose in Bear Creek at the convergence of NT-5 (BCK 10.5) for this Composite Analysis. This radionuclide waste inventory was based on waste acceptance records of the 13 radionuclides that had waste acceptance limits specified in the WAC Attainment Plan (DOE 2001b).

2.4.2 EMDF

The proposed EMDF has had no waste disposed to date. A source term for EMDF was developed in the EMDF Performance Assessment (UCOR 2020a) based on a predicted waste inventory. The predicted waste inventory is presented in Appendix B and the source term is developed in Sect. 2.3 of the EMDF Performance Assessment. This source term then was modeled to a drinking water well located 100 m from the waste in the predicted maximum contamination flow path using RESRAD-OFFSITE. This source term was also modeled to Bear Creek because the exposure scenario also assumed Bear Creek surface water would be used by the hypothetical receptor for agricultural purposes. An overview of this modeling is provided in Sect. 3.1 of the EMDF Performance Assessment and then detailed in Sect. 3.3.

Several modifications were made to the RESRAD-OFFSITE input parameters to predict the dose used for the EMDF in this Composite Analysis from using surface water in Bear Creek at its confluence with NT-11. This modeling is detailed in Sect. 3.4 of this Composite Analysis.

2.4.3 Radionuclide Screening Approach

The steps performed to develop a source term for the EMDF are detailed in the EMDF Performance Assessment (UCOR 2020a, Sect. 2.3). The steps used to develop the WAC for EMWMF are detailed in the EMWMF RI/FS and its addendum (DOE 1998a, DOE 1998b). Screening steps were performed during these activities based on waste characteristics and the radionuclide inventory for water and air pathways. Additional radionuclide screening for EMWMF and EMDF was not performed to support this Composite Analysis.

2.4.4 Graded Approach to Source Term Screening

A graded approach was applied to screen the potential sources of radiological contamination characterized in the BCV RI and FS to identify and describe the principal contributors to the source term for the other existing BCV sources.

Current and future impacts from contaminants released by the existing sources in BCV, which may interact with releases from EMWMF and the proposed EMDF, were analyzed under CERCLA and documented in the BCV RI (DOE 1997a) and FS (DOE 1997b). The FS developed and screened technically valid remedial alternatives for the sources in BCV such as the S-3 Ponds and the BCBG. An additional evaluation of remedial alternatives was conducted in the FFS for the BCBG (DOE 2008). While a decision document for remediation of the BCBG is yet to be developed, an assumed remediation of the facility to include capping and isolation of the area, as presented in the FS, is incorporated in the OREM lifecycle baseline for cleanup of the ORR. The Phase I BCV ROD (DOE 2000a) codified components of a response action developed to reduce uranium concentrations in surface water and limit exposure to a hypothetical receptor living just outside of the assumed DOE-restricted industrial area (Zone 3 on Fig. 2) (DOE 2000a, page 1-7). The point of compliance (i.e., the Integration Point) in the ROD was subsequently defined as BCK 9.2 in the 2018 RER (DOE 2018a, page 4-10). The RER reports concentrations of uranium in Bear Creek from water samples collected at this point in accordance with the Comprehensive Monitoring Plan (DOE 2012a). (As shown in Figs. 2 and 7, all of the existing sources of potential radiological contamination in BCV are upstream of this location.)

The following is a summary of the remedial actions selected and the conclusions reached in the Phase I BCV ROD (DOE 2000a, Table 2.8) as well as a status of the actions from the 2018 RER (DOE 2018a, Table F.3):

- An interceptor trench was to be installed at NT-1 for passive in situ treatment of shallow groundwater from the S-3 Site. This activity has not been completed.
- The 570 cy of soils in the OLF Soil Storage Facility were to be sent to a commercial offsite disposal facility and the building and concrete slab were to be decontaminated and disposed. These activities were completed and existing caps in the OLF area are being maintained.
- The primary source areas in the BYBY were to be excavated and disposed in EMWMF. Adjacent areas were to be hydraulically isolated primarily by re-contouring and clay capping. These activities were completed, the caps are being maintained, and contaminant levels in NT-3 have been reduced (DOE 2018a, pages 4-25 to 4-27).

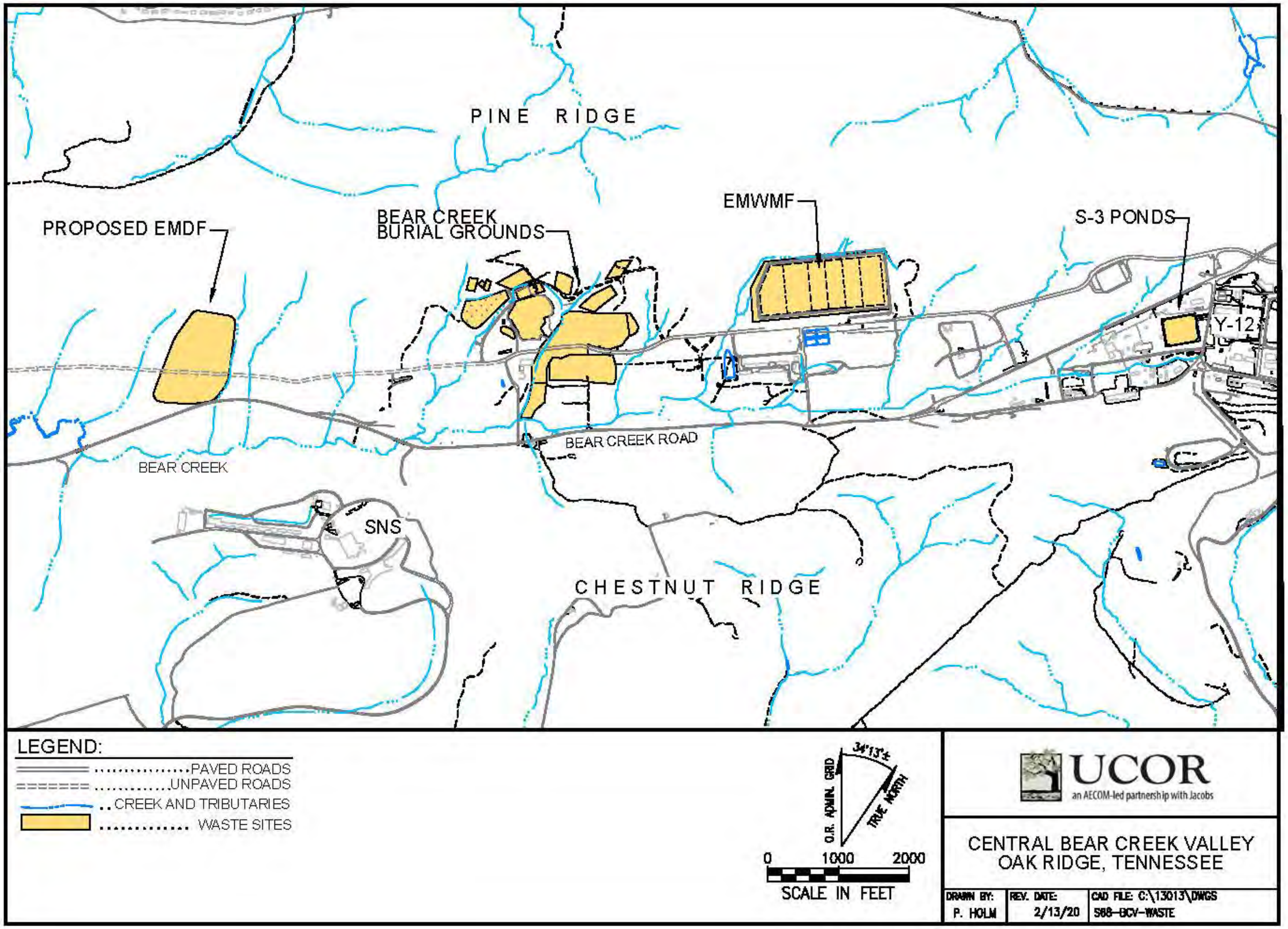
- The Phase I BCV ROD concluded that the HCDA was not a significant contributor to watershed contamination (page 2-58). The existing cap was to be tied to the BYBY cap and maintained. This was completed and the cap is being maintained.
- The existing SL-1 cap was to be maintained. The cap is being maintained.
- The estimated 4000 cy of soils in the Disposal Area Remedial Action Solids Storage Unit Facility were to be sent to a commercial offsite disposal facility and the building and concrete slab were to be decontaminated and disposed. Almost all of these soils were profiled for disposal in the EMWMF and were subsequently disposed. The remaining 21 cy carried a hazardous waste code and required offsite disposal (DOE 2018a, page 4-1). This waste was subsequently disposed at the Nevada National Security Site.
- The BCBG were not included in the Phase I BCV ROD and activities to reduce contaminant migration from these sources were deferred to a future decision under CERCLA. A ROD defining these activities has not been prepared.
- Field sampling results conducted to support the Phase I BCV ROD concluded that there were no contaminants of concern at the Bear Creek Road and Creekside Debris Burial Areas and no action was warranted under CERCLA (DOE 2000a, page 2-28).

Several BCV waste areas have been addressed under CERCLA and two of these areas (maintenance of the existing caps and establishment of institutional controls) are implementing the selected CERCLA action in a ROD effectively, eliminating the airborne, surface water, and groundwater exposure pathways for radionuclides. Spoil Area 1 and the SY-200 Yard sites, which were shown not to be a source of groundwater or surface water impacts, are not included in the source term for the other existing BCV sources using information and decisions in the following documents:

- *Remedial Investigation Report on Bear Creek Valley Operable Unit 2 (Rust Spoil Area, Spoil Area 1, and SY-200 Yard) at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (DOE 1995a)
- *Feasibility Study for the Y-12 Bear Creek Valley Operable Unit 2 Spoil Area 1, SY-200 Yard, and Rust Spoil Area, Oak Ridge, Tennessee* (DOE 1995b)
- *Record of Decision for Bear Creek Valley Operable Unit 2 (Spoil Area 1 and SY-200 Yard) at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee* (DOE 1996).

The BCV Operable Unit 2 RI concluded that soil contamination in the Rust Spoil Area may be providing contamination, or will impact groundwater in the future such that the maximum concentration level for TCE is currently exceeded and may be exceeded in the future (DOE 1995a, pages 3-15 and 8-6). For this reason, the Rust Spoil Area was not included in the BCV OU2 ROD (DOE 1996) and will be addressed as part of the overall BCV Operable Unit. However, since this contamination is predicted to be chemical contamination rather than radionuclides, the Rust Spoil Area is not included in the source term for other existing BCV sources in this Composite Analysis.

Based on the above information, it is concluded that for the purpose of this Composite Analysis, the S-3 Site and BCBG are the principal “other existing BCV sources” of radiological contamination in BCV (Fig. 6).



Source*:* Modified from DOE 2000a, Fig. 2.2

Fig. 6. Other existing BCV sources of contamination in Bear Creek Valley with EMWMF and the proposed EMDF

Fate and transport of contaminants in BCV was evaluated using two methods in the BCV RI and FS: (1) calculating contaminant mass flux using sampling results and measured water flows, and (2) predicting contaminant migration from sources using the contaminant fate and transport models. Hydrogeologic conceptual model data and sampling data allow estimates of the fate and transport of contaminants in the section of BCV that contains the waste sources. The BCV RI (DOE 1997a, Vol. 4, Appendix E) contains a detailed discussion of contaminant fate and transport. This information is supplemented with information from *The Oak Ridge Field Research Center Conceptual Model* (ORNL 2004, pages 34–47) and *Groundwater Strategy for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee* (DOE 2014, page B-19), and is presented in the following section.

Although some interpretations of the output from the model in the RI have changed over time based on analytical results of groundwater and surface water in BCV, there have been no major changes to the conceptual model and the modeling approach. No major revisions have been made to the model used to support the RI and the results of that modeling are still considered valid.

Uranium disposal was common in BCV. Unknown quantities of uranium were disposed of at BCBG, BYBY, and the S-3 Site. Sampling data indicate that uranium contamination is widespread, particularly in groundwater and surface water. The primary sources of uranium in the shallow groundwater/Bear Creek system and the Maynardville Limestone appear to be BCBG and the secondary sources underlying the S-3 Site (i.e., groundwater plumes).

Based on the analysis of sample data and modeling results for the numerous existing Bear Creek sources, the major radiological contaminants considered in this Composite Analysis are isotopes of uranium and Tc-99. As discussed above, remedial actions were required to mitigate future release of these radionuclides (DOE 2000a). The 2018 RER documents that goals for remedial actions in the Phase I BCV ROD are not being met (DOE 2018a, Tables 4.5 and 4.6). This can be mostly attributed to the actions at the S-3 Site not being implemented and decisions affecting the BCBG being deferred to a future ROD. Contaminant concentrations at BCK 9.2, are presented in Table 3 (taken from the 2018 RER [DOE 2018a, Table 4.5]) and are summarized in Sect. 2.4.4.2.

Table 3. Historic average activity of uranium isotopes at the Integration Point (BCK 9.2)

FY	U-234 (pCi/L)	U-235 (pCi/L)	U-238 (pCi/L)	Total uranium[a] (µg/L)	Average ORR rainfall[b] (in.)
2001	13.7	0.7	28.5	84	45.9
2002	12.4	0.8	24.8	73	52.7
2003	9.4	1.2	18.4	55	73.7
2004	8.5	1.1	17.7	53	56.4
2005	7.3	0.7	15.9	47	58.9
2006	9.9	0.9	21.3	63	46.4
2007	8.8	0.9	18.8	56	36.8
2008	9.1	0.9	21.0	62	49.3
2009	8.8	0.8	21.6	64	62.5
2010	7.9	0.8	17.0	50	55.8
2011	7.6	0.7	17.6	52	59.2
2012	6.3	0.6	16.1	48	61.8
2013	7.4	0.7	17.0	50	63.7
2014	7.0	0.7	17.5	52	48.8
2015	7.0	0.7	16.8	50	55.9

Table 3. Historic average activity of uranium isotopes at the Integration Point (BCK 9.2) (cont.)

FY	U-234 (pCi/L)	U-235 (pCi/L)	U-238 (pCi/L)	Total uranium[a] (µg/L)	Average ORR rainfall[b] (in.)
2016	6.7	0.5	15.4	46	50.2
2017	7.8	0.6	18.1	54	57.9

[a] Provided for comparison with DOE O 458.1 requirement to meet maximum concentration limits for uranium (30µg/L), in nearest drinking water body, which is the Clinch River. Uranium in Bear Creek waters will be well below this requirement by the time it enters the Clinch River.

[b] Average annual rainfall for rain gauges at Y-12, ETTP, ORNL, and DOE town site.

BCK = Bear Creek kilometer
DOE O = U.S. Department of Energy Order
ETTP = East Tennessee Technology Park
FY = fiscal year
ORNL = Oak Ridge National Laboratory
Y-12 = Y-12 National Security Complex

2.4.4.1 Contaminant migration pathways

The waste source areas in BCV are located in the Nolichucky Shale with a portion of the BCBG overlying the Maryville Limestone Formation (referred to hereafter as the Maryville Formation due to the limited amount of limestone at locations in BCV). Shallow groundwater is the primary mechanism and pathway for release of contaminants from the northern portion of the valley (however, the larger plumes from the S-3 Site have moved deep into the Nolichucky and there is uncertainty related to their flow paths at depth). Contaminants travel via short pathways (primarily intersected fracture networks) in the shallow groundwater to be discharged into tributaries of or directly to Bear Creek. Around 95 percent of rainfall recharge to shale units flow to and through the waste to the north tributaries into Bear Creek, and exits that portion of the valley at BCK 9.2, and thus BCK 9.2 is referred to as the Integration Point. Both in the Nolichucky Shale and the Maynardville Limestone, there is a great deal of interaction in the shallow groundwater and the surface water, resulting in gaining and losing reaches along streams. Appendix C of the BCV RI (DOE 1997a) presents detailed information on the hydrogeologic framework of BCV. This information serves as the basis for the description of the Composite Analysis Conceptual Model in Sect. 3.2 of this Composite Analysis. There is a key uncertainty in BCV associated with uranium migration and the losing reach of Bear Creek in the BYBY area (DOE 2014).

Some contaminants discharge directly into the Maynardville Limestone, a 200 ft thick limestone formation, containing a well-developed karst network created by dissolution and enlargement of fractures and joints. Groundwater flow in the Maynardville Limestone occurs in both shallow and deep karst features, and corresponding flow rates and volumes are much higher than in the shale-dominated formations. Releases from the sources have contributed to a comingled plume of volatile organic compounds (VOC), nitrate, and uranium-contaminated groundwater within the Maynardville Limestone. Over the years this Maynardville flow path has been monitored through a series of sentinel well transects or "pickets," as represented by Pickets C, B, A, and W at selected locations from northeast to southwest in BCV. There is also a line of Westbay wells at the S-3 Site that has not been regularly sampled. The picket monitoring shows that once contaminants enter the Maynardville Limestone, they flow southwest down the valley and re-enter Bear Creek through groundwater discharge to the creek channel and a series of seeps dominated by vertical, upward pressure (SS-4, SS-5), or continue to flow in the deeper zones, intersecting Picket W (as traced through nitrate detections). The fate of migration in the watershed turns northwest and flows through a gap in Pine Ridge, East of the Bear Creek/Grassy Creek surface water divide. Bear Creek flows north to EFPC and Grassy Creek flows west to the Clinch River. There is uncertainty as to whether or not this surface water divide represents a deep groundwater flow divide in the Maynardville (DOE 2014, page B-19).

Contaminant monitoring at the pickets indicates the following:

- All primary contaminants of concern are present at Pickets C (perpendicular to Bear Creek between NT-2 and NT-3 in the BYBY area) and B (approximately the confluence of NT-6 and Bear Creek).
- Nitrate and uranium are present at Picket A (immediately downstream of the confluence of NT-8 and Bear Creek in the BCBG area – approximately BCK 9.2).
- Low levels of nitrate, possibly background levels, are seen at Picket W (perpendicular to Bear Creek immediately upstream of BCK 7.73) (DOE 2014, page B-19, Fig. B-5).

This conceptual contaminant transport model is supported by the following nature and extent of contamination summaries for the primary sources of contamination in BCV from the BCV RI (DOE 1997a, Vol. 4, Appendix E).

Contamination derived from the S-3 Site can be identified in the Maynardville Limestone as far west as Picket W (immediately upgradient of BCK 7.73) and in surface water at BCK 4.55. At the S-3 Site, contaminated groundwater in the Nolichucky Shale is the main source of contaminants. More contaminant mass is discharged to the creek than is leaching from waste materials that remain in the former ponds. 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 UEFPC 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.

Contaminants have undergone differential retardation that has resulted in different distributions and exit pathways for the primary contaminants. 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. The more mobile metals, Tc-99, nitrate, and PCE 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. Maximum concentrations of PCE found at the site indicate the potential for a dense, non-aqueous phase liquid (DNAPL) plume 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. Although the extent west of the plume in shallow groundwater is well known, the leading edge of the plume in intermediate and deep groundwater is not known. The probable condition (based on nitrate in shallow wells) is that the plume in deep groundwater may be moving along strike to the west in groundwater below 100 ft depth, extends no further west than the plume in shallow groundwater, and that much of the contaminant mass in the plume is discharged to NT-2.

The Oak Ridge Field Research Center Conceptual Model (ORNL 2004, pages 34–47) presents a detailed evaluation of contaminant nature and extent at three areas in the immediate vicinity of the former S-3 Ponds. Area 1 is just south and down dip of the former S-3 Ponds, Area 2 is located several hundred feet to the southwest of the Ponds and along geologic strike of the Nolichucky Shale, and Area 3 is just west of (adjacent to) and directly down strike of the former Ponds. Area 3 is between the former S-3 Ponds and Area 2.

Contamination in Area 1 includes all of the contaminants generally associated with the S-3 Ponds groundwater plume (nitrate, Tc-99, uranium, VOCs, and relatively high concentrations of other common anions and cations). Contaminants have migrated from the Ponds to Area 1 via bed dipping fractures. Contaminant dispersal within Area 1, however, is along strike as this is the primary direction of groundwater flow in the saturated zone. Contaminant concentrations are significantly lower than typical for Area 3. Area 1 is down dip from the Ponds, which is not the preferred direction of groundwater under saturated conditions. Because Area 1 is down dip, contaminants must migrate across strike and this increases their variability and decreases their concentration. Groundwater concentration of Tc-99 ranges from 66 to 31,000 pCi/L and uranium ranges from 0.01 to 7.5 mg/L. As much as 375 mg/kg of uranium is associated with the solid phase material in Area 1.

Most contamination detected at Area 2 was probably transported from the Ponds through an historic stream channel of Bear Creek during operations. Because of this, the entire substance domain between Area 2 and Area 3 is most likely contaminated. Based on data from a 1988 tracer study, the rate of interstitial groundwater movement in the unconsolidated fill was calculated to range from 0.7 m/day to 4.5m/day, with an average rate of about 2.2 m/day. Hydraulic monitoring at the site indicates that the depth to groundwater is approximately 4.5 m from the surface and the hydraulic gradient ranges between 0.01 and 0.025 to the southwest towards Bear Creek. Vertical upward gradients between the shale bedrock and the unconsolidated zone are as great as 0.25.

Area 2 is a shallow pathway for the migration of groundwater contaminated with uranium to seeps in the upper reach of Bear Creek (which is adjacent and both down-dip and down strike to Area 2). Groundwater Tc-99 is generally detected below 600 pCi/L. Uranium concentrations in groundwater are variable. As much as 300-500 mg of uranium per kg of soil or rock could be associated with the solid phase material in Area 2.

The deep saprolite zone is probably the preferential pathway for contaminants away from the S-3 Ponds to Area 3. It is the zone where uranium concentrations are highest, suggesting a high contaminant mass flux through this regime. Contaminant plumes appear to move preferentially along strike, which is the preferred direction of groundwater flow, and vertically downward as a result of density-driven flow. Hydraulic monitoring indicates that the depth to groundwater is approximately 3.5 m from the surface and the hydraulic gradient is fairly flat. Tracer studies corroborated earlier findings that the transition zone directly above the bedrock is conducive to rapid preferential movement of solutes. Matrix diffusion into the saprolite blocks is also an important mechanism governing solute fate and transport. Numerical simulation of observed tracers concentration breakthrough profiles suggest solute mass transfer rates were on the timescale of months to years.

Contaminants are detected at the highest concentrations in both the groundwater and solid phase of Area 3 relative to Areas 1 and 2 due to the proximity of Area 3 to the S-3 Ponds. Technetium-99 and uranium concentrations are as high as 40,000 pCi/L and 60 mg/L, respectively, in groundwater. Peak concentrations of uranium in solution occur near the transition zone between 38 and 45 ft. This regime has a high discharge zone that has a measured bulk flux of 0.5 to 1.0 m/day. Concentrations of metals and radionuclides were highest near the southwest corner of the former Ponds. Additional borings were drilled and sampled to support a technology demonstration project in the residuum southwest of the Ponds. The samples were analyzed for uranium only. The maximum concentration of U-238 was 162 pCi/g (490 ppm). All of the samples from the residuum were depleted relative to the amount of U-235 present. Zones of elevated uranium in the unsaturated zone were detected at a depth of 2 to 3 ft near the water table depth of 9 to 10 ft and near the middle of the residuum at a depth of 19 to 20 ft. Additional core samples acquired to a depth of 50 ft (at bedrock) suggested the highest uranium solid phase concentrations were near the transition zone at a depth of 38 to 45 ft where upwards of 750 mg/kg of uranium were found on the sediments. Below 45 ft, solid phase uranium concentrations were well below 50 mg/kg due to the increasing presence of carbonate-bearing minerals and pH regimes above 6.5.

In general, organic contamination of environmental media at the BCBG is more widespread than inorganic and radionuclide contamination. Disposal of liquid wastes have resulted in a DNAPL in groundwater that may have reached depths of 600 ft. Dissolution of the DNAPL results in plumes of VOC-contaminated groundwater.

Uranium dominates the waste disposed in the BCBG with a total estimated mass of 18.6 million kg. Radiological contamination is infrequently detected in groundwater wells in the BCBG, but uranium is consistently detected in surface water. Collection of leachate in the NT-7 and NT-8 catchments significantly reduced the concentration of radiological and other contaminants in surface water. Radiological contamination occurs in the soils in the NT-8 floodplain and is probably related to past deposition of contaminated sediments from the drainage of the Burial Ground-B, -C, and -D areas.

Uranium and metal contaminants are in solid form and are slowly leaching from the BCBG trenches. The dominance of the hydrologic system by shallow flow restricts inorganic and radionuclide contamination to short flow paths in the shallow groundwater interval, whereas the density-driven flow of the organic wastes provides a mechanism for organic contamination to enter the shallow, intermediate, and deep bedrock intervals (DOE 1997a, Vol. 4, Appendix E).

The OLF Area includes the OLF, BYBY, HDCA, and SL-1. Contaminant flux information from the BCV RI is presented although the BYBY was remediated in accordance with the Phase I BCV ROD in the early 2000s. At BYBY, uranium and metal contaminants leached from waste materials (some of which were inundated with groundwater) and contaminated soils to groundwater, which subsequently discharged to surface water in NT-3. Uranium in groundwater that leached from fill material in the southern portion of the BYBY probably migrated directly to the Maynardville Limestone and Bear Creek via shallow groundwater flow. The fact that uranium fluxes in NT-3 have dropped significantly since BYBY was remediated, supports this contaminant nature and extent scenario in the OLF Area (DOE 1997a, Vol. 4, Appendix E; DOE 2018a, Table 4.6).

The BCV RI also described a contaminant nature and extent model for the Maynardville Limestone and Bear Creek Area. This area 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. This environmental media represent the down gradient pathways of contaminants migrating from sources on the Nolichucky Shale. The BCV RI listed the following as the primary sources of contaminant input to Bear Creek and the Maynardville Limestone (note that this was prior to remediation of the BYBY):

- S-3 Site—nitrate, radionuclides, and high total dissolved solids via discharge from NT-1 and NT-2, shallow groundwater discharges to Bear Creek and the 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 discharge from NT-7 and NT-8

- Past releases of organic contamination from an unknown site east of BYBY or the Rust Spoil Area
- Past releases of organic contamination from the Fire Training Area from the EFPC that may have migrated in karst in the Maynardville Limestone.

At monitoring points down gradient of BYBY (groundwater and surface water), the plumes from the S-3 Site and the BYBY source areas are completely comingled. It is only possible to identify additional source areas by using progressive changes in relative concentrations of contaminants in groundwater, surface water, and springs.

Surface water and shallow groundwater in the Maynardville Limestone are closely related and constitute 96 percent of water flowing along the valley. Contaminants in these media pathways are quickly diluted by rapid recharge of rainwater and inputs from uncontaminated tributaries. Concentrations of contaminants in the intermediate and deep groundwater pathways (100 to 300 ft deep) are not attenuated as rapidly as those in the shallow groundwater because this interval is somewhat isolated from inputs from recharge and tributaries.

Relevant conclusions for the uranium contamination include: uranium and Tc-99 contamination occurs close to the S-3 Site and continues west as far as BCK 9.47, uranium and Tc-99 contamination have not reached as far as west as Picket W, and the source of uranium from the BCBG is via discharge from NT-7 and NT-8.

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 disposal has caused shallow groundwater contamination. Leaching of solid materials, particularly uranium, is a current source of groundwater contamination. Where dense liquids were disposed 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 along the following pathways:

- Contaminated shallow groundwater at the 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 the deep groundwater in the Nolichucky Shale also migrate through fractures along strike and discharge into 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 intermittingly 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 large springs at the base of Chestnut Ridge, some of which have contaminated discharge (SS-1, SS-4, SS-5, and SS-6).
- Surface water in Bear Creek and shallow groundwater in the Maynardville Limestone constitute 96 percent of water flowing along the valley. Contaminants in these media pathways are quickly diluted.
- Deep groundwater in the Maynardville Limestone (100 to 300 ft), by rapid recharge of rainwater and inputs from uncontaminated tributaries, constitutes greater than 4 percent of water flowing along the valley. Concentrations of contaminants in this and the deep groundwater pathway are not attenuated as rapidly as those in the shallow groundwater, this pathway is an important source of long-distance

groundwater transport along the valley. (It is noted that uranium concentrations in deep groundwater are lower than uranium concentrations in surface water in the vicinity of BCK 9.2, see Sect. 5.2.)

- 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 percent of the available water from the upper portion of the valley passes through this location as either surface water or groundwater.

ORNL 2004 (page 14) provides additional detail on the nature and extent of contaminant migration in subsurface media on the ORR stating that it is conducive to extreme preferential flow. Physical, geochemical, and hydraulic non-equilibrium conditions between fractures and the surrounding soil matrix are commonplace. Two processes contribute significantly to retardation of solute transport and the storage of solute mass in the matrix: sorption and matrix diffusion. High clay content within the weathered matrix coupled with high porosity and small pore space impart a large surface area for sorption of reactive solutes within the matrix and, secondarily, on fracture surfaces. In addition, these same characteristics result in a large, relatively immobile volume of pore water that acts as a reservoir for storage of solute that diffuses into the matrix through the fracture walls. The result is a significant slowing of the transport rates and the creation of secondary sources within the matrix that can and do release solutes over long periods of time. Because fracture flow rates are high, mass can be transported rapidly through the preferred fracture flow pathways. This is particularly true of colloids and bacteria that reside only in the fractures due to size exclusion from the matrix. However, that overall mass flux may be low because of the low overall porosity and, in the case of solutes, because of mass transfer into the pores and onto solid surfaces.

2.4.4.2 Current valley-wide contaminant fluxes

Seventeen years of post-ROD Bear Creek surface water data have been collected and annual data summaries and evaluations have been conducted. The latest flux data for BCV are presented in Table 4.6 in the 2018 RER (DOE 2018a).

The results of the valley-wide contaminant flux assessment in 2015 indicated that most of the uranium measured at BCK 9.2 came from BCBG (about 75 percent). About one-quarter of the uranium measured at BCK 9.2 came from the S-3 Site (DOE 2015, Sect. 4.2.1.3). Other relevant conclusions from this information include:

- Uranium flux at BCK 12.34 (S-3 Site) and BCK 9.2 (primarily BCBG) exceed the uranium flux goals in the BCV Phase I ROD.
- Uranium flux at NT-3 (remediated BYBY) meets the uranium flux goal in the Phase I BCV ROD.
- Further remediation will be required at the S-3 Site and the BCBG to meet the goals in the Phase I BCV ROD.

2.4.4.3 Projected releases from the other existing BCV sources

The modeling results described in the BCV RI (DOE 1997a, Vol. 4, Appendix E) predicted that uranium would probably remain a major contaminant in groundwater and surface water if no remediation was performed. Leachate modeling indicated that, in the future, uranium could leach from BYBY (since remediated), the S-3 Site, and BCBG at significantly high rates. In addition, further modeling combined with dilution and mass balance calculations indicated that the concentrations of uranium in NT-1, NT-2, NT-3, NT-7, NT-8, and Bear Creek could either increase in the future or remain constant indefinitely.

It also was concluded that another radionuclide, Tc-99, may also migrate from existing waste sources at increased concentrations. This was supported by leachate modeling that suggested Tc-99 concentrations could increase, primarily from BCBG Area A North and BYBY (since remediated). Further, because the S-3 Ponds contain Tc-99, leaching from the current pond sludges beneath the cap due to groundwater intrusion could not be discounted.

Therefore, to comply with the Phase I BCV ROD remedial action objectives at the Integration Point (BCK 9.2), future releases from the other existing BCV sources have to be reduced. Additional remediation will be required in BCV to further mitigate the future release of these radionuclides and meet the ROD objectives.

2.5 SOURCE TERMS CONSIDERED IN COMPOSITE ANALYSIS

Peak doses during the compliance period for the following three source terms shown in Fig. 7 are quantified in this Composite Analysis:

- Other existing BCV sources of radiological contamination—dose from projected contaminant concentrations in Bear Creek at BCK 9.2 assuming appropriate remedial actions in BCV have been performed and there is compliance with the Phase I BCV ROD
- EMWMF—dose from modeled contaminant concentrations in Bear Creek at the confluence of NT-5 (BCK 10.5) from the closed EMWMF with a projected waste inventory based on actual waste disposed to-date
- Proposed EMDF—projected dose from modeled contaminant concentrations in Bear Creek at the confluence of NT-11 and Bear Creek (BCK 7.73) based on the predicted inventory and the modeling in the EMDF Performance Assessment.

2.5.1 Source Term for the Other Existing BCV Sources of Radiological Contamination

The locations of potential sources of contamination from existing disposal sites in BCV are shown in Fig. 6. The status of actions required by the Phase I BCV ROD (DOE 2000a) are summarized above and documented in the 2018 RER (DOE 2018a, Sect. 4). Data provided in the report confirm that uranium concentrations in Bear Creek are currently lower than uranium concentrations prior to and during remedial actions conducted in the early 2000s (primarily from remediation of BYBY). Additional remedial decisions and actions will be required in BCV to address attaining the ROD goals and to define remediation of the BCBG (DOE 2000a, DOE 2018a). The ROD presents predicted reductions (in percentages) in the amount of uranium that would be released from the existing sources following completion of the actions required in the ROD. The 2018 RER includes 17 years of uranium concentrations in Bear Creek at BCK 9.2. (See Table 3 in this Composite Analysis or Table 4.5 in DOE 2018a, page 4-19.) These uranium concentrations were averaged over the 17-year period (8.56 pCi/L for U-234, 0.78 pCi/L for U-235, and 19.03 pCi/L for U-238). The 2018 RER also includes 17 years of Tc-99 concentrations in Bear Creek at BCK 7.87 (downstream of BCK 9.2 and 140 m upstream of BCK 7.73) (DOE 2018a, Fig. 4.4). These Tc-99 concentrations were also averaged (27.78 pCi/L). This average concentration was adjusted using the mixing ratio in Bear Creek from BCK 7.87 to BCK 9.2 to estimate a Tc-99 concentration at BCK 9.2 (39.73 pCi/L).

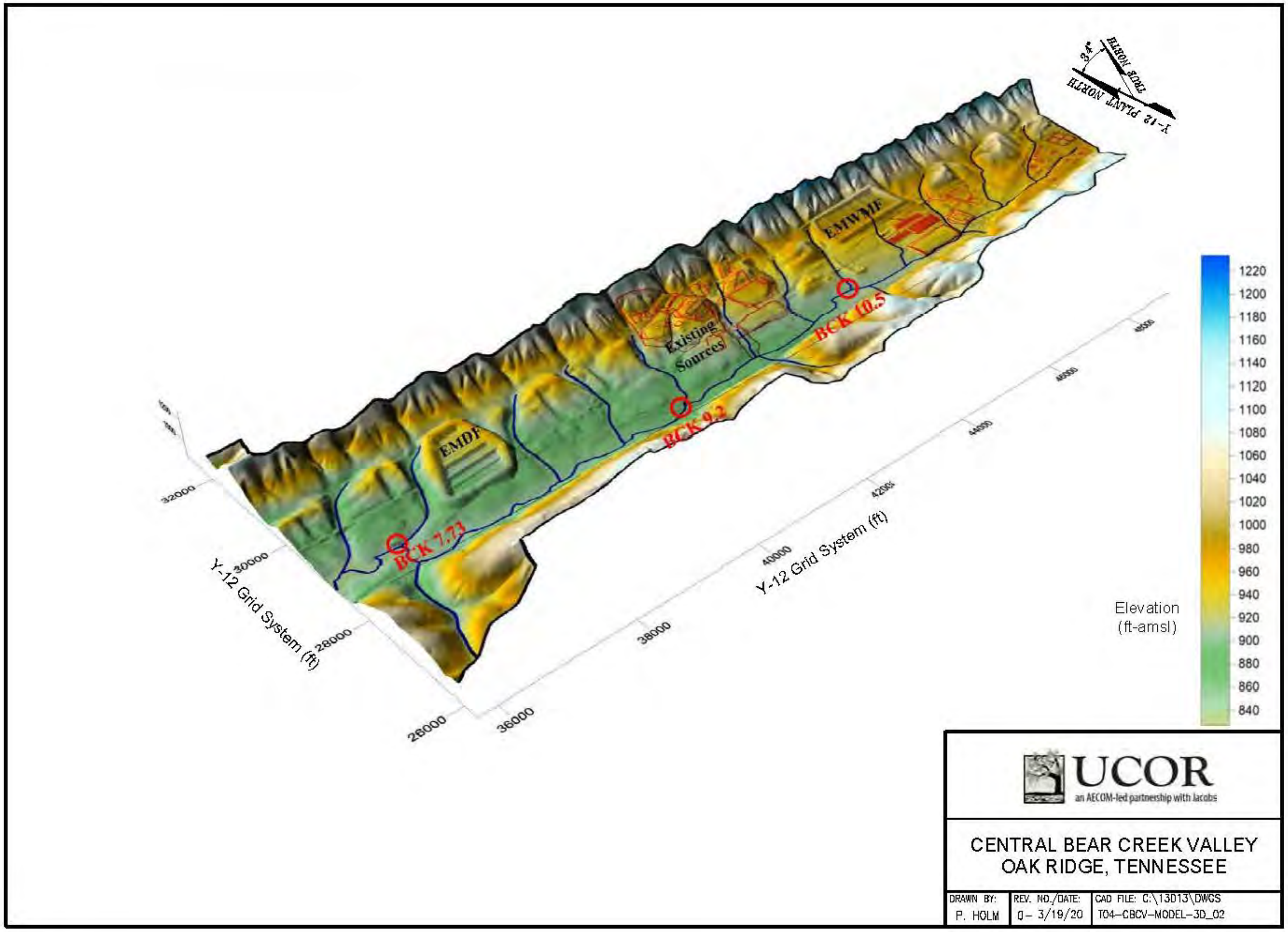


Fig. 7. Other existing BCV sources, EMWMF, and the proposed EMDF with points of compliance and Composite Analysis point of assessment (also BCK 7.73)

The derivation of mixing ratios for intervals in Bear Creek is described in Sect. 4.2. These average uranium and Tc-99 concentrations at BCK 9.2 were evaluated for compliance with the Phase I BCV ROD. It was determined that a 78 percent reduction in these concentrations would be required to comply with the ROD. Based on achieving the 78 percent reduction through implementation of remedial actions for the other existing BCV sources, resultant concentrations would be: 1.88 pCi/L for U-234, 0.17 pCi/L for U-235, 4.18 pCi/L for U-238, and 8.72 pCi/L for Tc-99.

The conversion of these concentrations to a dose for the other existing BCV sources was performed assuming a resident farmer exposure scenario. This is consistent with previous modeling performed to support the EMWMF and the Phase I BCV RODs, and the performance modeling that supports the EMDF Performance Assessment. Total equivalent uptake factors were calculated for uranium and Tc-99 by quantifying the equivalent uptakes for each surface water exposure pathway in the resident farmer exposure scenario. This quantification used amounts of food and water consumed, and transfer factors that were consistent with EMWMF and EMDF performance modeling. The equivalent uptake factors scale the use of Bear Creek water for drinking and agricultural purposes to an equivalent annual drinking water ingestion that would give the same annual constituent uptake as calculated to come from all pathways. The total equivalent uptake factor for the uranium radionuclides is 762.68 L/year and the total equivalent uptake factor for Tc-99 is 790.13 L/year (with the consumption of 2 L of water a day contributing 730 L/year to each equivalent uptake factor). Ingestion Rate Coefficients (from DOE 2011b) for Tc-99 and three uranium radionuclides were used to quantify doses for the four radionuclides using the equation:

$$\text{Dose (mrem/year)} = \text{surface water concentration (pCi/L)} \times \text{Equivalent Uptake Factor (L/year)} \times \text{Ingestion Rate Coefficient (mrem/pCi)}$$

This provided doses for the four radionuclides: U-234 = 0.31 mrem/year, U-235 = 0.03 mrem/year, U-238 = 0.62 mrem/year, and Tc-99 = 0.02 mrem/year. These doses were totaled to arrive at a dose of 0.98 mrem/year for the other existing BCV sources at BCK 9.2. The calculation of the dose for this source term is explained in Appendix C of this Composite Analysis.

This dose is based on a source term assuming remedial actions in BCV have been completed and contaminant concentrations in Bear Creek are in compliance with the Phase I BCV ROD. Since current conditions at BCK 9.2 exceed the ROD goals requiring additional remediation, a sensitivity analysis has been performed (see Sect. 5.2) to quantify the dose, including EMWMF and the proposed EMDF, under the assumption that no further remedial activities are performed and the 17-year average contaminant concentrations in Bear Creek remain.

2.5.2 Source Term for EMWMF

The currently operating EMWMF is a six-cell, 2.3 million cy RCRA, TSCA, and LLW waste disposal facility. Summary-level information on EMWMF is presented in Sect. 2.1.1. The design of the facility is detailed in the Remedial Design Report for the disposal of ORR CERCLA waste (DOE 2001c) and its addenda (DOE 2001d, DOE 2010). The primary components of EMWMF include the following:

- A leachate collection system overlying 5 ft thick multilayer liner system above a 10 ft low permeability geological buffer, surrounded by clean-fill dikes
- A multicomponent cover 11 ft thick will be placed over the waste to close the facility, greatly reduce the amount of water infiltrating into the waste and seeping from the facility to the environment, prevent erosion, and prevent intrusion of plants and animals into the waste.

The general location of EMWMF is shown in Fig. 1. The disposal cell footprint is superimposed on or adjacent to the other existing BCV sources and is located between NT-3 and NT-5 in East BCV on Figs. 6 and 7. NT-4 was diverted around the disposal cell and an underdrain was constructed in the former NT-4 channel beneath EMWMF.

Modeling performed to support the commitments in the EMWMF ROD and define the EMWMF WAC assumed the volume-weighted sum of fractions at closure would equal 1. However, at this time, EMWMF is filled to approximately 80 percent of capacity and the predicted volume-weighted sum of fractions for EMWMF at closure is 0.6. (In other words, contaminant concentrations in waste disposed to-date have been less than originally used to establish the WAC.) Therefore, actual waste disposal information was used to estimate an EMWMF radiological inventory at closure, assuming the current radiological composition remains unchanged (UCOR 2019a). It was conservatively assumed that radiological inventory in waste accepted for disposal occupied the entire facility capacity following disposal and facility closure.

This radiological inventory was used to calculate radiological concentrations at the confluence of NT-5 and Bear Creek (BCK 10.5). The concentrations at this location were predicted using the PATHRAE-RAD model and the modeling scenario as discussed in the EMWMF RI/FS and its addendum (DOE 1998a, DOE 1998b). Detailed discussion of the PATHRAE-RAD application and the modeling performed are provided in Appendix B. The predicted concentrations for the primary radionuclides in EMWMF at closure were used to calculate the resulting dose for the exposure pathways in DOE 1998a and 1998b. The resulting dose from EMWMF, with the current inventory assumed at closure, in Bear Creek at BCK 10.5, is 0.09 mrem/year (see Table B.7 in Appendix B). This dose is primarily comprised of mobile radionuclides such as C-14, H-3, I-129, and Tc-99 (see Appendix B).

2.5.3 Source Term for the Proposed EMDF

The proposed EMDF as well as the anticipated type, volume, and form of wastes generated by CERCLA environmental restoration actions on the ORR are briefly summarized in Sect. 2.1.2. These wastes are characterized in the EMDF Performance Assessment (UCOR 2020a, Sect. 2.3 and Appendix B). Essential aspects of the proposed EMDF and the waste it may contain include the following:

- Volume of 2.2 million cy of RCRA, TSCA, and LLW waste disposed in the form of soil and debris
- Disposal cell footprint of 70 acres with basal cell features consisting of a leachate collection system overlying 5 ft multilayer liner system above a 10 ft low permeability geological buffer and surrounded by clean-fill dikes
- Multicomponent cover 11 ft thick will be placed over the waste to close the facility, greatly reduce the amount of water infiltrating into the waste and seeping from the facility to the environment, prevent erosion, and prevent intrusion of plants and animals into the waste.

Waste that meets the facility's WAC will be placed and compacted over the operational period with periodic placement of interim covers to stabilize the waste and prevent wind erosion.

The general location of the proposed EMDF is shown in Fig. 1. The disposal footprint superimposed along with the existing sources and EMWMF located in East BCV are shown on Figs. 6 and 7.

The estimates of potential doses to the public from EMDF were calculated in Sect. 4.5 of the EMDF Performance Assessment (UCOR 2020a). This Composite Analysis uses the results of the performance modeling in the Performance Assessment and develops a dose estimate for EMDF at the confluence of NT-11 and Bear Creek using the same model used in the Performance Assessment (RESidual RADioactivity-OFFSITE). This modeling is described in Sect. 3.4 of this Composite Analysis. This dose, predicted to be 0.25 mrem/year, is primarily from exposure to C-14 by ingesting fish.

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3. ANALYSIS OF PERFORMANCE

This section uses the source terms previously defined and describes the method of quantifying the total dose for the base case assessment using the assumptions described in Sect. 1.5. The development of the contaminant fate-transport model used to support the assessment is summarized, the results are presented, and the relevance of the results are explained.

Investigations conducted to support remedial actions on the ORR under CERCLA have concluded that groundwater and surface water are the principal transport mechanisms and that the long northeast-southwest trending valleys and ridges on ORR define essentially isolated hydrologic systems (watersheds). These systems allow very little exchange of water from one valley to another. Furthermore, airborne movement of radioactive contaminants is not expected to be a major contributor to doses to the public from disposal sites at ORR, and significant airborne migration of contaminants from valley to valley is unlikely. Therefore, a hypothetical public receptor would only be exposed to contaminants released from sources within the watershed inhabited by the receptor or via groundwater or surface water entering the disposal facility's watershed from another, hydrologically connected watershed.

From these observations, it was determined that the Composite Analysis evaluation of potential radiological contamination from EMWMF and the proposed EMDF need consider only those additional sources of potential contaminant releases that are located in the BCV watershed. The BCV watershed delineation on the ORR is shown on Fig. 1 along with the locations of EMWMF and the proposed EMDF.

The BCV watershed is bordered by the crest of Pine Ridge on the northwest and the crest of Chestnut Ridge on the southeast. The eastward extension of the valley becomes Union Valley, with the boundary between BCV and Union Valley delineated by Scarboro Road. A natural groundwater and surface water divide in the vicinity of the S-3 Ponds at the west end of the Y-12 site delineates the east end of the Bear Creek watershed (and prevents contamination originating in the Y-12 facilities from migrating into BCV). Bear Creek originates near this divide and flows roughly westward through the valley. There is no evidence in the BCV RI that this divide is artificial or will not exist for a significant time in the future. Bear Creek turns northward through a gap in Pine Ridge just west of SR 95 and flows into Poplar Creek about 0.6 mile north of the intersection of SRs 95 and 58 (see Fig. 1). The eastern portion of the Bear Creek watershed encompasses the drainage area from the S-3 Ponds between Pine Ridge and Chestnut Ridge and west to just beyond SR 95.

Section 3.1 presents the doses for the three source terms being considered in this Composite Analysis: the EMWMF, the EMDF, and the other existing BCV sources. This section also defines the POA for this Composite Analysis. Section 3.2 details the conceptual model that was used to predict the contaminant fate and transport from the three source terms and arrive at the exposure pathways at the POA, and justifies its use. Several models were used to support the analysis of performance in this Composite Analysis. All are summarized in this section and then detailed in Appendix A (MODFLOW and MT3D), Appendix B (PATHRAE-RAD), or the EMDF Performance Assessment (RESRAD-OFFSITE). Section 3.2.3 describes the development of a three-dimensional Upper Bear Creek Valley (UBCV) groundwater flow model that used the MODFLOW and MT3D software packages. The UBCV and the EMDF flow model (from the EMDF Performance Assessment) were used to predict groundwater flow field, flow path, and contaminant discharge to surface water streams. These models also provided system water balance information in BCV and were used to determine if the site conceptual model and using only the surface water in the pathway analysis at the POA were appropriate. The potential exposure pathways for the hypothetical resident farmer at the POA are identified and evaluated in Sect. 3.3. Section 3.4 discusses the modeling that was performed to calculate a dose at the POA for the proposed EMDF using the RESRAD-OFFSITE model. RESRAD-OFFSITE was used to arrive at the EMDF dose that was incorporated into the base case assessment as well as the doses used for the EMDF in the post-1000-year maximum dose sensitivity analysis. Finally, Sect. 3.4 introduces the PATHRAE-RAD model that was previously used to support the CERCLA evaluation and the DASs for the EMWMF. To remain consistent with the results of that past modeling, PATHRAE-RAD was used to calculate the dose from the EMWMF in the base case assessment.

3.1 OVERVIEW OF ANALYSIS OF PERFORMANCE

The three source terms defined and doses calculated in Sect. 2.5 for the base case assessment in this Composite Analysis include the following:

- Other existing BCV sources—0.98 mrem/year in Bear Creek at BCK 9.2
- EMWMF—0.09 mrem/year in Bear Creek at the confluence of NT-5 (BCK 10.5)
- EMDF—0.25 mrem/year in Bear Creek at the confluence of NT-11 (BCK 7.73).

The confluence of NT-11 and Bear Creek (BCK 7.73) was selected as the POA in this Composite Analysis. The EMWMF as well as the other existing BCV sources of potential radioactive contamination in BCV are upstream of this location. The hypothetical receptor at this location is likely to receive the maximum exposure from contaminant release from all sources. This dose for the EMWMF occurs approximately 1.72 miles upstream of the Composite Analysis POA. The dose for the other existing BCV sources is at the Phase I BCV ROD Integration Point. This is approximately 0.91 mile upstream of the Composite Analysis POA. The POA for this Composite Analysis and the points of compliance for the EMWMF and the other existing BCV sources (near the confluence of Bear Creek and NT-8) are shown on Fig. 7. The hypothetical receptor at the POA was assumed to be a resident farmer using water from Bear Creek for all domestic and agricultural purposes. This is consistent with the hypothetical receptor assumed in the modeling scenario as discussed in the EMWMF RI/FS and its addendum (DOE 1998a, DOE 1998b) and the EMDF Performance Assessment (UCOR 2020a). A hypothetical resident farmer incorporates all exposure pathways (see Appendix C, Table C.1); is representative of past, pre-DOE land use; and is also consistent with the Phase I BCV ROD. However, it is conservative considering the EMDF ROD will extend the DOE-controlled restricted industrial land use (Zone 3 in the Phase I BCV ROD) to include the EMDF site.

3.2 COMPOSITE ANALYSIS CONCEPTUAL MODEL

3.2.1 Site Conditions

Geology

A full description of the geology for the Bear Creek watershed is found in the BCV RI Report (DOE 1997a). The ORR is located in the southwestern portion of the Valley and Ridge physiographic province, which is characterized by a series of long, parallel ridges and valleys that follow a northeast-to-southwest trend. The topographically high ridges are underlain by more resistant geologic formations with broad intervening valleys underlain by less resistant formations. BCV is underlain by a thick sequence of early Paleozoic sedimentary rocks stacked within adjacent thrust sheets and that generally strike northeast-southwest around N-50 degrees-E. Bedding planes mostly dip to the southeast, with dip angles averaging around 45 degrees, but dips may vary widely on a local scale.

Bedrock on the ORR consists of a variety of interbedded clastic and carbonate sedimentary rocks. The rocks are variably fractured and weathered, resulting in significant vertical and horizontal subsurface heterogeneity. The differing degrees of resistance to erosion of the shales, sandstones, and carbonate rocks that comprise the regional bedrock influence local relief. Carbonate units (limestone/dolostone) are commonly extensively weathered with massive clay overburden with dispersed residual chert nodules and pinnacled bedrock surfaces. The more resistant clastic rocks (sandstone, siltstone, mudstone/shale) generally weather to an extensively fractured residuum (saprolite) with highly interconnected fracture networks overlying less weathered to unweathered more intermittently fractured bedrock.

The sequence of geologic formations underlying BCV from Pine Ridge southward to Bear Creek includes the Rome Formation of lower Cambrian age and formations of the Middle Cambrian Conasauga Group. Resistant sandstone beds of the upper Rome Formation form the crest of Pine Ridge (Lemiszki 2000). The Conasauga Group is overlain by the Knox Group formations that outcrop along the southern border of BCV. Cherty dolomite beds of the Knox Group form the crest of Chestnut Ridge along the south side of the valley. The stratigraphic sequence of formations in the Conasauga Group in BCV consists from bottom to top the Pumpkin Valley Shale, the Rutledge Formation, the Rogersville Shale, the Maryville Formation, the Nolichucky Shale, and the Maynardville Limestone. The Rutledge and Maryville Formations within BCV consist mostly of insoluble clastic rocks. Among the Conasauga Group formations, only the Maynardville Limestone has been recognized as containing significant conduit flow and karst features associated with limestone dissolution along the strike path of the Maynardville subcrop. That subcrop belt runs roughly parallel with the axis of Bear Creek draining toward the southwest along the margin of Chestnut Ridge.

The EMDF and EMWMF sites are underlain by the moderately to steeply dipping beds of the Maryville Formation on the northern end and by Nolichucky Shale on the southern end. Based on the location of the contact between the Nolichucky Shale and the Maynardville Limestone at the EMDF site, the distance from the southernmost margin of the facility to the karstic Maynardville unit is approximately 300 ft. The EMWMF was constructed a little farther north on the geologic section.

Bedrock fractures in Bear Creek Valley

Descriptions and data on bedrock fractures are available from previous site investigations and research in BCV and elsewhere on the ORR. The BCV RI Report (DOE 1997a) and other documentation (ORNL 1992a) addresses bedrock fractures in BCV and notes that because of the large-scale faulting and folding characteristic of ORR geology, all bedrock lithologic units in BCV are highly fractured, consisting of extensional, hybrid, and shear fractures.

Overall, the primary permeability of the rocks underlying BCV is very low. However, diagenesis, fracturing, and solution weathering of bedrock has resulted in secondary porosity and permeability through which most groundwater movement occurs. In addition, orientations of well-connected fractures or solution conduits are predominantly parallel to geological strike and/or bedding planes, enhancing the effect of anisotropy caused by layering. As a result, groundwater flow paths parallel to geological strike and bedding predominate.

Fracture aperture width generally decreases with depth in all formations and thus restricts the depth of active groundwater circulation. Hydraulically active fractures, and thus active groundwater circulation, occur at greater depths in the Knox Group and the Maynardville Limestone, which exhibit karstic features, than in the Conasauga Group.

In general, fracture spacing is a function of lithology and bed thickness. Fractures in more massively bedded formations tend to have longer trace lengths and are more widely spaced. An average fracture density of approximately 60/ft was measured in saprolites of the Maryville Formation and Nolichucky Shale (Dreier et al. 1987). At the other extreme, a minimum of five fractures per meter (1.5/ft) was measured in fresh rock (Sledz and Huff 1981). Fewer open fractures occur at deeper levels. Fracture frequency is variable, but most fractures observed in cores occur within limestone or sandstone layers greater than 1.6 ft thick and many are filled or partly filled with secondary minerals.

Most fractures are short, a few centimeters to approximately 3.3 ft in length (longest dimension). Fracture length at outcrops is relatively uniform (about 5 in.) in shale, but increases with bed thickness in siltstone (Sledz and Huff 1981). There are numerous fractures from approximately 0.3 to 5 ft long in limestone and sandstone units of the Conasauga Group and Rome Formation (Haase et al. 1985).

Detailed logging of core from wells at the BCBG site has provided information on the relative changes in densities of open (hydraulically active) fractures in the Nolichucky Shale compared to depth and lithology (Dreier and Davidson 1994). The resulting estimates for spacing of hydraulically active fractures ranged from ~3 ft in the shallow intervals to more than 20 ft in the deep intervals.

Characteristics of regolith and surficial deposits

In the humid subtropical climate of the southeast, the rocks have weathered over time to create an unconsolidated surficial regolith of topsoil, clayey residuum, and highly weathered rock (saprolite) covering the unweathered competent bedrock below. Unconsolidated mixtures of mud, sand, and gravel deposits (alluvium) occur along stream valleys, and relatively thin surficial deposits of colluvium may occur along the flanks of steeper slopes.

Regolith includes all materials that overlay competent bedrock, corresponding to the overburden in engineering terminology. Depending on the site topography and local conditions, the regolith in BCV may include surficial soils and clayey residuum, colluvium and alluvium along flanks and floors of the NT valleys, and underlying saprolite. For practical purposes, the depth of the regolith/top of competent bedrock may be considered as auger refusal drilling depth, which typically ranges from 10 to 30 ft. The typical subsurface profile in undisturbed upland areas underlain by predominantly clastic rocks of the Conasauga Group includes (1) a thin topsoil layer, (2) a clayey residuum interval, (3) variably weathered bedrock (saprolite), and (4) unweathered bedrock.

The thin topsoil layer of organic rich soil varies from a few inches to less than 1 ft thick. The zone of fine-grained residuum varies from less than 2 up to 10 ft in thickness. The underlying interval of highly weathered sedimentary rock (saprolite) can generally be drilled using a hollow-stem auger rig to the depth of auger refusal where the transition to less weathered or unweathered bedrock occurs. The thickness of these intervals varies and downward transition from one to the next may be rapid or gradual depending on the topographic position and history of profile development. Pore structure within the clayey residuum reflects surface soil formation processes, including macropore structures related to root growth and bioturbation (e.g., earthworm activity). Structural features of the underlying saprolite reflect the bedding and fracture geometry of the parent sedimentary rocks. The degree of weathering and fracturing generally decreases with depth, with corresponding decreases in porosity and permeability. There is extensive filling in saprolite fractures at the base of the soil zone due to translocation of clays. These clays and associated iron and manganese deposits contribute to the decrease in permeability with depth within the regolith.

Along the valley floors of Bear Creek tributaries, the upper portion of the surface profile may be replaced with stream channel and floodplain sediments (alluvium) that vary in width and thickness. Colluvial deposits may occur along the lower slopes of these valleys. A thicker belt of alluvial deposits occurs along the bottom of BCV.

Hydrogeology

Groundwater hydrology overview

A full description of the hydrogeologic conceptual model for the Bear Creek watershed is found in the BCV RI (DOE 1997a) and FS (DOE 1997b). These reports, approved by the regulators, reached the following conclusions. Groundwater flow and contaminant transport within the bedrock geologic units are important factors in the migration of contaminants in the watershed. In the northern portion of the valley, shallow groundwater and storm water flow through unconsolidated material and weathered bedrock is an important component of groundwater recharge and contaminant migration from source units to Bear Creek and its tributaries. Waste and contamination at the sources in BCV are situated in the subsurface, and shallow groundwater is the principal mechanism and pathway for release of contaminants. After release, most contaminants travel via short pathways in shallow groundwater to be discharged into tributaries to Bear Creek. Some contaminants, in particular those from the former operational S-3 Ponds, remain entrained in groundwater and discharge directly into the Maynardville Limestone.

The southern portion of the valley is underlain by the Maynardville Limestone, which contains a well-developed karst network created by dissolution and enlargement of fractures and joints. The underlying geology results in an asymmetric topographic cross-section of the valley, with the lowest elevations on the south side coincident with the Maynardville Limestone. Groundwater flow in the Maynardville Limestone occurs in both shallow and deep karst features, and corresponding flow rates and volumes are much higher than in the shale-dominated formation underlying the central and north portions of the valley. Large, individual springs or groups of springs mark the locations of discharge from both the shallow and deep karst flow systems into the surface water system. In addition, surface water flow in Bear Creek is highly connected with groundwater in the underlying Maynardville Limestone through karst features and losing and gaining reaches of the creek. Because of these characteristics, the interconnected Bear Creek stream channel and underlying karst system acts as the principal hydraulic drain for the valley and is part of the carbonate aquifer system in the BCV conceptual site model. By comparison, the shale-dominated formations in the central and northern portions of the valley function as aquitards with shallower and shorter flow paths.

The BCV hydrogeologic conceptual model differentiates between the surface water and groundwater flow within and across the predominantly clastic lithology underlying most of the valley floor from and the flow along Bear Creek, including groundwater flow within the karstic carbonate rocks along the southern margin of BCV. Across the clastic outcrop belts, hydraulic gradients that drive groundwater flow at shallow to intermediate depth tend to direct flow toward the south to southwest, whereas hydraulic gradient and groundwater flow within the Maynardville and along Bear Creek tends to more closely parallel the geologic strike toward the southwest. Local hydraulic gradients within the clastic rocks north of Bear Creek mirror the topography and are much steeper than gradients along the valley floor and Maynardville Limestone outcrop. The steep gradients within the clastic bedrocks, coupled with differential weathering of the interbedded formations, lead to anisotropic aquifer hydraulic conductivity that favors strike-parallel groundwater flow from local upland areas to the interspersed surface streams. The EMDF and EMWMF sites are centered across outcrop belts of the Maryville Formation and the lower portion of the Nolichucky Shale (corresponding to the lower half of the BCBG footprint).

Hydrologic subsystems for areas underlain by predominantly clastic (non-carbonate) rocks include the shallow stormflow zone, the vadose zone, three intervals within the saturated zone (water table, intermediate, and deep intervals), and an aquiclude at great depth where minimal water flux is presumed to occur. A majority of the estimated subsurface water flux occurs via two subsurface intervals: (1) the stormflow zone within the surficial topsoil/root zone, and (2) the uppermost part of the saturated zone (defined as the water table interval) (ORNL 1992b).

Subsurface flow within these intervals is directed downward and laterally from higher elevations toward stream valleys where shallow groundwater discharge occurs. Water flux through the intervening vadose zone is primarily vertically downward. The vertical component of flow in the water table interval varies according to topographic position (recharge versus discharge areas). Flux in the stormflow zone and water table elevation and flux through the water table interval respond rapidly to heavier precipitation events and contribute much of the quick flow component of storm-period runoff. At increasing depths (on the order of 100 ft or more), flow within the intermediate and deep intervals of the saturated zone contributes proportionally less than the upper intervals to the overall subsurface flux. Watershed studies generally confirm that most of the active groundwater flux occurs in the stormflow zone and uppermost (water table) interval of the saturated zone.

Another important aspect of the conceptual model relates to groundwater flow paths and rates that are dominant along fractures that trend parallel to geologic strike. Tracer tests and investigations of groundwater contaminant plumes on the ORR and in BCV demonstrate that groundwater tends to move more rapidly along fracture flow paths that are parallel to geologic strike versus flow paths that are perpendicular to strike. This is particularly true for the water table and upper intermediate intervals of the saturated zone where most groundwater flux occurs.

The distinction between the water table/intermediate levels and deeper levels is based on variation in groundwater chemical composition with depth thought to be related to water residence time. The approximate boundary between mixed-cation-bicarbonate (HCO_3) water and Na-HCO_3 water was defined at depths ranging from approximately 100 to 165 ft for the predominantly clastic rocks on the ORR such as those in BCV. The deep “aquiclude” composed of saline water having total dissolved solids ranging from 2000 to 275,000 mg/L lies beneath the deep interval at depths in portions of BCV believed to be greater than approximately 1000 ft (ORNL 1992b).

According to the conceptual contaminant transport model shown in Fig. 8 and used in the BCV FS, the primary contaminant migration pathways consist of shallow groundwater migration in the shale formations to surface water and transport in Bear Creek and Maynardville Limestone. The majority of the available water in upper BCV (precipitation minus evapotranspiration) quickly exits through the shallow system via flow in Bear Creek. Approximately 60 percent of precipitation in BCV is lost to evapotranspiration. One of the main points raised by the conceptual model is that although the largest mass of water 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 parallel to strike with the discharge points at tributaries to Bear Creek. Of the water available for flow (precipitation minus evapotranspiration) to the clastic formations on Pine Ridge, 94 percent leaves through discharge to the northern tributaries to Bear Creek. Approximately 6 percent of the water available to the clastic formations recharges the bedrock groundwater and, of this amount, less than 1 percent leaves by way of flow parallel to strike, and slightly over 5 percent leaves by way of groundwater flow into the Maynardville Limestone. As noted in Sect. 2.4.4.1, contaminants migrating from the waste sites in BCV converge at BCK 9.47/SS-5. More than 99 percent of the available water from the upper portion of the valley passes through this location as either surface water or groundwater.

A small portion of the available water remains in the Maynardville Limestone and moves down valley along strike flow. This is supported by particle tracking in a three-dimensional model that shows shallow groundwater moves quickly to nearby tributaries (DOE 1997a). The rate of transport increases during storms, moving contaminants either into Bear Creek or into the Maynardville Limestone. This interconnection between the shallow groundwater system and the Maynardville Limestone is supported by detection of uranium at all stretches of Bear Creek downgradient of source units and at all major springs in Upper Bear Creek, suggesting that uranium moves between Bear Creek and the Maynardville Limestone as it migrates down valley.

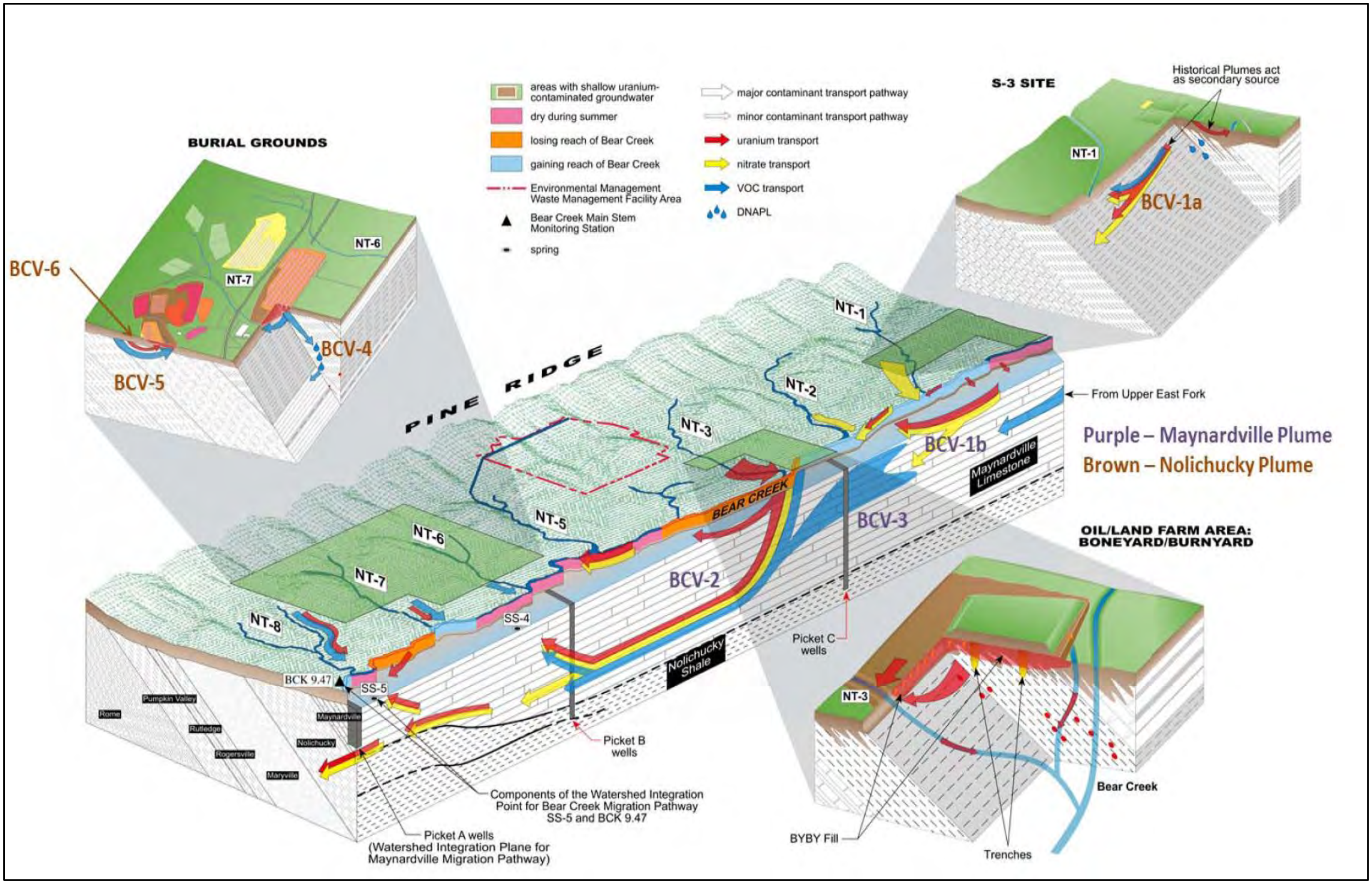

Fig. 8. Conceptual model for contaminant flow in Bear Creek Valley

Except for the uppermost sections of Bear Creek, stream flow along Bear Creek below BCK 9.47 is perennial. Upstream of BCK 9.47, Bear Creek has several gaining and losing reaches related to the karst conduit system in bedrock underlying Bear Creek, and stream flow disappears along stretches of the channel between NT-3 and NT-8 during low flow periods. Downstream from NT-8 and BCK 9.47, flow in the Bear Creek channel is gaining and perennial, even in low flow periods. Conduit flow continues in bedrock below that point, but the subsurface conduits remain saturated preventing complete capture of stream flow from the surface channel. Based on measurements collected from October 1, 2001 to December 31, 2014, the flow rate in Bear Creek at BCK 9.2 ranged from a daily low flow rate of 17.60 gpm to a daily high rate of 66,478.65 gpm with an average flow rate of 1106.5 gpm. The BCV RI (DOE 1997a, Appendices C and D), includes detailed information and analysis of the surface and subsurface flow system along Bear Creek.

The depth to the water table or unsaturated zone thickness varies across a relatively wide range from upland to lowland areas. Vadose zone thickness is greatest below upland areas such as those along Pine Ridge and along the subsidiary ridges underlying the Maryville outcrop belt. In these topographic positions, the water table can lie within the less-weathered and fractured bedrock, at depths exceeding 30 ft below the surface. Away from these upland areas of groundwater recharge, the vadose zone thins along the transition to groundwater discharge areas in valley floors where the water table is at or near the ground surface. In lower elevation areas, the water table lies within the weathered bedrock (saprolite) materials at depths less than 20 ft below the surface.

Groundwater within the saturated zone converges and discharges into stream channels along the tributary valley floors, supporting base flow, primarily during the wetter portions of the year. During drier periods, groundwater may make little or no contribution to stream channel base flow, but may continue to slowly migrate southward toward Bear Creek along the tributary valley floor areas within alluvium, saprolite, and bedrock fractures below the active stream channels. Deeper groundwater that does not discharge to the tributaries moves southward toward Bear Creek along pathways through the less fractured bedrock of the intermediate interval. Most of the groundwater flux within the saturated zone has been demonstrated to occur via the shallow water table interval with progressively less flux occurring at intermediate and deeper intervals. The flux decreases in proportion to a general decrease in saturated hydraulic conductivity (K_{sat}) with depth that is associated with smaller fracture apertures and an overall decrease in the number and density of interconnected fractures capable of transmitting groundwater.

Shallow groundwater also discharges to springs in narrow headwater ravines of Pine Ridge and across broader seepage faces along portions of the tributary valleys. Groundwater from these discharge locations contributes to stream channel base flow, particularly during the wet season. Water level hydrographs indicate that recharge to the water table interval occurs rapidly in response to significant rainfall events in most areas, but the response may be subdued and delayed in wells below upland areas where the water table is at greater depth and recharge rates are slower (DOE 2017b). In general, water table elevations are several feet higher (DOE 2019, Sect. 7.2), on average, during the wet season (approximately December through March or April) compared to the remainder of the year.

The following subsections provide additional detail of the hydraulic characteristics of materials and flow systems within the unsaturated (vadose) and saturated zone.

Unsaturated zone hydraulic characteristics

Unsaturated flow in undisturbed areas will migrate to the water table through the typical sequence of topsoil, silty/clayey residuum, and saprolite, which also includes veneers of alluvial and colluvial materials along the flanks and floors of the tributary valleys. Most of the water infiltrating the surface during and immediately after storm events travels laterally and relatively quickly through the topsoil stormflow zone to discharge with surface runoff along stream channels.

Recharge through the unsaturated zone in undisturbed natural settings is episodic and occurs along discrete permeable features that may become saturated during storm events, even though surrounding macro and micropores remain unsaturated and contain trapped air. During recharge events, flow paths in the unsaturated zone are complex, controlled to a large degree by the nature and orientation of structures such as relict fractures in saprolite (ORNL 1992b). It is important to note that much of the surficial material at the CBCV site will be removed during site preparation for EMDF construction, and that highly permeable vadose pathways will be less prevalent in the residual, geologic buffer, and structural fill materials below the disposal unit.

Most efforts to determine hydraulic conductivity (K) (i.e., slug tests, packer tests, borehole flow meter tests, and pumping tests) reported from sites in BCV have been conducted in the saturated zone or using laboratory tests on soil samples designed to determine K under saturated conditions. Saturated K measurements have been made in the vadose zone using infiltration tests and packer tests (ORNL 1992b) and the data are lognormally distributed with a geometric mean K_{sat} of 1.9E-03 m/day (2.2E-06 cm/sec) and a range (± one standard deviation) of 1.74E-07 cm/sec to 1.0E-04 cm/sec.

Saturated zone hydraulic characteristics

Hydraulic characteristics of the saturated zone in BCV have been determined by numerous investigations at sites in BCV. The following summarizes the findings from site investigations and research in BCV most relevant to the hydraulic characteristics of saturated subsurface materials at the CBCV site.

Porosity, Effective Porosity and Matrix Diffusion in the Saturated Zone. Estimates of porosity and effective porosity reported for subsurface materials in BCV vary along the vertical subsurface profile and among geologic units. This variation is closely correlated with variability in hydraulic conductivity measurements that are available.

While total porosity can be high (> 0.4) in fine-grained (silty clay), porous materials of the upper regolith in BCV, the drainable porosity is typically lower because the small pore size and high capillarity of the fine-grained materials prevent water from freely draining from the bulk of the material. Effective porosity (the fraction of total porosity associated with fluid advection) under hydraulic gradient conditions other than gravity-driven drainage can be higher than the drainable fraction of the total porosity.

Below the clay-rich upper residuum, the highly weathered and fractured saprolite and the upper bedrock materials are associated with higher total and effective porosities than the deeper, less weathered and fractured bedrock at depth. Within the saprolite, porosity also varies between fragments of less-weathered rock that are embedded in the highly weathered matrix material. These general features and downward transitions are evident in tube samples and test pits of soils and saprolite, and in bedrock cores. Local variations in porosity also reflect variability in the density and size of fractures in both saprolite and less weathered bedrock.

Values of effective porosity were obtained using petrophysical methods on bedrock core samples of mudrock specimens from Conasauga Group formations (Dorsch et al. 1996). Two hundred specimens were analyzed from among the Nolichucky, Maryville, Rogersville, Rutledge, and Pumpkin Valley formations. A mean value of 0.099 ± 0.026 was obtained using the immersion-saturation method (judged as the most reliable of the methods used) based on a total of 56 measurements. The authors noted that the values were significantly higher than those previously reported to range between 0.001 and 0.034.

In a separate study (Dorsch and Katsube 1996), effective porosities of saprolite were determined using Rotasonic core samples collected in the saprolite zone of the Nolichucky Shale in west BCV. Calculated interval effective porosities that characterize larger volumes of saprolite matrix and integrated both mudrock-fragment and groundmass effective porosities were determined to range from 0.51 to 0.26. These results suggest considerably higher effective porosity values for saprolite versus fractured bedrock and much higher values than those noted above (ORNL 1992b) for the top of the groundwater interval, which typically fluctuates within the saprolite zone. The calculated interval effective porosity data displayed a smooth decrease with depth, mirroring the saprolite weathering profile.

Effective porosity values reported by Dorsch et al. 1996 and Dorsch and Katsube 1996 are at least one to two (or more) orders of magnitude higher than those reported by ORNL (1992b) and Moore and Toran (1992) for the saturated zone, which were partly derived from analysis of groundwater level recession curves. In general estimates based on laboratory techniques for estimating porosity or other bulk sample characteristics range from a few percent to around 30 percent. Estimates of effective porosity based on pumping tests or other hydraulic analyses are generally less than 1 percent (field methods integrate the combined influences of the voids and the solid matrix over a larger volume). This dependence on analytical methods highlights the difference between the porosity associated with hydraulically efficient fracture networks and the larger porosity associated with the geologic matrix materials, which may be effective, but have much lower permeability than the factures.

The uncertainty and analytical variability in estimating effective porosity highlights the potential importance of contaminant mass transfer between highly conductive hydraulic pathways and less permeable zones. Contaminant mass transfer between highly mobile and less mobile domains is commonly referred to as matrix diffusion, though both advective and diffusive transport may occur between flow in more permeable and less permeable material zones. The availability and permeability of weathered matrix materials decreases with depth below the water table in the clastic rocks of BCV. Matrix diffusion is thought to play a critical role in attenuating the migration rates and concentrations of contaminants from source areas to downgradient locations. Depending on the rate of contaminant decay or degradation processes, diffusion of dissolved contaminants from more transmissive zones into less mobile micropores and microfractures can result in enhanced attenuation along flow paths.

Hydraulic Conductivity of the Saturated Zone. The most recent compilation of K_{sat} values reported for BCV (UCOR 2014) span seven orders of magnitude ranging from a minimum of 5E-05 ft/day (Nolichucky Shale) to a maximum of 164 ft/day (Maynardville Limestone). The values range from low K values determined from packer tests in deep coreholes to relatively high values measured in wells completed in karst conduits in the Maynardville Limestone. The K_{sat} varies by lithology, degree of weathering and fracturing, and depth. The K_{sat} values are influenced by the test method; borehole or well completion interval tested; number and vertical spacing among permeable fractures/fracture intervals and intervening relatively impermeable rock matrix intervals; and other factors.

In BCV, 232 conductivity tests were selected from 153 wells for statistical analysis: 63 in regolith, 164 in bedrock, and 5 in deep bedrock (Connell and Bailey 1989). Within BCV, the tested wells were located at the BCBG, OLF, and S-3 Ponds waste sites near EMWMF, and from a proposed Exxon Nuclear site between SR 95 and the Clinch River. These results include wells completed in the same geologic formations underlying and downgradient of the EMDF site and are, therefore, representative of the range of K_{sat} values that may be expected. The median K_{sat} values for the clastic rock formations underlying the EMDF site (i.e., Maryville Formation and Nolichucky Shale) are roughly an order of magnitude lower than the median K_{sat} value of the Maynardville Limestone.

In addition, BCV specific information included K_{sat} data from a total of 120 packer tests, 66 slug tests, and 4 pumping tests across a broad area of west BCV (Golder 1988). In this report, the K_{sat} data was subdivided into three depth horizons, 0 to 50 ft, 50 to 300 ft, and > 300 ft, for analysis. It was concluded that, "*there does not appear to be a strong relationship between K and geologic formation. However, K is clearly depth dependent*." The 0 to50 ft interval was considered the most permeable and most representative of saprolite or shallow bedrock, with progressive decreases in K with depth for the lower horizons. From shallow to deep, geometric mean K_{sat} values were assigned for the three horizons of 1E-04 cm/sec, 1E-05 cm/sec, and 1E-07 cm/sec.

A comprehensive compilation, summary, and analysis of K_{sat} data from multiple sites in BCV were presented in the BCV FS (DOE 1997b). The data were derived from slug tests/bailer recovery tests, packer tests, and pumping tests, including packer test intervals conducted in deep coreholes between depths of approximately 250 to 950 ft. The results of the K_{sat} tests presented in the BCV FS are summarized in Table 4. Plots of the data with depth provided in the BCV FS indicate that while there is considerable scatter in the range of K_{sat} values by depth, the data suggest an overall general tendency toward reduced K_{sat} values with depth that is consistent with less weathering and fracturing evident in subsurface samples/rock cores, and a general reduction in transmissive fractures with depth.

Table 4. Summary statistics compiled by for K data in BCV

Hydrogeologic unit	K (min) (ft/day)	K (max) (ft/day)	K (avg) (ft/day)	Count
Knox	0.0002	3.67	0.511	27
Maynardville Limestone	0.000027	99.0	8.132	41
Nolichucky Shale	0.000009	7.1	0.723	109
Maryville/Rutledge/Rogersville	0.00003	2.08	0.192	33
Pumpkin Valley/Rome	0.00086	1.156	0.223	18

Source: DOE 1997b.

BCV = Bear Creek Valley
DOE = U.S. Department of Energy
K = hydraulic conductivity

Anisotropy of Hydraulic Conductivity. Hydraulic conductivity tends to be anisotropic in BCV, with higher K_{sat} associated with bedding planes and joints in the strike-parallel direction relative to joint sets oriented at right angles to geologic strike. Expressed in general terms of the relationship of strike-parallel, dip-parallel, and cross-strata fracture flow pathways, $K_{strike} >> K_{dip} > K_{cross\text{-}strata}$ on a whole-rock basis. Anisotropy has been observed and estimated in BCV and elsewhere on the ORR by the tendency of tracers and contaminant plumes to elongate in the direction of strike, and by elongations in the cone of depression during pumping tests (described in Sect. C.3 in Appendix C of the BCV RI [DOE 1997a]). Some estimates of the degree of anisotropy in BCV range from 1:1 to 38:1, but most fall between 2:1 and 10:1.

A sensitivity analysis of anisotropy was conducted by varying K_{sat} values for strike and dip flow and comparing the actual groundwater head at numerous wells with that predicted by modeling (Bailey and Lee 1991). The analysis found that anisotropy of 1.1 to 1.25:1 provided the best matches between modeled and actual groundwater head and that preferential flow along strike is not indicated in BCV, except in the Maynardville Limestone. However, results of tracer tests conducted in the predominantly clastic formations of the Conasauga Group also exhibit anisotropy. A particle tracking model was used to investigate anisotropy in BCV and found empirically that particle tracks best mimic the S-3 Ponds contaminant plume at an anisotropy ratio of 10:1 (Evans et al. 1996). Sensitivity analysis indicated that anisotropy ratios lower than 10:1 provided better fits to the contaminant plume than did ratios higher than 10:1.

Hydraulic gradients

Hydraulic head patterns show convergent flow to the Maynardville Limestone in the valley floor aligned with the southwesterly flow along Bear Creek and indicating that it serves as the hydraulic drain for BCV. The anisotropy associated with strike-parallel fracture pathways tends to modify local flow directions.

The potentiometric surfaces in BCV are primarily influenced by topography and local recharge. Horizontal gradients tend to vary in proportion to the local topography so that steeper gradients occur along the steeper south flanks of Pine Ridge and adjacent to the subsidiary ridges/knolls underlain by the Maryville Formation. There is subdued mounding of the potentiometric surface under the knolls within the Maryville Formation outcrop belt. Piezometer measurements respond quickly during precipitation events then decrease rapidly to average conditions within days. Seasonal variations are evident, with higher potentiometric surfaces in late winter when precipitation occurs and vegetation is dormant. The lower potentiometric surface elevations occur in early fall when precipitation is low and plants are still growing. Where paired piezometers are present, a comparison of the shallow and deeper piezometers demonstrate a downward to flat gradient in the knoll areas, and slight upward gradients in areas away from the knoll areas. These gradients and the immediate response to precipitation show that the shallow groundwater is locally recharged by infiltration of precipitation on the knoll.

Water level monitoring confirms the overall groundwater flow direction from Pine Ridge towards Bear Creek and the Maynardville limestone, with lateral flow to the northern tributary drainages. Previous investigations in BCV indicate deep groundwater flow from Pine Ridge to Bear Creek and the Maynardville Limestone across bedding planes and geologic contacts, and may have higher potentiometric surfaces (upward gradients) at greater depths. However, flow conditions at depth discharge primarily to the Maynardville Limestone and are not found at elevations corresponding to the proposed EMDF.

Groundwater geochemical zones

The boundaries between the shallow, intermediate, and deep groundwater zones defined in the hydrologic framework for the ORR and BCV (ORNL 1992b) are transitional and not precisely defined. The boundaries vary with changes in local topography, vadose zone thickness, degree and depth of regolith and bedrock weathering, and bedrock stratigraphy. Hydrogeochemical processes involving exchange of cations on clays and other minerals result in a change from calcium bicarbonate (Ca-HCO_3) to sodium bicarbonate (Na-HCO_3) and ultimately to a sodium chloride (Na-Cl) type water at depth. These geochemical zones reflect groundwater residence times and reduction of water flux with depth.

The top of the intermediate zone is marked by a change in the dominant cations from Ca, Mg, and Na-HCO_3 to predominantly Na-HCO_3, and extends from approximately 100 ft to over 275 ft, where the transition to the deep zone is marked by a gradual increase in Na-Cl (Haase et al. 1987; Bailey and Lee 1991). The intermediate and deep zones are distinguished from the shallow zone by a change from a Ca-Mg-HCO_3 chemistry to a chemistry dominated by Na-HCO_3 (Moore and Toran 1992). The transition from Ca-Mg-HCO_3 to Na-HCO_3-dominant water is abrupt, occurring between depths of 80 to 200 ft in the Nolichucky Shale underlying BCV (Haase 1991), which suggests a well-defined flow boundary (Haase 1991). This water type is common to all Conasauga Group formations (Dreier et al. 1987) at intermediate and deep depths except in the Maynardville Limestone, and appears to be unrelated to stratigraphic changes. The Maynardville Limestone and adjacent Copper Ridge Dolomite exhibit both a Na-HCO_3 water type with distinct zones of Ca-Mg-Na-sulfate (SO_4) water. These sulfate-rich water zones appear to be related to the presence of gypsum beds in the carbonate units.

Summary

The BCV conceptual site model forms the basis for the current understanding of contaminant fate and transport in the valley. The models used in the contaminant fate and transport modeling performed to support this Composite Analysis were constructed to represent the BCV conceptual site model. Although the BCV conceptual site model cannot be direct input to the contaminant fate and transport modeling, the models used input parameters that represent the material conditions and water balance relationships in the BCV conceptual site model and assumptions consistent with the BCV conceptual site model. This section presents a justification for use of the BCV conceptual site model because it is the primary driver of the results from the Performance Assessment and Composite Analysis contaminant fate and transport modeling and the technical appropriateness of those results is assessed against the BCV conceptual site model. The remainder of this section describes the origin of the BCV conceptual site model and its evolution over the past 20-plus years. It summarizes fieldwork and the results of fieldwork that were used to check and calibrate the BCV conceptual site model. Finally, it documents the regulatory acceptance of the BCV conceptual site model.

Hydrogeological conceptual models for the ORR were developed in the early 1980s and 1990s to facilitate site characterization and remediation of contaminant sources and plumes within the unique site conditions across the ORR. The conceptual model for the BCV watershed is detailed in the BCV RI Report (DOE 1997a), which incorporates the hydrologic framework for the ORR developed by ORNL researchers (Moore and Toran 1992, ORNL 1992b), with the specific conditions unique to BCV and to contaminant fate and transport within BCV.

In developing the BCV hydrogeologic conceptual model, data collected during RI field activities within BCV were combined with a wealth of previous studies that have been carried out in BCV or elsewhere on the ORR. Interest in contaminant transport associated with the waste disposal sites in BCV motivated the Oak Ridge Y-12 Plant to develop a large database of environmental data from studies of the disposal areas and of potential exit pathways within the valley. BCV specific studies have included quarterly water level measurements summarized in an annual Groundwater Quality Report, data from studies carried out in BCV between 1984 and 1994 (for example, work by Golder Associates, and Geraghty and Miller provided hydraulic characteristics, as described in Sect. C.3 in Appendix C of the BCV RI [DOE 1997a]), an Exit Pathway Monitoring Program (that provided information on the Maynardville Limestone as described in Sects. C.3 and C.4 in Appendix C of the BCV RI), data from RIs conducted in BCV during 1994 and 1995, and other more specific studies carried out by the Environmental Sciences Division at Oak Ridge National Laboratory for the Groundwater Protection Program or the ORR Hydrology and Geology Studies program (e.g., Dreier et a1. 1993; Goldstran 1995; Moline and Schreiber 1995). Using these data, the BCV hydrogeologic conceptual model builds on the previous theories and hypotheses for groundwater movement on the ORR (e.g., ORNL 1992b; Moore and Toran 1992). A summary of the BCV hydrogeologic conceptual model was presented in the Phase I BCV ROD (DOE 2000a) that was approved by DOE, EPA, and the state of Tennessee. Figure 8 in this Composite Analysis appears as Fig. 2.4 in the Phase I BCV ROD.

The BCV conceptual site model formed the basis for the performance modeling for the EMWMF in the RI/FS and its addendum (DOE 1998a, DOE 1998b). The conclusions from that evaluation resulted in an approved ROD in which the selected remedy was the construction of the EMWMF (DOE 1999b). More recently, in December 2018 the EMWMF received an Operating DAS from DOE-Headquarters. This Operating DAS was issued following the development of adequate corrective actions to address issues from the LFRG relating to the addition of Cell 6 that increased the capacity of the EMWMF (DOE 2018b). The BCV conceptual site model as presented in the RI/FS and calibrated with the results of more recent investigations in BCV was integral to the modeling simulations used to address those issues.

To build consensus around a path forward for managing ORR groundwater challenges, a Groundwater Strategy Team was convened in 2013 and six workshops were held with representatives from DOE, EPA, and the state of Tennessee. Three of the workshops reviewed conceptual site models for the ORR watersheds. BCV was selected as the test case for the first workshop held in January 2013. The BCV conceptual site model is presented in Appendix B of the workshop documentation (DOE 2014). Figure 8 also appears as Fig. B.5 in this appendix. The appendix also presents a chronology of events associated with the Bear Creek Watershed.

The site-specific conceptual models for the proposed EMDF site presented in the EMDF RI/FS (DOE 2017b), the Performance Assessment (UCOR 2020a), and the UBCV groundwater model for this Composite Analysis are subsets of the overall conceptual model for the BCV watershed. The BCV conceptual site model predicts that the potential future release of contaminants via groundwater and surface water pathways would migrate initially from the footprint areas downgradient across the lower elevation areas of BCV dissected by the NTs and ultimately toward the main channel of Bear Creek. Recently, two major phases of characterization activities at the CBCV site occurred from February 2018 to January 2019 (DOE 2018e, DOE 2019). The focus of this characterization was to collect hydrogeological and geotechnical data for the evaluation of geology, groundwater, and geotechnical properties of soil and rock at the proposed EMDF site. The geologic and hydrogeologic data collected were consistent with the conceptual site model for this portion of BCV.

A ROD for EMDF will be written and approved based on this conceptual site model. However, a sensitivity analysis was performed in Sect. 5.8 of this Composite Analysis to quantify the composite dose using an alternate site conceptual model.

3.2.2 Source Term Release

Potential radiological contamination from EMWMF and the proposed EMDF are predicted to be released from the disposal cells through the liner system and the vadose (unsaturated) zone into the shallow groundwater beneath the cells. Similarly, water infiltration through the capped BCBG and the S-3 Ponds is predicted to become radiologically contaminated and enter the shallow groundwater. The shallow groundwater then flows toward one or more of the north tributaries or directly to Bear Creek until it is intercepted by and flows into a surface water feature (a north tributary or Bear Creek). North tributaries flow into Bear Creek and Bear Creek flows southwestward toward SR 95.

A source term for EMWMF was developed in the EMWMF RI/FS and its addendum based on a predicted waste inventory (DOE 1998a, Appendix B). This source term was then modeled to a hypothetical drinking water well located in the Maynardville Limestone near the confluence of NT-5 and Bear Creek and Bear Creek (for agricultural purposes) using PATHRAE-RAD (DOE 1998a, DOE 1998b). Neither the source term release model nor the conceptual model for radionuclide transport was modified for this Composite Analysis. However, the predicted waste inventory from EMWMF RI/FS was replaced with a predicted inventory at facility closure based on waste disposed to-date (UCOR 2019a).

A source term for EMDF was developed in the Performance Assessment (UCOR 2020a, Sect. 2.3) based on a predicted waste inventory (UCOR 2020a, Appendix B). This source term was then modeled to a drinking water well located 100 m from the waste in the predicted maximum contamination flow path and to Bear Creek (for agricultural purposes) using RESRAD-OFFSITE (UCOR 2020a, Sect. 3.3). Neither the source term release model nor the method of radionuclide transport was modified for this Composite Analysis.

Source term release modeling was not performed for the other existing BCV sources in this Composite Analysis. Uranium concentrations at the Integration Point (BCK 9.2) were quantified in the 2018 RER assuming post-remediation goals in the Phase I BCV ROD were being achieved. The 2018 RER (DOE 2018a) also presents concentrations of Tc-99 in Bear Creek. The conversion of these concentrations to a dose for the other existing BCV sources at the Integration Point is detailed in Sect. 2.5.1 of this Composite Analysis.

3.2.3 Radionuclide Transport

A three-dimensional UBCV groundwater flow model was developed during preparation of this Composite Analysis (see Appendix A). This model was used to predict groundwater flow field, flow path, and discharge to surface water streams. It also provided system water balance information in BCV and was used to determine if the site conceptual model and the composite exposure scenario using only the surface water in the pathway analysis at BCK 7.73 were appropriate. Additionally, the results of the modeling were used to assess the appropriateness of the location of the POA for this Composite Analysis.

The UBCV model was used because the large areal extent required of the model exceeded the existing EMWMF model and other site-specific models in BCV. Also, some of the site physical conditions changed from the mid-1990s when the regional watershed groundwater model (BCV model) was developed (DOE 1997b). The major physical changes included the construction of the EMWMF, the remediation and capping of the Boneyard/Burnyard, and capping of other waste source areas. The BCV model also has a scale that is too large (coarse grid) for a source release impact evaluation. The UBCV model is based on the regional Bear Creek watershed model developed during the Bear Creek watershed FS and detailed site-specific models developed during the waste disposition RI/FS for EMWMF and other supporting evaluations (DOE 1998a, DOE 1998b, BJC 2003, and BJC 2010).

The EMDF model, developed to aid the preliminary design of EMDF and used for the Performance Assessment of the EMDF, was then used to supplement the determination of the impact from the EMDF based on preliminary design (UCOR 2020a). The results of characterization performed on and adjacent to the EMDF site were incorporated in the EMDF model.

The UBCV model used the MODFLOW-2000 code (Harbaugh et al. 2000), and the EMDF models used the MODFLOW-2005 code (Harbaugh 2005) and the enhanced finite-difference groundwater flow MODFLOW codes developed by the U.S. Geological Survey (USGS) (USGS 1988), to simulate the groundwater flow condition and predict the interaction between groundwater and surface water. MODFLOW was selected for BCV because it is in the public domain and is widely used by the industrial, scientific, and governmental communities worldwide. This code has been rigorously tested and verified, and a variety of software tools are available for graphical pre- and post-processing. Various MODFLOW models have been developed for the Oak Ridge area and were developed for the BCV RI and FS as well as EMWMF design and performance evaluations. The results from these models have received tri-party approval under the CERCLA process (DOE 1996, DOE 1998b).

A telescopic mesh refinement (TMR) modeling approach was used to develop the UBCV model from the calibrated regional Bear Creek flow model (DOE 1997b). The TMR approach enables the user to develop a site-specific model using existing regional information and allows focusing on areas of interest with increased model grid resolution and more accurate representation of site-specific features. The TMR approach utilizes the results from the calibrated regional flow model to initialize boundary conditions (constant heads) and model parameters in the new TMR model that reduces the need for detailed recalibration. However, to better represent the locations of streams and waste disposal units including EMWMF and EMDF, further refinement was made after the site-specific flow model was constructed.

The model used in this Composite Analysis represents future site conditions, including the proposed EMDF. The model also incorporates the expected final EMWMF design and the proposed EMDF facility preliminary design features to predict the long-term performance after the disposal facilities are constructed and closed.

Groundwater Vistas, a model graphic user interface program, was used in the model development and pre- and post-modeling processes (Environmental Simulations, Inc. 2017). Construction of the UBCV model with the existing EMWMF and the proposed EMDF consisted of the following steps:

1. **Establish model domain and dimension**

   The TMR method was used to develop the UBCV model from the calibrated regional BCV flow model (DOE 1997a) by extracting boundary conditions, model layers, and model properties. A refined grid cell size (10 ft × 10 ft) was used for the new model domain to better represent detailed disposal facility design features.

2. **Model Refinement**

   To represent the detailed current site-specific features, the following refinements were made after the site-specific flow model domain was constructed:

   a) The refined and improved parameters used in the extensively calibrated EMWMF and EMDF models were incorporated into the UBCV model.

   b) Detailed adjustments were made to areas to smooth the transition along the model boundaries and parameter zones to more precisely represent the field conditions. The hydraulic conductivity zones and boundaries were adjusted based on field conditions and geological maps for the refined (smaller-spaced) grids.

   c) Parameters representing surface water features at the site (creeks and tributaries) were incorporated into the refined model to more precisely represent the site-specific conditions. To best represent the surface water-groundwater interaction, all of the surface-water features in BCV were incorporated into the model, including Bear Creek and its tributaries and their actual elevations. All of the site features (natural [i.e., ditches and channels] and engineered [i.e., underdrains]) were also represented in the model. The surface drainage features are represented in the model as drain cells.

   d) Final EMWMF six-cell design and proposed EMDF conceptual design were incorporated into the future condition model to predict the flow condition after disposal facility construction.

   e) Parameters representing the construction/engineered features for EMWMF and the proposed conceptual design of EMDF were incorporated into the model. Modifications were made to represent site-specific facility design and construction features (i.e., channel backfill, berms, underdrains, geologic buffer material, and surface drainages) associated with facility construction near the sites.

   f) Future landfill performance parameters (i.e., long-term recharge rate through waste zone) were included.

   g) Future landfill performance parameters for the existing waste areas in the BCBG were included based on information contained in the FFS for BCBG (DOE 2008).

Detailed UBCV flow model development and the appropriateness of the MODFLOW model are discussed in Appendix A.

Based on the flow model simulation, the movement of contaminants from the waste disposal cells and other existing BCV sources were simulated using MT3D (Zheng 1990), a three-dimensional fate-transport model code. The MT3D model and its appropriateness are discussed in Appendix A. Advective contaminant transport modeling scenarios were simulated during this Composite Analysis for the three source terms:

- Other existing BCV sources
- EMWMF
- Proposed EMDF.

Results of the UBCV contaminant transport modeling scenarios are shown on Figs. 9-11. The other existing BCV sources simulation predicts that contamination from the S-3 Ponds discharges into surface water streams (see Fig. 9). The simulation is consistent with current surface water monitoring data. This simulation also predicts that only some BCBG sources have groundwater contamination plumes (with low contaminant concentration) that extend west of the BCK 9.2 area. This also is consistent with current surface water and groundwater monitoring data.

The EMWMF source simulation (see Fig. 10) shows that contaminants predicted to be released from the cells will migrate into shallow groundwater and discharge into surface water streams near the cells. The simulation also shows that groundwater contamination plumes that migrate into the more permeable Maynardville Limestone will decrease in concentration rapidly due to mixing and will discharge downstream into Bear Creek. The BCV FS estimated that 97 percent of water available for leaching contaminants exited the upper section of the valley as surface water flow. In addition, of water available for flow in the predominantly clastic formations outcropping on Pine Ridge, 94 percent exited these formations via surface water in tributaries and 6 percent exited via subsurface flow (DOE 1997b, Sect. 1.2.1.8). Figure 10 represents the predicted maximum extent of contamination with no consideration of depth and time. Groundwater contamination plumes resulting from EMWMF and the BCBG do not reach BCK 7.73. Similar to the EMWMF source simulation, contaminants predicted to be released from EMDF will migrate into shallow groundwater and discharge into surface water streams and Bear Creek (see Fig. 11).

However, low concentrations of contamination from EMDF are predicted in shallow groundwater west of BCK 7.73 to about NT-14. (This is evaluated as a sensitivity analysis in Sect. 5.6.) To fully evaluate the EMDF plume, the modeled result from the EMDF site-specific groundwater model simulation performed during the EMDF Performance Assessment was also applied. Details concerning this source simulation modeling are discussed in Appendix A.

Consistent with the site conceptual model, these simulations show that groundwater contamination from all upper BCV sources discharge into Bear Creek before reaching BCK 7.73. These simulations also reinforce the appropriateness of using only surface water in the pathway analysis at BCK 7.73. The surface water location at the POA provides the closest (most impacted) location to the EMDF for the composite impact from all potential sources of radiological contamination in BCV.

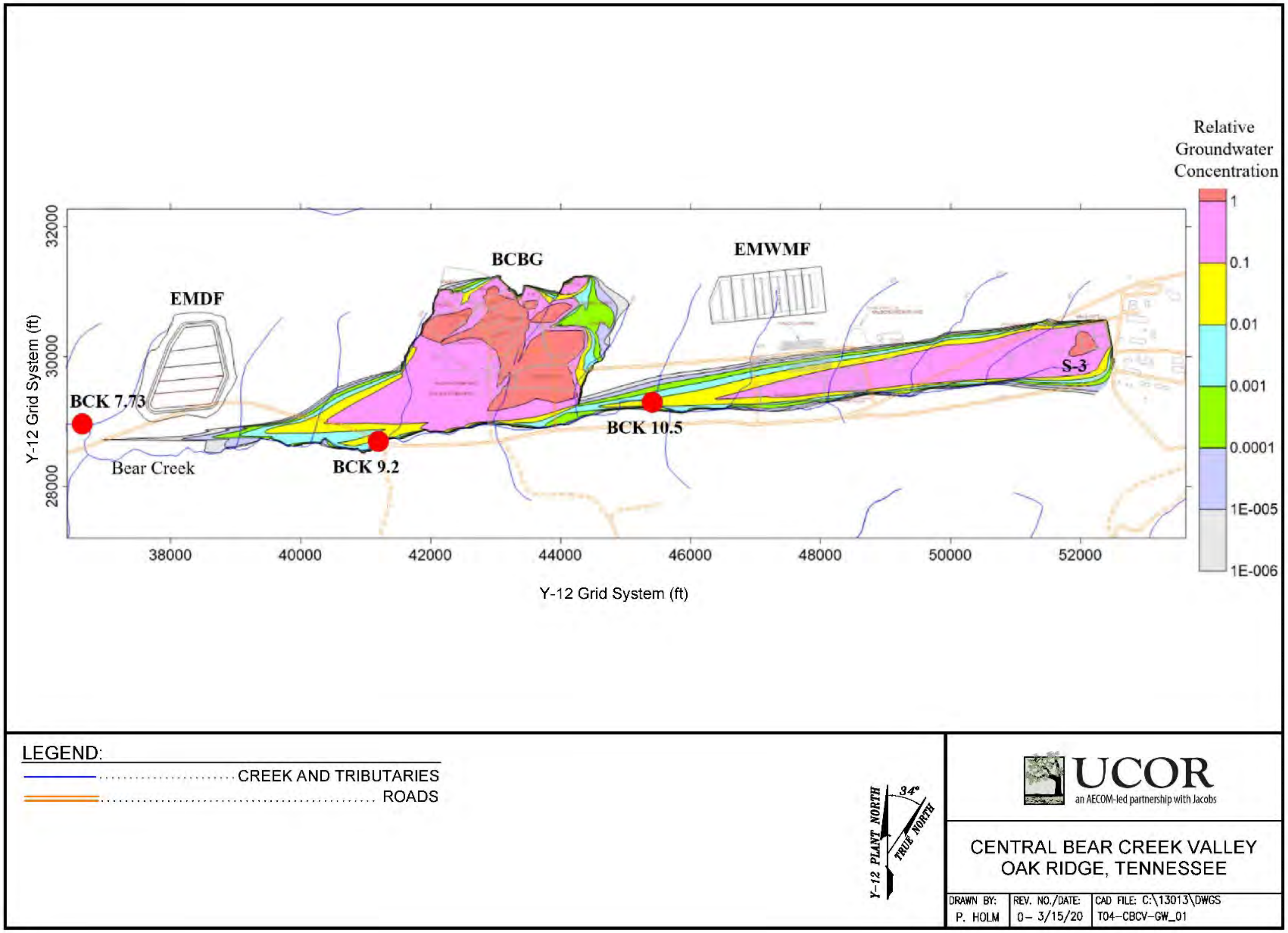

Fig. 9. UBCV model-predicted maximum extent of groundwater plumes from the other existing BCV sources (assumes a constant and infinite source)

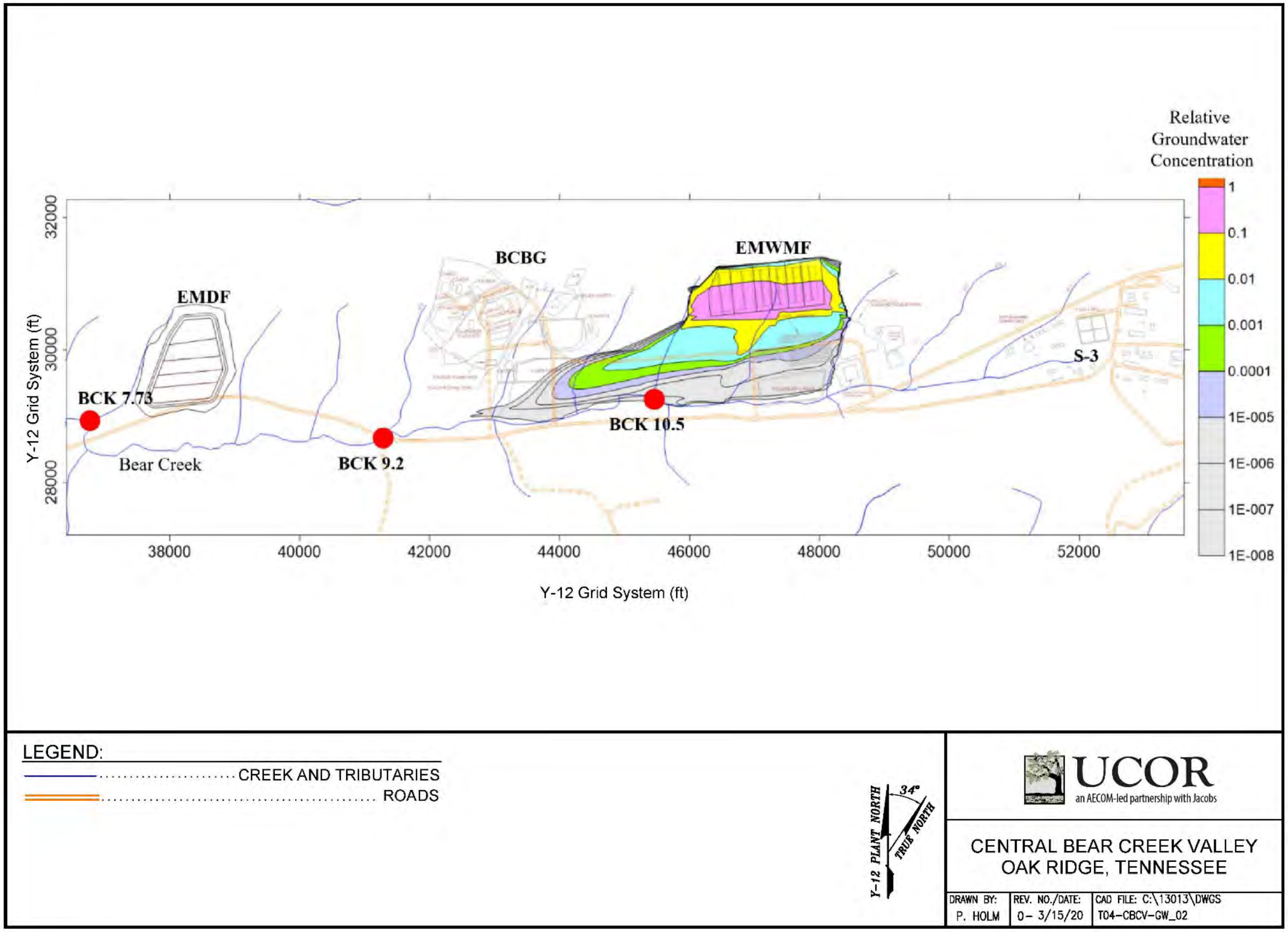

Fig. 10. UBCV model-predicted maximum extent of contaminated groundwater plume from EMWMF (assumes a constant and infinite source)

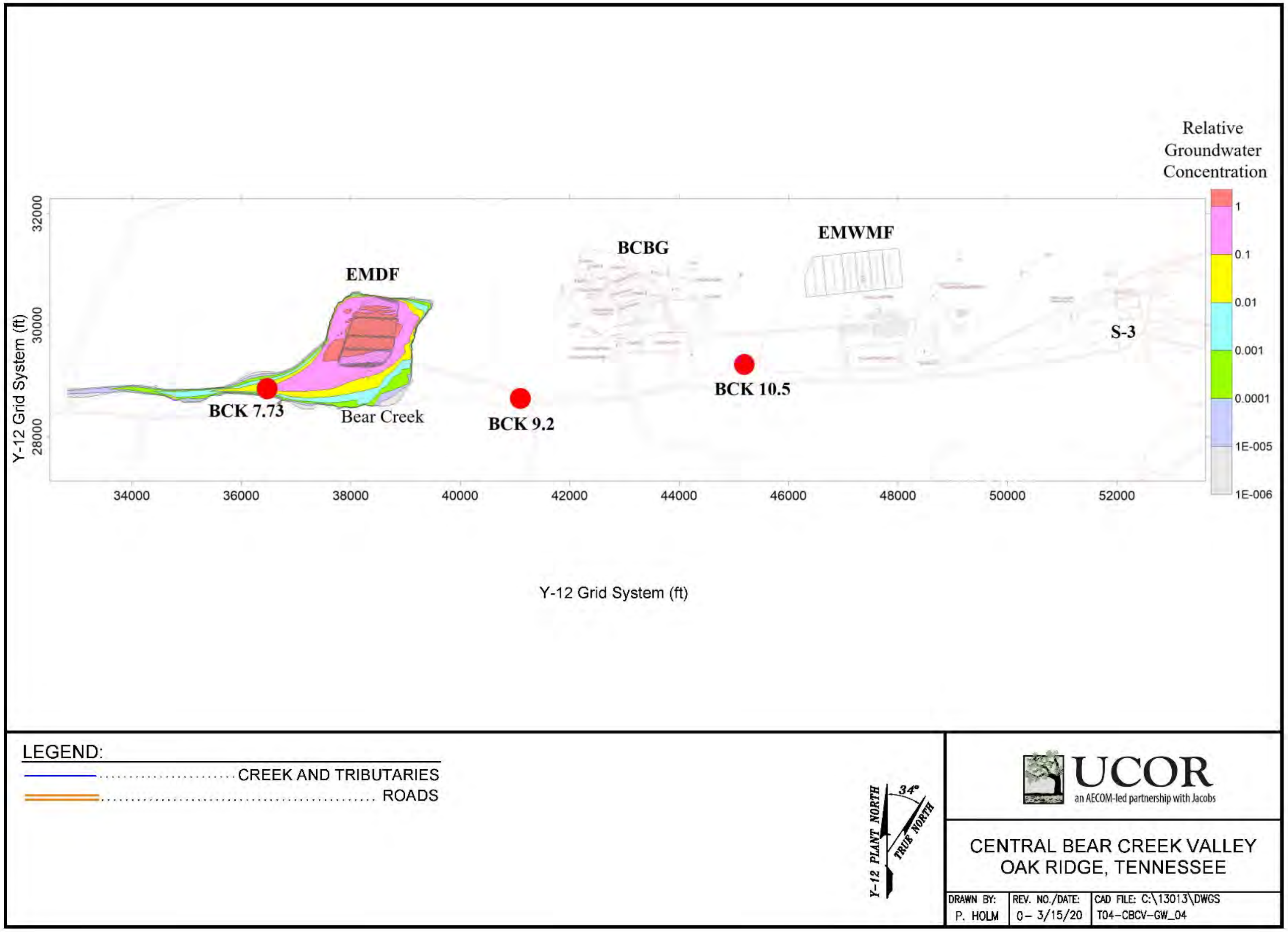

Fig. 11. EMDF model-predicted maximum extent of contaminated groundwater plume from EMDF (assumes a constant and infinite source)

3.3 EXPOSURE PATHWAYS AND SCENARIOS

The potential exposure pathways from waste sources include external radiation through direct exposure to the waste, inhalation through air exposure to contaminated dust and radon, and ingestion of contaminated onsite soil and domestic/agricultural use of water contaminated by the sources.

All the exposure pathways and environmental pathways to the hypothetical receptors are listed in Table 5. Of these pathways, external radiation, inhalation, and ingestion of onsite soil are not likely because waste sources will either be removed or capped and land use restrictions will eliminate these environmental pathways to the receptor. The only exposure pathways capable of exposing the hypothetical receptor to radiological contamination from the sources are ingestion of water and ingestion of food supported by the agricultural use of water (see Table 5). The resident farmer at the POA provides the most complete scenario for the quantification of total dose from the exposure to potential radiological contaminants for this Composite Analysis.

Table 5. Environmental and exposure pathways

Environmental pathway	Exposure pathway	Potentially contributes to dose at Composite Analysis receptors?	Justification for elimination of pathway/comments
Direct exposure	External radiation	No	Potential sources will be removed or capped Land use controls prevent public access to potential sources (EMWMF and other existing BCV sources), EMDF ROD will required long-term maintenance of cover under CERCLA
Air exposure – dust/H-3	Inhalation	No	Potential sources will be removed or capped Land use controls prevent public access to potential sources (EMWMF and other existing BCV sources) Calm regional wind regime, receptor location predominantly downwind of potential sources Evaluation performed in Sect. 3.2.2 of EMDF Performance Assessment (UCOR 2020a)
Air exposure – radon	Inhalation	No	Potential sources will be removed or capped Land use controls prevent public access to potential sources (EMWMF and other existing BCV sources) Evaluation performed in Appendix H of EMDF Performance Assessment (UCOR 2020a)
Onsite soil	Ingestion	No	Potential sources will be removed or capped, land use controls prevent public access to potential sources (EMWMF and other existing BCV sources), EMDF ROD will prevent public access and require cover maintenance under CERCLA
Released contaminated water consumption	Ingestion	Yes	Used for all drinking water at point of assessment

Table 5. Environmental and exposure pathways (cont.)

Environmental pathway	Exposure pathway	Potentially contributes to dose at Composite Analysis receptors?	Justification for elimination of pathway/comments
Plant foods	Ingestion	Yes	Ingestion of plant foods irrigated with contaminated water
Livestock – meat	Ingestion	Yes	Ingestion of meat includes uptake from contaminated water and plant foods ingested by livestock
Livestock – milk	Ingestion	Yes	Ingestion of milk includes uptake from contaminated water and plant foods ingested by livestock
Aquatic foods	Ingestion	Yes	Considers fish caught from contaminated Bear Creek surface water

BCV = Bear Creek Valley
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
ROD = Record of Decision

The resident farmer exposure scenario had been used as a hypothetical receptor to develop the EMWMF WAC. The hypothetical receptor in the Phase I BCV ROD located at BCK 9.2 was also assumed to be a resident farmer. To be consistent with the ROD and WAC development, the hypothetical receptor at the POA for this Composite Analysis (BCK 7.73) also is assumed to be a resident farmer. The exposure pathways for this exposure scenario are also consistent with the exposure pathways evaluated for EMWMF and the other existing BCV sources. It is also consistent with the land use assumptions in the Phase I BCV ROD and the exposure scenario for the EMDF evaluated in the EMDF Performance Assessment.

Based on the conceptual site model and the supporting contaminant fate and transport discussion in Sect. 2.4.4.1, the base case assumes all contamination is received via the surface water pathway. (The resident farmer is assumed to draw contaminated surface water from Bear Creek at the point where most of the contaminated groundwater from the EMDF is predicted to discharge.) Under this assumption, the hypothetical receptor in the base case assessment ingests contamination from all three sources by drinking water from Bear Creek and by using Bear Creek water for agricultural purposes. The residential exposure scenario adopted for this all-pathways analysis assumes the use of local surface water for drinking and agricultural use, even though BCV is served by the City of Oak Ridge municipal water distribution system. The assumptions regarding the use of only surface water resources by the resident farmer are consistent with the exposure scenarios used in the evaluation of EMWMF performance (DOE 1998a), the development of the EMWMF waste acceptance criteria (DOE 1998b), the Phase I BCV ROD (DOE 2000a), and the EMDF Performance Assessment (UCOR 2020a). Note that since the UBCV modeling concluded there is no contamination from the EMWMF and the other existing BCV sources in the groundwater at the POA (see Figs. 9 and 10), the dose from consumption and/or use of surface water at BCK 7.73 must be quantified in order for contamination from the EMWMF and the other existing BCV sources to be included in a composite dose.

Use of water resources

In Eastern Tennessee, abundant rainfall and numerous surface water reservoirs support extensive use of surface water resources. Based on a recent Tennessee Valley Authority (TVA) water use report, in

Anderson and Roane Counties (the counties in which the Oak Ridge Reservation is located), surface water withdrawals for public water supply and crop irrigation are much greater than groundwater withdrawals for those two uses (TVA 2012, page 16). The proportion of total public water supplies withdrawn from groundwater sources in 2010 was 1.6 percent and 16 percent for Anderson and Roane Counties, respectively (Table 6).

Table 6. Groundwater and surface water withdrawals in Anderson and Roane Counties for 2010

Tennessee county and water use		Surface water withdrawal (2010) in million gal/day (% of total)	Groundwater withdrawal (2010) in million gal/day (% of total)
Anderson	Public supply	13.2 (98%)	0.22 (1.6%)
Roane	Public supply	6.65 (84%)	1.28 (16%)
Anderson + Roane	Public supply	19.85 (93%)	1.5 (7%)
Anderson	Irrigation	0.45 (98%)	<0.01 (<2.2%)
Roane	Irrigation	0.04 (> 80%)	<0.01 (< 20%)
Anderson + Roane	Irrigation	0.49 (96%)	< 0.02 (3.9%)

Source: TVA 2012, Table 2-21 (public supply) and Table 2-24 (irrigation).

TVA = Tennessee Valley Authority

In Anderson and Roane Counties, relatively little groundwater withdrawal for agriculture is required to supplement natural precipitation and surface water. For irrigation of crops, the proportions of water withdrawals from groundwater and surface water in 2010 for Anderson and Roane Counties were similar to proportions withdrawn for public supply (Table 6). The predominant use of surface water for irrigation reflects its accessibility. When a source is available, reliable, and convenient, such as Bear Creek, surface water is used for irrigation rather than groundwater. The Tennessee Department of Environment and Conservation states that withdrawal of water from wells for irrigation in Tennessee is much less than the national average (<10 percent versus approximately 30 percent) (Tennessee Department of Environment and Conservation 2016, page 37).

County level water use data available from the USGS indicates that withdrawals of surface water to support livestock exceed groundwater withdrawals for that purpose by a factor of 2 or more (http://waterdata.usgs.gov/tn/nwis/water_use/). In the USGS database for 2010, Anderson and Roane Counties together used 0.27 million gal/day for livestock, which is less than the irrigation total for that year based on the TVA water use report (TVA 2012, Table 3.7). Information from the TVA report is summarized in Table 6. However, the USGS data for years 2000, 2005, 2010, and 2015 all indicate that surface water withdrawals for livestock are two to ten times larger than total crop irrigation withdrawals, which is consistent with the abundant rainfall and ready availability of surface water sources to support agriculture in Anderson and Roane Counties. The predominant use of surface water for irrigation and livestock in the vicinity of the ORR supports the Composite Analysis exposure scenario assumption that water from Bear Creek is used for agriculture.

While not unrealistic, this all-pathways exposure scenario is based on a local agricultural subsistence lifestyle that is uncommon in present day Eastern Tennessee, which provides bias toward more highly exposed individuals. A subsistence farmer is specified as the representative receptor to incorporate a diverse set of exposure pathways. For purposes of this Composite Analysis, the exposure at the time of peak dose is evaluated relative to the performance objective of 100 mrem/year.

3.4 MODELING TOOLS

RESRAD-OFFSITE modeling was performed in the base case assessment in this Composite Analysis to estimate the contribution to a composite dose for a hypothetical receptor using Bear Creek water at the confluence of NT-11 from the closed EMDF. The modeling performed in the Performance Assessment using RESRAD-OFFSITE is detailed in Sect. 3.3.4 of the EMDF Performance Assessment. Note that the Performance Assessment also modeled contaminant flow to a surface waterbody (Bear Creek). Therefore, the only modification to that modeling to support this Composite Analysis was to revise the intake of water by the hypothetical receptor from well water to surface water. The Performance Assessment (UCOR 2020a) summarizes the RESRAD-OFFSITE model, as described below.

For purposes of modeling the total EMDF disposal system, including source release, environmental transport, exposure pathways, and dose analysis, the computational code RESRAD-OFFSITE version 3.2 was selected (Yu et al. 2007, Gnanapragasam and Yu 2015). In general, the detailed hydrologic and radionuclide transport processes in the vadose and saturated zones (described in the Performance Assessment) have simplified conceptualizations and parameterizations in RESRAD-OFFSITE (UCOR 2020a, Fig. 3.27). The total system model provides a holistic, integrated representation of the EMDF disposal system. As the total system model and detailed models were developed in parallel, predicted concentrations and fluxes in EMDF subsystems can be compared to provide confidence that simplified total system sub-model results are consistent with more complex models of the system. RESRAD-OFFSITE also was used as an initial radionuclide screening tool (UCOR 2020a, Sect. 2.3.2) and for the inadvertent human intrusion dose analysis (UCOR 2020a, Sect. 6.6).

Total system simulations were performed for a post-closure period of 10,000 years to provide the dose estimates for comparison with the Composite Analysis performance measures, focusing on a predicted total dose outside of the 1000-year compliance period (see Sect. 5.3). Potential future release of relatively immobile radionuclides with significant expected inventories (e.g., U-234) was evaluated with a 100,000-year RESRAD-OFFSITE simulation to identify peak concentrations at the (BCK 7.73) POA (see Sect. 5.3). The RESRAD-OFFSITE simplified representation of EMDF and its site is summarized in Sect. 3.3.4 of the Performance Assessment. It also describes parameterization of the abiotic radionuclide transport pathways, including source release and the vadose and saturated zones. The RESRAD-OFFSITE exposure scenario, biotic pathways, and dose analysis are described in Sect. 3.3.4 of the Performance Assessment; there are hundreds of input parameters for RESRAD-OFFSITE, but only the important parameters are presented in Sect. 3.3.4 of the Performance Assessment. Detailed explanation of all RESRAD-OFFSITE input parameters and tabulation of all base case parameter values is provided in Appendix G of the Performance Assessment.

RESRAD-OFFSITE identifies subsystems, including the primary contamination (EMDF waste), cover soil layer, a layered vadose zone below the waste, the aquifer (saturated zone), and dwelling and agricultural areas that can be affected by the release of radionuclides from the primary contamination.

Three-dimensional groundwater flow and radionuclide transport models for the CBCV site were developed to assess the impact of the proposed EMDF in the Performance Assessment. These models were used to guide the implementation of the RESRAD-OFFSITE model of the EMDF system. A description of these models, initial model development and revisions made to support the Performance Assessment, justification for use of the models, and description of the input parameters are included in Appendices D and F of the EMDF Performance Assessment and in Appendix A of this Composite Analysis.

To calculate the dose from EMDF, several modifications were made to the RESRAD-OFFSITE input parameters to predict the dose from using surface water within Bear Creek at its confluence with NT-11. It was assumed that the stretch of Bear Creek impacted by contaminated groundwater was 100 m long, 5 m wide, and 0.5 m deep, which is consistent with Sect. 3.3.4.6 in the Performance Assessment. The mean residence time of water in this section of Bear Creek was specified as 0.0001 years, which relates to an average flow rate of 0.08 m^3/sec. The distance from the down gradient EMDF edge of waste to the assumed impacted portion of Bear Creek was modeled as 315 m. To assess the predicted dose resulting from using water and consuming fish from Bear Creek that is potentially contaminated with groundwater migrating to the surface water body, it was assumed in the model that all water for human and animal consumption originated from the hypothetically impacted portion of Bear Creek. To represent this assumption in RESRAD OFFSITE, two parameters in the Water Use parameter input menu were modified from their value in the Performance Assessment model. In the Performance Assessment model, all water for consumption and indoor use was assumed to come from a production well located 100 m from the edge of waste, and the fractions of water from the impacted well for consumption by humans and indoor dwelling use were accordingly assigned a value of 1 (indicating 100 percent). In the Composite Analysis model, the fraction of water from the surface water body (Bear Creek) consumed by humans and the fraction of water used in the indoor dwelling were specified as 1 (all water originating from Bear Creek). All irrigation water also is assumed to originate from the hypothetically impacted section of Bear Creek. In addition to assuming all water used for consumption and irrigation originated from Bear Creek, it also was assumed that all fish consumed came from the affected surface water body. The modeling assumes that three-quarters of the beef and one-half of the other food that is consumed originates from outside of this exposure scenario. (This is consistent with the EMDF Performance Assessment.) The results of the RESRAD-OFFSITE modeling following the compliance period were used to support the post-1000-year maximum dose calculation in Sect. 5.3.

The dose from EMDF for the base case assessment in this Composite Analysis is estimated at 0.25 mrem/year in Bear Creek at the convergence of NT-11. This dose results primarily from exposure to C-14 from the ingestion of fish.

PATHRAE-RAD (Rogers and Associates 1995) was used to quantify a dose in Bear Creek at BCK 10.5 from the EMWMF following closure for the base case assessment. This dose was quantified assuming a waste inventory at closure based on actual waste disposed to-date. PATHRAE-RAD was used to develop the WAC for EMWMF in 1998. For this reason, PATHRAE-RAD was used to repeat the EMWMF modeling for this Composite Analysis using the updated waste inventory. Its use in supporting the base case assessment, as well as a detailed description, justification, and input parameters, is included in Appendix B of this Composite Analysis. The results of the PATHRAE-RAD modeling following the compliance period were used to support the post-1000-year maximum dose calculation in Sect. 5.3.

PATHRAE-RAD is a computer code capable of assessing multiple transport pathways for radiological contaminants that have the potential to impact human receptors. PATHRAE-RAD was originally developed for EPA (PATHRAE-EPA) to use in preparing standards for management of LLW (EPA 1987). PATHRAE-RAD can be used to estimate risks and doses to humans from possible releases and subsequent transport of contaminants through multiple pathways from land disposal units containing chemical and radioactive wastes. The code can be used to calculate risks at specified points in time and peak risks (in time) to individuals at any number of key locations inside or outside the boundaries of a disposal facility.

The dose from EMWMF for the base case assessment in this Composite Analysis is estimated at 0.09 mrem/year in Bear Creek at the convergence of NT-5. This dose results primarily from exposure to the mobile radionuclides C-14, I-129, H-3, and Tc-99 by consuming Bear Creek water.

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4. RESULTS OF THE ANALYSIS

4.1 SOURCE TERMS

The three source terms defined and quantified for the base case assessment include the following:

- Other existing BCV sources—0.98 mrem/year at BCK 9.2
- EMWMF—0.09 mrem/year at the confluence of NT-5 and Bear Creek (BCK 10.5)
- EMDF—0.25 mrem/year at the confluence of NT-11 and Bear Creek (BCK 7.73).

The confluence of NT-11 and Bear Creek also is the POA for this Composite Analysis.

4.2 ENVIRONMENTAL TRANSPORT OF RADIONUCLIDES

The composite impact at the POA (BCK 7.73) from the other existing BCV sources, EMWMF, and the proposed EMDF is governed by surface water flow because groundwater contamination enters Bear Creek upstream of the POA and is mixed as it flows to the POA. The Bear Creek surface water flow rate data in the Oak Ridge Environmental Information System was analyzed to quantify this mixing.

Bear Creek stream flow has been continuously monitored at BCK 9.2 (the Phase I BCV ROD Integration Point and just downstream from NT-8) and BCK 11.54 (just downstream from NT-3) since 2001. The average flow rate at BCK 9.2 is 1100.9 gpm and the average flow rate at BCK 11.54 is 383.8 gpm based on daily average data from October 1, 2001 to September 30, 2018. Flow rates have only been intermittently measured at other points along Bear Creek during this period. A comparison of long-term monitoring data collected at locations BCK 9.2 and BCK 11.54 (two points upstream of BCK 7.73) between January 2003 and December 2014 indicate the continuous flow and gaining nature of the stream. Flow at the downstream location (BCK 9.2) is continuous and greater (typically four to five times greater) than flow at the upstream location (BCK 11.54) indicating a gaining stream.

The use of an average flow rate in the creek is considered appropriate because it is assumed that the hypothetical receptor uses water from the creek every day of the year. It may be argued that water from the creek would be needed for agricultural purposes primarily during periods of little precipitation and corresponding periods of lower flow in the creeks (presumably resulting in higher levels of contamination in the creek water). However, periods of lower flow in the creek occur in late fall when no crops are grown in Eastern Tennessee. Information provided in Sect. 3.3 documents that in Anderson and Roane counties, very little water is required on an annual basis to supplement natural precipitation. Additionally, lower flow in the creek does not necessarily result in higher concentrations of contamination because lower flow in the creek would be the result of less precipitation, which would leach and transport less contamination from the sources.

Regular flow rate measurements are not collected at BCK 10.5 (the confluence of NT-5 and Bear Creek, the location that would include potential contamination from EMWMF) and flow rate data collected to support the BCV RI and FS studies were only short term in nature and were not suitable for direct comparison to the long-term, continuously measured data at BCK 9.2. To obtain a reasonable flow ratio between BCK 9.2 and BCK 10.5, a surface drainage area analysis was conducted. The surface planar areas above BCK 10.5 and BCK 9.2 were digitized along the surface water divides using a detailed topographic map. The area above BCK 10.5 is about 2.70×10^7 sf. The total area above BCK 9.2 is 4.43×10^7 sf. The planar area (indirectly related to rainfall) ratio between BCK 9.2 and BCK 10.5 is 1.64. Using the same area/flow rate relationship, the inferred flow rate at BCK 10.5 would be 671.3 gpm. This inferred flow rate of 671.3 gpm is reasonable for the BCK 10.5 location when compared to the measured rate of 383.8 gpm at the upstream location of BCK 11.54. Additionally, the calculated planer area ratio between BCK 9.2 and BCK 11.54 is 2.63. This compares well with the average surface water flow ratio of 2.87. Based on flow rate and surface area analysis, a flow rate mixing ratio of 1.64 was selected for the Bear Creek interval between BCK 9.2 and NT-5 (EMWMF contaminant inflow). The resulting dose at BCK 9.2 from EMWMF was determined by using the mixing ratio in Bear Creek from BCK 10.5 downstream to BCK 9.2.

Similarly, there is no direct surface water flow measurement at BCK 7.73 (the POA for this Composite Analysis at the confluence of NT-11 and Bear Creek). The same surface area and flow rate relationship was applied to calculate the flow rate at BCK 7.73. As discussed above, the flow rate at BCK 9.2 is well defined, with the BCV surface area having the same characteristics in terms of geological units, weathering characteristics, and vegetation. Therefore, using the 1.43 ratio of the surface area between the areas above BCK 9.2 and above BCK 7.73, the likely surface water flow rate at BCK 7.73 can be calculated based on long-term field measurements at BCK 9.2. The calculated flow rate at BCK 7.73 is 1574.3 gpm. This estimated flow rate then is reasonable when compared to 1100.9 gpm at the upstream location of BCK 9.2. This mixing ratio is then used to calculate the overall surface water concentration (dose) at BCK 7.73 from the sources upstream of this POA. The mixing ratio between BCK 9.2 and BCK 7.73 is predicted to be 1.43.

There are two advantages to using this two-step process to define the contaminant mixing in Bear Creek between EMWMF and the POA. First, it enables a dose to be predicted from EMWMF and the other existing BCV sources that exit Zone 3 (as currently defined by the Phase I BCV ROD), if needed. Second, it allows the incorporation of field flow data that exist for BCK 9.2 to derive the flow rate at BCK 7.73 (so that other sensitivity analyses may be conducted, such as the Oak Ridge Reservation-wide impact in Sect. 5.9).

4.3 EXPOSURE AND DOSE

The analysis methodology considered the information presented in the above sections to arrive at a total dose (in mrem/year) for a hypothetical receptor at the POA (BCK 7.73). The dose from EMWMF at the confluence of NT-5 and Bear Creek was reduced by a factor of 1.64 to simulate the mixing in Bear Creek between NT-5 and BCK 9.2, and then was reduced by a factor of 1.43 to simulate the mixing between BCK 9.2 and BCK 7.73. The dose from the other existing sources in BCV at BCK 9.2 was reduced by a factor of 1.43 to simulate the mixing in Bear Creek between BCK 9.2 and BCK 7.73. The two doses were added to the dose from the proposed EMDF to arrive at a total dose to the hypothetical public receptor at the POA for the base case assessment in this Composite Analysis. No mixing is considered in Bear Creek for the dose from the EMDF because BCK 7.73 also is the POA. The resulting cumulative annual dose for the base case assessment is 0.98 mrem/year. The base case assessment is summarized in Table 7.

Table 7. Base case assessment summary

Source term	Dose and location (mrem/year)	Bear Creek mixing ratios		Dose at Composite Analysis POA (mrem/year)
		BCK 10.5 to BCK 9.2	BCK 9.2 to BCK 7.73	
Other existing BCV sources	0.98 (BCK 9.2)	NA	1.43	0.69
EMWMF	0.09 (BCK 10.5)	1.64	1.43	0.04
Proposed EMDF	0.25 (BCK 7.73)	NA	NA	0.25
			Total dose	**0.98**

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
NA = not applicable
POA = point of assessment

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5. SENSITIVITY AND UNCERTAINTY ANALYSIS

DOE guidance (DOE 2017a) for preparing a composite analysis requires that a limited sensitivity or uncertainty analysis be conducted to facilitate the interpretation of the results of the composite analysis. The primary purpose of the sensitivity and uncertainty analysis is to support the determination that the results of the Composite Analysis lead to a conclusion that there is a reasonable expectation of meeting the performance measures. The sensitivity or uncertainty analysis is to consider sources of contamination, other than the LLW disposal facility, that triggered the preparation of the Composite Analysis (i.e., EMWMF and the proposed EMDF) and to focus on land use controls and exposure scenarios. The analysis must also consider uncertainties in source terms (i.e., inventories and release rates) for each of the sources considered in the Composite Analysis. For sources of contamination subject to future remedial action under CERCLA, the sensitivity to different selected remedial alternatives should also be analyzed.

The following sensitivities were evaluated in this Composite Analysis:

- Sensitivity to Land Use—A qualitative assessment of the results of this Composite Analysis in the event that the proposed EMDF and adjacent land remains DOE-controlled in the future.
- Sensitivity to Remedial Actions on Other Existing BCV Sources—(i) An assessment that uses Bear Creek contaminant levels to estimate a dose at BCK 9.2 and incorporates that dose into the base case results for EMWMF and the proposed EMDF at the POA under the assumption that no further remediation is completed in BCV. (ii) This analysis also uses groundwater contaminant levels in the BCK 9.2 area to assess the dose to a receptor that uses groundwater in the BCK 9.2 area for domestic purposes and Bear Creek water for agricultural purposes to confirm that a receptor using only Bear Creek water is appropriate for this sensitivity analysis.
- Post-1000-Year Maximum Dose—The estimation of a maximum dose at the POA for this Composite Analysis within 10,000 years post-closure. To be consistent with the Performance Assessment, a composite concentration has been estimated at 100,000 years; incorporating the expected contribution of uranium radionuclides.
- Sensitivity to Bear Creek Flow Rates at the Confluence of NT-11—An assessment of the base case dose in the event the flow rate in Bear Creek between BCK 9.2 and BCK 7.73 (the POA) is overestimated.
- Sensitivity to the Groundwater and Surface Water Pathway—An estimate of the dose to a receptor at the POA that uses groundwater from the well defined in the EMDF Performance Assessment for domestic purposes and Bear Creek water for agricultural purposes rather than Bear Creek water for all uses as assumed in the composite exposure scenario in the base case assessment.
- Sensitivity to Percent of Contaminant Mass Discharge from EMDF—An assessment of the effect of defining the POA for this Composite Analysis in Bear Creek at NT-14, where the receptor would be exposed to 100 percent of the contaminant mass from the proposed EMDF rather than the 98 percent at the confluence of Bear Creek and NT-11.
- Sensitivity to Agreements in Phase I BCV and EMWMF CERCLA RODs—An assessment, performed for OREM, that calculates a composite dose using the commitments that are codified in the respective CERCLA RODs for the EMWMF and BCV. These risk commitments were converted to doses for the EMWMF and the other existing BCV sources and added to the dose for the EMDF from the base case assessment.
- Sensitivity to an Alternate Conceptual Site Model—An assessment that calculates the composite dose assuming the hypothetical receptor uses shallow groundwater in the BCK 9.2 area as a drinking water

source and Bear Creek at the POA as the source for water for agricultural uses. Contaminated groundwater from the EMDF is assumed to flow to the southeast from the facility to the groundwater well, rather than to the southwest as predicted by the conceptual site model.

- Sensitivity to ORR-wide Impact—An assessment of the impact at the confluence of Clinch River and Poplar Creek from the potential contamination from the three source terms in this Composite Analysis.

Table 8 summarizes the sensitivity analyses that were performed to support this Composite Analysis. This table presents an overview of the source terms used in each sensitivity analysis, the POA location, the compliance period(s), and the implication on the dose calculated in the base case assessment. The highlighted sections of the table indicate the changes made to the base case assessment in each of the sensitivity analyses. These sensitivity analyses represent a comprehensive range of envisioned variations to the base case assessment in this Composite Analysis. The results of all analyses are substantially less than the performance measures in the DOE order.

Sensitivity analyses of differing remedial actions for the other existing BCV sources were not conducted. The source term selected for the other existing BCV sources in the base case assessment represents maximum levels of contamination allowed under an approved ROD. The discussion in Sect. 5.2, Sensitivity to Remedial Actions on Other Existing BCV Sources, evaluates the dose based on current conditions. If future monitoring indicates the concentrations of radiological contamination are increasing, an evaluation of the impact on the results of this Composite Analysis may be required (see Sect. 7).

5.1 SENSITIVITY TO LAND USE

The base case assessment and all quantitative sensitivity analyses performed in this section assume the future land use in BCV is consistent with that defined as the basis for remediation levels in the Phase I BCV ROD. On that basis, the closest hypothetical receptor for unrestricted use of BCV that is potentially exposed to radiological contamination from the three source terms described in this Composite Analysis is at BCK 7.73 (see Fig. 2). A zone defined as recreational use (Zone 2) separates the sources of potential contamination in East BCV (Zone 3) from unrestricted use (Zone 1), but in the long-term, Zone 2 is defined as unrestricted, allowing the consideration of a resident farming exposure scenario. Thus, BCK 7.73 has been used as an unrestricted land use location. The proposed EMDF is in Zone 2 and adjacent to the hypothetical resident farmer at BCK 7.73. However, this land use scenario is considered pessimistic given that DOE is required to maintain control over land containing radionuclides sources until the land can be safely released pursuant to DOE O 458.1, *Radiation Protection of the Public and the Environment* and CERCLA.

All of the land in BCV is currently under DOE control and is used for multiple purposes to meet the mission goals and objectives of DOE. The nearest Oak Ridge communities include Country Club Estates (0.8 mile away on the north side of Pine Ridge) and the historic Scarboro community as well as isolated homes located across the more rural intervening area. Pine Ridge separates these residential areas from Y-12 and BCV. Neither of these are in the BCV watershed (DOE 2017b). The ROD for the EMDF will change the future land use in BCV. That ROD will establish the same land use restrictions in Zone 2 as currently defined in Zone 3. A change to a more restrictive land use would necessitate relocation of the POA or a different set of exposure pathways for this Composite Analysis. The result would be a lower composite dose. Therefore, the land use assumptions in this Composite Analysis are considered bounding. The conclusions in this Composite Analysis would not change if DOE controlled land in BCV west of BCK 7.73.

Table 8. Summary of sensitivity analyses

	Evaluation Conditions					
Scenario	**EMDF source term**	**EMWMF source term**	**Other existing BCV sources source term**	**POA location**	**Compliance period**	**Implication**
Composite Analysis Base Case Assessment (Section 4.3)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	BCK 7.73 (NT-11/ Bear Creek confluence)	1000 years	
Sensitivity to Land Use (Section 5.1)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	Bear Creek – downstream from BCK 7.73	1000 years	Lower Dose
Sensitivity to Remedial Actions on Other Existing BCV Sources (Section 5.2)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	17-year average Bear Creek concentrations at BCK 9.2	BCK 7.73	1000 years	Higher Dose
Post-1000-year Maximum Dose (Section 5.3)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	BCK 7.73	Post-1000 years	Higher Dose
Sensitivity to Bear Creek Flow Rates at Confluence of NT-11 (Section 5.4)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	BCK 7.73 with BCK 9.2 Flow Rate (lower flow rate in Bear Creek than base case assessment)	1000 years	Higher Dose
Sensitivity to the Groundwater and Surface Water Usage Pathway (Section 5.5)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	BCK 7.73 (surface water for agricultural use) and Performance Assessment 100-m well (drinking water)	1000 years	Higher Dose
Sensitivity to Percent of Contaminant Mass Discharge from EMDF (Section 5.6)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	Bear Creek/NT-14 confluence (downstream from BCK 7.73)	1000 years	Lower Dose

Table 8. Summary of sensitivity analyses (cont.)

	Evaluation Conditions					
Scenario	**EMDF source term**	**EMWMF source term**	**Other existing BCV sources source term**	**POA location**	**Compliance period**	**Implication**
Sensitivity to Agreements in Phase I BCV and EMWMF CERCLA RODs (Section 5.7)	Performance Assessment – expected waste inventory	1E-05 ELCR for all rads	1E-05 ELCR for all rads	BCK 7.73	1000 years	Lower Dose
Sensitivity to an Alternate Conceptual Site Model (Section 5.8)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	BCK 9.2 (shallow groundwater for drinking water); Bear Creek/NT-11 confluence (surface water agricultural use)	1000 years	Higher Dose
Sensitivity to ORR-wide Impact (Section 5.9)	Performance Assessment – expected waste inventory	Predicted actual waste profile at closure	Predicted Bear Creek concentrations in compliance with the Phase I BCV ROD	CRM-10	1000 years	Lower Dose

Highlighted cells indicate the difference between the sensitivity analysis and the base case assessment.

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CRM = Clinch River mile marker
ELCR = excess lifetime cancer risk
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
NT = North Tributary
ORR = Oak Ridge Reservation
POA = point of assessment
ROD = Record of Decision

5.2 SENSITIVITY TO REMEDIAL ACTIONS ON OTHER EXISTING BCV SOURCES

The Phase I BCV ROD codified goals for contamination exiting Zone 3 from the other existing BCV sources. Since those goals are not being met, the base case assessment assumes remedial actions will be performed in BCV and the resulting contaminant concentrations in Bear Creek will comply with the ROD. A sensitivity analysis was performed to quantify the dose to the hypothetical receptor at the POA if no further actions are performed and contaminant concentrations for radioisotopes in Bear Creek remain at levels averaged over the last 17 years. Note that 17 years of monitoring data exist in the 2018 RER (DOE 2018a) since 2001. Figure 4.4 in the 2018 RER shows that concentrations of Tc-99, U-233/234, and U-238 have generally decreased at BCK 7.87 since 2001 (DOE 2018a, page 4-16) and Table 3 in this Composite Analysis substantiates this conclusion for the Integration Point (BCK 9.2).

The following subsection quantifies the dose from the other existing BCV sources at BCK 9.2 (the Integration Point in the Phase I BCV ROD) to a hypothetical receptor that uses water from Bear Creek for both domestic and agricultural purposes and incorporates that dose into a total dose at the POA (BCK 7.73) for comparison to the dose for the base case assessment. Section 5.2.2 quantifies the dose from the other existing BCV sources at BCK 9.2 to a hypothetical receptor that uses groundwater from a well for domestic purposes and uses Bear Creek water for agricultural purposes. This dose at BCK 9.2 is compared to the dose to the hypothetical receptor that uses only Bear Creek water at BCK 9.2 to demonstrate that evaluating a hypothetical receptor using only Bear Creek water in this sensitivity analysis is appropriate.

5.2.1 Sensitivity to Remedial Actions Using Only Water from Bear Creek

Seventeen-year average concentrations for the three uranium isotopes identified as major radiological contaminants in Sect. 2.3 (U-234, -235, and -238) at BCK 9.2 are 8.56 pCi/L, 0.78 pCi/L, and 19.03 pCi/L, respectively (see Table 3 in this Composite Analysis). Concentrations of Tc-99 are not regularly measured at BCK 9.2. A 39.73 pCi/L concentration for Tc-99 was estimated at BCK 9.2 based on 17-years of Tc-99 detections at BCK 7.87 (downstream of BCK 9.2) (DOE 2018a, Fig. 4.4) and the consideration of mixing in Bear Creek (see Appendix C). The assumed activity concentrations yielded a dose of 4.44 mrem/year at BCK 9.2 for the other existing BCV sources. The dose was calculated using the surface water concentrations, equivalent uptake factors, and ingestion dose coefficients as detailed in Sect. 2.5.1. The ingestion dose coefficients for the radionuclide contaminants in the water were from DOE standard guidance (DOE 2011b). Table 9 lists the parameters used to calculate the dose.

Table 9. Dose calculation for sensitivity to remedial actions – surface water consumption only

Radionuclides	Surface water concentration at BCK 9.2 (pCi/L)	Equivalent uptake for water ingestion (L/year)	Ingestion dose coefficient (mrem/pCi)	Dose (mrem/year)
U-238	19.03	762.68	1.94E-04	2.82
U-235	0.78	762.68	2.03E-04	0.12
U-234	8.56	762.68	2.15E-04	1.40
Tc-99	39.73	790.13	3.33E-06	0.10
			Total dose	**4.44**

BCK = Bear Creek kilometer

Mixing in Bear Creek from BCK 9.2 to BCK 7.73 was applied to this dose (giving a dose of 3.10 mrem/year at BCK 7.73). This dose then was combined with the base case assessment dose for EMWMF (factoring in mixing in Bear Creek) and the base case assessment dose for the proposed EMDF (0.04 mrem/year and

0.25 mrem/year, respectively) to give a total dose of 3.39 mrem/year at the POA (BCK 7.73) for this sensitivity analysis. This dose compares to the total dose of 0.98 mrem/year at the POA in the base case assessment.

This total dose occurs within the first 1000 years following closure of EMWMF and the proposed EMDF. Since a ROD has been signed for BCV, it is unlikely that 1000 years would pass without the required remedial actions being performed. The more likely scenario would be that the ROD is revised. If the ROD is revised, consideration of the impacts to this Composite Analysis would be required.

5.2.2 Sensitivity to Remedial Actions Using Groundwater and Bear Creek Water

The 2018 RER stated that only U-238 and U-234 have been detected in the BCK 9.2 area above the Phase I BCV ROD concentration goals during the monitoring program (DOE 2018a, page 4-18). The highest U-238 concentration in groundwater wells in the BCK 9.2 area following remediation of the BYBY is 9 pCi/L. The highest U-234 concentration in these groundwater wells during this period was 6 pCi/L (DOE 2018a, Fig. 4.13). Until recently, both isotopes showed a decreasing trend in groundwater concentrations. For the groundwater use dose calculation, values of 9 and 6 pCi/L were used for U-238 and U-234, respectively. For the minor radionuclides, 0.60 pCi/L and 39.73 pCi/L were used for U-235 and Tc-99, respectively. The U-235 groundwater concentration was estimated based on the ratio of U-234 to U-235 in surface water. A dose conversion was performed using the 17-year average surface water concentrations for the uranium radionuclides and a 39.73 pCi/L concentration for Tc-99 and these groundwater uranium concentrations (as detailed in Sect. 2.5.1).

The parameters and calculation for the dose at BCK 9.2 resulting from the other existing BCV sources are shown in Table 10, assuming groundwater for domestic use and surface water for all other agricultural uses. The calculated dose is 2.60 mrem/year.

Table 10. Dose calculation for sensitivity to remedial actions – surface water/groundwater consumption

Radionuclides	Water type	Concentration (pCi/L)	Equivalent uptake for water ingestion (L/year)	Dose coefficient for ingestion (mrem/pCi)	Dose (mrem/year)
U-238	SW	19.03	32.68	1.94E-04	0.12
	GW	9	730	1.94E-04	1.27
U-235	SW	0.78	32.68	2.03E-04	0.01
	GW	0.60	730	2.03E-04	0.09
U-234	SW	8.56	32.68	2.15E-04	0.06
	GW	6	730	2.15E-04	0.94
Tc-99	SW	39.73	60.13	3.33E-06	0.01
	GW	39.73	730	3.33E-06	0.10
				Total dose	**2.60**

GW = groundwater
SW = surface water

This total dose of 2.60 mrem/year at BCK 9.2 for the combined groundwater and surface water pathway is less than the 4.44 mrem/year for the surface water pathway (see Sect. 5.2.1). This provides confirmation that assuming exposure to contamination from only surface water in Bear Creek in this sensitivity analysis is appropriate. For these reasons, a composite dose at the POA was not calculated in Sect. 5.2.2 and only the results from the surface water evaluation in Sect. 5.2.1 are presented in the summary tables in Sect. 5.10. Additionally, because this dose is lower than the dose in Sect. 5.2.1, it is demonstrated that a surface water user will receive a higher dose than a surface water/groundwater user at the same location. This supports the appropriateness of using a surface water exposure scenario in the base case assessment.

5.3 POST-1000 YEAR MAXIMUM DOSE

Guidance for this Composite Analysis states that the sensitivity/uncertainty analysis should include the calculation of the maximum dose beyond the 1000-year compliance period. The RESRAD-OFFSITE modeling performed to quantify a dose from the proposed EMDF in the base case assessment also quantified a maximum dose within 10,000 years in Bear Creek at BCK 7.73 (0.13 mrem/year at approximately 7200 years after closure). This dose is primarily comprised of I-129 from meat ingestion. The PATHRAE-RAD model used to quantify a dose from the EMWMF in the base case assessment also quantified a post-1000-year maximum dose in Bear Creek at BCK 10.5 (0.79 mrem/year; see Table B.7 in Appendix B). This dose is from long-lived, relatively immobile radioisotopes, such as uranium.

The maximum composite dose within 10,000 years used the base case assessment dose for the other existing BCV sources (0.98 mrem/year) in Bear Creek at BCK 9.2 and the EMWMF post-1000-year maximum dose (0.79 mrem/year). (Note that the EMWMF post-1000-year maximum dose is considered high for this time period because the earliest peak doses [for U-233 and U-234] occur at approximately 45,000 years post-closure.) The three doses were totaled (factoring in mixing in Bear Creek for the doses from EMWMF and the other existing BCV sources) to give a total dose of 1.16 mrem/year at the POA (BCK 7.73). This dose compares to the 0.98 mrem/year dose inside the compliance period in the base case assessment.

To be consistent with the EMDF Performance Assessment, a maximum concentration for the proposed EMDF within 100,000 years of 8.61 pCi/L is predicted from uranium isotopes migrating from the facility (at approximately 79,000 years after closure). This concentration results primarily from the ingestion of meat and then the ingestion of water. Incorporating this concentration with the base case assessment concentration for the other existing BCV sources and the post-1000-year maximum concentration for the EMWMF yields a total post-1000-year maximum concentration of 28.09 pCi/L at the POA (factoring in mixing in Bear Creek) from all three source terms. The radiological concentration would increase to 34.19 pCi/L if the Tc-99 concentration from the other existing BCV sources was included with the uranium.

The above doses and concentrations from the three source terms are assumed to occur at the same time and are, therefore, summed within the time periods described above.

5.4 SENSITIVITY TO BEAR CREEK FLOW RATES AT CONFLUENCE OF NT-11

As discussed in the base case assessment, the surface water flow rate at the confluence of NT-11 and Bear Creek (BCK 7.73) is calculated based on a linear surface area and flow rate relationship. The flow rate is derived based on long-term field measurements at BCK 9.2 and the additional contribution area downstream of BCK 9.2.

Even though the flow rate at BCK 9.2 is well defined with 17 years of detailed and continuous field measurements, there is an uncertainty on the additional water contribution between BCK 9.2 and BCK 7.73. Therefore, a sensitivity analysis was conducted to assess the likely impact from a change in the surface water flow rate in Bear Creek.

The estimated flow rate at BCK 7.73 could be higher or lower relative to the rate calculated for the base case assessment. However, the lowest possible flow rate at BCK 7.73 would be the measured flow rate at BCK 9.2, if it is assumed there is no additional surface water contribution from the area downstream of the

BCK 9.2 location. If the same surface water flow rate at BCK 9.2 is used as the flow rate at BCK 7.73 (that is, no additional mixing), the resulting total dose from all sources, including EMDF, would be 1.38 mrem/year.

This composite dose is comprised of the dose from the other existing BCV sources (0.98 mrem/year) at BCK 9.2, the dose from the closed EMWMF accounting for mixing in Bear Creek from BCK 10.5 to BCK 9.2 (0.05 mrem/year), and the dose from the closed EMDF (0.35 mrem/year). The dose from the EMDF was calculated in RESRAD-OFFSITE using a longer residence time for radionuclides in Bear Creek at BCK 7.73 to account for the assumed reduced flow in the creek. (The EMDF C-14 dose is sensitive to the residence time at BCK 7.73.) The longer residence time used in RESRAD-OFFSITE was based on the mixing ratio from BCK 9.2 to BCK 7.73 as detailed in Sect. 4.2.

Although this total dose is higher than the base case dose of 0.98 mrem/year, it is still well below the 100 mrem/year performance measure. Note that this sensitivity analysis assumes Bear Creek is not a gaining stream. (Bear Creek was documented as a gaining stream in Sect. 2.3.7.) Therefore, this sensitivity analysis effectively calculates a dose at the POA using a lower flow rate in Bear Creek than the average flow rate considered in the base case assessment.

5.5 SENSITIVITY TO THE GROUNDWATER AND SURFACE WATER USAGE PATHWAY

The base case assessment assumed all contamination is received via the surface water pathway (see Sect. 3.3). Under this assumption, the hypothetical receptor at the POA for this Composite Analysis (BCK 7.73) gets all its contamination from all three sources (the other existing BCV sources, EMWMF, and the proposed EMDF) by all exposure pathways by using Bear Creek water for both domestic and agricultural purposes. Another exposure scenario is possible. The hypothetical receptor could drill a well and use groundwater contaminated from the upgradient EMDF for domestic use and use Bear Creek water that is contaminated from the upstream EMWMF and the other existing BCV sources for agricultural purposes. A sensitivity analysis was performed to quantify this exposure scenario.

In this exposure scenario, the total dose from the base case assessment is assumed to be the dose for only the Bear Creek water used for agricultural purposes. This dose in the Bear Creek water at the POA would be 0.69 mrem/year from the other existing BCV sources, 0.04 mrem/year from EMWMF, and 0.25 mrem/year from the proposed EMDF. The total dose in water used for agricultural purposes would be 0.98 mrem/year. Note that this dose is considered pessimistically high because it includes the drinking water ingestion dose.

In this exposure scenario, the dose from using groundwater from a well is assumed to be the dose received by drinking water from the well located 100 m from the edge of the waste modeled in the EMDF Performance Assessment (UCOR 2020a, Sect. 4.5), which is 1.03 mrem/year. Note that this dose is also pessimistically high due to the same biases associated with the consumption of shallow groundwater explained in Sect. 1.7 of the Performance Assessment.

The dose from the well, along with the dose from the other existing BCV sources and EMWMF, totals 2.01 mrem/year. This dose is higher than the base case dose of 0.98 mrem/year, but is significantly lower than the performance measure of 100 mrem/year.

5.6 SENSITIVITY TO PERCENT OF CONTAMINANT MASS DISCHARGE FROM EMDF

The site-specific EMDF groundwater model was used to delineate the impact of the potential disposal facility leakage to the groundwater and surface water (see Sect. 3.2.3). As indicated by the model, the potential contamination from the other existing BCV sources and EMWMF is predicted to discharge from groundwater to Bear Creek and its tributaries upstream of NT-11 (see Figs. 9 and 10). For the surface water contamination, NT-11 is predicted to receive most of the mass discharge from EMDF (89 percent), followed by Bear Creek upstream of NT-11 (11 percent). However, approximately 2 percent of the potential contamination from EMDF is predicted to be in groundwater west of NT-11 (see Fig. 11). Some contamination is predicted in groundwater until it discharges into NT-14, a major tributary to Bear Creek in the valley. The groundwater model predicts that the BCK 7.73 location receives 98 percent of the total contaminant mass of surface water discharge at 1000 years, suggesting that BCK 7.73 at the confluence of NT-11 and Bear Creek is the appropriate location to evaluate a potential dose from the EMDF in this Composite Analysis.

To capture the impact for 100 percent of the mass release of EMDF, a sensitivity analysis was conducted by assuming the POA for this Composite Analysis would be at the confluence of Bear Creek and NT-14. The expected flow rate at this location is estimated using the same method as discussed for the base case assessment (see Sect. 4.2). To derive the likely flow rate at the confluence of NT-14 and Bear Creek, the same linear surface area and flow rate relationship was applied. The mixing ratio between the confluence of NT-14 and Bear Creek and BCK 7.73 is predicted to be 1.40. Applying this surface water flow ratio to the base case dose (0.98 mrem/year), the expected dose is 0.70 mrem/year at the confluence of NT-14 and Bear Creek location where all contaminant releases from the Bear Creek sources would have discharged into the surface water. This dose compares to the base case assessment dose of 0.98 mrem/year at BCK 7.73; confirming that BCK 7.73 at the confluence of NT-11 and Bear Creek is the appropriate location for the POA for this Composite Analysis.

5.7 SENSITIVITY TO AGREEMENTS IN BCV AND EMWMF CERCLA RODS

This sensitivity analysis provides OREM with the composite dose at the POA (BCK 7.73) using the commitments in the approved CERCLA Phase I BCV ROD (DOE 2000a, pages 1-7 and 2-61), the EMWMF ROD (DOE 1999b, pages 2-20 and B-4), and the EMWMF WAC Attainment Plan (DOE 2001b, Sect. 1.2) as the bases for the doses for the other existing BCV sources and the EMWMF source terms. (The dose from the proposed EMDF in this sensitivity analysis is the same as in the base case assessment.)

The doses for EMWMF and the other existing BCV sources were calculated based on a total radionuclide dose corresponding to a 1×10^{-5} ELCR at their respective points of compliance. Consistent with guidance issued in “Radiation Risk Estimation from Total Effective Dose Equivalents (TEDEs), August 9, 2001” (DOE 2002), a risk/dose factor from EPA’s Federal Guidance Report 13 (*Cancer Risk Coefficients for Environmental Exposure to Radionuclides* [EPA 1999]) was used to convert from risk to a dose in mrem/year. This conversion used an age-averaged cancer morbidity factor of 8.46×10^{-2} risk of cancer cases listed in Table 7.6 (page 182). A 30-year life-time exposure was then applied to the conversion. This corresponds to a 3.0×10^{-4} ELCR equaling a 12 mrem/year dose.

This conversion resulted in a dose of 0.39 mrem/year for a 1×10^{-5} ELCR. This dose for EMWMF is at the EMWMF receptor at the confluence of NT-5 and Bear Creek (BCK 10.5). This dose for the other existing BCV sources is at the Phase I BCV ROD point of compliance (at BCK 9.2).

The doses for the closed EMWMF and the remediated BCV were added to the base case assessment dose for the proposed EMDF (0.25 mrem/year). Factoring in mixing in Bear Creek, the total dose for this sensitivity analysis is 0.69 mrem/year.

5.8 SENSITIVITY TO AN ALTERNATE CONCEPTUAL SITE MODEL

This sensitivity analysis calculates a composite dose using an alternate conceptual site model for BCV. The conceptual site model detailed in Sect. 3.2 assumes that most radiological contamination from the EMWMF and the other existing BCV sites would migrate in the shallow groundwater system to Bear Creek upstream of the POA in the base case assessment (BCK 7.73). Most of this migration in the shallow groundwater system is expected to occur along geologic strike. The conceptual site model for the EMDF assumes that most contamination migrates in shallow groundwater to the southwest (along geologic strike) to NT-11 and to Bear Creek at the POA. The conceptual site model also assumes that although there is extensive surface water and shallow groundwater interaction, most contamination from the upstream sources ultimately resides in Bear Creek as it passes the Integration Point at BCK 9.2 (see Surface Water subsection in Sect. 2.3.7). This conceptual site model is consistent with surface water and groundwater in the vicinity of BCK 9.2, in that radiological contaminant concentrations in groundwater in that area are less than concentrations in Bear Creek. However, the contaminant levels in the groundwater wells in the vicinity of BCK 9.2 are not from samples of shallow groundwater.

This sensitivity analysis assumes that through extensive surface water and groundwater interaction, the shallow groundwater at BCK 9.2 is contaminated at the same levels as the surface water. (The BCV RI states “that surface water and shallow groundwater in the Maynardville are closely related and constitute 96 percent of water flowing along the valley”; see Sect. 2.4.4.1 of this Composite Analysis.) It also assumes that a shallow groundwater well located in the Maynardville Limestone between BCK 9.2 and BCK 7.73 serves as the source of drinking water for a hypothetical receptor. The water from this well is assumed to have contamination from the EMWMF, the other existing BCV sources, and the EMDF. It is assumed that contamination from the proposed EMDF migrates to the southeast from the EMDF towards Bear Creek (across geologic dip and approximately perpendicular to expected shallow groundwater flow) and is intercepted by the well. Finally, it is assumed that surface water at the POA in this Composite Analysis is used for agricultural purposes.

The dose via the drinking water pathway in this sensitivity analysis was totaled based on the following assumptions for the three source terms. The dose from the EMWMF is the dose in Bear Creek at BCK 9.2 in the base case assessment (0.05 mrem/year). However, that dose is assumed to be in the shallow groundwater in the hypothetical well. The dose from the other existing BCV sources assumes groundwater consumption at the Integration Point (BCK 9.2). The shallow groundwater is assumed to be contaminated at the same concentrations as the surface water in Bear Creek at BCK 9.2. This dose is 0.98 mrem/year. The dose from the proposed EMDF is assumed to be the dose in the 100-m groundwater well in the Performance Assessment (1.03 mrem/year). No mixing in the groundwater is assumed between that hypothetical well in the Nolichucky Shale and this hypothetical well in the Maynardville Limestone. This dose for the consumption of water totals 2.06 mrem/year.

Water for agricultural use is assumed to be Bear Creek surface water at BCK 7.73. Therefore, this dose is the composite dose from the base case assessment (0.98 mrem/year).

These doses were composited to quantify a dose for this sensitivity analysis (3.04 mrem/year).

It is important to note that this exposure scenario is a biased representation of the consumption of drinking water by the hypothetical receptor. Extraction of water for domestic use from a well in the shallow aquifer is not consistent with state of Tennessee guidelines (Tennessee Department of Environment and Conservation 2019) for water well installation. State of Tennessee guidelines include casing a well at least 5 ft into competent bedrock, effectively sealing potentially contaminated shallow groundwater (with high amounts of suspended particulates) from the well. This exposure scenario also overestimates the dose that is received by the hypothetical receptor. It unrealistically assumes the hypothetical receptor consumes shallow groundwater from two wells, the EMDF Performance Assessment 100-m well and a well in the Maynardville Limestone, without further mixing. Therefore, a portion of the dose from water used for domestic purposes is "double-counted." Depending on the assumed location of a single drinking water well, one or both of the doses would be mixed compared to the doses used in this exposure scenario. Contaminant fate and transport information from ORNL 2004 presented in Sect. 2.4.4.1, indicates that a significant reduction in contaminant concentrations could be expected if transport was down geologic dip rather than along geologic strike (see the descriptions of contaminant concentrations from the S-3 Ponds in Area 1 [adjacent and across dip] and Area 3 [adjacent and along strike]). This reduction in levels of contamination would apply to water migrating southeast from the EMDF toward Bear Creek. Levels of contamination in Bear Creek and groundwater at BCK 9.2 would also be expected to decrease the further from the sources (primarily BCBG) northeast of BCK 9.2. (The BCV RI states that contaminants in surface water and shallow groundwater in the Maynardville Limestone are quickly diluted by rapid recharge of rainwater and inputs from uncontaminated tributaries, see Sect. 2.4.4.1 of this Composite Analysis.) There are no known sources of radiological contamination in BCV southwest of BCK 9.2 and there are two NTs (NT-9 and NT-10) between BCK 9.2 and the POA for this Composite Analysis.

5.9 SENSITIVITY TO ORR-WIDE IMPACT

ORR is comprised of several watersheds (see Fig. 1). However, water from all of these watersheds eventually flows into the Clinch River, one of the two major tributaries to the Tennessee River system (see Fig. 1). The downstream ORR boundary is located near Clinch River Mile Marker 10 (CRM-10), just west of ETTP. Therefore, all of ORR contributes to the water quality at this point.

Bear Creek water flows into Poplar Creek above ETTP and Poplar Creek empties into Clinch River after passing through ETTP. This Composite Analysis estimated the total annual dose from all sources in BCV watershed upstream from the POA (BCK 7.73). Since this dose includes all the sources in the watershed, including EMWMF and the proposed EMDF, the contribution of radiological contamination from the watershed to the Clinch River at CRM-10 can be estimated based on a surface water flow relationship. As discussed earlier, surface water is the only transport media from the BCV watershed since all groundwater discharges into Bear Creek within the BCV.

The stream flows in Clinch River and the two major ORR tributaries, White Oak Creek and Poplar Creek, are summarized in *Remedial Investigation/Feasibility Study for Lower Watts Bar Reservoir Operational Unit* (DOE 1995c). The Clinch River at Melton Hill Dam, just upstream of the White Oak Creek and Poplar Creek, has an annual average flow of 4400 cfs. The White Oak Creek and Poplar Creek have annual average rates of 13.5 and 228 cfs, respectively (DOE 1995c, Sect. 2.5.1, page 2-17). Therefore, the total stream flow at CRM-10 is approximately 4641.5 cfs.

The calculated average flow rate at BCK 7.73 is 1574.3 gpm (3.51 cfs). Thus, the mixing factor between CRM-10 and BCK 7.73 is 1323.26. If the base case assessment dose (0.98 mrem/year) at BCK 7.73 is used, the resulting dose from all BCV sources at CRM-10 would only be 7.4×10^{-4} mrem/year.

The 10-year (2001 to 2010) average concentration of U-238 at BCK 9.2 is 20.5 pCi/L (DOE 2018a, Table 4.5). This concentration is the highest 10-year average concentration of the uranium isotopes analyzed at BCK 9.2. Using the mixing factor between CRM-10 and BCK 9.2 based on field measurements (1892.26), the concentration of U-238 at CRM-10 originating from all Bear Creek sources is 0.01 pCi/L. This concentration is one magnitude lower than the detection limit for uranium isotopes using alpha spectroscopy. Based on these estimates, the impact to the Clinch River from the BCV sources at the ORR boundary is extremely small and cannot be detected using a standard laboratory analysis.

5.10 SUMMARY OF SENSITIVITY/UNCERTAINTY ANALYSIS

A summary of the quantitative sensitivity/uncertainty analyses conducted is provided on Table 11. As indicated in the table, the analyses predict that the doses will be below the 100 mrem/year performance measure at the Composite Analysis POA (BCK 7.73).

Table 11. Summary of sensitivity/uncertainty analyses

Sensitivity/uncertainty	Source term	Dose at POA (mrem/year)	Method of analysis (for all pathways dose)
Sect. 5.2.1 Sensitivity to Remedial Actions on Other Existing BCV Sources	Other existing BCV sources	3.10	Seventeen-year average uranium and Tc-99 concentrations in Bear Creek; conversion from concentrations to dose
	EMWMF	0.04	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment
	Proposed EMDF	0.25	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment
		3.39	**Total dose**
Sect. 5.3 Post-1000-year Maximum Dose (within 10,000 years)	Other existing BCV sources	0.69	Post-remediation dose assuming compliance with Phase I BCV ROD
	EMWMF	0.34	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5
	Proposed EMDF	0.13	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term
		1.16	**Total dose**
Sect. 5.4 Sensitivity to Bear Creek Flow Rates at Confluence of NT-11	Other existing BCV sources	0.98	Post-remediation dose assuming compliance with Phase I BCV ROD, no mixing in Bear Creek from BCK 9.2 to POA
	EMWMF	0.05	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5, no mixing in Bear Creek from BCK 9.2 to POA
	Proposed EMDF	0.35	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment (considering reduced Bear Creek flow)
		1.38	**Total dose**

Table 11. Summary of sensitivity/uncertainty analyses (cont.)

Sensitivity/uncertainty	Source term	Dose at POA (mrem/year)	Method of analysis (for all pathways dose)
Sect. 5.5 Sensitivity to Groundwater and Surface Water Usage Pathway in Base Case Assessment	Other existing BCV sources	0.69	Post-remediation dose assuming compliance with Phase I BCV ROD from base case assessment
	EMWMF	0.04	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment
	Proposed EMDF	1.28	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term plus dose from 100-m well in Performance Assessment
		2.01	**Total dose**
Sect. 5.6 Sensitivity to Percent Contaminant Mass Discharge from EMDF	Other existing BCV sources	0.49	Post-remediation dose assuming compliance with Phase I BCV ROD from base case assessment, mixing in Bear Creek to NT-14
	EMWMF	0.03	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5 from base case assessment, mixing in Bear Creek to NT-14
	Proposed EMDF	0.18	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term, mixing in Bear Creek to NT-14
		0.70	**Total dose**
Sect. 5.7 Sensitivity to Agreements in Phase I BCV and EMWMF CERCLA RODs	Other existing BCV sources	0.27	Risk to dose conversion at BCK 9.2
	EMWMF	0.17	Risk to dose conversion at BCK 10.5
	Proposed EMDF	0.25	Dose in Bear Creek from RESRAD-OFFSITE modeling of EMDF source term from base case assessment
		0.69	**Total dose**
Sect. 5.8 Sensitivity to an Alternate Conceptual Site Model	Other existing BCV sources (domestic water)	0.98	Post-remediation dose assuming compliance with Phase I BCV ROD in shallow groundwater well in BCK 9.2 area
	EMWMF (domestic water)	0.05	Predicted waste inventory in EMWMF at closure, PATHRAE-RAD modeling to BCK 10.5, mixing in Bear Creek to shallow groundwater well in BCK 9.2 area
	Proposed EMDF (domestic and agricultural water)	2.01	Dose in 100-m well in Performance Assessment assumed in shallow groundwater well in BCK 9.2 area, plus total base case assessment dose in Bear Creek at BCK 7.73
		3. 04	**Total dose**

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
NT = North Tributary
POA = point of assessment
ROD = Record of Decision
RER = Remediation Effectiveness Report
RESRAD = RESidual RADioactivity

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6. INTEGRATION AND INTERPRETATION OF RESULTS

6.1 COMPARISON OF RESULTS TO PERFORMANCE MEASURES

The base case assessment predicts a total dose of 0.98 mrem/year at the POA (BCK 7.73). This dose is significantly less than the 100 mrem/year limit discussed in the performance measures in Sect. 1.2.1. It is also significantly less than the administratively limited dose constraint of 30 mrem/year that would require an options analysis. For this reason, an options analysis was not performed in this Composite Analysis.

This composite dose includes a predicted contribution of 0.25 mrem/year from the EMDF and a predicted contribution of 0.09 mrem/year from the EMWMF. At these predicted doses, neither of these disposal facilities is a significant contributor to a receptor dose in the context of the performance measure of 100 mrem/year. Also, neither of these doses exceeds the general screening value of 1 mrem/year in the DOE Standard *Disposal Authorization Statement and Tank Closure Documentation* (DOE 2017a). The requirement in DOE M 435.1-1 Chg. 2, Chapter IV.P.(3) defines the uses for the results of a composite analysis:

> The composite analysis results shall be used for planning, radiation protection activities, and future use commitments to minimize the likelihood that **current low-level waste disposal activities** will result in the need for future corrective or remedial actions to adequately protect the public and the environment (emphasis added).

At these predicted doses, the EMWMF and the proposed EMDF cannot lead to the need for future corrective or remedial actions. This conclusion is supported by the disposal facility example on page 3-3 in the above DOE Standard. Sensitivity analyses show that the highest projected annual dose from all potential sources of radioactive contamination in BCV occurs if no further remediation is performed in BCV. A composite dose of 3.39 mrem/year is predicted at the POA. This is not considered realistic because the dose predicted from the other existing BCV sources in this sensitivity analysis does not comply with the Phase I BCV ROD. All other sensitivity analyses performed for times in the 1000-year compliance period resulted in predicted doses of less than 3.39 mrem/year. The post-1000-year maximum composite dose, 1.16 mrem/year, is slightly higher than the dose from the base case assessment, but is lower than the dose if no further remediation is performed in BCV.

While there is uncertainty in the parameters that went into estimating the projected doses, there are biases towards higher doses in the estimates. Therefore, it is extremely unlikely that any of the uncertainties in the parameters used to estimate the doses (see Sects. 3 and 5) will cause actual future doses to exceed 30 mrem/year. The conclusion that the dose constraint will be met is robust.

To emphasize the extent of conservatism built into the Composite Analysis, the major biases are discussed below:

- The assumed POA for this Composite Analysis does not take credit for the existence of land use or other institutional controls beyond 100 years post-closure. The EMDF ROD will require the same land use restrictions in Zone 2 of BCV as those in Zone 3. The likelihood that DOE or successor federal agencies will maintain control of the closed EMDF is considered as an aspect of defense in depth for the proposed EMDF in the EMDF Performance Assessment. A change to a more restrictive land use would necessitate relocation of the POA or a different set of exposure pathways for this Composite Analysis. The results would be a lower composite dose.

- While not unrealistic, the all-pathways exposure scenario is based on a local agricultural subsistence lifestyle that is uncommon in present day Eastern Tennessee, which provides bias toward more highly exposed individuals. (This Composite Analysis assumes all of the water that is consumed is contaminated and about one-half of the food that is consumed is supported by contaminated water.) A subsistence farmer was specified as the representative receptor in this Composite Analysis to incorporate a diverse set of exposure pathways and to be consistent with previous risk evaluations conducted under CERCLA for the EMWMF and the Phase I BCV ROD, and the EMDF Performance Assessment.
- The total doses for EMWMF (during and following the 1000-year compliance period) were quantified based on the assumption that individual radionuclides peak at the same time. Of course, the peak doses from the individual radionuclides will not occur simultaneously (i.e., be purely additive). Therefore, actual peak doses will be less than the estimates of peak doses from EMWMF that are used in this Composite Analysis.
- In projecting concentrations of contaminants of concern in surface water from the points at which they were estimated for the other existing BCV sources and EMWMF, only mixing in the increased water flow of the creek to the POA was taken into account. The possible effects of dispersion into media surrounding the creek and sorption in creek sediments were ignored. Both of these effects, if taken into account, have the potential of reducing peak doses to the hypothetical receptor at the POA. Note that radionuclide accumulation in the sediment would not be expected to be a significant exposure pathway for a recreational user at the POA in Bear Creek (the only place where exposure to contamination from all three sources would occur). EMWMF and the other existing BCV sources are upstream of the POA and surface water concentrations are very low on arrival at the POA. EMDF also contributes a very low contaminant concentration at the POA. The resulting sediment concentrations from the contaminated surface water due to partitioning (controlled by K_d) would be even lower. Considering the dominant exposure pathway is through ingestion of water, an exposure pathway from sediment would have minimal contribution. Even if all of the radionuclides were assumed to be in the sediment, the dose would not exceed the base case assessment dose. Furthermore, a recreational user at the POA that is exposed to only contaminated sediment would have a lower dose than a resident farmer at the same location.

These biases in the analyses used to estimate the combined peak annual dose for this Composite Analysis are sufficient to outweigh any potential deleterious effects of the uncertainties in the analyses.

6.2 USE OF COMPOSITE ANALYSIS RESULTS

The results of this Composite Analysis can be used to demonstrate the following:

- When the currently operating EMWMF is closed, the composite annual radiological dose to a hypothetical receptor at the POA will be significantly below the performance measures discussed in DOE O 435.1, under the assumption that the proposed EMDF is constructed, operated, and closed.
- The proposed EMDF can be constructed, operated, and closed without adding an annual dose to the composite annual dose from existing sources of potential radiological contamination in BCV, including EMWMF, which would jeopardize compliance with the performance measures discussed in DOE O 435.1.

7. PERFORMANCE EVALUATION

DOE O 435.1 requires that the adequacy of the Composite Analysis be determined on an annual basis. Additionally, maintenance of the Composite Analysis is required to evaluate changes that could affect performance, design, and operating basis for the LLW disposal facility. Maintenance also shall include the conduct of research, field studies, and monitoring needed to address uncertainties or gaps in existing data or the addition of potential sources of radiological contamination in BCV. The Composite Analysis shall be reviewed and revised when changes of waste forms or containers, radionuclide inventories, facility design and operations, closure concepts, or the improved understanding of the performance of the waste disposal facility, in combination with features of the site on which it is located, alter conclusions or the conceptual model(s) of the existing Composite Analysis. A process to evaluate and document these changes is formalized for EMWMF in UCOR procedure PROC-MP-2203, *EMWMF Operations DOE O 435.1 Changed Condition Evaluations, Notifications, and Environmental Reporting Requirements*. An equivalent evaluation and documentation process has been formalized for EMDF in UCOR procedure PROC-EMDF-0001, *EMDF Design DOE Order 435.1 Changed Condition*.

Since the base case assessment in this Composite Analysis was developed using commitments in the signed Phase I BCV ROD, this Composite Analysis would require a review for continued adequacy in the event that the ROD was revised in the future. In particular, the signed Phase I BCV ROD requires that a 1×10^{-5} ELCR is met at the Integration Point (BCK 9.2). The primary sources of radiological contamination in BCV are currently the BCBG and the S-3 Ponds. Releases of uranium from these sources currently exceed the post-remediation goals defined in the ROD. Therefore, future remedial actions will be required in these areas. If additional remedial actions are not conducted or if completed remedial actions cannot meet the requirements of the ROD, a revision to the ROD will be required. If this ROD is revised, an analysis would be required to assess the impact of the revisions on this Composite Analysis. The sensitivity analysis conducted in Sect. 5.2 predicted a dose in the event that no further remedial actions were completed in BCV using current contaminant concentrations in Bear Creek. The predicted dose is below the administratively limited dose of 30 mrem/year specified by DOE M 435.1-1. If the radionuclides change and/or the concentrations in Bear Creek significantly increase, an evaluation of the effect on the conclusions in this Composite Analysis may be required. Table 12 summarizes the potential sources of radiological contamination in BCV that were considered when the source term for the other existing sources was being defined. This table has been added to assist in tracking the status of these potential sources, such as completion of remedial actions, etc., during the maintenance of this Composite Analysis.

Table 12. Status of potential sources of radiological contamination in Bear Creek Valley

Potential existing source of radiological contamination in BCV	Included in "Other Existing BCV Sources" source term?	Justification	Reference
S-3 Site	Yes	Remedial actions in Phase I BCV ROD not completed; uranium flux exceeds goal in ROD	Sect. 2.3.9.1, Phase I BCV ROD,[a] 2018 RER[b]
Oil Landfarm Soils and Soil Storage Facility (Containment Pad)	No	Soils and facility disposed offsite	Sect. 2.3.9.2, Phase I BCV ROD, 2018 RER
Boneyard/Burnyard	No	Remedial actions complete	Sect. 2.3.9.3, 2018 RER

Table 12. Status of potential sources of radiological contamination in Bear Creek Valley (cont.)

Potential existing source of radiological contamination in BCV	Included in "Other Existing BCV Sources" source term?	Justification	Reference
Hazardous Chemicals Disposal Area	No	Not a significant contributor to BCV contamination	Sect. 2.3.9.3, Phase I BCV ROD
Oil Landfarm	No	Closed under RCRA in 1989	Sect. 2.3.9.2, Phase I BCV ROD
Sanitary Landfill 1	No	Closed and capped in 1985	Sect. 2.3.9.4, BCV FS[c], Phase I BCV ROD
Disposal Area Remedial Action Soils	No	Waste disposed at EMWMF and NNSS	Sect. 2.3.9.6, Phase I BCV ROD
Bear Creek Burial Grounds	Yes	Remedial actions in Phase I BCV ROD not completed; uranium flux exceeds goal in ROD	Sect. 2.3.9.5, Phase I BCV ROD, 2018 RER
Bear Creek Road Debris Area	No	No COCs at this site	Sect. 2.3.9.6, Phase I BCV ROD
Creekside Debris Burial Area	No	No COCs at this site	Sect. 2.3.9.6, Phase I BCV ROD
Rust Spoil Area	No	Contamination predicted to be chemical rather than radiological	Sect. 2.3.9.6
Spoil Area 1	No	Selected alternative under CERCLA being implemented	Sect. 2.4.4, BCV OU2 ROD[d]
SY-200 Yard	No	Selected alternative under CERCLA being implemented	Sect. 2.4.4, BCV OU2 ROD

[a] DOE 2000a.
[b] DOE 2018a.
[c] DOE 1997b.
[d] DOE 1996.

BCV = Bear Creek Valley
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COC = contaminant of concern
DOE = U.S. Department of Energy
EMWMF = Environmental Management Waste Management Facility
FS = Feasibility Study
NNSS = Nevada National Security Site
OU = Operable Unit
RCRA = Resource Conservation and Recovery Act of 1976
RER = Remediation Effectiveness Report
ROD = Record of Decision

There is the possibility for additional sources of potential radiological contamination to be identified (or constructed) in or in the vicinity of BCV. Any additional sources will be evaluated to determine if the information presented has a significant impact on the results of this Composite Analysis and if this Composite Analysis requires a revision. For example, the Spallation Neutron Source (SNS) is located on Chestnut Ridge. There is no evidence that radiological contamination is originating from this operating facility. However, radiological contamination from SNS could potentially migrate into Bear Creek upstream of the POA for this Composite Analysis. If contamination from the SNS is identified in the future, an assessment of its impacts on the results of this Composite Analysis will be conducted.

This Composite Analysis evaluated a source term for EMWMF for a projected waste inventory at closure, which was based on actual waste disposed to date. It is doubtful that changes in the remaining inventory and/or operations would cause an impact that would exceed the results of these evaluations. However, significant changes in EMWMF inventory or operations will be evaluated should they occur. Additionally, the Operating DAS issued for the EMWMF in December 2018 (DOE 2018b) requires a closure performance assessment for the EMWMF to be prepared in compliance with all the requirements of DOE M 435.1-1 prior to the final closure cap design and closing the facility. That document will be evaluated for impacts to the results of this Composite Analysis. This Composite Analysis will be revised if needed.

The modeling and evaluations conducted in this Composite Analysis depend on and are sensitive to the information and assumed exposure scenarios, contaminant transport pathways, and/or uncertainties in parameters (such as solid-to-liquid partition coefficients [K_d values] of radionuclides in the waste) included in the modeling for EMWMF and the EMDF Performance Assessment (UCOR 2020a). The Operating DAS for the EMWMF (DOE 2018b) requires a closure performance assessment to be prepared. The closure performance assessment for the EMWMF and any future revisions to the EMDF performance assessment will be evaluated to determine if there are significant impacts on the results of this Composite Analysis and if it requires a revision. Final design and associated CERCLA documentation also will be prepared for the potential EMDF. The design could contain information that affects the results of this Composite Analysis and will need to be evaluated to determine if the information presented has a significant impact on the results of this Composite Analysis and if it requires a revision. Since the source term for the proposed EMDF was based on a radiological inventory from waste expected to be disposed in EMDF, a radiological WAC for the proposed EMDF and presented in a CERCLA document could reduce the EMDF source term developed in the Performance Assessment. A reduction in the source term would not require a revision to this Composite Analysis as the resultant dose would be lower.

Once EMDF waste operations begin, the disposed waste will be evaluated to determine if the waste streams and waste forms disposed impact the conclusions discussed in this Composite Analysis (primarily source term assumptions). This Composite Analysis will be revised appropriately based on this evaluation.

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8. QUALITY ASSURANCE

The *Quality Assurance Report for the Performance Modeling of the Bear Creek Valley Low-level Radioactive Waste Disposal Facilities, Oak Ridge, Tennessee* (UCOR 2020b, the Quality Assurance [QA] Report) was prepared to comprehensively document the QA record for this Revision 2 Composite Analysis (and the companion Revision 2 EMDF Performance Assessment [UCOR 2020a]). This QA Report accompanies this Composite Analysis and details the QA protocol applied during the preparation of this Composite Analysis. It identifies the electronic files created during the modeling and their location; it identifies the modeling input parameters and documents their technical assessment; and it documents the technical review of the draft Composite Analysis before it was finalized. An assessment of the QA associated with the development of this Composite Analysis must include a review of the QA Report.

UCOR, in accordance with DOE O 414.1C, 10 *Code of Federal Regulations* 830, Subpart A, federal regulations, and contractual requirements, maintains a Nuclear QA (NQA)-1-compliant QA program. Drummond Carpenter, PLLC (Drummond Carpenter) and Jacobs provided groundwater and contaminant fate and transport modeling support to this Composite Analysis under UCOR Professional Services Agreement and a Request for Offsite Services, respectively. UCOR flows its QA requirements to companies providing support via the Professional Services Agreements and Requests for Offsite Services.

The salient components of the QA program that were implemented during the preparation of this Composite Analysis include the following:

- Incorporation of the data quality objectives (DQO) process
- Software QA procedures for code verification and documentation for each model code per UCOR PPD-IT-6007, *Software Quality Assurance Program*
- Formal independent checking and review of calculation and data packages that document input parameter values and other model assumptions, model implementation, model output data, and post-processing activities for each Composite Analysis model
- Documentation of Composite Analysis model development, implementation, sensitivity-uncertainty analyses, and Composite Analysis model integration contained in the Composite Analysis and appendices
- Configuration management for Composite Analysis documents and calculation packages per UCOR procedures for document control
- Independent technical review of the completed Composite Analysis prior to its formal release
- Maintenance of the digital modeling information archive of Composite Analysis documents, model codes, model input and output files, formal QA documentation, and reference materials in compliance with requirements of the UCOR QA Program (UCOR 2019b), DOE QA Program (DOE 2012b, Attachments G and H), and DOE O 414.1D (DOE 2013).

These components are detailed in the QA Report and are summarized below.

8.1 DATA QUALITY OBJECTIVES CONSIDERATIONS

During preparation of the 1999 EMWMF Composite Analysis, a DQO process was developed and used as a flexible planning tool to structure and prepare the two composite analyses being performed on the ORR at that time. A multidisciplinary technical steering committee (TSCOM) for a Composite Analysis was formed to develop a coherent composite analysis strategy for two LLW disposal facilities on the ORR: (1) the existing Interim Waste Management Facility (IWMF) in Solid Waste Storage Area (SWSA) 6 and (2) the proposed onsite disposal facility in East BCV (EMWMF). The committee members were selected from the DOE ORR Waste Management and Environmental Restoration programs as well as from independent technical resources outside the ORR who possess expert knowledge and experience in the CERCLA process, performance assessments under DOE O 5820.2A (DOE 1988), and development of composite analyses.

Beginning in July 1996, a series of TSCOM meetings analyzed current and evolving composite analysis requirements and guidance, general site-specific conditions on the ORR, RCRA and CERCLA processes completed or underway that pertain to the composite analyses, and the performance assessment (IWMF in SWSA 6) and risk assessment (for EMWMF) for the LLW disposal facilities. On the basis of these meetings, the TSCOM structured an approach for performing the composite analyses (DOE 1999a). Considerations relevant to this Composite Analysis are included below because they support several of the above key assumptions in Sect. 1.5 and document consistency with the approved 1999 Composite Analysis for EMWMF:

- A Composite Analysis for any LLW disposal facility sited on ORR should only consider waste buried within the watershed where the facility is, or may be located, because the ridge and valley hydrogeology of ORR does not support the interaction of separate watersheds through the groundwater pathway.
- Airborne contamination is not a significant exposure pathway for waste disposal units on ORR and will, therefore, not be evaluated.
- Groundwater within a watershed discharges to surface water within the watershed and surface water aggregates contaminant impacts within a watershed.
- The most likely potential points of high public exposure for IWMF and EMWMF are the confluence of White Oak Creek or Poplar Creek (the creek into which Bear Creek flows) with the Clinch River, respectively, with the use of river water as a residential water supply. However, for the proposed disposal facility (EMWMF), public exposure locations in BCV also may be permitted by future land use considerations.
- For as low as reasonably achievable analysis, a hypothetical public water supply will be assumed to be located downstream of the watershed creek’s confluence with the Clinch River, accounting for the dilution of the watershed’s creek flow by the Clinch River. The Clinch River surface water will serve the domestic requirements of a population equal in size to that of Oak Ridge.
- Public exposures for EMWMF and other Bear Creek watershed sources will use the risk assessment that defined the WAC for the EMWMF RI/FS (DOE 1998a) as well as the risk assessments developed in the BCV RI (DOE 1997a) and FS (DOE 1997b).

DOE O 435.1 requires the use of DQOs or an equivalent process for waste generated. The process defined in *Guidance for Data Quality Objectives Process* (EPA 2000) was used to develop the DQOs for this Composite Analysis. The DQO checklist is included in Appendix D. Two DQO problem statements were prepared in Steps 1 and 2:

1) Develop a technically defensible Composite Analysis
2) Develop a reasonably adequate and technically defensible source term for the proposed EMDF.

The sources of the historical data and the available process knowledge are identified in Step 3. The sources of contamination and the boundaries of the Composite Analysis are defined in Step 4. Steps 5 and 6 outline the process for determining if the problem statements have been satisfactorily addressed. For this document, that process consists of defined sensitivity analyses discussed in Sect. 5. Software QA also assisted in the determination.

8.2 SOFTWARE QUALITY ASSURANCE

Documentation of software QA, including code validation on computers used for Composite Analysis modeling follows the requirements of the UCOR SQA procedure PROC-IT-6008, “Application Lifecycle Management.” All Composite Analysis model codes have been categorized as UCOR category C (Business Impacting Software). Documentation of code validation, including model input and output files for validation runs are available for each Composite Analysis model code as required by UCOR procedure PROC-IT-6008 in the UCOR Server Asset Management and Official Applications (SAMOA) System. In addition, all software QA documentation is included in the EMDF Library.

8.3 INPUT DATA QUALITY ASSURANCE

Development and independent checking of one or more calculation packages for each Composite Analysis model code is the basis for ensuring the accuracy and consistency of model input data. Calculation packages are prepared and reviewed in accordance with written procedures. This is documented on the calculation cover sheet. Data and calculation packages for each model code document input parameter values and other model assumptions, information sources, model implementation, model outputs, and post-processing activities. The calculation package for the EMDF estimated radiological inventory that documents the data structure and data sources used to estimate the expected inventory is a supporting QA document for all of the radionuclide transport models.

The QA Report documents that model input parameters were technically reviewed for appropriateness and the correct parameters were used in the model simulations.

A list of all Composite Analysis calculation packages and the model(s) supported by each is shown on Table 13. All calculation packages, including model input and output files, data for supporting calculations, and copies of all supporting references will be maintained in electronic format (pdf) and available on digital media or in controlled hard copy form as required.

Table 13. Data and calculation packages for the Composite Analysis

UCOR document number	Calculation package title
CAW-90EMDF-F897	EMWMF %Full
CAW-90EMDF-G002	Calculation of the Base Case Assessment, the Mixing Ratios in Bear Creek, and the Sensitivities in Revision 2 of the EMDF and EMWMF Composite Analysis
CAW-90EMDF-G257	Calculation and Data Package for the PATHRAE Model
CAW-90EMDF-G247	Dose Calculation for the “Other Existing BCV Sources”
CAW-90EMDF-E660	EMDF Composite Analysis – Calculation of the Base Case Dose, the Mixing Ratios in Bear Creek, and the Sensitivities in the EMDF and EMWMF Composite Analysis
CAW-90EMDF-G183	EMDF RESRAD-OFFSITE Performance Assessment and Composite Analysis Calculations Package
CAW-90EMDF-G494	Calculation Package for the Upper Bear Creek Valley Groundwater Model

BCV= Bear Creek Valley
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
RESRAD = RESidual RADioactivity

8.4 DOCUMENTATION OF MODEL DEVELOPMENT AND OUTPUT DATA

Model development and output data for the Composite Analysis model codes is documented in the appendices to the Composite Analysis and additional detail is provided in model-specific calculation packages (Table 13). Model output files (including model verification and validation) and separate electronic tabulations of model output used for plotting or post-processing are included for archival purposes as digital attachments to calculation packages.

8.5 CONFIGURATION MANAGEMENT AND MAINTENANCE OF COMPOSITE ANALYSIS MODELING INFORMATION ARCHIVE

Calculation packages have been developed according to the calculation procedures and quality management protocols of the specific company responsible for model development (UCOR, Jacobs, or Drummond Carpenter). All calculation packages have been reviewed and approved under either the existing UCOR procedure PROC-DE-0704, *Project Calculations*, or PROC-WM-2031, *Waste Management Calculations*. Configuration control of calculation packages will be governed by contractor-specific protocols for change control of calculations as well as UCOR protocol. Both of these procedures require submittal of approved calculation packages to the Document Management Center (DMC) in accordance with UCOR procedure PROC-OS-1001, *Records Management, Including Document Control*. Both of the calculation procedures also require a hardcopy submittal and an electronic copy in native format (such as Word or Excel) to the DMC when possible. This requirement is being interpreted as including digital files (such as input and output files) created during the performance modeling simulations.

Configuration control and archival of digital files for the Composite Analysis, supporting data, and calculation packages will be performed in accordance with UCOR procedure PROC-OS-1001, *Records Management, Including Document Control*. This procedure allows for the submittal and defines the requirements for submitting records on media other than paper (such as input and output files from performance modeling simulations. This Composite Analysis, as well as the QA Report, will be entered into the DMC upon transmittal to DOE for distribution. At that time, all associated “records” will be submitted to the DMC.

8.6 INDEPENDENT TECHNICAL REVIEW OF THE REVISED COMPOSITE ANALYSIS

UCOR performed an independent technical review of the final draft of the Revision 2 Composite Analysis prior to its transmittal to DOE for distribution. This review was conducted using the UCOR Form-141, “Document Review Request.” These forms document the names of those reviewing the document, the scope (purpose) of the reviews, how comments on the documents were transmitted from the reviewers to the preparer, and that comments were resolved.

The scope of this review process included the following (at a minimum):

- An OREM (DOE) review (two reviewers, a technical review by a subcontractor)
- A review by the UCOR EMDF Project Manager
- A technical, consistency review by the primary author of the Revision 2 Performance Assessment (UCOR)
- A review of the Composite Analysis Conceptual Model (Sect. 3.2) and Contaminant migration pathways (Sect. 2.4.4.1) by Dick Ketelle (a commitment in the corrective action for Composite Analysis Secondary Issue EMDF-S06-CA15-03, “Surface water concentrations for contaminants of concern”)

- Technical reviews by various subject matter experts (primarily geologists)
- Verification that values in the document that originated in calculation packages, modeling, etc. have been correctly transcribed to the document from those sources.

More details, as well as the competed Forms-141, are included in the QA Report.

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9. PREPARERS

Marshall Davenport, PG

Marshall Davenport is a Professional Geologist (PG) (registered in Tennessee and Arkansas) with Edgewater Technical Associates in Oak Ridge, Tennessee providing technical support to UCOR. Mr. Davenport characterizes, profiles, and supports disposal of hazardous, radioactive, and mixed waste for disposal at DOE and commercial disposal outlets, including EMWMF. Mr. Davenport was the primary author and is responsible for the technical content of this Composite Analysis.

Mr. Davenport has more than 25 years of radioactive waste management experience, including providing technical and management support to the preparation of the EMWMF RI/FS (DOE 1998a), Proposed Plan/Composite Analysis (DOE 1999a), and ROD (DOE 1999b). Mr. Davenport managed the site characterization effort for EMWMF. After approval of the EMWMF ROD, Mr. Davenport provided technical support to Bechtel Jacobs Company, LLC on the design and construction. He provided regulatory support to EMWMF by preparing the Explanation of Significant Differences for the acceptance of classified waste. In 2003, he led the evaluation of engineering options for lowering the water table beneath EMWMF and wrote the final report that recommended the installation of an underdrain (BJC 2003).

Mr. Davenport provided technical support to onsite disposal initiatives at the Paducah and Portsmouth Gaseous Diffusion Plants (GDPs). At Paducah, he managed the development and field activities for a seismic investigation intended to support the RI/FS for an onsite disposal facility for the cleanup waste at the GDP. He also wrote the seismology section of the RI/FS. At the Portsmouth site, he provided regulatory support and preliminary cost estimates that supported the scoping of an evaluation of onsite disposal similar to that conducted in Oak Ridge. Mr. Davenport also managed the preparation of the Composite Analysis and Performance Assessment for SWSA 6 at ORNL (DOE 2000b, DOE 2000c).

His previous experience includes the preparation of integrated CERCLA and National Environmental Policy Act documentation for the New York and New Jersey sites in DOE’s Formerly Utilized Sites Remedial Action Project. Prior to that, Mr. Davenport supported the DOE Office of Civilian Radioactive Waste Management by preparing licensing and site characterization documentation for the Deaf Smith County, Texas Salt Repository Project and the Yucca Mountain Site Characterization Project in Nevada.

Chad Drummond, PE, D.WRE, BCEE

Chad Drummond is a Principal Engineer/Modeler with Drummond Carpenter, PLLC and has over 19 years of experience conceptualizing, developing, and applying environmental numerical models for sites across the United States and in Australia. Mr. Drummond provided RESRAD-OFFSITE modeling support to the development of the EMDF source term dose at the Composite Analysis POA. Prior to that, he provided modeling support on the EMDF Performance Assessment (UCOR 2020a). His role on the EMDF Performance Assessment included RESRAD-OFFSITE model conceptualization, model parameterization, and model simulation. Documentation of the RESRAD-OFFSITE modeling is included in Appendix G, the main Performance Assessment report text, and associated calculations packages.

Over his career, Mr. Drummond’s technical focus has been on unsaturated flow, groundwater hydrogeology, environmental assessment and remediation/restoration, and the fate and transport of various contaminants, including emerging contaminants and radionuclides. He has nearly 10 years of project experience performing environmental modeling at several DOE sites, including the Paducah GDP, ORR, and the Tuba City DOE Legacy Management site.

Modeling performed at the Paducah GDP was primarily performed as part of the RI/FS and included sitewide groundwater flow and contaminant transport simulations, VOC and radionuclide leaching simulations, radon emanation modeling, and WAC modeling. The WAC modeling was performed to assess disposal criteria for nearly 100 potential contaminants of interest. His experience at ORR includes the Performance Assessment documented herein, as well as a review of the ORR sitewide model to facilitate development of the site-specific RESRAD-OFFSITE model. His tasks at the Tuba City DOE Legacy Management site included configuring and assessing pump tests to provide parameters for the site groundwater model.

In addition to DOE projects, Mr. Drummond has worked on projects for other federal entities, including the National Air and Space Agency, Air National Guard, U.S. Army Corps of Engineers, and U.S. Air Force. He also has experience in private sector projects and has been accepted as an expert witness and has deposition and court testimony experience.

Mr. Drummond is a licensed Professional Engineer and his certifications include BCEE (Board Certified Environmental Engineer) by the American Academy of Environmental Engineers and Scientists and D.WRE (Diplomat, Water Resources Engineer) by the American Academy of Water Resources Engineers. He has taught environmental modeling and environmental engineering courses to undergraduate and graduate students.

Ryan Hupfer, MS, PG

Ryan Hupfer is a Senior Staff Geologist with Drummond Carpenter, PLLC and has 4 years of experience performing environmental assessment and remediation and aquifer characterization activities. He has developed, calibrated, and applied environmental numerical models at sites in the eastern United States. Mr. Hupfer provided RESRAD-OFFSITE modeling support to the development of the EMDF source term dose at the Composite Analysis POA. Prior to that, he provided modeling support on the EMDF Performance Assessment (UCOR 2020a). His role on the EMDF Performance Assessment included parameterizing the RESRAD-OFFSITE model, conducting inadvertent human intruder and base case model simulations, and performing the sensitivity analysis and probabilistic model simulations. Mr. Hupfer provided documentation support of the completed RESRAD-OFFSITE modeling included in Appendix G, the main Performance Assessment text, and associated calculations packages.

His technical focus is on hydrogeology, geochemistry, and the predictive migration and attenuation of various contaminants, including chlorinated solvents, inorganics, and radionuclides. Mr. Hupfer's project experience includes working in a variety of geologic settings, including unconsolidated sediment, fractured bedrock, and karst environments. He has applied geographic information system platforms, computer-aided design, and Python scripting to facilitate pre- and post-processing model data. In addition to his RESRAD-OFFSITE modeling experience, he has developed and used MATLAB, Surfer, AQTESOLV, and MODFLOW to assess environmental condition. He holds a bachelor's degree and a master's degree (Rutgers) in geology and is credentialed as a PG in Tennessee and a Geologist-in-Training in Florida.

Changsheng Lu, Ph.D., PG

Changsheng Lu is a PG (registered in Tennessee) and senior hydrogeologist with Jacobs in Oak Ridge, Tennessee. Dr. Lu performed the groundwater modeling and supporting calculations, including the Bear Creek mixing ratios, for the base case assessment and the sensitivity analyses in this Composite Analysis and prepared Appendices A and B.

He has over 30 years of environmental modeling application experience, including 25 years of groundwater and contaminant fate and transport modeling in BCV, with support for EMWMF and the proposed EMDF.

Dr. Lu has provided technical and modeling support for the EMWMF RI/FS (DOE 1998a) and Composite Analysis (DOE 1999a, Appendix A) and the RI/FS and Performance Assessment for the onsite disposal facility at the Portsmouth GDP as well as many other DOE, Department of Defense, EPA, and industrial clients.

Dr. Lu provided contaminant fate and transport modeling support on the EMDF Performance Assessment (UCOR 2020a). His contributions to the development of the EMDF Performance Assessment included vadose zone flow and transport analysis (STOMP model implementation, Appendix E), 3-D saturated zone flow and radionuclide transport analysis (MODFLOW and MT3D model implementation, Appendices D and F), cover and liner performance modeling (RUSLE2 model implementation and EMDF bathtub analysis in Appendix C) and the analysis of radon flux (Appendix H).

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APPENDIX A.
DETERMINATION OF SOURCE RELEASE IMPACTS USING GROUNDWATER MODELS

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CONTENTS

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FIGURES

TABLE

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ACRONYMS

BCBG	Bear Creek Burial Grounds
BCK	Bear Creek kilometer
BCV	Bear Creek Valley
BJC	Bechtel Jacobs Company LLC
DOE	U.S. Department of Energy
EMDF	Environmental Management Disposal Facility
EMWMF	Environmental Management Waste Management Facility
FS	feasibility study
MOC	Method of Characteristics
NT	North Tributary
POA	point of assessment
RI	remedial investigation
TMR	telescopic mesh refinement
UBCV	Upper Bear Creek Valley
USGS	U.S. Geological Survey

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A.1. INTRODUCTION

In order to identify and confirm the radionuclide migration pathways and the most appropriate location to evaluate the composite dose from all the potential contributing sources for this Composite Analysis (the point of assessment [POA]), groundwater modeling analyses were performed since groundwater is the only releasing pathway for the sources of potential radionuclide contamination in Bear Creek Valley (BCV). The sources include the proposed Environmental Management Disposal Facility (EMDF), the existing Environmental Management Waste Management Facility (EMWMF), and the other existing BCV sources. A three-dimensional groundwater flow model for the Upper Bear Creek Valley (UBCV) model that included all of the potential sources was developed during the conceptual design stage of the EMDF. Combined with the site-specific EMDF model used for the Performance Assessment (UCOR, an Amentum-led partnership with Jacobs, 2020), these model analyses prove that the surface water pathway at Bear Creek kilometer (BCK) 7.73 represents the most appropriate compliance point (the POA) for the Composite Analysis.

The UBCV model was developed and used because the large areal extent required of the model exceeded the existing EMWMF model and other site-specific models in BCV. Also, some of the site physical conditions changed from the mid-1990s when the regional watershed groundwater model (BCV model) was developed (U.S. Department of Energy [DOE] 1997a). The major physical changes included the construction of the EMWMF, the remediation and capping of the Boneyard/Burnyard, and capping of other waste source areas. The BCV model also has a scale that is too large (coarse grid) for a source release impact evaluation. The UBCV model is based on the regional Bear Creek watershed model developed during the Bear Creek watershed feasibility study (FS) and detailed site-specific models developed during the waste disposition remedial investigation (RI)/FS for EMWMF and other supporting evaluations (DOE 1998a, DOE 1998b, Bechtel Jacobs Company LLC [BJC] 2003, and BJC 2010).

The EMDF model, developed to aid the preliminary design of EMDF and used for the Performance Assessment of the EMDF, was then used to supplement the determination of the impact from the EMDF based on preliminary design (UCOR 2020). The results of characterization performed on and adjacent to the EMDF site in 2018 and 2019 were incorporated in the EMDF model.

The UBCV model used the MODFLOW-2000 code (Harbaugh et al. 2000), and the EMDF model used the MODFLOW-2005 code (Harbaugh 2005) and the enhanced finite-difference groundwater flow MODFLOW codes developed by the U.S. Geological Survey (USGS) (USGS 1988), to simulate the groundwater flow condition and predict the interaction between groundwater and surface water. MODFLOW was selected for BCV because it is in the public domain and is widely used by the industrial, scientific, and governmental communities worldwide. This code has been rigorously tested and verified, and a variety of software tools are available for graphical pre- and post-processing. Various MODFLOW models have been developed for the Oak Ridge area and were developed for the BCV RI and FS as well as EMWMF design and performance evaluations. The results from these models have received tri-party approval under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 process (DOE 1998b).

Based on the MODFLOW flow model simulations, the movement of contaminants from existing sources and the waste disposal facilities within BCV were predicted using MT3DMS (Zheng and Wang 1999), an improved version of the original three-dimensional fate-transport model code MT3D (Zheng 1990). MT3D is a comprehensive three-dimensional numerical simulation code that models the fate and transport of dissolved contaminants in complex groundwater systems. MT3D calculates concentration distributions, concentration histories at selected points and hydraulic sinks (e.g., extraction wells), and the mass of contaminants in the groundwater system. The code can simulate three-dimensional transport in complex steady-state and transient flow fields and can represent anisotropic dispersion, source-sink mixing processes, first-order transformation reactions, and linear and nonlinear sorption. MT3D offers the user a choice of four solution options that make it uniquely well suited for handling a wide range of conditions, including the Method of Characteristics (MOC) technique, which is best-suited for handling advection-dominated problems. MT3D is linked with the USGS groundwater flow simulator, MODFLOW, and is designed specifically to handle advectively dominated transport problems without the need to construct refined models specifically for solute transport. MT3D is the world's most popular three-dimensional solute transport code and has been used successfully to model thousands of sites. MT3D is widely accepted by regulators and the groundwater consulting and research communities.

The results of the model simulations were used to support the selection of the exposure pathway and the POA from all potential sources radioactive contamination in the BCV watershed for this Composite Analysis. The groundwater models use MODFLOW flow packages (drain and river) to represent the groundwater and surface water interactions. Since the models were used to simulate the long-term period of the flow condition, steady-state flow model simulations were performed. Since the MT3D application is based on flow simulation result, the groundwater and surface interaction is also represented for the plume evaluation.

A.2. UPPER BEAR CREEK VALLEY FLOW MODEL DEVELOPMENT AND APPLICATION

A telescopic mesh refinement (TMR) modeling approach was used to develop the UBCV model from the calibrated regional flow model that was originally constructed by the Jacobs Environmental Management Team for the BCV FS (DOE 1997a). The TMR approach enables the user to develop a site-specific model using existing regional information and allows focusing on areas of interest with increased model grid resolution and more accurate representation of site-specific features. The TMR approach utilizes results from the calibrated regional flow model to initialize boundary conditions (constant heads) and model parameters in the new TMR model that reduces the needs for detailed model recalibration. However, to better represent the precise locations of streams, hydrogeological units, and waste disposal units (including EMWMF and EMDF), further refinement was made after the site-specific flow model was constructed. As mentioned earlier, the UBCV model was developed during the early conceptual design stage of the EMDF. However, the footprints of the proposed disposal facility design between conceptual design and preliminary design are very similar; therefore, the UCBV model application for the EMDF site is appropriate.

Groundwater Vistas, a model graphic user interface program, was used in the model development and pre- and post-modeling processes (Environmental Simulations, Inc. 2017). Construction of the UBCV model with the existing EMWMF and the proposed conceptual design for the EMDF consisted of the following steps:

1. **Establish model domain and dimension.**

   The TMR method was used to develop the UBCV model from the calibrated regional BCV flow model (DOE 1997a) by extracting boundary conditions, model layers, and model properties. A refined grid cell size (10 ft × 10 ft) is used for the new model domain to better represent detailed disposal facility design features.

2. **Model refinement.**

To represent the detailed current site-specific features, the following refinements were made after the site-specific flow model domain was constructed:

a) The refined and improved parameters used in the extensively calibrated EMWMF model were incorporated into the UBCV model.

b) Detailed adjustments were made to areas to smooth the transition along the model boundaries and parameter zones to more precisely represent the field conditions. The hydraulic conductivity zones and its boundaries were adjusted based on field conditions and geological maps for the refined (smaller-spaced) grids.

c) Parameters representing surface water features at the site (creeks and tributaries) were incorporated into the refined model to more precisely represent the site-specific conditions. To best represent the surface water-groundwater interaction, the surface water features in BCV were incorporated into the model, including Bear Creek and its tributaries and their actual elevations. The site features (natural [e.g., ditches and channels] and engineered [e.g., underdrains]) are also represented in the model. The surface drainage features are represented in the model as drain cells.

d) Final EMWMF six-cell design and proposed EMDF conceptual design were incorporated into the future condition model to predict the flow condition after disposal facility construction.

e) Parameters representing the construction/engineered features for EMWMF and the proposed conceptual design of EMDF were incorporated into the model. Modifications were made to represent site-specific design and construction features (e.g., channel backfill, berms, underdrains, geologic buffer material, and surface drainages) associated with construction near the sites.

f) Future landfill performance parameters (e.g., long-term recharge rate through waste zone) were included.

g) Future landfill performance parameters for the existing waste areas in the Bear Creek Burial Grounds (BCBG) were included based on information contained in the Focused FS for BCBG (DOE 2008).

A.2.1 UBCV MODEL DOMAIN AND DISCRETIZATION

The UBCV model covers an area from east of the S-3 Ponds to west of North Tributary (NT)-11 (17,200 ft from east to west) and from the top of Chestnut Ridge to the top of Pine Ridge (5000 ft from south to north). The model domain and topography is shown on Fig. A.1 and includes the final design of the EMWMF and the proposed conceptual design of the EMDF, the Composite Analysis POA at BCK 7.73, the Phase I BCV Record of Decision Integration Point at BCK 9.2, and the EMWMF point of compliance at BCK 10.5.

Model discretization refers to the assignment and alignment of the numerical cells in the model and the relationship of those cells to actual engineered and natural conditions. A uniform horizontal grid size of 10 ft × 10 ft is used for the model domain. There are 1720 rows and 500 columns in the UBCV model. To better represent the hydrogeologic property orientation and anisotropy nature in the model, the model grid is rotated from its true north and aligns with the southwest to northeast valley and ridge direction.

Fig. A.1. UBCV model domain and topography

The UBCV model uses five model layers to represent the vertical variation in the hydraulic properties, similar to the BCV regional model. The top of the model (layer 1) reflects the topography for the current condition model (circa 2012) and proposed disposal facility design topography around the proposed EMDF. The first layer represents the engineered design features, residuum saprolite, and weathered bedrock zone. The model layer has variable thicknesses ranging from 25 to 75 ft. The bottom of the layer corresponds approximately to the unweathered fractured bedrock surface. Fractured bedrock is represented by layer 2, which is 100 ft thick. Layers 3, 4, and 5 are 150 ft, 200 ft, and 300 ft thick, respectively, representing less fractured and less permeable deeper bedrock. There are a total of 4,300,000 cells in the UBCV model, with 3,156,180 active in the groundwater flow model.

The vertical discretization for this future condition model along the two cross-sections (Fig. A.1) is shown on Fig. A.2.

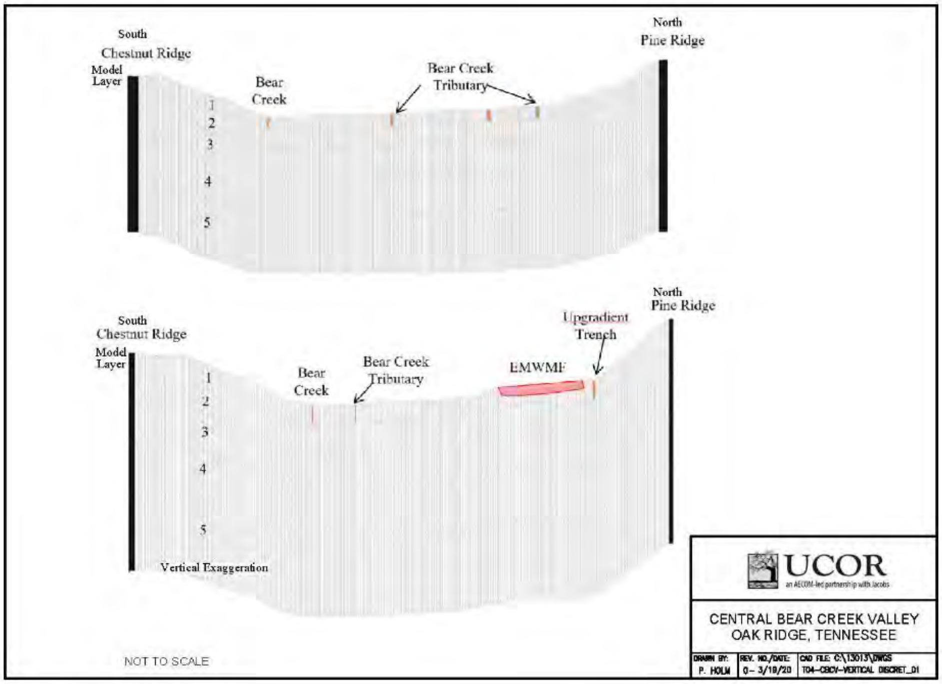

Fig. A.2. UBCV model vertical discretization

A.2.2. MODEL BOUNDARY CONDITIONS

The UBCV model has a no-flow boundary at the top of Pine Ridge to the northwest (Fig. A.1), at the top of Chestnut Ridge to the southeast, and at the groundwater divide between BCV and Upper East Fork Poplar Creek and the Y-12 National Security Complex to the northeast. These boundaries approximate the natural groundwater divide between the watersheds (see Sect. 2.3.1 of the Composite Analysis). Constant head boundary conditions to the southwest were assumed based on a steady-state simulation of the calibrated regional BCV groundwater flow model. The model boundary was established at a sufficient large distance from all disposal sites and assessment locations so as not to be affected by topographic alterations associated with disposal facility development.

The vertical base of the model is a no-flow boundary because minimal flow of active groundwater occurs below this depth. The model incorporates Bear Creek and its tributaries as well as site features for EMWMF and the proposed EMDF (i.e., ditches and channels, cut and filled areas, underdrain features, and French drains). The surface drainage features (Fig. A.3) are represented in the model as drain cells. Drain cells allow groundwater to discharge into a surface water body. Actual stream bottom elevations were assigned in the model.

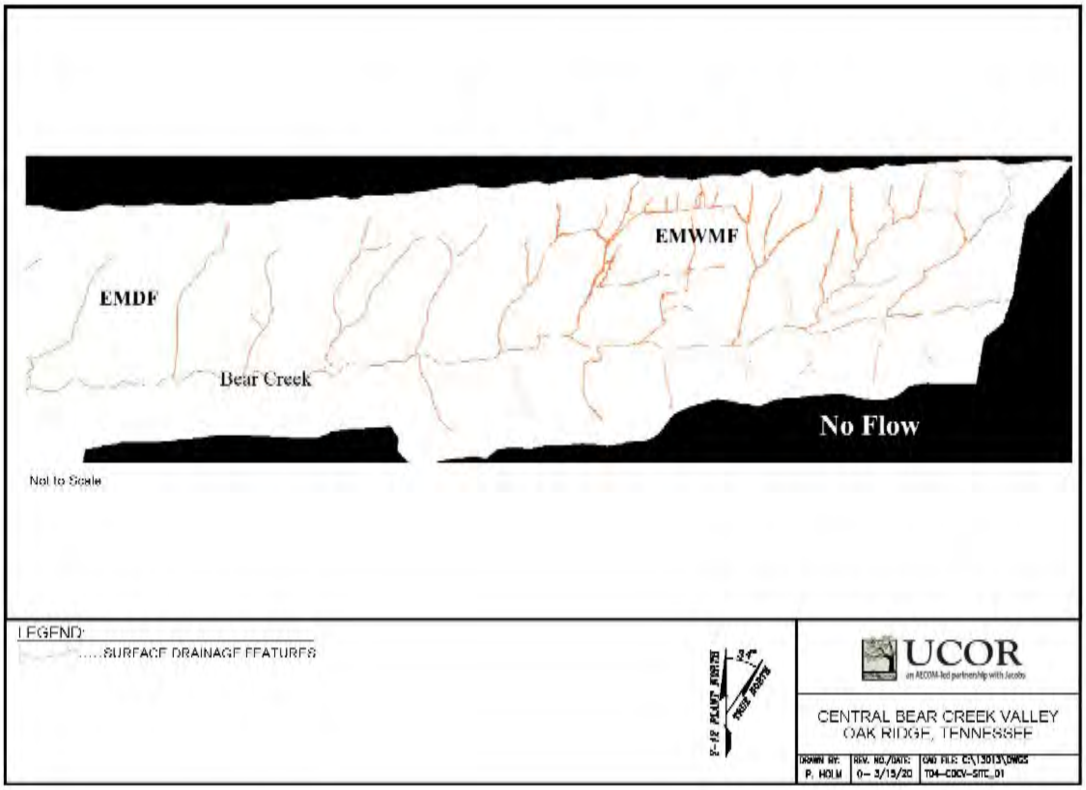

Fig. A.3. Boundary conditions and surface drainage features in the UBCV model

Infiltration from precipitation is assumed to be the sole source of inflow to groundwater for the model because the site is bounded on three sides by no-flow boundaries. Infiltration is precipitation minus runoff and evapotranspiration, and the recharge rate is a function of geologic media, surface slope, and vegetation. Several recharge rates were assigned in the model (Fig. A.4) to correspond to geological units and their hydrologic properties (see Table A.1 for recharge rates):

- Natural recharge to the Maynardville Limestone and Knox Group carbonates
- Natural recharge to the Nolichucky Shale
- Natural recharge to the Conasauga Group Shales and Siltstones and to Rome Formation Sandstone
- Reduced recharge through existing caps at former disposal sites
- The worst case (long-term) recharges for EMWMF based on waste acceptance criteria development assumptions
- The worst case (long-term) recharges rate assumed for the conceptual design of the proposed EMDF disposal facility in a future closed state, as determined in the Hydrologic Evaluation of Landfill Performance (referred to as HELP) model.

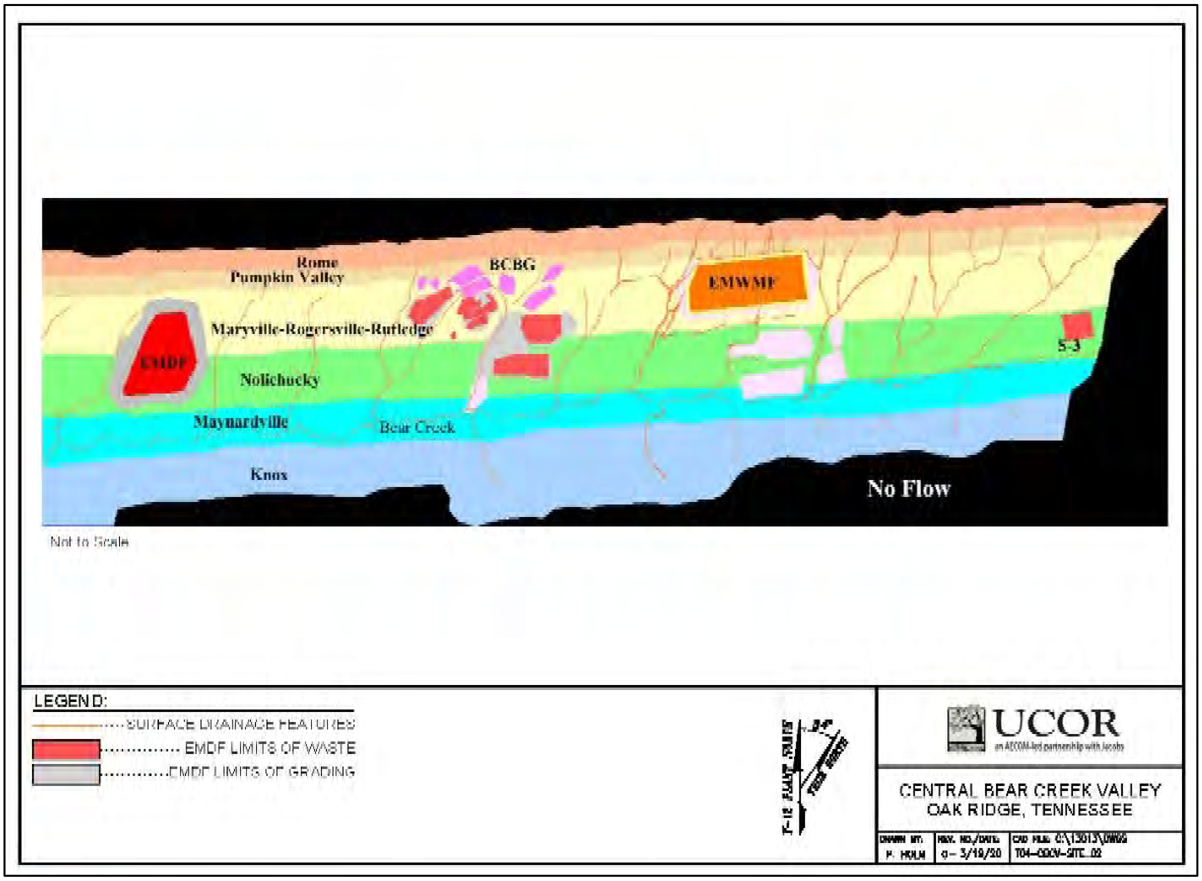

Fig. A.4. Recharge zones in the UBCV model

Table A.1. UBCV groundwater model parameter summary

Grid Information		
Number of rows	1720	
Number of columns	500	
Number of layers	5	
Total cells	4,300,000	
Total active cells	3,156,180	
Percent inactive	73.40%	
Grid Dimensions		
Row spacing	10	ft
Column spacing	10	ft
Vertical spacing		
Layers 1	Variable (25–75)	ft
Layers 2	100	ft
Layer 3	150	ft
Layer 4	200	ft
Layer 5	300	ft
Coordinate Transformation		
X offset (to Y-12 coordinate system)	53,624.30	ft
Y offset (to Y-12 coordinate system)	27,274.08	ft
Rotation	90.23	degree

Table A.1. UBCV groundwater model parameter summary (cont.)

Model Boundary Conditions		
Constant heads	2484	# of cells
Rivers	0	# of cells
Drains	10,360	# of cells
General heads	0	# of cells
Wells	0	# of cells
No flow	1,143,820	# of cells

Recharge		
Areas	**Recharge rate**	**Unit**
Rome	2.00E-03	ft/day
Pumpkin Valley	1.60E-03	ft/day
Maryville-Rogersville-Rutledge	1.60E-03	ft/day
Nolichucky	2.00E-03	ft/day
Maynardville	3.00E-03	ft/day
Knox	3.00E-03	ft/day
Closed landfill with clay cover	2.80E-04	ft/day
Closed landfill with RCRA cover	1.80E-04	ft/day
EMWMF	9.00E-05	ft/day
EMDF	2.28E-04	ft/day

Hydraulic Conductivity					
Material or geologic formation	**Model layer**	**K_x**	**K_y**	**K_z**	**Unit**
Knox	1	1.56E+00	7.80E+00	1.56E+00	ft/day
Knox	2	9.18E-03	9.18E-02	9.18E-03	ft/day
Knox	3	2.54E-03	2.54E-02	2.54E-03	ft/day
Knox	4	1.16E-03	1.16E-02	1.16E-03	ft/day
Knox	5	3.60E-04	3.60E-03	3.60E-04	ft/day
Maynardville	1	2.13E+00	1.07E+01	2.13E+00	ft/day
Maynardville	2	1.21E-02	1.21E-01	1.21E-02	ft/day
Maynardville	3	3.34E-03	3.34E-02	3.34E-03	ft/day
Maynardville	4	1.52E-03	1.52E-02	1.52E-03	ft/day
Maynardville	5	4.80E-04	4.80E-03	4.80E-04	ft/day
Nolichucky	1	1.50E-01	7.50E-01	1.50E-01	ft/day
Nolichucky	2	3.60E-03	3.60E-02	3.60E-03	ft/day
Nolichucky	3	2.52E-03	2.52E-02	2.52E-03	ft/day
Nolichucky	4	6.10E-04	6.10E-03	6.10E-04	ft/day
Nolichucky	5	5.00E-05	5.00E-04	5.00E-05	ft/day
Maryville-Rogersville-Rutledge	1	4.95E-02	2.48E-01	4.95E-02	ft/day
Maryville-Rogersville-Rutledge	2	4.72E-03	4.72E-02	4.72E-03	ft/day
Maryville-Rogersville-Rutledge	3	1.35E-03	1.35E-02	1.35E-03	ft/day
Maryville-Rogersville-Rutledge	4	3.20E-04	3.20E-03	3.20E-04	ft/day
Maryville-Rogersville-Rutledge	5	4.50E-05	4.50E-04	4.50E-05	ft/day
Pumpkin Valley	1	3.00E-02	1.50E-01	3.00E-02	ft/day
Pumpkin Valley	2	4.72E-02	4.72E-01	4.72E-02	ft/day
Pumpkin Valley	3	1.75E-03	1.75E-02	1.75E-03	ft/day
Pumpkin Valley	4	4.20E-04	4.20E-03	4.20E-04	ft/day
Pumpkin Valley	5	5.60E-04	5.60E-03	5.60E-04	ft/day

Table A.1. UBCV groundwater model parameter summary (cont.)

Material or geologic formation	Model layer	K_x	K_y	K_z	Unit
Rome	1	8.00E-02	4.00E-01	8.00E-02	ft/day
Rome	2	5.00E-03	5.00E-02	5.00E-03	ft/day
Rome	3	2.00E-03	2.00E-02	2.00E-03	ft/day
Rome	4	5.00E-04	5.00E-03	5.00E-04	ft/day
Rome	5	8.00E-05	8.00E-04	8.00E-05	ft/day

EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
RCRA = Resource Conservation and Recovery Act of 1976
UBCV = Upper Bear Creek Valley
Y-12 = Y-12 National Security Complex

A.2.3 HYDRAULIC CONDUCTIVITY FIELD

Similar to the BCV regional model, six distinct hydraulic conductivity zones were used in the UBCV model to represent the eight geologic units that exist in BCV (Knox Dolomite, Maynardville Limestone, Nolichucky Shale, Maryville-Rogersville-Rutledge Formations, Pumpkin Valley Shale, and Rome Sandstone) based on their hydrological properties. Anisotropy ratios (K_y versus K_x [K_z]) of 5:1 (for saprolite/weathered bedrock zone) and 10:1 (for fractured bedrock zone) were used to represent the preferred fracture/bedding orientation of the geologic units. In this case, K_y represents the conductivity parallel to strike, K_x is the horizontal conductivity perpendicular to strike, and K_z represents the vertical hydraulic conductivity. Both field data and previous modeling sensitivity analyses support the anisotropic ratios used in the model. Field data included analytical plume distribution and aquifer test data within BCV. Extensive modeling sensitivity analyses were conducted during the Bear Creek regional model development and were reported in the BCV FS. All of these data indicated an anisotropic flow regime in the BCV aquifer. A detailed summary of the aquifer test data is provided in the BCV FS (DOE 1997a, Appendix F).

Modifications were made to the UBCV model to represent future conditions and site-specific features associated with disposal facility construction. Engineered features that were added include berms, underdrains, geologic buffer material, and the low permeability clay liner. All of the engineered and reworked materials were modeled as isotropic units in the horizontal plane (i.e., hydraulic conductivity does not vary with direction).

In summary, the site is modeled as a single unconfined aquifer, with five vertical layers to simulate the changes in hydraulic parameters with depth, and the 45 degree dip in the geological formation is represented by staggering hydrogeologic units with depth. Model layer 1 represents the unconsolidated/weathered bedrock zone. Model layer 2 represents the top bedrock interval between 50 to 150 ft. Model layers 3, 4, and 5 represent the intermediate/deep bedrock zone.

Fig. A.5 shows the zones of hydraulic conductivities used to represent hydrogeologic units in layer 1 of the UBCV model. The hydraulic conductivity field is shown in a vertical south-north cross-section on Fig. A.6, which illustrates the staggering of hydrogeologic units with depth to simulate the 45 degree dip. Detailed model parameters for the UBCV model are provided in Table A.1.

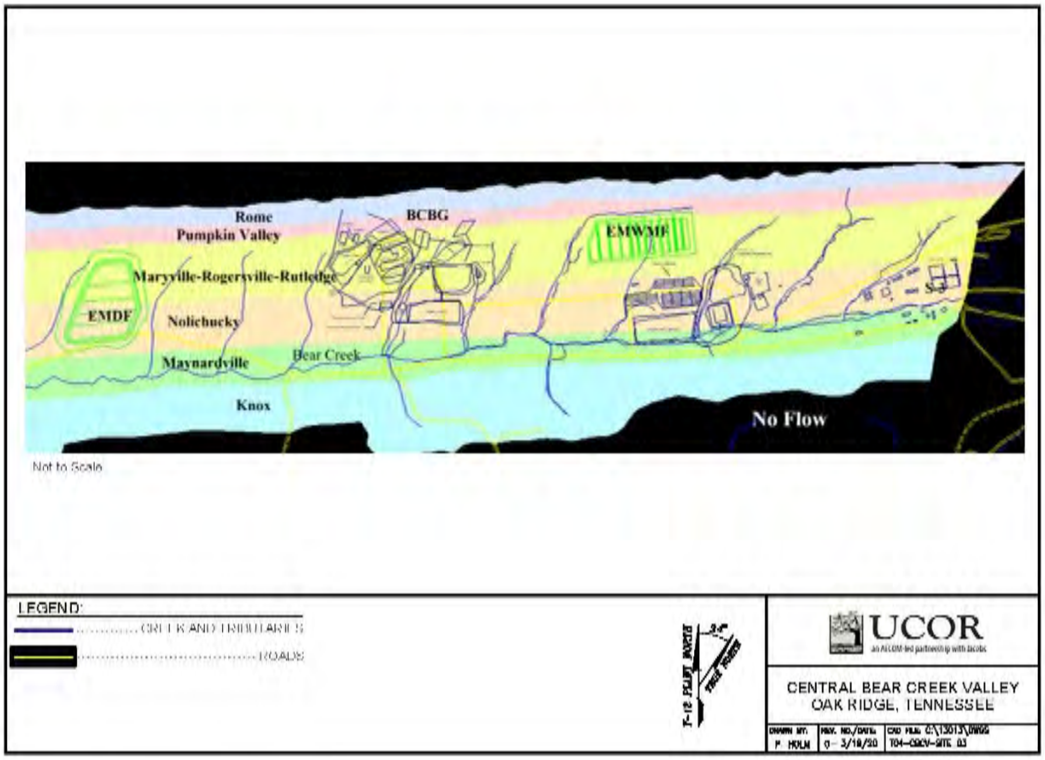

Fig. A.5. Hydraulic conductivity representation in the model - layer 1

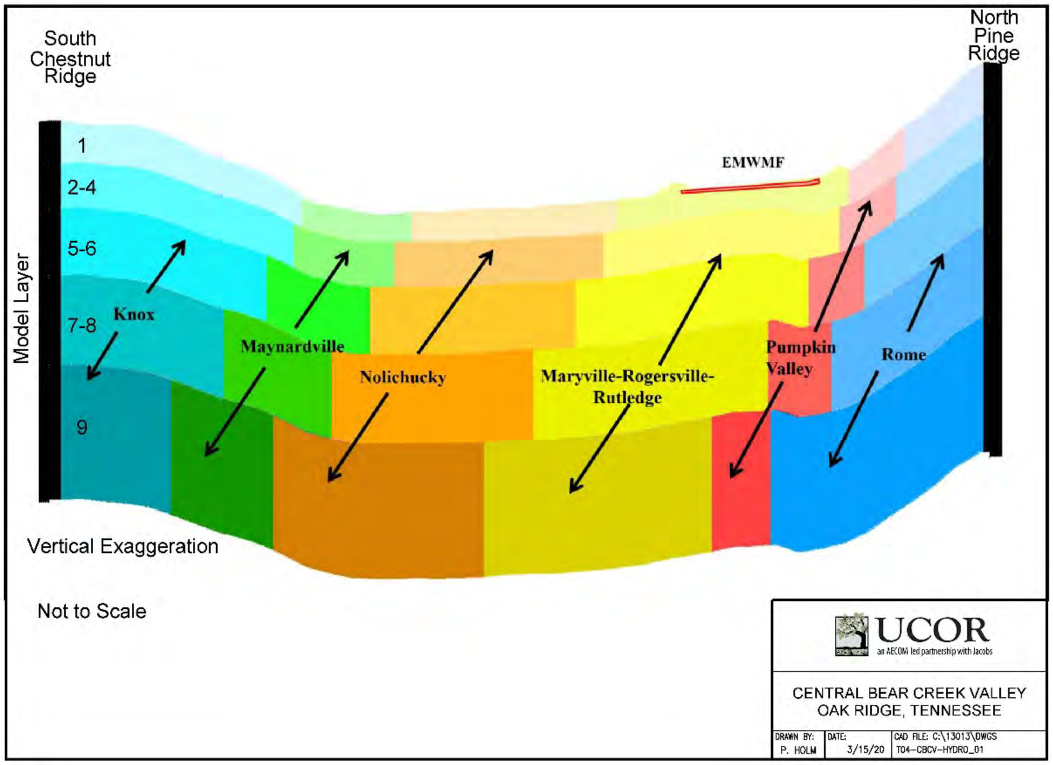

Fig. A.6. Hydraulic conductivity representation in the model - vertical direction

A.2.4 MODEL CALIBRATION

Calibration of a groundwater flow model refers to the process of adjusting model input parameters (e.g., hydraulic conductivity) and boundary conditions (e.g., precipitation recharge, stream and seep conductivity) to obtain a reasonable match between observed (actual groundwater levels from monitoring wells) and simulated hydrogeologic conditions. In practice, this usually involves an iterative process of adjusting hydraulic properties and/or boundary conditions assigned in the model. At all stages of the model calibration process, parameter values and boundary conditions should be constrained by hydrogeologic data collected in the field and engineering design values.

The UBCV model was constructed using the TMR approach based on the calibrated BCV regional model and used extensive knowledge derived from the EMWMF site-specific model. An advantage of the TMR approach is that a high-resolution (small-scale) model can be developed that retains the regional flow characteristics. Because the parameters and boundary conditions associated with the UBCV model are derived from the regional groundwater flow model and EMWMF model, no additional calibration of the UBCV model was conducted since no new monitoring locations were added prior to the conceptual design of the EMDF.

The water balance error for the UBCV model simulation is 0.20 percent and is within the typically accepted limit of model calibration. The water balance shows that essentially all water has been mathematically accounted for and that the MODFLOW simulation has correctly solved the governing flow equations.

A.2.5 UBCV FLOW MODEL RESULT

The area is modeled as a single unconfined aquifer, with all model layers assumed to be in an unconfined condition since the modeled hydraulic conductivity decreases with depth. All flow model simulations were conducted using the MODFLOW-2000 code (Harbaugh et al. 2000), an improved version of the original MODFLOW code (USGS 1988).

The model-predicted groundwater water table condition (model layer 1) is shown on Fig. A.7. The simulated groundwater flow field is consistent with the site conceptual model, water level maps constructed based on monitoring data, and a general understanding of the site. Generally, the result based on flow model particle tracking indicates that shallow groundwater discharges into Bear Creek and its tributaries.

Groundwater in the fractured bedrock zone (model layer 2) also is strongly influenced by Bear Creek and hydrogeologic unit orientation (Fig. A.8). Although the intermediate groundwater zone does not show the strong influence from tributaries in the shallow groundwater zone, the intermediate groundwater shows the influence of Bear Creek while migrating downstream.

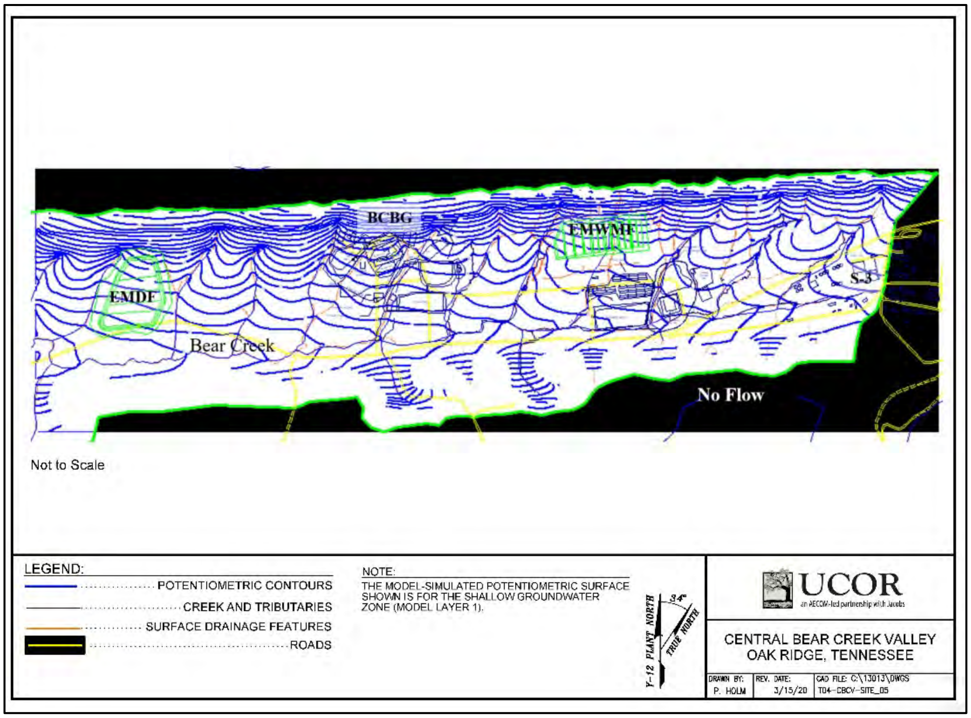

Fig. A.7. Model-predicted shallow water level

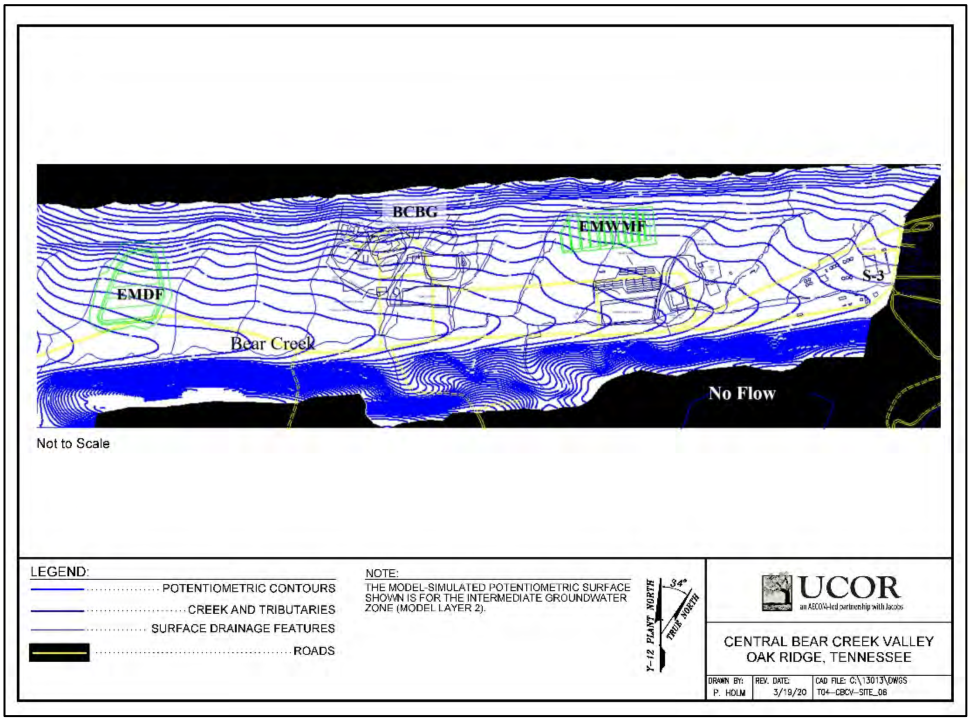

Fig. A.8. Model-predicted levels in the intermediate zone

A.3. FATE-TRANSPORT (MT3D) MODEL APPLICATION USING UBCV MODEL

The movement of contaminants from all the sources to various locations (i.e., to the exposure locations) outside of the source zones via groundwater was simulated using the MT3DMS code (Zheng and Wang 1999). MT3DMS code is a modular three-dimensional multi-species transport model for simulation of advection, dispersion, and chemical reactions of constituents in groundwater systems. MT3DMS is an expanded capability version of the original MT3D code (Zheng 1990). Based on results of the MODFLOW simulation for the future closed EMDF and EMWMF scenario, MT3D is used to predict potential contaminant plume distribution and discharge in the BCV area, specifically at the assessment locations.

A.3.1 SITE-SPECIFIC MT3D MODEL APPLICATION

Although MT3D can be used to simulate the concentration of a specific contaminant at various locations based on a given flow field, it is used to determine a single relative concentration at a given location compared to an assumed constant leachate source concentration in this application. The flow field is supplied by the MODFLOW simulation.

To determine all possible impacts of the disposal facilities to the existing and future site conditions, the following source terms were modeled:

- Other existing BCV sources (S-3 Site and BCBG)
- EMWMF (final design)
- Proposed EMDF (conceptual design).

A constant leaching (recharge) from the waste sources to the groundwater was assumed as input to the model. The sources are assumed to be constant. Assigning a constant leaching and non-depleting source is a very conservative assumption because the contaminant mass (thus leaching rate) in all sources will decrease with time due to decreasing mass in the disposal facilities and source areas. Since the purpose of the model is to predict the potential maximum impact of plume migration for each of the disposal sites and its individual pathways, all sources are assumed to have a uniform leaching source concentration of 1.

Although the MT3D model will consider all fate-transport processes, only the advection process was considered. No hydrodynamic dispersion or retardation processes were considered in the MT3D simulations. The MOC solution method was used for all the simulations to minimize the potential error from numerical dispersion. These assumptions will result in the largest potential impacts for the area and at the assessment locations.

The model simulations were run to a near steady-state condition for the plumes for each model simulation. The steady-state condition means that the concentrations at all locations on the model domain do not change and the plumes reach their maximum extent. For all of the model simulations, a near steady-state condition is achieved after 2500 years.

A.3.2 MT3D MODEL RESULTS

The model-predicted maximum extent of groundwater plumes from the other existing BCV sources (S-3 Site and BCBG) are shown on Fig. A.9. The plumes shown are the maximum composite plumes in all model layers. The plumes are very similar to the plumes delineated from the monitoring data and consistent with contaminant fate and transport site conditions and the conceptual site model as discussed in the BCV RI (DOE 1997b) and FS (DOE 1997a) and summarized in Sects. 2.4.4.1 and 3.2 of the Composite Analysis. The simulations show that the groundwater contamination near the BCK 9.2 area is all from BCBG sources. All the releases to the groundwater from the other existing BCV sources discharges to the surface water before the POA (BCK 7.73).

For the EMWMF source, model simulation indicate that the resulting groundwater plumes discharge into the Bear Creek surface water body before reaching the BCK 9.2 location (Fig. A.10). The majority of the source release moves in the shallow groundwater zone and into the surface water streams. The remaining minor plume moves in the more permeable hydrogeological unit near Bear Creek and discharges into Bear Creek further downstream. There is no impact to the groundwater downstream of BCK 9.2 from potential EMWMF radiological contamination. All the release to the groundwater from the EMWMF discharges to the surface water before the POA (BCK 7.73).

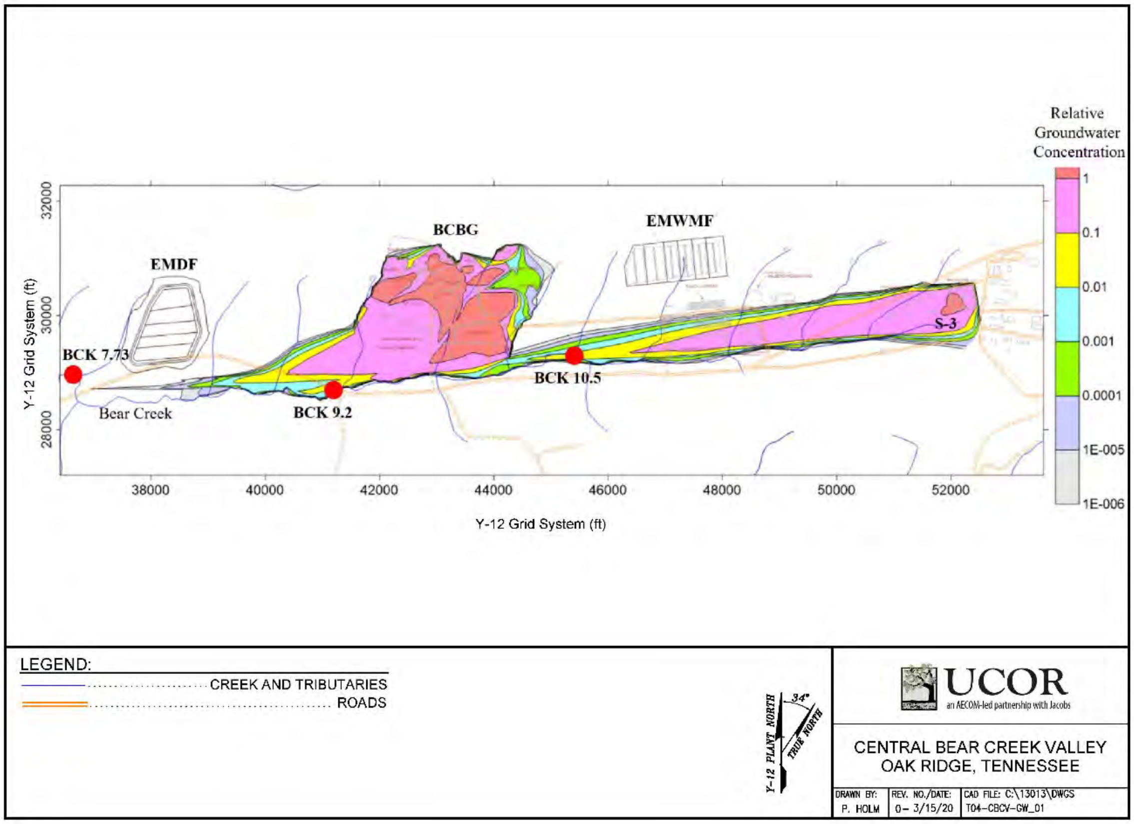

Fig. A.9. UBCV model-predicted maximum extent for groundwater plumes from the other existing BCV sources

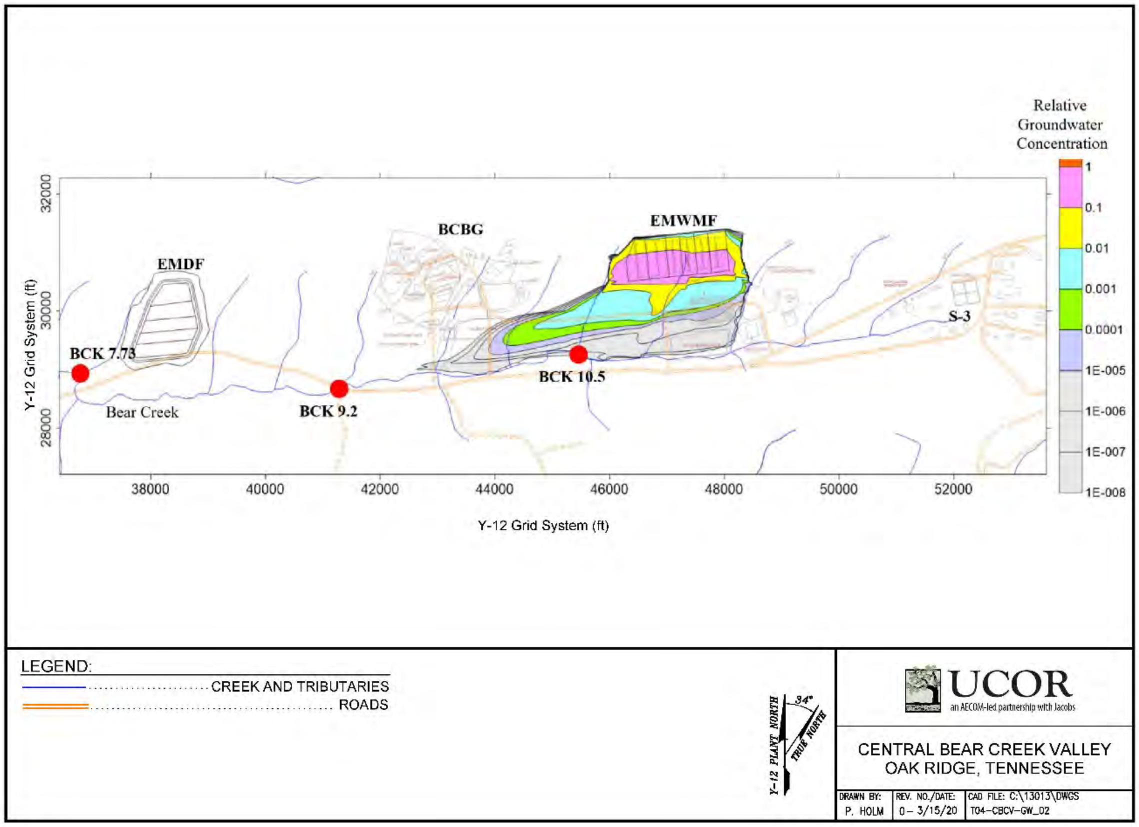

Fig. A.10. UBCV model-predicted maximum extent for groundwater plumes from the EMWMF source

For the proposed EMDF source, model simulation based on the conceptual design indicates the majority of the resulting groundwater plume discharges into NT-11 and Bear Creek surface water body (Fig. A.11). Similar to the EMWMF site, the majority of source release moves in the shallow groundwater zone and into the surface water streams. However, the modeled plume suggests there is likely some contamination that may flow southwest (down valley) beyond the model boundary. To fully evaluate the EMDF plume, the modeled result from the EMDF site-specific groundwater model simulation performed during the EMDF Performance Assessment was also applied.

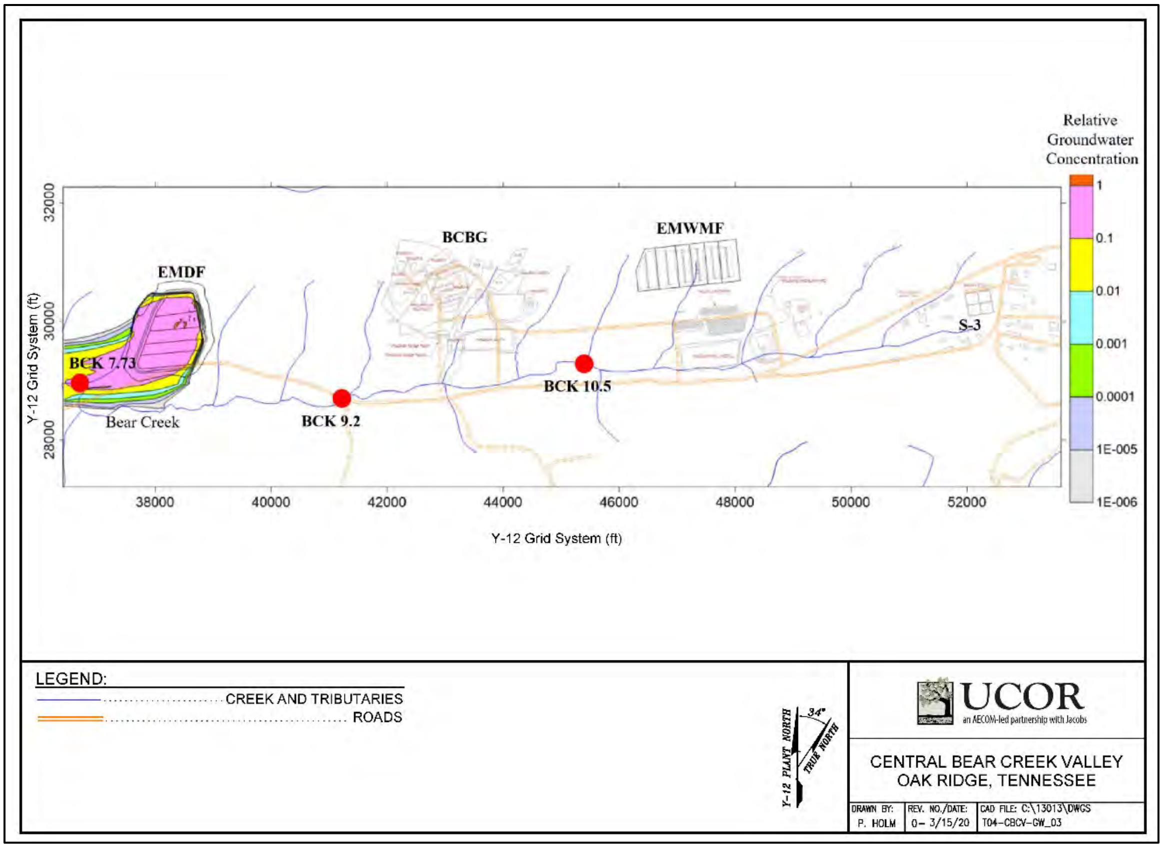

Fig. A.11. UBCV model-predicted maximum extent for groundwater plumes from the EMDF source

A.4. EMDF MODEL APPLICATION

The EMDF site-specific three-dimensional groundwater flow model was constructed to support preliminary EMDF design and the EMDF Performance Assessment (UCOR 2020, Appendix D). The EMDF model incorporated all site-specific field investigation data from 2018 to 2019 and information from the EMDF preliminary design. The EMDF model covers an area from west of NT-8 to west of NT-14 (Gum Branch) from northeast to southwest and from the top of Chestnut Ridge to the top of Pine Ridge. Detailed model information is presented in Appendix D of the Performance Assessment.

Similar to the UBCV model application, advection-only fate-transport modeling was conducted to delineate the maximum plume extent due to release from EMDF (UCOR 2020, Appendix F). The maximum composite EMDF plumes in all model layers are shown on Fig. A.12, based on the EMDF model results. As indicated by the EMDF model, most of the contaminant mass discharge from the EMDF (>88 percent) is received by NT-11, followed by some minor discharge to NT-10. Compared to the total groundwater discharge to surface water within the EMDF model domain, the junction of Bear Creek and NT-11 sees a total of over 98 percent of the contaminant mass, suggesting that only these three near-disposal facility surface water segments should be evaluated for surface water resource protection. The model results also validate use of the junction of Bear Creek and NT-11 (BCK 7.73) as the compliance point to conduct impact evaluations for EMDF and the location of the POA for this Composite Analysis.

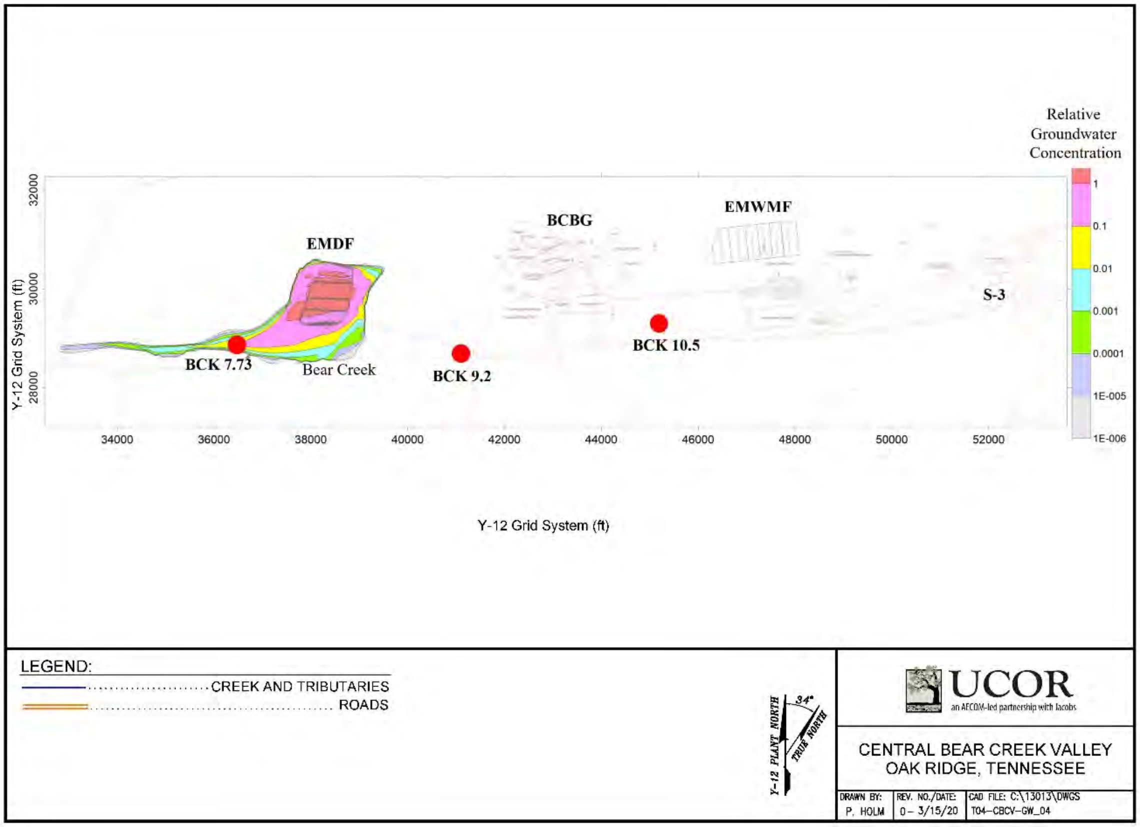

Fig. A.12. EMDF model-predicted maximum extent for groundwater plumes from the EMDF source

A.5. MODELING CONCLUSIONS

The model results demonstrate that any groundwater contamination from future releases from the disposal facilities and other source zones would move mostly into Bear Creek and its tributaries near the site after migration into the groundwater beneath the sites. The plume would then move downstream along the more permeable formations and then eventually discharge into Bear Creek surface water. The model-predicted plume migration and pathway agree with the current understanding of contaminant migration in BCV. The model simulation results for the other existing BCV sources are also in agreement with the historical and ongoing monitoring data.

The model results are consistent with the description of the conceptual site model in Sect. 3.2 of this Composite Analysis. Any potential future radiological releases from EMWMF and the other existing sources in BCV would have almost no impact on groundwater at the POA (BCK 7.73) area. This is consistent with the description of contaminant fate and transport in Sect. 2.4.4.1 of this Composite Analysis. The surface water location at the POA provides the closest (most impacted) location to the EMDF for the composite impact from all potential future sources of radiological contamination in BCV.

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APPENDIX B.
ENVIRONMENTAL MANAGEMENT WASTEMANAGEMENT FACILITY DOSE ANALYSIS

CONTENTS

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TABLES

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ACRONYMS

BCK	Bear Creek kilometer
BCV	Bear Creek Valley
BJC	Bechtel Jacobs Company LLC
DF	dilution factor
DOE	U.S. Department of Energy
EMWMF	Environmental Management Waste Management Facility
EPA	U.S. Environmental Protection Agency
EU	equivalent uptake
NT	North Tributary
RESRAD	RESidual RADioactivity
RI/FS	Remedial Investigation/Feasibility Study
WAC	waste acceptance criteria

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B.1. INTRODUCTION

The Environmental Management Waste Management Facility (EMWMF) is located in the Bear Creek Valley (BCV) on the Oak Ridge Reservation. Contribution of the dose from EMWMF to the Composite Analysis was determined using the PATHRAE-RAD model (Rogers and Associates 1995), the same method applied for the waste acceptance criteria (WAC) development and subsequent performance evaluations associated with cell expansions (U.S. Department of Energy [DOE] 1998a, DOE 2001, and Bechtel Jacobs Company LLC [BJC] 2010). More recently, in December 2018 the EMWMF received an Operating Disposal Authorization Statement from DOE-Headquarters in part based on additional evaluation of Cell 6, performed using the PATHRAE-RAD model to address issues from the DOE Low-level Waste Disposal Facility Federal Review Group (DOE 2018). To be consistent with these previous modeling efforts, the PATHRAE-RAD code was used in this Composite Analysis to quantify doses for the EMWMF.

PATHRAE-RAD is a computer code capable of assessing multiple transport pathways for radiological contaminants that have the potential to impact human receptors. PATHRAE-RAD was originally developed for use by the U.S. Environmental Protection Agency (EPA) (PATHRAE-EPA) in preparation of standards for management of low-level (radioactive) waste (EPA 1987). PATHRAE-RAD can be used to estimate risks and doses to humans from possible releases and subsequent transport of contaminants through multiple pathways from land disposal units containing chemical and radioactive wastes. The code also can be used to calculate risks at specified points in time and peak risks (in time) to individuals at any number of key locations inside or outside the boundaries of a disposal facility.

The PATHRAE-RAD code can model the movement of contaminants via groundwater to surface water. This pathway consists of the downward movement of contaminants from the overlying waste through the unsaturated zone. This movement results from the leaching of contaminants by precipitation that infiltrates through the cap and percolates through the waste. A one-dimensional model of this movement through a uniform medium was used. Once the contaminants reached the saturated zone, their horizontal movement to the point of discharge into the surface water was modeled as one-dimensional movement through a uniform medium. For migration of radionuclides through the saturated zone, the in growth of daughter radionuclides can be calculated for any of seven radioactive decay chains.

The PATHRAE-RAD code performs similar tasks to other pathway analysis codes, such as RESidual RADioactivity (RESRAD). A benchmarking comparative study by a RESRAD team concluded that the doses predicted by the RESRAD and PATHRAE-RAD codes for the inhalation and ingestion pathways were in relatively good agreement (Fallace et al. 1994). An advantage of the PATHRAE-RAD codes is the simplicity of operation and presentation of results, while still allowing the analysis of a comprehensive set of contaminants and pathways to human receptors. This allows the easy identification of parameters important for the protection of the public from potential releases.

The PATHRAE-RAD model was used to estimate the resulting dose for a receptor at the Bear Creek and North Tributary (NT)-5 (Bear Creek kilometer [BCK] 10.5) location from an estimated closure waste inventory in the EMWMF based on latest operational data using the same method and model parameter assumptions used for the EMWMF Remedial Investigation/Feasibility Study (RI/FS) (DOE 1998a), its addendum (DOE 1998b), and subsequent performance evaluations associated with cell expansions (BJC 2010). The dose then was applied for downstream receptor locations in this Composite Analysis.

B.2. EMWMF WASTE PROFILE

Based on the operational EMWMF waste profile information (UCOR, an Amentum-led partnership with Jacobs, 2019) available during the preparation of this Composite Analysis (through March 2019), EMWMF was filled to approximately 79 percent of capacity with a carcinogenic volume-weighted sum of fractions of 0.6. The waste disposal information was used to estimate an EMWMF source term at closure, assuming the radionuclide composition in waste disposed remains the same for the remainder of cell operations. Although a total of 65 radionuclides were initially modeled to support the development of EMWMF WAC, only 13 of the radionuclides have WAC limits at EMWMF; therefore, the waste placement information contains just these radionuclides. Table B.1 lists the reported activity disposed in the EMWMF and the calculated total waste inventories at the cell closure which were used to conduct EMWMF dose calculation.

Table B.1. Radionuclide activity in the EMWMF

Radionuclide	Reported activity at FY19 (Ci)	Calculated activity after closure (Ci)
Am-241	2.02E+01	2.55E+01
C-14	2.77E+00	3.50E+00
H-3	1.21E+01	1.53E+01
I-129	1.15E-03	1.45E-03
Np-237	1.40E+00	1.77E+00
Pu-239	1.01E+01	1.28E+01
Pu-240	1.59E+00	2.01E+00
Pu-239/240[a]	2.47E+00	3.12E+00
Tc-99	1.70E+02	2.15E+02
U-233	1.75E+00	2.21E+00
U-234	2.09E+02	2.64E+02
U-233/234[a]	2.22E+02	2.81E+02
U-235	3.53E+01	4.46E+01
U-236	6.80E+00	8.59E+00
U-238	2.58E+02	3.26E+02

[a] The waste mass reported for Pu-239/240 was combined with the waste mass for Pu-240 to obtain the total waste mass of Pu-240 and then modeled as a single radionuclide. Similarly, the waste mass reported for U-233/234 was combined with the waste mass for U-234 to obtain the total waste mass of U-234 and then modeled as a single radionuclide.

EMWMF = Environmental Management Waste Management Facility
FY = fiscal year

B.3. PATHRAE-RAD MODELING

The same model input parameters used in the EMWMF performance evaluations (DOE 1998a, DOE 1998b, BJC 2010) were used for this Composite Analysis. The PATHRAE-RAD input values were obtained from both literature sources and measured, site-specific values (such as stream flow rates). Some key parameters were calculated using additional models and site-specific information (e.g., water infiltration rates, groundwater transport parameters, and contaminant release rates for various waste forms). Key parameters used in the PATHRAE-RAD model are summarized in Table B.2.

Table B.2. Key PATHRAE-RAD parameters used in EMWMF Performance Evaluation

Physical process	Solution methodology	Parameters needed
Rate of water infiltration into the waste cell	HELP model	Site-specific climatic parameters; disposal cell design parameters; vadose zone hydrological parameters
Contaminant release rates from the waste disposal forms to the surrounding backfill soils	K_d leaching mechanisms and waste diffusion processes	Site-specific and generic K_d factors for soils; generic diffusion parameters
Material retardation characteristics (i.e., ability of a material to retard the movement of contaminants) within and away from the disposal facility	K_d equilibrium mechanisms with backfill soils, vadose zone soils, and saturated media	Site-specific and generic K_d factors for soils and saturated zone media
Groundwater transport characteristics	MODFLOW and MT3D models	Site-specific and generic hydrogeologic parameters
Groundwater interactions with surface water	MODFLOW, MODPATH, and PATHRAE-RAD model	Surface water flow parameters and MODFLOW/MODPATH results
Contaminant uptake parameters for the food chain, and the intake rates for human receptors consuming contaminated food and water	PATHRAE-RAD model	EPA and Nuclear Regulatory Commission literature values

EMWMF = Environmental Management Waste Management Facility
EPA = U.S. Environmental Protection Agency

The site-specific input parameters for EMWMF design and conditions (BJC 2010) were used and are presented in Table B.3.

Table B.3. EMWMF parameters for PATHRAE-RAD

Zone	Parameter	Value	Unit
Top/surface	Cover thickness	4	m
	Porosity of surface soil	0.25	vol/vol
Waste zone	Waste volume	1.67E+06	m^3
	X (along groundwater flow)	137	m
	Y (cross groundwater flow)	788	m
	Disposal cell surface area	107,956	m^2
	Waste thickness (average)	15.4	m
	Waste density	1600	kg/m^3
	Recharge rate to groundwater from waste zone	9.10E-03	m/year
Vadose zone	Depth to groundwater	7.2	m
	Bulk soil density	1600	kg/m^3
	Porosity of vadose zone	0.25	vol/vol
	Saturated hydraulic conductivity of vadose zone	1.00E-06	cm/sec
Groundwater	Bedrock density	1800	kg/m^3
	Soil/weathered bedrock porosity	0.2	vol/vol
	Bedrock porosity	0.05	vol/vol
	Longitudinal dispersivity in bedrock aquifer	6	m
	Transverse dispersion coefficient in bedrock aquifer	0	$m^2/year$
	Horizontal groundwater velocity (calculate using particle tracking trajectories)	4.2	m/year

Table B.3. EMWMF parameters for PATHRAE-RAD (cont.)

Zone	Parameter	Value	Unit
Surface water	Stream flow rate at compliance point (Junction NT-5 and Bear Creek)	2.23E+05	m^3/year
	Distance from nearest edge of waste to surface water compliance location	101	m
Groundwater well	Groundwater well dilution factor	0.0006	unitless

EMWMF = Environmental Management Waste Management Facility
NT = North Tributary

The PATHRAE-RAD model was used to calculate the arrival and peak time for the radioactive constituents at the point of compliance location (BCK 10.5) for the calculated EMWMF waste inventory at its closure. The peak surface water concentrations at the locations were also predicted using the PATHRAE-RAD for the EMWMF site.

PATHRAE-RAD modeling was also used to determine the equivalent annual water consumption per year for the creek water for all the exposure pathways (defined as the equivalent uptake [EU]). This EU water consumption was derived by scaling the use of creek water for drinking and agricultural purposes to an equivalent annual drinking water ingestion that would give the same annual constituent uptake as calculated from all pathways, such as groundwater for drinking and surface water for other uses.

The same uptake parameters and exposure pathways for a resident farmer using impacted groundwater and surface water for domestic needs and agricultural purposes used in EMWMF WAC development and performance evaluation (DOE 1998a, DOE 1998b, BJC 2010) were used for this uptake calculation. Although the fish pathway in surface water was not considered to be viable at the EMWMF point of compliance location for EMWMF WAC development due to the upstream location in BCV, the pathway was included in this analysis since the point of assessment (BCK 7.73) for the Composite Analysis is located further downstream.

The general uptake and exposure parameters used to derive the EU are listed on Table B.4. The key radionuclide specific uptake parameters are listed on Table B.5.

Table B.4. General exposure and uptake parameters

Uptake parameter	Unit	Value
Watershed infiltration rate	m/year	0.5
Porosity of soil		0.2
Agriculture productivity for pasture grass	kg/m^2	0.67
Agriculture productivity for other vegetation	kg/m^2	0.65
Weathering removal constant from vegetation	hr^{-1}	2.10E-03
Hours for irrigation of pasture grass	hr	438
Hours for irrigation of other vegetation	hr	438
Delay time between harvest and consumption of products	hr	0
Fraction of the year animals graze on pasture grass		1
Fraction of the year’s animal feed that is pasture grass		0.83
Amount of feed consumed daily by cattle	kg	50
Amount of feed consumed daily by goats	kg	6
Transport time from animal feed into milk	hr	48
Delay time between catching and consumption of fish	hr	48

Table B.4. General exposure and uptake parameters (cont.)

Uptake parameter	Unit	Value
Fraction of year the crops are irrigated		0.05
Irrigation rate	L/m^{2}hr	0.0008
Amount of water consumed by milk cows	L/day	60
Amount of water consumed by goats	L/day	8
Amount of water consumed by beef cattle	L/day	50
Human uptake of leafy vegetation	kg/year	14
Human uptake of produce	kg/year	176
Human uptake of cow milk	L/year	110
Human uptake of goat milk	L/year	0
Human uptake of meat	kg/year	95
Human uptake of drinking water	L/year	730
Human uptake of fish	kg/year	6.9
Radionuclide retention fraction on plant surface		0.25

Table B.5. Radionuclide-specific uptake parameters

Radionuclide	Soil-to-plant transfer factor	Soil-to-plant uptake factor for grain	Forage-to-milk transfer factor for cows (day/L)	Forage-to-milk transfer factor for goats (day/L)	Forage-to-beef transfer factor (day/kg)	Water-to-fish transfer factor (L/kg)
H-3	4.80E+00	4.80E-01	1.00E-02	0	1.20E-02	9.00E-01
C-14	5.50E+00	5.50E-01	1.20E-02	0	3.10E-02	4.60E+03
Tc-99	2.50E-01	2.50E-02	1.00E-03	0	1.00E-04	1.50E+01
I-129	2.00E-02	2.00E-03	7.00E-03	0	1.00E-02	4.00E+01
U-233	2.50E-03	2.50E-04	5.00E-04	0	3.40E-04	2.00E+00
U-234	2.50E-03	2.50E-04	5.00E-04	0	3.40E-04	2.00E+00
U-235	2.50E-03	2.50E-04	5.00E-04	0	3.40E-04	2.00E+00
U-236	2.50E-03	2.50E-04	5.00E-04	0	3.40E-04	2.00E+00
U-238	2.50E-03	2.50E-04	5.00E-04	0	3.40E-04	2.00E+00
Np-237	2.50E-03	2.50E-04	5.00E-06	0	2.00E-04	1.00E+01
Pu-239	2.50E-04	2.50E-05	2.00E-06	0	1.40E-05	3.50E+00
Pu-240	2.50E-04	2.50E-05	2.00E-06	0	1.40E-05	3.50E+00
Am-241	2.50E-04	2.50E-05	5.00E-06	0	2.00E-04	2.50E+01

Using the exposure and uptake parameters, the total EU factors through ingestion exposure pathway for the radionuclides were calculated using PATHRAE-RAD. As shown in Table B.6, drinking water ingestion pathway is the dominant contributor to the total dose.

Table B.6. Total EU factors and dose contribution for key radionuclides

Radionuclide	Ingestion dose coefficient (mrem/pCi)	Total equivalent uptake factor (L/year)	Drinking water		All other consumption (plants food, meat, milk, and fish)	
			L/year	Dose %	L/year	Dose %
H-3	7.77E-08	1.166E+03	7.300E+02	62.6	4.360E+02	37.4
C-14	2.10E-06	9.564E+02	7.300E+02	76.3	2.264E+02	23.7
Tc-99	3.33E-06	7.371E+02	7.300E+02	99.0	7.100E+00	1.0
I-129	4.48E-04	8.293E+02	7.300E+02	88.0	9.930E+01	12.0
U-233	2.89E-04	7.356E+02	7.300E+02	99.2	5.600E+00	0.8
U-234	2.15E-04	7.356E+02	7.300E+02	99.2	5.600E+00	0.8
U-235	2.03E-04	7.356E+02	7.300E+02	99.2	5.600E+00	0.8
U-236	2.69E-04	7.356E+02	7.300E+02	99.2	5.600E+00	0.8
U-238	1.94E-04	7.356E+02	7.300E+02	99.2	5.600E+00	0.8
Np-237	4.40E-03	7.348E+02	7.300E+02	99.3	4.800E+00	0.7
Pu-239	3.50E-03	7.305E+02	7.300E+02	99.9	5.000E-01	0.1
Pu-240	3.50E-03	7.305E+02	7.300E+02	99.9	5.000E-01	0.1
Am-241	3.60E-03	7.303E+02	7.300E+02	100.0	3.000E-01	0.0

EU = equivalent uptake

B.4. DOSE FROM TOTAL WASTE DISPOSED IN EMWMF

The resulting dose from a radionuclide can be calculated using the following equation:

Dose (mrem/year) = Concentration (pCi/L) × EU (L/year) × Ingestion Dose Coefficient (mrem/pCi)

Since the hypothetical exposure scenario is a resident farmer for the EMWMF site using groundwater well water for domestic use and creek water for other uses, the total dose for the pathways can be calculated using the relationship below:

Total dose (mrem/year) = $\text{Dose}_{\text{-gw}}$ + $\text{Dose}_{\text{-sw}}$

where:

$\text{Dose}_{\text{–sw}}$ (mrem/year) = $\text{Concentration}_{\text{–sw}}$ (pCi/L) × EU (L/year) × ingestion dose coefficient (mrem/pCi)

$\text{Dose}_{\text{–gw}}$ (mrem/year) = $\text{Concentration}_{\text{–gw}}$ (pCi/L) × EU (L/year) × ingestion dose coefficient (mrem/pCi).

Although PATHRAE-RAD also can model movement of contaminants to a groundwater well, it uses a simple one-dimensional flow assumption that would not be representative of the complex BCV groundwater flow regime. Therefore, the contaminant movement in the aquifer system is modeled using the MODFLOW and MT3D codes. Detailed discussions of this approach are provided for EMWMF in the EMWMF RI/FS (DOE 1998a) and in the EMDF Performance Assessment (UCOR 2020, Appendices D and F).

The calculated dilution factors (DFs) for the creek and residential well were used to scale the constituent concentrations in the creek to the corresponding well concentrations. The DF calculations are as follows:

- The well (groundwater) dilution factor, DF_{well}, is the steady-state well concentration (maximum concentration, C_{well}) ratioed to a unit seepage from the disposal cell (C_{LF}). The DF_{well} is obtained from the MT3D model simulation and is dependent on the location of the well within the conceptual model. The steady state was established by assuming a constant non-depleting leaching source from the landfill ($C_{LF} = 1$ for groundwater modeling) for the duration of the MT3D model simulation. This establishes that a constant DF ratio for the given well location is used in the calculations.
- The creek (surface water) dilution factor, DF_{creek}, is equivalent to the total volumetric water flux from the disposal cell divided by the average creek water volumetric flow rate measured at a weir location on Bear Creek at NT-5 (BCK 10.5).
- These two equations are written in terms of C_{LF} and are set equal to each other to solve for the contaminant concentration in the well due to a unit waste concentration: $C_{well} = (DF_{well}/DF_{creek}) \times C_{creek}$ (where C_{creek} is the peak contaminant concentration in the surface water that is calculated by the PATHRAE-RAD model). For the EMWMF site, the DF_{well}/DF_{creek} is 0.13 for the well location (DOE 1998b).

Table B.7 shows the model-predicted creek peak concentrations for the radionuclides and their peak times.

Table B.7. Total peak dose for the actual EMWMF waste profile

Radionuclide	Peak Concentration (Ci/m^3)	Peak Time (Year)	Ingestion Dose Coefficient (mrem/pCi)	EU (L/year)	Dose (mrem/year)
H-3[a]	1.47E-14	3.28E+02	7.77E-08	1.17E+03	6.06E-10
C-14[a]	4.44E-09	3.82E+02	2.34E-06	9.56E+02	3.34E-03
Tc-99[a]	2.46E-07	4.09E+02	3.33E-06	7.40E+02	8.62E-02
I-129[a]	6.76E-12	9.03E+02	4.48E-04	8.29E+02	5.88E-04
U-234	1.98E-08	4.48E+04	2.15E-04	7.38E+02	4.38E-01
U-235	1.84E-09	5.30E+04	2.03E-04	7.38E+02	3.84E-02
U-236	3.54E-10	4.64E+04	2.69E-04	7.38E+02	9.80E-03
U-238	1.34E-08	5.30E+04	1.94E-04	7.38E+02	2.67E-01
Np-237	5.09E-11	1.01E+05	4.40E-03	7.34E+02	2.21E-02
Pu-239	2.29E-11	9.49E+04	3.50E-03	7.33E+02	7.84E-03
Pu-240	6.71E-15	9.25E+04	3.50E-03	7.33E+02	2.30E-06
Am-241[b]	--	--	3.60E-03	7.34E+02	0.00E+00
U-233	7.49E-11	4.47E+04	2.89E-04	7.38E+02	2.23E-03
		Total dose for the compliance period (1000 years)[a]			**0.09**
	Total dose for EMWMF following the 1000-year compliance period				**0.79**

[a] Radionuclides are predicted to peak inside 1000 years following EMWMF closure and contribute to the total dose for the compliance period.
[b] No concentration predicted at the surface water location due to higher K_d and short half-life.

EMWMF = Environmental Management Waste Management Facility
EU = equivalent uptake

For the EMWMF dose calculation, the predicted peak water concentrations for each radionuclide were used. The ingestion dose coefficients are obtained from the Derived Concentration Technical Standard (DOE 2011). Using the dose equation listed above, the total pathway doses for each radionuclide were calculated and they are listed in Table B.7.

The resulting total dose at BCK 10.5 from EMWMF is 0.876 mrem/year. Please note that this total dose is an addition of all of the individual radionuclide doses without consideration of peak times for each radionuclide. In reality, the peak times are different, so the total dose will be lower for a particular time period (i.e., total dose for the first 1000 years is mostly from H-3, C-14, Tc-99, and I-129). The total dose for the compliance period (1000 years) is 0.09 mrem/year at the EMWMF compliance point (BCK 10.5). The total dose for EMWMF following the 1000-year compliance period is 0.786 mrem/year (rounded to 0.79 mrem/year in this Composite Analysis) and is mostly from uranium isotopes.

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APPENDIX C.
OTHER EXISTING BEAR CREEK VALLEY SOURCES DOSE CALCULATION

CONTENTS

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TABLES

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ACRONYMS

BCK	Bear Creek kilometer
BCV	Bear Creek Valley
CSP	radionuclide concentration in soil
DOE	U.S. Department of Energy
EMDF	Environmental Management Disposal Facility
EMWMF	Environmental Management Waste Management Facility
EPA	U.S. Environmental Protection Agency
EU	equivalent uptake
POA	point of assessment
ROD	Record of Decision

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C.1. INTRODUCTION

Three source terms contribute to the composite dose at the Composite Analysis point of assessment (POA) in Bear Creek Valley (BCV): the proposed Environmental Management Disposal Facility (EMDF), the operational Environmental Management Waste Management Facility (EMWMF), and the other existing BCV sources (in the upper BCV). The EMDF and EMWMF are potential sources of future contaminant releases. The other existing BCV sources are releasing contaminants and these releases are monitored at the "Integration Point" at Bear Creek kilometer (BCK) 9.2 as defined in the Phase I BCV Record of Decision (ROD) (U.S. Department of Energy [DOE] 2000) and other locations in BCV. The primary radionuclide concentrations in surface water and groundwater have been measured continuously since 2001. These measured radionuclides include uranium isotopes (U-234, U-235, and U-238) and Tc-99.

This appendix demonstrates how BCV groundwater and Bear Creek surface water contaminant concentration data are used to quantify doses at BCK 9.2 from the other existing BCV sources for use in calculating a BCV composite dose for this Composite Analysis. This appendix addressed both how the data are used in the base case assessment and in a sensitivity analysis. The base case assessment exposure scenario assumed at this location is a resident farmer that uses Bear Creek surface water for both domestic and other uses (primarily agricultural) uses (Sect. 2.5.1). The base case assessment also assumes that remediation of the other existing BCV sources has been completed and complies with agreements concerning the protection of human health and the environment codified in the Phase I BCV ROD (DOE 2000). A complete food chain calculation was performed using the Presto-U.S. Environmental Protection Agency (EPA) food chain analysis method (EPA 1987) to convert measured contaminant concentrations in Bear Creek to a dose.

A sensitivity analysis is presented in Sect. 5.2 of the Composite Analysis to assess the base case assessment assumption that future remediation for the BCV other sources occurs. This analysis quantifies doses using measured contaminant concentrations in Bear Creek under the assumption that no further remediation of the other existing BCV sources has been completed. These concentrations are not in compliance with the agreements in the BCV ROD.

The exposure scenario in Sect. 5.2.1 also assumes the resident farmer uses Bear Creek water for all uses and the results of an evaluation assessing this assumption is also presented in Sect. 5.2.2. This evaluation is not a sensitivity analysis but rather an analysis to determine which assumption (only uses surface water or uses both surface water and groundwater) was to be used in the base case assessment and sensitivity analysis. This evaluation for the other existing BCV sources assumes the resident farmer uses Bear Creek surface water for agricultural purposes and uses water from a well in the BCV 9.2 area for domestic purposes rather than using Bear Creek water for all uses. Because the dose for the resident farmer using only Bear Creek surface water is higher than the dose for the resident farmer using groundwater and surface water, only the dose for the other existing BCV sources from Sect. 5.2.1 was carried forward into a composite dose at the Composite Analysis POA.

C.2. ENVIRONMENTAL PATHWAYS CONSIDERATION

Human dose exposures from radionuclides at a receptor location can be from direct contact, an air pathway, or a water pathway. Since receptor locations considered in this Composite Analysis are not located at the source areas and all the sources have or will have final covers installed and maintained, direct contact with remaining waste is not possible at the sources or at the integration point (BCK 9.2). Radionuclides in air that have migrated through the cover may impact humans by either external or internal radiological doses. External doses may result from immersion in a plume of contaminated air or by exposure to soil surfaces contaminated by deposition from the plume. Internal doses may result from inhalation of contaminated air or ingestion of food products contaminated by deposition from the air plume. However, because the other existing BCV sources, EMWMF, and EMDF are all covered with long-lasting materials that are maintained and designed for long-term performance, the air pathway is also not a feasible pathway. Therefore, the water exposure pathway through source leakage and migration to water is the only pathway applicable for the Composite Analysis. More detail on the exposure pathways is presented in Sect. 3.3 of the Composite Analysis.

Radionuclides in water may impact humans through internal exposure, either directly from domestic use (i.e., drinking water) or indirectly (e.g., farming use of irrigation water for crops or watering cattle or from fish from a contaminated stream). The water impacted by the other existing BCV sources, either as surface water or groundwater, can be assumed to be used for drinking water. The use of surface water can also be assumed for irrigation to grow vegetables or grains or direct animal and fish intake. The vegetables and grains grown on the site then are used for direct human consumption and/or animal feed. The animal meat and milk from contaminated animal feed are then consumed by human. The impacted water usages in the human food chain are following:

- Groundwater and surface water – human direct ingestion through drinking
- Surface water
  - Animal direct ingestion through drinking (cattle and poultry) and living (fish)
  - Irrigation for vegetables and grains
    - Impacted vegetables and grains – human consumption and animal feed
      - Impacted animal/milk/fish – human consumption.

Table C.1 provides a complete summary of the applicable users/pathways and associated products for the water pathway. Calculations were performed to obtain the impact from human consumption of each food source.

Table C.1. Exposure pathways and association with contaminated water source

Products			Users				
			Milk Cow	**Beef Cattle**	**Poultry**	**Fish**	**Human**
Direct Consumption		Water	X	X	X	X	X
Water Body		Fish				X	X
Irrigation	Direct Products	Vegetables					X
		Grain	X	X	X		X
		Grass	X	X			
	Resulting Products	Milk					X
		Beef Meat					X
		Poultry meat/egg					X
Air Deposition		Pathway not applicable					
Inhalation		Pathway not considered					

C.3. FOOD CHAIN CALCULATION

The doses from all exposure pathways are calculated based on methods discussed in the Presto-EPA food chain analysis (EPA 1987). Concentrations of the radionuclides in surface water or groundwater are used to calculate radionuclide concentrations in foodstuff. Foodstuff concentrations and ingestion rates are used to calculate the radionuclide intake per individual at the receptor location.

The impact on humans from direct consumption of drinking water is represented by the following equation:

$$Q_{ing} = C_w \times U_{drinking}$$

where:

Q_{ing} = annual intake via drinking water ingestion (pCi/year)

C_w = radionuclide concentration in water (pCi/L)

$U_{drinking}$ = the amount of water ingested through drinking (L/year).

Concentrations of radionuclides in foodstuffs that result from spray irrigation with contaminated surface water are estimated using two equations: one addressing the application rate of water used for irrigation and the other estimating the concentration of radionuclides in resulting irrigated vegetables.

The application rate of the water used for irrigation, I_r, is expressed as:

$$I_r = C_w \times W_I$$

where:

I_r = radionuclide application rate (pCi/m^2-hr)

C_w = radionuclide concentration in irrigation water (pCi/L)

W_I = irrigation rate (L/m^2-hr).

The contaminant concentration in irrigation water, C_w, is assumed to be the surface water concentration of radionuclides.

The following equation estimates the concentration, C_{veg}, of a radionuclide in vegetables that are consumed at the receptor location:

$$C_{veg} = [I_r\, R[1\text{-Exp}(-\lambda_e T_w)]/(Y_{veg}\lambda_e) + ([B \times CSP \times F_i]/D_{ss})]\ \text{Exp}(-\lambda_d T_{veg})$$

where:

C_{veg} = radionuclide concentration in pCi/kg

I_r = radionuclide application rate (pCi/m^2-hr)

R = fraction of retained on crops (unitless)

λ_e = effective removal rate constant for the radionuclide from crops by weathering (hr^{-1})

T_w = time period that crops are exposed to contamination during the growing season (hr)

Y_{veg} = agricultural productivity or yield [kg (wet weight)/m^2]

B = radionuclide concentration factor for uptake from soil by edible parts of crops [pCi/kg (dry weight) per pCi/kg dry soil]

CSP = soil radionuclide concentration assuming a steady rate of deposition (pCi/m^2)

F_i = fraction of year that irrigation occurs

D_{ss} = effective surface density for soil [kg(dry soil)/m^2]

λ_d = the radiological decay constant (hr^{-1})

T_{veg} = time interval between harvest and consumption of the vegetable (hr).

The radionuclide concentration in soil (CSP) is a time dependent parameter involving a complex calculation (EPA 1987, pg. 2-37). If the farming is performed on the disposal site, then CSP is set equal to D_{ss} to give soil concentration of 1 pCi/kg for the purpose of calculating the unit uptake factor. This unit uptake factor describes the rate of contaminant ingestion per unit concentration in the soil, and represents the relationship between a radionuclide's soil concentration and its resulting dose via ingestion.

Similarly, the concentrations in grain products and animal feed grass can be calculated using the same equation above. However, there is no practice in east Tennessee for irrigation of animal feed grassland due to abundant precipitation; therefore, the water-feeding-grass food chain pathway is not applicable.

Based on the derived radionuclide concentration in vegetables and grain products, the annual radionuclide intake for human direct consumption from vegetables or grains can be calculated based on the following equation:

$$Q_{veg} = C_{veg} \times U_{veg} \times F_{os}$$

where:

Q_{veg} = annual intake via vegetable ingestion (pCi/year)

C_{veg} = concentration of radionuclides in vegetables that are consumed at the receptor location (pCi/kg)

U_{veg} = annual consumption of vegetables (kg/year)

F_{os} = the fraction of consumed vegetable grown on-site (unitless).

Similar equations apply to human consumption of grain, meat, milk, and fish food pathways.

The grass and grain are also used to feed animals from which meat and milk products will be used for human consumption. The concentration of each radionuclide in each animal forage type (grass or grain) can be calculated by use of the following equation:

$$C_f = f_p f_s C_p + (1 - f_p f_s) C_s$$

where:

C_f = the radionuclide concentration in the animals' feed (pCi/kg)

C_p = the radionuclide concentration on pasture grass (pCi/kg)

C_s = the radionuclide concentration in stored feeds (pCi/kg)

f_p = the fraction of the year that animals graze on pasture (unitless)

f_s = the fraction of daily feed that is pasture grass when the animals graze on pasture (unitless).

The concentration of each radionuclide in milk from milk cows is estimated as:

$$C_{milk} = F_{milk} (C_{fgrass}U_{fgrass} + C_{fgrain}U_{fgrain} + C_w \times U_w)\cdot Exp(-\lambda_d T_{milk})$$

where:

C_{milk} = the radionuclide concentration in milk (pCi/L)

F_{milk} = the average fraction of the animal's daily intake of a given radionuclide that appears in each liter of milk (forage-to-milk transfer factor) (day/L)

C_{fgrass} = the radionuclide concentration in the milk cow's grass feed (pCi/kg)

U_{fgrass} = the amount of grass feed consumed by the milk cow (kg/day)

C_{fgrain} = the radionuclide concentration in the milk cow's grain feed (pCi/kg)

U_{fgrain} = the amount of grain feed consumed by the milk cow (kg/day)

C_w = radionuclide concentration in feeding water (pCi/L)

U_w = the amount of water ingested by milk cow (L/year)

T_{milk} = the delay time from the feed into the milk and to the receptor consumption (hr).

The radionuclide concentration in beef depends on the amount of feed consumed and its level of contamination. The radionuclide concentration in beef is estimated using:

$$C_{meat} = F_{meat} (C_{fgrass}U_{fgrass} + C_{fgrain}U_{fgrain} + C_w \times U_w)\cdot Exp(-\lambda_d T_{meat})$$

where:

C_{meat} = the radionuclide concentration in beef (pCi/kg)

F_{meat} = the fraction of the animal's daily intake of a given radionuclide that appears in each kilogram of meat (forage-to-beef transfer factor) (day/kg)

C_{fgrass} = the radionuclide concentration in the animal's grass feed (pCi/kg)

U_{fgrass} = the amount of grass feed consumed by the animal (kg/day)

C_{fgrain} = the radionuclide concentration in the animal's grain feed (pCi/kg)

U_{fgrain} = the amount of grain feed consumed by the animal (kg/day)

C_w = radionuclide concentration in feeding water (pCi/L)

U_w = the amount of water ingested by animal (L/year)

T_{meat} = the average time from slaughter to consumption (hr).

Similarly, the radionuclide concentration in poultry meat at human consumption is estimated using:

$$C_{poultry} = F_{poultry} (C_{fgrass}U_{fgrass} + C_{fgrain}U_{fgrain} + C_w \times U_w)\cdot Exp(-\lambda_d T_{poultry})$$

where:

$C_{poutlry}$ = the radionuclide concentration in poultry meat (pCi/kg)

$F_{poultry}$ = the fraction of the animal's daily intake of a given radionuclide that appears in each kilogram of meat (forage-to-poultry transfer factor) (day/kg)

C_{fgrass} = the radionuclide concentration in the animal's grass feed (pCi/kg)

U_{fgrass} = the amount of grass feed consumed by the animal (kg/day)

C_{fgrain} = the radionuclide concentration in the animal's grain feed (pCi/kg)

U_{fgrain} = the amount of grain feed consumed by the animal (kg/day)

C_w = radionuclide concentration in feeding water (pCi/L)

U_w = the amount of water ingested by animal (L/year)

T_{meat} = the average time from slaughter to consumption (hr).

Different from the land animals, the radionuclide concentration in fish living in the surface water for consumption was calculated directly used the bioaccumulation factor (water-to-fish transfer factor).

$$C_{fish} = F_{fish} C_w \times \mathrm{Exp}(-\lambda_d T_{fish})$$

where:

C_{fish} = the radionuclide concentration in fish (the meat consumed) (pCi/kg)

F_{fish} = bioaccumulation factor (water-to-fish transfer factor) (L/kg)

C_w = the concentration of radionuclides in water in which the fish live (pCi/L)

T_{fish} = the average time from catch to consumption (hr).

Similar to human direct consumption of vegetables and grain products, the annual radionuclide intake for human consumption for the milk, meat, and fish at a receptor location can be calculated based on food chain concentration, annual consumption rate, and on-site usage rate.

Once radionuclide concentrations in all the various foodstuffs are calculated, the total annual human intake rate for each radionuclide for all the food chain is estimated by the following equation:

$$Q = Q_{ing} + Q_{veg} + Q_{grain} + Q_{milk} + Q_{meat} + Q_{poultry} + Q_{fish}$$

where the variables represent individual annual intakes of a given radionuclide via direct ingestion and ingestion of vegetation, grain, milk, meat, poultry, and fish, respectively, in pCi/year.

The general consumption and exposure parameters used to derive the intake rate are listed on Table C.2.

Table C.2. General exposure and uptake parameters

Exposure/uptake parameter	Unit	Value
Watershed infiltration rate	m/year	0.5
Soil Porosity	unitless	0.4
Bulk density of soil	kg/L	1.5
Depth of contaminated soil zone	m	0.15
Effective surface density for soil	kg/L	1.5
Agriculture productivity for pasture grass	kg/m^2	0.67
Agriculture productivity for vegetables	kg/m^2	0.65
Agriculture productivity for grains	kg/m^2	0.67
Irrigation rate	L/m^2hr	0.0008
Hours for irrigation of pasture grass per year	hr	0
Hours for irrigation of vegetables per year	hr	438
Hours for irrigation of grains per year	hr	43.8
Fraction of irrigation water retained on crop surface	unitless	0.25
Weathering removal constant from vegetation	hr^{-1}	1.03E-04
Fraction of year that irrigation occurs for pasture grass	unitless	0
Fraction of year that irrigation occurs for vegetables	unitless	0.05
Fraction of year that irrigation occurs for grains	unitless	0.005
Delay time between harvest and consumption of grass	hr	0
Delay time between harvest and consumption of vegetables	hr	24
Delay time between harvest and consumption of grains	hr	1440
Fraction of the year animals graze on pasture grass	unitless	0.65
Fraction of the year’s cows and cattle feed that is pasture grass	unitless	1
Fraction of the year’s poultry feed that is pasture grass	unitless	0
Amount of grass feed consumed daily by milk cow	kg/day	44
Amount of grain feed consumed daily by milk cow	kg/day	14
Amount of water consumed by milk cows	L/day	160
Amount of grass feed consumed daily by cattle	kg/day	14
Amount of grain feed consumed daily by cattle	kg/day	54
Amount of water consumed daily by cattle	L/day	50
Amount of grain feed consumed daily by poultry	kg/day	0.2
Amount of water consumed daily by poultry	L/day	1
Delay time from harvest to consumption for milk	hr	24
Delay time from slaughter to consumption for cattle meat	hr	48
Delay time from slaughter to consumption for poultry	hr	48
Delay time between catching and consumption of fish	hr	12
Human uptake of drinking water	L/year	730
Human uptake of leafy vegetable	kg/year	17
Fraction of leafy vegetable from on-site	unitless	0.5
Human uptake of grain	kg/year	176
Fraction of grain from on-site	unitless	0.5
Human uptake of cow milk	L/year	110
Fraction of milk from on-site	unitless	0.5
Human uptake of cattle meat	kg/year	55.4
Fraction of cattle meat from on-site	unitless	0.5
Human uptake of poultry meat	kg/year	36.5
Fraction of poultry meat from on-site	unitless	0.5
Human uptake of fish	kg/year	2.43
Fraction of fish from on-site	unitless	1.0

Uranium and Tc-99 are the primary radionuclides in the Bear Creek that are exceeding Phase I BCV ROD limits and are being monitored. Therefore, the dose impact from Tc-99, U-234, U-235, and U-238 are evaluated. The radionuclide-specific parameters are listed on Tables C.3 and C.4.

Table C.3. Radionuclide-specific property parameters

Radionuclide	K_d (L/kg)	Half-life (year)
Tc-99	0.72	2.11E+05
U-234	50	2.45E+05
U-235	50	7.04E+08
U-238	50	4.47E+09

Table C.4. Radionuclide-specific transfer parameters

Radionuclide	Soil-to-vegetable transfer factor	Soil-to-plant uptake factor for grain	Forage-to-milk transfer factor for cows (day/L)	Forage-to-beef transfer factor for cattle (day/L)	Forage-to-poultry transfer factor (day/kg)	Water-to-fish transfer (bioaccumulation) factor (L/kg)
Tc-99	1	0.1	0.001	0.0001	0.0001	20
U-234	1	0.1	0.0006	0.00034	0.00034	10
U-235	1	0.1	0.0006	0.00034	0.00034	10
U-238	1	0.1	0.0006	0.00034	0.00034	10

Since a single surface water body (BCV) is assumed to be the initial water source for all the food chain calculations, the food chain analysis would apply to all different water concentration conditions as long as the consumption and exposure pathways are the same. Therefore, all the intake of radionuclides for each food chain pathway can be referenced to a unit surface water source (1 pCi/L), which is then assumed to be received by consuming water. The total equivalent annual water consumption per year (defined as the equivalent uptake [EU]) for the creek water is the sum of all the exposure pathways. Therefore, this EU water consumption is derived by scaling the use of creek water for drinking and agricultural purposes to an equivalent annual drinking water ingestion use that would give the same annual constituent uptake as calculated to come from all pathways.

Using the exposure and uptake parameters, the EU factors for each ingestion exposure pathway for Tc-99 and uranium isotopes are calculated. The EU factors for drinking water and all other food chain consumption are presented in Table C.5. The total EU factor for each radionuclide is also shown in the table. The calculation shows that the dominant contributing dose pathway for both of the radionuclides is direct ingestion of drinking water at the consumption rate of 2 L/day for an adult (EPA 2000, DOE 2011).

Table C.5. EU factors and contribution for key radionuclides

Food chain	Tc-99	U-234	U-235	U-238
EU – drinking water	730	730	730	730
EU – vegetable	1.512	1.536	1.536	1.536
EU – grain	1.227	1.230	1.230	1.230
EU – milk	8.808	5.285	5.285	5.285
EU – beef meat	0.141	0.478	0.478	0.478
EU – poultry/egg	0.002	0.006	0.006	0.006
EU – fish	48.6	24.3	24.3	24.3
Total EU factor (L/year)	**790.290**	**762.835**	**762.835**	**762.835**

Note: All values are in L/year.

EU = equivalent uptake

C.4. DOSES FROM THE OTHER EXISTING BCV SOURCES AT BCK 9.2

C.4.1 BASE CASE ASSESSMENT DOSE FOR THE OTHER EXISTING BCV SOURCES

Since BCK 9.2 is the Integration Point with detailed uranium surface water and groundwater monitoring data, the dose calculation based on the monitoring data and EU factors for the uranium isotopes was conducted at this point. To calculate the base case assessment dose for the other existing BCV sources at BCK 9.2, average uranium surface water concentration data over a 17-year period from 2001 to 2017 (DOE 2018, Table 4.5) were used. The 17-year average concentrations for the three uranium isotopes (U-234, U-235, and U-238) at BCK 9.2 are 8.56, 0.78, and 19.03 pCi/L, respectively.

Concentrations of Tc-99 are measured at BCK 7.87 rather than BCK 9.2; therefore, a concentration of Tc-99 at BCK 9.2 had to be calculated. Figure 4.4 in the 2018 Remediation Effectiveness Report (DOE 2018) presents Tc-99 concentrations at BCK 7.73 for the last 17 years. These concentrations are averaged for a concentration of 29.73 pCi/L. Note that the first Tc-99 concentration in this graph is not used because this measurement occurred during the remediation of the Boneyard/Burnyard and is not considered representative of post-remediation conditions. To adjust this concentration to the upstream location of BCK 9.2, the mixing ratio in Bear Creek between BCK 9.2 and BCK 7.73 of 1.43 is used (BCK 7.87 is only 140 m from BCK 7.73). Adjusting for the 1.43 mixing ratio referenced in Sect. 4.2 of the Composite Analysis, the Tc-99 concentration used in the dose calculation is 39.73 pCi/L.

The resulting dose from a radionuclide can be calculated using the following equation:

Dose (mrem/year) = Concentration (pCi/L) × EU (L/year) × Ingestion Dose Coefficient (mrem/pCi)

The ingestion dose coefficients are from the Derived Concentration Technical Standard (DOE 2011). Using the average surface water concentrations presented in the text above, the resulting doses from the radionuclides are calculated and shown on Table C.6.

Table C.6. Results of dose calculation for surface water pathway

Radionuclides	17-year average SW concentrations @ BCK 9.2 (pCi/L)	Ingestion dose coefficient (mrem/pCi)	Equivalent Uptake Factor for all pathways for a resident farmer (L/year)	Dose (mrem/year)
Tc-99	39.73	3.33E-06	790.29	0.10
U-234	8.56	2.15E-04	762.84	1.40
U-235	0.78	2.03E-04	762.84	0.12
U-238	19.03	1.94E-04	762.84	2.82
			Total Dose	**4.44**

BCK = Bear Creek kilometer
SW = surface water

The calculation yields a total dose of 4.44 mrem/year at BCK 9.2 from the surface water for the other existing BCV sources. The base case assessment assumes remediation in BCV has been completed and radionuclide concentrations in Bear Creek are in compliance with the agreements in the Phase I BCV ROD. To calculate a total dose that complies with the ROD, assumed contributions of the various radionuclides to the total goal had to be determined. The contributions of each of the four radionuclides to the final BCV ROD goal were 6 percent for Tc-99, 30 percent for U-234, 3 percent for U-235, and 61 percent for U-238, based on the ratios of measured concentrations in Bear Creek. The resulting concentrations for each of the four radionuclides that contribute to the goal in the ROD were then quantified. This calculation resulted in the following concentrations by radionuclide: 8.72 pCi/L (Tc-99), 1.88 pCi/L (U-234), 0.17 pCi/L (U-235), and 4.18 pCi/L (U-238). Finally, these concentrations were converted to doses using the same methodology in Table C.6. The resulting doses, by radionuclide and total, are presented in Table C.7. This total dose (0.98 mrem/year) at BCK 9.2 is then used as the dose for the other existing BCV sources in the base case assessment. Note that this dose was adjusted using the Bear Creek mixing ratio as described in Sect. 4.2 for use in the composite dose at the POA (BCK 7.73) for the base case assessment in this Composite Analysis.

Table C.7. Results of dose calculation for surface water pathway (assuming Phase I BCV ROD compliance)

Radionuclides	17-year average SW concentration @ BCK 9.2 (pCi/L)	% of contribution to goal	Concentration to meet 1E-05 risk (SOF=1) (pCi/L)	Dose to meet 1E-5 risk (mrem/year)
Tc-99	39.73	6	8.72	0.02
U-234	8.56	30	1.88	0.31
U-235	0.78	3	0.17	0.03
U-238	19.03	61	4.18	0.62
			Total Dose	**0.98**

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
ROD = Record of Decision

SOF = sum of fractions
SW = surface water

C.4.2. DOSES FOR THE OTHER EXSITING BCV SOURCES IN "SENSITIVITY TO REMEDIAL ACTIONS ON OTHER EXISTING BCV SOURCES" (COMPOSITE ANALYSIS SECT. 5.2)

The sensitivity analysis presented in Sect. 5.2 of this Composite Analysis assesses the base case assessment assumption that future remediation for the other existing BCV sources occurs. This analysis quantifies doses using measured contaminant concentrations in Bear Creek under the assumption that no further remediation of the other existing BCV sources has been completed. Doses for the other existing BCV sources are quantified for two exposure scenarios in this sensitivity analysis. These concentrations are not in compliance with the agreements in the Phase I BCV ROD.

The exposure scenario in Sect. 5.2.1 (Sensitivity to Remedial Actions Using Only Water from Bear Creek) also assumes the resident farmer uses Bear Creek water at BCK 9.2 for all uses. This dose is 4.44 mrem/year, as presented in Table C.6. Note that this dose was adjusted using the Bear Creek mixing ratio (see Sect. 4.2) for use in the composite dose at the POA (BCK 7.73) for this sensitivity analysis.

The exposure scenario in Sect. 5.2.2 (Sensitivity to Remedial Actions Using Groundwater and Bear Creek Water) assumes the resident farmer uses Bear Creek water for agricultural uses and drinking water supplied by a well rather than the creek at the BCK 9.2. The dose from this evaluation was compared to the dose in Sect. 5.2.1 to support the appropriateness of assuming only a surface water user in the base case assessment. The annual drinking water volume of 730 L/year supplied by the well is subtracted from the creek water EU to estimate the effective drinking water ingestion associated with agricultural uses for the creek surface water. Only U-238 and U-234 were detected in the groundwater wells in the BCK 9.2 area above the concentration goals during the monitoring program (DOE 2015). The highest U-238 concentration in groundwater wells in the BCK 9.2 area following remediation of the Boneyard/Burnyard is 9 pCi/L; the highest U-234 concentration in the groundwater wells during this period was 6 pCi/L (DOE 2018, Fig. 4.13) (see Attachment 2). For the groundwater use calculation, values of 9 pCi/L and 6 pCi/L were used for U-238 and U-234 respectively. Both uranium isotopes show a decreasing trend in groundwater concentrations. For other minor radionuclides, 0.6 pCi/L and 39.73 pCi/L were used for U-235 and Tc-99, respectively. The 0.6 pCi/L concentration for U-235 was based on the ratio of U-234 to U-238 in surface water. For Tc-99, a groundwater concentration is assumed to be the same as in the surface water (39.73 µg/L). The dose calculation results are shown on Table C.8.

Table C.8. Results of dose calculation for surface water and groundwater pathways

Radionuclides	Water source	Water concentration @ BCK 9.2 (pCi/L)	Ingestion dose Coefficient (mrem/pCi)	Equivalent Uptake Factor for all pathways for a resident farmer (L/year)	Dose (mrem/year)
Tc-99	GW	39.73	3.33E-06	730	0.10
	SW	39.73	3.33E-06	60.29	0.01
U-234	GW	6	2.15E-04	730	0.94
	SW	8.56	2.15E-04	32.84	0.06
U-235	GW	0.6	2.03E-04	730	0.09
	SW	0.78	2.03E-04	32.84	0.01
U-238	GW	9	1.94E-04	730	1.27
	SW	19.03	1.94E-04	32.84	0.12
				Total Dose	**2.60**

BCK = Bear Creek kilometer
GW = groundwater
SW = surface water

The total dose at BCK 9.2 of 2.60 mrem/year for surface water and groundwater pathways is lower than the 4.44 mrem/year for all surface water pathways due to the lower concentrations in groundwater. Since this groundwater/surface water dose is lower than the dose from surface water (in Sect. 5.2.1), the composite dose at the POA for this sensitivity analysis was calculated using 4.44 mrem/year. Additionally, because this dose is lower than the dose in Sect. 5.2.1, it is demonstrated that a surface water user will receive a higher dose than a surface water/groundwater user at the same location. This supports the appropriateness of using a surface water exposure scenario in the base case assessment.

C.5. REFERENCES

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APPENDIX D.
COMPOSITE ANALYSIS FOR THE ENVIRONMENTAL MANAGEMENT WASTE MANAGEMENT FACILITY AND THE PROPOSED ENVIRONMENTAL MANAGEMENT DISPOSAL FACILITY DATA QUALITY OBJECTIVES CHECKLIST

Composite Analysis for the Environmental Management Waste Management Facility and the Proposed Environmental Management Disposal Facility
Data Quality Objectives Checklist

1. State the Problem and the Decision (DQO Steps 1 and 2)	
What are the problem statements?	Develop a technically defensible Composite Analysis for the EMWMF and the proposed EMDF in accordance with DOE O 435.1 (DOE 2001a) and its implementing manual DOE M 435.1-1 (DOE 2011). Determine the dose in BCV after closure of the EMWMF and the EMDF and document in a technically defensible Composite Analysis.
Who needs information about the waste?	DOE Oak Ridge Environmental Management, DOE-Headquarters LFRG, Tennessee Department of Environment and Conservation, and the U.S. Environmental Protection Agency.
What are the contaminants of interest?	Radiological isotopes (U-234, U-235, U-238, and Tc-99 for the “other existing sources BCV sources”); EMWMF radiological WAC constituents (e.g., Am-241, C-14, H-3, I-129, Np-237, Pu-239 and -240, Tc-99, U-233, U-234, U-235, U-236, and U-238; and potential radiological source term constituents for the proposed EMDF (e.g., Am-241 and -243; C-14; Cf-249 and -250; Cm-244, -245, -246, -247, and -248; H-3; I-129; K-40; Nb-94; Ni-59; Np-237; Pa-231; Pu-238, -239, -240, -241, -242, and -244; Se-79; Si-32; Tc-99; U-233, -234, -235, -236, and -238; and Zr-93).
What decisions need to be made?	Do the source terms for EMWMF (using information from waste disposed to date) and the other existing BCV sources of potential radioactive contamination in BCV (using contaminant concentrations in Bear Creek to quantify a post-remediation dose that complies with the Phase I BCV ROD [DOE 2000]), adequately address the problem statements and meet the source term requirements in DOE O 435.1?
2. Inputs to the Decision (DQO Step 3)	
What historical data exist?	Historical contaminant concentrations for surface water and groundwater are included in the 2018 RER (DOE 2018) (a compilation of 17 years of monitoring information supporting the implementation of the Phase I BCV ROD) and OREIS. Modeling to support compliance with DOE O 5820.2A for EMWMF is listed in the EMWMF RI/FS and its addendum (DOE 1998a, DOE 1998b). Source term development for the proposed EMDF is detailed in the PA for the proposed EMDF (UCOR, an Amentum-led partnership with Jacobs, 2020), including information regarding the waste predicted to be disposed in the EMDF; Bear Creek flow rate data listed in OREIS; and information regarding waste disposed in EMWMF to date are available from the EMWMF WAC Attainment Team.

2. Inputs to the Decision (DQO Step 3) (cont.)	
What process knowledge exists?	The BCV RI report (DOE 1997a) and FS (DOE 1997b) contain information on the other existing BCV sources of radiological contamination. The Phase I BCV ROD contains the "Integration Point," the required actions in the selected alternative, and the regulator-approved compliance standard. The ROD for EMWMF (DOE 1999a) and the EMWMF WAC Attainment Plan (DOE 2001b) contain the hypothetical receptor location for WAC development and the compliance standard. The Proposed Plan for EMWMF contains the initial Composite Analysis for EMWMF (DOE 1999b) that was approved by the LFRG. The RI/FS for EMWMF and its Addendum, and the Bechtel Jacobs report *Calculation Package for the Analysis of Performance of Cells 1-6 with Underdrain of the Environmental Management Waste Management Facility. Oak Ridge, Tennessee* (BJC 2010) contain the performance modeling results used to demonstrate compliance with DOE O 5820.2A and DOE O 435.1 for EMWMF and the design of the disposal facility. The PA for the proposed EMDF contains the source term at the hypothetical receptor location at a water well 100 m from the waste and a description of the disposal facility design. The Bear Creek conceptual site model and contaminant fate and transport modeling was prepared for the BCV RI and FS and was used in the EMWMF RI/FS and its Addendum, and the Remedial Design Report and Addenda. The BCV Focused Feasibility Study (DOE 2008) contains information on the capping of the Bear Creek Burial Grounds. The 2018 RER contains a status of the actions required by the Phase I BCV ROD.
What are the radiological contaminants of concern for the EMDF source term?	See "What are the contaminants of interest" in DQO Steps 1 and 2 above.
What additional data must be collected?	None.
3. Boundaries to be Considered (DQO Step 4)	
What is the potential contamination?	Radiological only (see Problem Statements).
What are the sources of contamination?	Three source terms will be developed for the Composite Analysis: (1) other existing BCV sources of potential radiological contamination defined by the Phase I BCV ROD and the 2018 RER, (2) currently operating EMWMF (defined by waste disposed to date), and (3) proposed EMDF (assumptions based on the EMDF PA). Waste from the Y-12 and Oak Ridge National Laboratory will be received by the proposed EMDF.

3. Boundaries to be Considered (DQO Step 4) (cont.)	
What are the physical boundaries to the study using the source term for the proposed EMDF?	Potential sources of radiological contamination will be limited to the BCV watershed. This area is geographically defined by a groundwater/surface water divide in east BCV that separates the three source terms from existing sources of potential contamination at Y-12, the top of Pine Ridge to the northwest, and the top of Chestnut Ridge to the southeast. The POA at BCK 7.73 is just west of the proposed EMDF at the confluence of North Tributary-11 and Bear Creek (in Zone 2 as defined in the Phase I BCV ROD). All potential sources of radiological contamination are upstream of the POA. The exposure scenario for the hypothetical receptor at the POA is a resident farmer using only contaminated surface water from Bear Creek. This is consistent with the exposure scenario in the Phase I BCV ROD and EMWMF ROD.
Are there other boundaries that will be considered?	Yes, the exposure time period for the hypothetical receptor at the POA will be 1000 years following closure of the operating EMWMF and the proposed EMDF and completion of remedial actions required by the Phase I BCV ROD. For the purpose of the study, it is assumed that these will occur simultaneously. Note that a sensitivity/uncertainty analysis will predict a post-1000-year maximum composite dose.
4. Decision Statement and Uncertainty (DQO Steps 5 and 6)	
What are the decision rules?	Meet the performance measures stated in DOE O 435.1 and applicable standards for LLW disposal facilities in the Composite Analysis.
What are the allowable decision errors?	Estimates of dose in the Composite Analysis and PA must not exceed the performance measures stated in DOE O 435.1 (i.e., 100 mrem/year composite dose in the Composite Analysis and 25 mrem/year dose for the proposed EMDF). Applicable standards include the following: 1) Waste characterization—LLW must be characterized using direct or indirect methods and the characterization must be documented in sufficient detail to ensure safe management and compliance with the waste acceptance requirements of the facility receiving the waste. Relevant to management of the waste, the DQO process shall, at a minimum, include physical and chemical characteristics; volume, including waste and any stabilization or absorbent media; weight of the container and contents; identities, activities, and concentrations of major radionuclides; and any other information needed to prepare and maintain the disposal facility PA or demonstrate compliance with the applicable performance measures. 2) Site evaluation and facility design—Proposed locations for LLW disposal facilities must be evaluated to identify relevant features that should be avoided or must be considered in facility design and analyses, including the following:

4. Decision Statement and Uncertainty (DQO Steps 5 and 6) (cont.)	
What are the allowable decision errors? (cont.)	a) Each site for a proposed LLW disposal facility shall be evaluated considering environmental characteristics, geotechnical characteristics, and human activities, including whether it is located to accommodate the projected volume of waste to be received; located in a floodplain, a tectonically active area, or in the zone of a water table fluctuation; or located where radionuclide pathways are predictable and erosion and surface runoff can be controlled. b) Proposed sites with environmental characteristics, geotechnical characteristics, and human activities for which adequate protection cannot be provided through facility design shall be deemed unsuitable for the location of the facility. c) LLW disposal facilities shall be sited to achieve long-term stability and minimize, to the extent practicable, the need for active maintenance following final closure.
What are the steps to be taken after the analytical results are received?	Model verification will be performed in accordance with *URS/CH2M Oak Ridge LLC Quality Assurance Program Plan, Oak Ridge, Tennessee* (UCOR 2019).
5. Optimize the Design (DQO Step 7)	
State the type of data to be obtained.	A set of sensitivity analyses will be performed using variations in source terms for the other existing BCV sources (defined by the Phase I BCV ROD and 2018 RER), and waste disposed in EMWMF. A summary and the results of these sensitivity analyses will be presented in the Composite Analysis, along with the base case dose. Large-scale uncertainty/sensitivity analyses will be performed in Sect. 5 of the Composite Analysis, including a sensitivity to remedial actions (a composite dose if no further remediation of the other existing BCV sources is performed), a post-1000-year maximum dose, quantification of the dose for the combination groundwater/surface water usage (to confirm the evaluation of surface water use is conservative), a quantification of a composite dose based on agreement in the approved BCV and EMWMF RODs, and an alternative conceptual site model.

BCK = Bear Creek kilometer
BCV = Bear Creek Valley
BJC = Bechtel Jacobs Company LLC
DOE = U.S. Department of Energy
DOE M = DOE Manual
DOE O = DOE Order
DQO = data quality objective
EMDF = Environmental Management Disposal Facility
EMWMF = Environmental Management Waste Management Facility
LFRG = Low-level Waste Disposal Facility Federal Review Group
LLW = low-level (radioactive) waste
OREIS = Oak Ridge Environmental Information System
PA = Performance Assessment
POA = point of assessment
RER = Remediation Effectiveness Report
RI/FS = Remedial Investigation/Feasibility Study
ROD = Record of Decision
WAC = waste acceptance criteria
Y-12 = Y-12 Nuclear Security Complex

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