CRESP

Consortium For Risk Evaluation with Stakeholder Participation

Consortium Universities: **Vanderbilt University**, Georgia Tech, Howard University, New York University, Oregon State University, Rutgers University, University of Arizona, University of Wisconsin - Madison

METHODOLOGY FOR THE HANFORD SITE-WIDE RISK REVIEW PROJECT

Revision 0

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Acknowledgements and Disclaimer

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As is CRESP practice with major review products, a draft of this methodology document was reviewed for factual accuracy by key individuals and entities. Such reviews are not “peer reviews”. Rather, they are intended only to solicit information about the accuracy of citations and other factual matters discussed. These factual accuracy reviews typically help CRESP improve the quality and veracity of data and identify additional relevant sources of information. Those individuals and entities asked to carry-out such factual accuracy reviews are assured that participation in the factual accuracy review process in no way commits them to agree or disagree with the judgments, opinions, interpretations, conclusions, findings or recommendations contained in the review draft. Additionally, participation in the factual accuracy review is not intended to affect or limit any position reviewers may have on content within the final report. All reviewers, other than the authors of the draft and final versions of a CRESP report, retain their separate and independent rights and obligations. Factual accuracy reviews of this interim progress report were completed by, among others, officials of the U.S. Department of Energy, the U.S. Environmental Protection Agency and the State of Washington.

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Executive Summary

In January 2014, the U.S. Department of Energy (DOE) requested that the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) conduct an independent Hanford site-wide evaluation of human health, nuclear safety, environmental, and cultural resource risks associated with current hazards, environmental contamination and remaining cleanup activities (hereinafter referred to as the "Risk Review Project"). The overarching goal of the Risk Review Project is to carry out a screening process for risks and impacts to human health and resources. The results of the Risk Review Project are intended to provide the DOE, regulators, Tribal Nations, and the public with a more comprehensive understanding of the remaining cleanup at the Hanford Site to help inform (1) decisions on sequencing of future cleanup activities, and (2) selection, planning and execution of specific cleanup actions, including which areas at the Hanford Site should be addressed earlier for additional characterization, analysis, and remediation. This document describes the methodology being used to execute the Risk Review Project.

To accomplish the project's goal, the most recent, available information about hazards (i.e., contaminant inventories, physical chemical forms) and existing environmental contamination within each of the units being evaluated is gathered, described, and analyzed. At certain points in time and under various circumstances, such as facility degradation, seismic activity, accidents, or fire, the identified hazards and environmental contamination may lead to contaminant travel along multiple pathways, creating exposure or impact (referred to as "risk") to human health and/or resources.

This document details the approach used for evaluating risks and impacts to human health and resources for each of the evaluation units considered. Human health and resources include facility workers, co-located people, the public, groundwater and the Columbia River, and ecological and cultural resources. For each unit evaluated under the Risk Review Project, risks are considered in the context of the evaluated unit's status currently, during cleanup activities, and after cleanup activities. This includes taking account of current barriers to dispersion of contaminants and resultant adverse consequences to receptors, the mechanisms of barrier failures, and the likelihood and magnitude of adverse consequences.

Hanford Site is located along the Columbia River in Southeast Washington and is comprised of an area 586 square-miles (half the size of the State of Rhode Island). For over 40 years, the Site played a major role in the development and production of plutonium and other defense materials as part of the Manhattan Project during World War II and afterwards during the Cold War.

In 1989, Hanford's mission shifted from supporting weapons development to environmental cleanup of facilities, soil, and groundwater. Today, Hanford Site consists of waste management and former production areas, active and closed research facilities, waste storage and disposal sites, and huge swaths of natural resources and habitat. Cleanup at the Site has proven to be more costly, has taken longer, and is more technically challenging than expected when cleanup began. DOE's near term vision calls for reduction of the active cleanup footprint to 75 square miles in the center of the Site, reducing overhead costs, and shifting resources that would allow full scale cleanup of the Central Plateau. To date, considerable progress has been made in achieving this vision. For example, hazards near the Columbia River have been eliminated by completing cleanup of most of the River Corridor and treating contaminated groundwater near the Columbia River. Despite these successes, more than $100 billion are expected to be spent on cleanup at Hanford during the next 50 years. Additionally, while earlier studies have evaluated portions of the Hanford Site, there has never been a comprehensive, site-wide review of the risks to human health and resources from contamination, waste management, and cleanup activities.

It is also important to be clear regarding what the Risk Review Project is not. The Risk Review Project is neither intended to be a substitute for, nor preempt, any requirement imposed under applicable federal or state laws or treaties. As important, the Risk Review Project is not intended to make or replace any decisions made under the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) and/or 2010 Consent Order, or amendments. Furthermore, the Risk Review Project is neither a Comprehensive Environmental Response, Compensation, and Liability Act risk assessment nor a Natural Resources Damage Assessment evaluation. Finally, the Risk Review Project is not intended to interpret treaty rights that exist between the United States and Native American Tribes.

The Risk Review Project focuses on summary-level risk characterization or description based on existing information. This process includes describing hazards, existing environmental contamination and potential risks in terms of probability and consequence. Risk characterization is a necessary predecessor to risk management, but the characterization that is completed in this Risk Review does not include risk management decisions. Thus, a rank ordered priority list of cleanup actions from the risk characterization effort will not be an outcome of this review.

The development of a final prioritization list of future actions is the sole purview of DOE and its regulators, with consideration of many additional factors. The DOE, the State of Washington, and the U.S. Environmental Protection Agency (EPA) clearly recognize that the results of the Risk Review Project, including evaluations of hazards and risks, are only one of many inputs to prioritization of future cleanup activities at Hanford.

One essential, additional factor that DOE and regulators must consider in setting priorities for cleanup are the values that stakeholders, community members, governmental entities, and Tribal Nations have identified (e.g., access to the Site, gathering roots, berries, and medicines, and hunting), and how various cleanup options would affect these identified values. The Risk Review Project is limited to considering a plausible range of current and future cleanup actions for different types of contaminant sources to provide to DOE and regulators a better understanding of the range of potential risks and impacts to receptors that may be caused by those cleanup actions.

Furthermore, the Risk Review Project will not select cleanup endpoints or cleanup technologies. However, in addition to risks posed by contaminants, such as radionuclides or chromium, cleanup actions themselves can pose risks or impacts to receptors (e.g., worker safety, groundwater, ecological and cultural resources).

This document describes the methodology developed to execute the Risk Review Project and reflects revisions that were incorporated in response to comments received on the draft methodology document made available for public comment in September 2014. The methodology also reflects the lessons learned from the pilot case studies completed in the summer of 2014 to test the draft version of the methodology as well as input received from independent experts. The methodology consists of the following elements:

1. **Identification of Evaluation Units (EU).** The remaining cleanup sites at Hanford as of October 1, 2015 have been divided into approximately 60 evaluation units (EUs), which have been organized into five categories composed of geographically co-located sites to the extent possible, considering the commonality among source types and the overlapping of impacts and

risks to receptors[7]. The five categories are[8]: 1) legacy source sites[9], such as past practice liquid waste disposal and buried solid waste sites; 2) tank waste and farms and associated legacy contamination sources; 3) groundwater plumes; 4) inactive facilities undergoing decommissioning, deactivation, decontamination, and demolition (D4); and 5) operating facilities used as part of the cleanup process. *See Chapter 3.*

2. **Summary Evaluation Templates.** Each EU will be described in detail using most recent available information, including regulatory documents, maps, and studies[10]. Information gathered on each EU includes the unit description and history; an inventory of waste and contamination history; selected or potential range of cleanup approaches; and the ratings of risks to receptors, which are determined by providing rough order of magnitude relative grouping or binning of risks to each type of receptor. The primary groupings are Very High, High, Medium, Low, and Not Discernible. *See Appendix B for the Summary Evaluation Template.*
3. **Risk Ratings.** The receptors being rated or binned are facility workers, co-located people, public, groundwater, and the Columbia River, and ecological resources. The groupings of risk ratings (e.g., "high", "medium", etc.) for each type of receptors are determined by application of the specific methodology developed for that receptor. Demarcation between ratings uses recognized regulatory or literature thresholds applicable to the specific receptor, if they exist, as screening levels, as well as other factors. This approach is intended to provide relative risk ratings *within* receptor categories (relative binning of risks to the Columbia River, groundwater, ecology, etc.). Risk ratings for each receptor are then used to inform urgency of addressing specific hazards. An overall risk rating is not being provided for cultural resources; however, information about cultural resources within or near (within 500 m) each EU is gathered, described, and analyzed as a planning guide or tool for future activities. Although the integration across receptor categories is considered inherently driven by individual and collective values, the Risk Review Project will provide examples that illustrate how grouping or binning that integrates the ratings across receptor categories (e.g., integrated risk binning that combines risks to human health with risks to ecology and groundwater) could be carried out.[11] *See Chapters 5 through 8 for detailed descriptions of each receptor methodology.*
4. **Temporal Evaluation Periods.** Risks are evaluated based on four distinct periods: 1) current status of the EU, typically prior to cleanup, although cleanup has been initiated for some EUs, 2) active cleanup period (or until 2064), 3) near-term post-cleanup (until 2164, or assuming a 100-year duration for institutional controls associated with areas transferred from federal control), and 4) long-term post-cleanup (or until 3064)[12]. Each EU and selected EU components are evaluated as if cleanup were not to occur for 50 years to provide insights into the potential risks of delay to help inform sequencing of cleanup actions. ***However, this is not to infer that delay of cleanup for 50 years is recommended.*** *See Chapter 2.*

[7] The EU concept was developed by the Risk Review Project to provide a tractable basis for reviewing the myriad of cleanup challenges at the Hanford Site.
[8] The EU groupings used here were developed for the Risk Review Project to understand potentially overlapping risks and not common practice at the Hanford Site.
[9] In this context, "legacy" refers to resulting from past practices that are no longer occurring, even though the Hanford Site has been under federal control from the time it was established as part of the Manhattan Project.
[10] The information available for each EU is highly variable, depending on documentation of past site practices, the currently regulatory status, currently planned near-term cleanup activities and other factors.
[11] This will be included in the final report but not the interim progress report.
[12] Where information is available that indicates risks that may be present beyond the year, 3064, such information is noted (such as with slow groundwater migration of contaminants).

5. **__Initiating Events.__** The likelihood of initiating events, both localized and regional in scale that may occur during any or all of the evaluation periods, such as fire, volcanic eruptions, loss of power, and plane crashes, is described. This is to establish a consistent basis for identifying and categorizing phenomena that may remove or degrade barriers, placing receptors at risk from contaminants. Nuclear safety is considered in the context of potential initiating events and risks to receptors. *See Chapter 4.*

The focus of this document is on methodology rather than outcomes. This means the general approach is described in detail with illustrative examples. Project evaluations and results of EUs evaluated will be discussed in both an interim progress report, completed in 2015, and a final report planned to be completed in 2016. These reports also will contain observations made from the work completed and completed EU Evaluation Templates.

The Risk Review Project is led by a team of CRESP researchers in regular dialogue with a Core Team comprised of senior management from DOE, EPA, and the State of Washington Departments of Ecology and Health, which provides through a Core Team that provides advice on the development and execution of the Risk Review Project. Pacific Northwest National Laboratory is providing research, analytical, and other assistance to CRESP.

CRESP is a multi-disciplinary consortium of universities with a mission to advance environmental cleanup by finding ways to improve the scientific and technical basis for management decisions, and to engage stakeholders and the public. CRESP has completed risk-informed characterization projects involving complex issues at DOE Office of Environmental Management sites around the country.

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Abbreviations and Acronyms

AWQC	Ambient Water Quality Criteria
BCG	Biota Concentration Guide
BOF	Balance of Facilities
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLUP	Comprehensive Land Use Plan
CP	co-located person
CR	Columbia River
CRCRA	Columbia River Component Risk Assessment
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CSB	Canister Storage Building
CSM	Conceptual Site Model
CWC	Central Waste Complex
D&D	deactivation (decontamination) and decommissioning
D4	deactivation, decontamination, decommissioning, and demolition
DFHLW	Direct Feed High-Level Waste
DFLAW	Direct Feed Low Activity Waste
DOE	U.S. Department of Energy
DSA	documented safety analysis
DWS	drinking water standard
ECAP	Ecological Compliance and Assessment Project
EIS	environmental impact statement
EM	Office of Environmental Management (DOE)
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
EU	evaluation unit
GIS	Geographic Information System
GRM	groundwater threat metric
GW	groundwater
HA	hazard analysis
HAMMER	Volpentest Hazardous Materials Management and Emergency Response Federal Training Center
HLW	High-Level Waste (Vitrification Facility)
IDA	intentional destructive act
IDF	Integrated Disposal Facility
IS	insufficient information
LAB	Analytical Laboratory
LAW	Low Activity Waste (Vitrification Facility)
LIGO	Laser Interferometer Gravitational Wave Observatory
LLW	low-level waste
MBTA	Migratory Bird Treaty Act
MCL	maximum contaminant level
MLLW	mixed low-level waste
MOI	maximally exposed off-site individual
MOU	memorandum of understanding
NA	not applicable

NDA	nondestructive assay
NDE	nondestructive examination
NP	Not present at significant quantities for indicated EU
NPH	natural phenomena hazards
NRC	Nuclear Regulatory Commission
OU	operable unit
PC	primary contaminant
PCB	polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory
PT	Pretreatment (Facility)
PUREX	Plutonium Uranium Extraction Plant
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction-Oxidation Plant
RI/FS	remedial investigation / feasibility study
ROD	record of decision
SARAH	Safety Analysis and Risk Assessment Handbook
SHPO	State Historic Preservation Officer
SIM	Soil Inventory Model
SWOC	Solid Waste Operations Complex
SZ	saturated zone
TBD	to be determined
TC&WM	Tank Farm Closure and Waste Management (environmental impact statement)
TCE	trichloroethylene
TCP	traditional cultural place
TEDE	total effective does equivalent
TRU	transuranic
TRUM	transuranic mixed
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
UCL	upper confidence level
VZ	vadose zone
WESF	Waste Encapsulation and Storage Facility
WMA	waste management area
WIPP	Waste Isolation Pilot Plant
WQS	water quality standard
WRAP	Waste Receiving and Processing Facility
WTP	Waste Treatment and Immobilization Plant

Probability and Consequence Ratings

A	Anticipated
BEU	Beyond Extremely Unlikely
EU	Extremely Unlikely
H	High
L	Low
M	Moderate
NA	Not Applicable
ND	Not Discernible
U	Unlikely
VH	Very High
--	For NA events the likelihood is not evaluated

Risk Review Project Risk Ratings

	Low
	Medium
	High
	Very High
ND	Not Discernible
NA	Not Applicable

Terminology and Definitions

The primary objective of the Risk Review Project is to characterize risks and impacts to human health (facility worker, co-located persons, and public) ecological resources, cultural resources, groundwater, and the Columbia River. These terms are collectively referred to as "receptors." For the purposes of this document, the following definitions apply:

Bioindicator – species (species group) or characteristic of a species (or species group) that is used to assess the condition of a species, population, community, or ecosystem.

Biomonitoring – regular, periodic assessment of human or ecological health and well-being.

Buffer – area around the evaluation unit (EU), equal to the widest diameter of the EU. It is an area potentially impacted by remediation activities on the EU.

Co-Located Person – a hypothetical on-site individual located at the distance from the point of potential contaminant release at which the maximum dose occurs (at a point equal to or greater than 100 m from the point of release, the boundary of the facility *or the activity boundary)*. If the release is elevated, the on-site individual is assumed to be at the location of greatest dose, which is typically where the plume touches down. (*This is functionally equivalent to the "Co-located Worker" as defined and used in the* DOE-STD-3009-2014 and the *DOE Safety Analysis and Risk Assessment Handbook (SARAH)).*

Completed Pathway – the transport (transfer or movement) of radionuclides or chemical contaminants from existing environmental contamination sources, hazards (i.e., contained contaminant inventories, physical-chemical forms), or facilities (including those used for materials and waste processing, storage, and disposal) through air, water, or soil to any receptor through a specific set of mechanisms or transport paths. If the transfer is currently occurring, the pathway is referred to as "complete." If the transfer may occur in the future, the pathway may become complete. Other potential pathways may never become "complete" if there is cleanup or interdiction (barriers) or if receptors are kept out of harm's way, for example, by future land use restrictions or institutional controls.

Conceptual Site Model – a comprehensive depiction of sources, potential initiating events, and completed or potential pathways that may result in (or prevent) exposure, risks, and/or impacts to receptors and resources, as well as barriers that interdict the exposure or mitigate the impacts.

Contaminant Sources (or Sources) – chemical and/or radiological contaminants or waste present in a specific form and geographic location. Example sources include contaminated soils, vadose zone, groundwater, buildings, tanks and drums, as well as historical, current, and future waste disposal areas, waste storage, and processing facilities.

Controlled Access Person – an individual, who is granted limited access to the site, within the current site security boundary, for a specific purpose or set of activities. (*This is functionally equivalent to the "On-site Public" as defined and used in the DOE SARAH and DOE-STD-3009-2014*.)

Criticality – an inadvertent self-sustaining nuclear chain reaction, with the potential release of high levels of radiation.

Cultural Resources – a collective term applicable to 1) pre-historic and historic archaeological sites and artifacts designating past Native American use of the Hanford Site; 2) historic archaeological sites and artifacts indicating post Euro-American activities relating to the pre-Hanford period; 3) Hanford Site Manhattan Project and Cold War Era buildings, structures, and artifacts; 4) landscapes, sites, and plants and animals of cultural value to the Native American community; and 5) landscapes, sites, and materials of traditional cultural value to non-Native Americans.

D&D or D4 – D&D officially refers to deactivation and decommissioning of facilities that are no longer used. D4 is a more comprehensive term including deactivation, decommissioning, decontamination, and demolition of excess facilities.

Ecological Resources – any living resource, including species, populations, communities, and ecosystems.

Ecosystem – the physical and living resources in a defined area, including topography, physical structures, water resources, plants, and animals (species to communities).

Evaluation Period – the timeframe considered over which risks or impacts may occur. This Risk Review Project considers three time intervals in addition to the current condition: 1) active cleanup, 2) near-term post-cleanup, and 3) long-term post-cleanup.

Evaluation Unit Summary Template (or Evaluation Template) – a standardized format used to summarize information and risk ratings for each evaluation unit.

Evaluation Units (EUs) – groupings of sources, aggregated for evaluation as part of this Risk Review Project. Sources may be aggregated into an EU based on potential impacts to a common set of receptors or receptor geographic area, common past waste management practices, or integration in the waste management process. The grouping of sources to form specific EUs is discussed in Chapter 3.

Facility Worker – any worker or individual within the facility or activity geographic boundary as established for DSA and located less than 100 m from the potential contaminant release point. This definition is consistent with the SARAH definition of a facility worker (HNF-8739 2012 and DOE –STD-3009-2014).

Groundwater – the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations.

Groundwater Sites – groundwater areas at the Hanford Site that have been adversely impacted by contamination.

Hazard – any source of potential damage, harm, or adverse health effects. Hazard must be distinguished from risk, since risk should reflect any actions that may have been implemented to reduce the hazard.

Impacts – the damage or consequences (death, illness, reduced reproduction, resource impairment, or access limitation) from current or post-remediation residual contamination, or from cleanup, including degradation of resources (including ecosystems, cultural resources, economic assets, groundwater, and surface water above defined thresholds).

Indicator – a physical or biological endpoint used to assess the health and well-being of humans, other species, or ecosystems.

Initiating Events – natural or man-made events or processes that may result in the release or accelerated movement of contaminants from a source. Examples include water infiltration, earthquakes, fires, cleanup activities, volcanic eruptions, and sudden structural collapses or failures. Initiating events relevant to this Risk Review Project are discussed in Chapter 4.

Insufficient Information (IS) – adequate data or other forms of information are not available to complete the indicated part of the Evaluation Template.

Key Sources – the set of contaminated areas, wastes, and facilities within an EU that pose the primary risks from the EU. Key sources would not include minor contributors to the overall risks.

Legacy Source Sites – sites containing contaminant releases to the ground, surface, or subsurface resulting from prior actions, including waste disposal actions that are no longer being carried out at a particular location and that are potentially subject to cleanup.

Maximally Exposed Off-site Individual (MOI) – hypothetical individual defined to allow dose or dosage comparison with numerical criteria for the public. This individual is an adult typically located at the point of maximum exposure on the DOE site boundary nearest to the facility in question (ground level release), or may be located at some farther distance where an elevated or buoyant radioactive plume is expected to cause the highest exposure (airborne release). (*MOI used here is not the same as the Maximally Exposed Individual or the Representative Person used in DOE Order 458.1 for demonstrating compliance with DOE public dose limits and constraints.*)

Mitigated Hazards, Exposures, or Risks – there are many hazardous facilities and materials that could reach and harm receptors (see Unmitigated Hazards, Exposures, or Risks). Before and during remediation a variety of engineered and administrative controls are used to reduce sources and interdict exposure pathways, thereby mitigating exposures and reducing risks.

Monitoring – the regular, periodic assessment of the condition of humans or ecosystems (and their component parts). Usually involves surveillance for humans, and bioindicators for ecosystems.

Not Applicable (NA) – the indicated part of the Evaluation Template that is not applicable to the specific EU or evaluation period being considered.

Not Discernible (ND) – the indicated risk or potential impact is not distinguishable from surrounding conditions.

Novel Remediation Approach – a remedial approach that is unprecedented or contains components that are unprecedented.

Operable Units (OU) – group of land disposal sites placed together for the purposes of a remedial investigation/feasibility study and subsequent cleanup actions under CERCLA. The primary criteria for placing a site into an operable unit includes geographic proximity, similarity of waste characteristics and site type, and the possibility for economies of scale. OU can also be applied to areas of groundwater contamination.

Operating Sites – operating facilities at the Hanford Site that are currently being used as part of the cleanup process.

Primary Contaminants (PCs) – contaminants that are considered either risk drivers from specific contaminant sources or site-wide contaminants (uranium, plutonium, technetium, etc.) for the Hanford Site. The terminology "primary contaminants" is used to differentiate the usage in this Risk Review Project from the regulatory usage of the terminology of "contaminants of potential concern."

Primary Sources – the origin of a potential or known release of contaminants to the environment (e.g., tanks, buildings, burial grounds, lagoons, cribs, plants that carry contaminants).

Public – represented by the MOI, a hypothetical receptor located at or beyond the Hanford Site boundary at the distance and in the direction from the point of release at which the maximum dose occurs. (*This is functionally equivalent to the "Off-site Public" as defined and used in the DOE SARAH and DOE-STD-3009-2014.)*

Pyrophoric – the property of some compounds (such as fine metal shavings of uranium) to spontaneously ignite in air.

Receptors – human populations, biota and ecological systems, environmental resources (ground and surface water), and cultural resources that may be exposed to contaminants via one or more contaminant transport and uptake pathways or otherwise adversely impacted by the contamination or cleanup actions.

Resources – a source, either material or non-material, that is considered an asset or from which a benefit is produced or derived. Resources have three main characteristics: utility, limited availability, and potential for depletion or consumption.

Risk – the potential (likelihood and magnitude) for adverse consequences to receptors. For human health, risks originate from exposure to contaminants or trauma associated with the presence of contaminants and/or cleanup of contaminant sources. For other receptors, such as groundwater and ecological and cultural resources, risks reflect the potential for damages or losses of the resource. Risk does not exist in the absence of exposure, although exposure and risks can be identified as "potential" (see also Mitigated and Unmitigated). Mitigated risk reflects those actions that have been implemented to reduce hazards, probability, and consequences of adverse events (e.g., source reduction or engineered barriers that prevent or reduce the transport of contaminants of concern from a source to a receptor).

Risk Assessment – used to characterize the nature and magnitude of health risks to humans (e.g., residents, workers, recreational visitors) and ecological receptors (e.g., birds, fish, wildlife) from radiological and chemical contaminants and other stressors that may be present in the environment.

Risk Characterization – a review of available information, including identification of key information gaps, to provide a comparative qualitative and semi-quantitative (order of magnitude) evaluation of relative risks to a set of receptors posed by a wide range of existing contamination of environmental media and sources of potential future additional environmental contamination. Risk characterization is in contrast to a regulatory risk assessment, which provides quantitative estimates of human health risks.

Risk Evaluation – an evaluation of the available information to evaluate potential harm to receptors and their ecosystems. It falls short of a formal risk assessment, and relies on available information.

Rough Order of Magnitude Relative Rating – binning to distinguish major differences in a risk to a specific receptor (i.e., human health, ecology, etc.) between multiple EUs by assigning values of Very High, High, Medium, Low, or Not Discernible (i.e., relative risks posed when comparing amongst EUs).

Secondary Sources – locations in the environment that have received material from a primary source such that they can also act as sources (e.g., soil, groundwater, sediments).

Tank Waste Sites – areas at the Hanford Site (often referred to as tank farms) that contain single- and double-shell underground tanks that house high-level radioactive and chemical wastes that are the byproduct of "reprocessing" spent nuclear fuel.

Unmitigated Hazards, Exposures, or Risks – there are many hazardous facilities and materials that could reach and harm receptors if not mitigated. The Risk Review Project considers these in terms of probability and consequence, assuming no effective mitigation measures (engineered and administrative controls) are in place (see Mitigated Hazards, Exposures, or Risks).

Urgency – higher urgency refers to projects where the risks or impacts to receptors are likely to increase due to degradation at the source, further dispersion of contamination in groundwater, loss of structural integrity, or loss of institutional memory. Lower urgency refers mainly to passively stable hazard configurations and when radiologic decay significantly reduces risk depending on the half-life of each radionuclide.

Vadose Zone – zone of soil or rock between the land surface and the water table. Pore spaces in the vadose zone are partly filled with water and partly filled with air. The vadose zone is bounded by the land surface above and by the water table below.

PART 1. OBJECTIVES AND APPROACH OVERVIEW

CHAPTER 1. RISK REVIEW PROJECT SCOPE AND EXECUTION

1.1. GOAL, OBJECTIVES, AND SCOPE

In January 2014, the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) was requested by the Deputy Under Secretary of the U.S. Department of Energy (DOE) to conduct a Hanford site-wide evaluation of human health, nuclear safety, environmental, and cultural resource risks (see Appendix A); hereinafter referred to as the "Risk Review Project." The goal of the Risk Review Project is to carry out a screening process for risks and impacts to human health and resources. Accomplishing this goal includes identifying and characterizing potential risks to the public, facility workers, co-located people, groundwater and the Columbia River, and ecological and cultural resources (collectively referred to as "receptors"). The Risk Review Project's results are expected to provide DOE and regulators with a common understanding of the risks posed by hazards (i.e., contained contaminant inventories, physical-chemical forms, structural integrity, vulnerability to initiating events), existing environmental contamination, and cleanup actions (including mitigation measures that offset or reduce risk associated with cleanup). The resulting information is intended to help inform the sequencing of future cleanup actions, recognizing that there are a wide range of additional inputs and factors that influence the cleanup prioritization decisions made by DOE and its regulators at the Hanford Site. This information also is intended to aid in the efficient use of DOE Office of Environmental Management (EM) resources.

Specific objectives of the Risk Review Project are to:

1. Review hazards and existing environmental contamination Site-wide and determine the potential for contaminants and cleanup actions to cause risks to receptors, and identify key uncertainties and data gaps;
2. Provide relative ratings of risks to receptors from hazards and existing environmental contamination, and identify the most urgent risks to be addressed, to better enable the Tri-Parties (DOE, EPA, State of Washington) to make decisions on the sequencing of Hanford cleanup activities; and
3. Provide context for understanding how the hazards, existing environmental contamination, current risks and risks posed by cleanup at the Hanford Site compare to risks and impacts posed by other large-scale regional sites and analogous cleanup activities.[1]

Meeting all three objectives is a daunting task. Within the Risk Review Project, risk characterization is designed to assemble and evaluate existing information gathered from Hanford records that is then assembled and evaluated to determine risks. These risks are to grouped or binned risks to each type of receptor as "Very High", "High", "Medium", "Low", or "Not Discernible" (ND). This approach is intended to provide relative risk ratings *within* receptor categories (i.e., relative binning of risks to the Columbia River and groundwater, ecology, etc.).

It is important to recognize that the role of risks to different receptors changes with respect to different types of cleanup decisions at the Hanford Site because of the nature of the hazards, existing environmental contamination, and prior cleanup actions. The risks posed to human health for people potentially exposed and environmental resources, notably groundwater and the Columbia River, are of

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[1] This objective is not covered in this methodology document and will not be covered the interim progress report, but will be addressed as part of the final report.

primary importance to the urgency and sequencing of specific cleanup activities. In contrast, the potential risks and impacts to ecological resources and cultural resources are of primary importance to the selection and execution of cleanup approaches. Furthermore, the extent of cleanup and the final status of areas containing remaining contaminants at the completion of cleanup (e.g., permitted disposal facilities) are of primary importance to future uses of different areas within the Hanford Site.

The Risk Review Project also will provide several examples that illustrate how grouping that integrates the ratings across receptor categories (e.g., integrated risk binning that combines risks to human health with risks to ecology and groundwater) can be carried out. Integration across receptor categories is considered inherently driven by individual and collective values, and thus, multiple outcomes are possible. This is because of the wide range of individual and collective values that are naturally present within the Hanford community and nationally.

It is also important to be clear about what the Risk Review Project is not:

1. The Risk Review Project is not intended to substitute for or preempt any requirement imposed under applicable federal or state environmental laws. As important, the Risk Review Project is not intended to make or replace any decision made under the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) and/or 2010 Consent Order, or amendments.
2. The Risk Review Project is not intended to interpret treaty rights that exist between the United States and Native American Tribes.
3. The Risk Review Project is focused only on portions of the Hanford Site where cleanup or waste management activities are ongoing and will continue past October 1, 2015 or where cleanup or waste management activities will occur beginning October 1, 2015 or later. Cleanup actions considered completed by the Tri-Parties are not part of the Risk Review Project and therefore will not be evaluated. Specific areas of the Hanford Site that are included as well as those that are excluded from the Risk Review Project are described in Chapter 3 of this document.
4. The Risk Review Project is focused on risk characterization, which is a necessary predecessor to risk management, but does not focus on risk management decisions. Nonetheless, cleanup actions can cause risks to receptors, which are a part of risk management decisions. The Risk Review Project, however, will not recommend which cleanup option should be selected. Instead, the Risk Review Project considers a plausible range of cleanup actions for different types of hazards and existing environmental contamination to better understand the range of potential risks that may be caused by future cleanup actions.
5. The Risk Review is not a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) risk assessment or a Natural Resources Damage Assessment evaluation. Evaluations of hazards, existing environmental contamination, and rough order-of-magnitude estimates of risks to receptors using existing information will be the basis for developing groupings, or bins, of risk and identifying the most urgent risks to be addressed.

The Risk Review Project is being carried out in dialogue with senior management from DOE, EPA, and the State of Washington Departments of Ecology and Health through a Core Team that provides advice on the Project's development and execution. Pacific Northwest National Laboratory (PNNL) provides analytical and research assistance, which includes gathering existing information on each unit being evaluated.

The Risk Review Project is led by CRESP, which is responsible for its execution, results, observations, conclusions, and recommendations. CRESP consists of a consortium of universities and is supported by

DOE through a cooperative agreement.[2] The CRESP mission is to advance environmental cleanup by improving the scientific and technical basis for management decisions, while at the same time fostering opportunities for public participation. CRESP has completed risk-informed characterization projects that involve complex issues at both large and small DOE-EM sites.

The Risk Review Project is being carried out in three stages:

1. Development of the risk characterization methodology and testing of the methodology on pilot case sites representing the primary sources of contamination at Hanford Site (e.g., operating facilities and tank waste and tank farms). The methodology has been adapted from prior risk characterization approaches used at Hanford and elsewhere and tailored to fit the Hanford Site's unique cleanup and waste management activities, diversity of information, and the goal and objectives of the Risk Review Project. The methodology is the subject of this document.
2. Completion of an interim progress report that provides risk characterization of approximately half of the contaminant sources at the Hanford Site.
3. Completion of a final report that includes risk characterization of the full set of contaminant sources at the Hanford Site included within the Risk Review Project.

In 1989, Hanford's mission shifted from supporting weapons development to environmental cleanup of facilities, soil, and groundwater. Today, Hanford Site, which is 586 square miles, consists of waste management and former production areas, active and closed research facilities, waste storage and disposal sites, and huge swaths of natural resources and habitat. DOE's near term vision calls for reduction of the active cleanup footprint to 75 square miles in the center of the Site, reducing overhead costs, and shifting resources that would allow full scale cleanup of the Central Plateau. (DOE/RL-2014-11 2014) To date, considerable progress has been made in achieving this vision. For example, hazards near the Columbia River have been eliminated by completing cleanup of most of the River Corridor and treating contaminated groundwater near the Columbia River.

Cleanup at Hanford has proven to be a much lengthier, more complex, more technically challenging, and more expensive undertaking than was envisaged in 1989 when Hanford's mission shifted to waste management and cleanup. In fact, the Hanford Site is the most complex and costly cleanup project in the United States. Overall cleanup has been projected to cost more than $100 billion over the next 50 years (DOE/RL-2014-11 2014). While earlier studies have evaluated portions of the Hanford Site, a comprehensive, site-wide review of the risks to human health and resources from the Hanford contamination, waste management, and cleanup activities has never been carried out. For all these reasons, then, it is appropriate for DOE to have requested a comprehensive site-wide review of risks to receptors that also would provide opportunities for input at key points from individuals, organizations, agencies, elected officials, and Tribal nations.

1.2. EXTERNAL REVIEW

To ensure that the methodology ultimately used to conduct the Risk Review Project is credible and of the highest quality, it is important that a broad spectrum of stakeholders, the public, Native American Tribes, and government agencies have an opportunity to provide comments. In early September 2014, a draft of this document was posted on a CRESP web page (www.cresp.org/hanford) dedicated to the Risk Review Project, and was made available for written comment. In addition, CRESP team members met

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[2] CRESP is supported by the DOE, under Cooperative Agreement Number DE-FC01-06EW07053, titled *The Consortium for Risk Evaluation with Stakeholder Participation III*, awarded to Vanderbilt University.

with the Hanford Advisory Board (public invited), Tribal nation representatives, affected government agencies, and local elected officials to explain the methodology and encourage feedback. Finally, Core Team members and their staff reviewed the draft methodology, as did a peer-review group of experts.

All written input received on this document was acknowledged and considered, and provided important input for improving the methodology used to execute the Risk Review Project. A list of the comments received and an overview of revisions reflected in this methodology document are available as a separate summary document on the CRESP web site.

Written comments will be solicited from a broad spectrum of stakeholders, the public, Tribes, and government entities at two other key points during the Risk Review Project: after release of the interim progress report (concurrent with the release of this methodology document) and after release of the draft final report. The methodology, interim progress report and the final report for the Risk Review Project are considered public documents.

1.3. THE PURPOSE OF THIS DOCUMENT

The purpose of this methodology for the Risk Review Project is to present the scope and process used to carry out the project, including specific metrics and scales for qualitative and rough order-of-magnitude relative rating and binning of risks to human health, groundwater and the Columbia River, and ecological resources. An overall risk rating will not be provided for cultural resources; however, information about cultural resources will be gathered, described, and analyzed as a planning guide or tool for future activities. The focus of this document is on the elements of the methodology itself, rather than on outcomes of the ratings or binning of risks to receptors. The methodology developed for the Risk Review Project first will be executed on the first set of 25 EUs and the results will be presented in the interim progress report. The final report will reflect the evaluation and results of the remaining EUs using the same methodology.

1.4. REFERENCES

DOE/RL-2014-11 2014, *2015 Hanford Lifecycle Scope, Schedule and Cost Report Rev. 0.* U.S. Department of Energy, Richland Washington.

CHAPTER 2. OVERVIEW OF THE RISK CHARACTERIZATION METHODOLOGY

2.1. RISK CHARACTERIZATION METHODOLOGY

To accomplish the Risk Review Project's goal, the most recent, available information about hazards (i.e., contaminant inventories, containment conditions, physical chemical forms), existing environmental contamination, and events that may result in adverse impacts to receptors at the Hanford Site is gathered, described, and analyzed. The Risk Review Project is using most recent available information and reasonable planning assumptions for development of the interim progress report.[3]

The general risk characterization paradigm being used to evaluate risks to human health and other receptors includes the following steps:

1. **Evaluation Units (EUs).** The remaining cleanup sites[4] at Hanford, as of October 1, 2015, have been divided into approximately 60 EUs, which have been organized into five categories composed of geographically co-located sites, to the extent possible, considering commonality among source types and the overlapping of impacts and risks to receptors. The Risk Review Project developed the EU concept to provide a tractable basis for reviewing the challenges posed by cleanup at Hanford Site and to understand potentially overlapping risks. The categories are not common practice at Hanford Site. The five categories are: 1) legacy source sites, such as past practice liquid waste disposal and buried solid waste sites; 2) tank waste and farms and co-located legacy contamination sources; 3) groundwater plumes; 4) inactive facilities undergoing decommissioning, deactivation, decontamination, and demolition (D4); and 5) operating facilities used as part of the cleanup process. Further descriptions of the sources, grouping methodology, and sources included in each EU, as well a listing of the complete set of EUs, are provided in Chapter 3.
2. **Summary Evaluation Templates.** Each EU will be described in detail using existing information, including regulatory documents, maps, and studies (environmental impact statements [EISs], CERCLA remedial investigations, preliminary documented safety analyses, etc.). Information gathered on each EU includes the unit description and history; an inventory of waste and contamination history; and selected or the potential range of cleanup approaches. This information is highly variable, depending on many factors, including documentation of past site practices, current regulatory status, and planned near-term cleanup activities. The ratings of risks to receptors then are based on a rough order of magnitude relative grouping[5] or binning of risks to each different type of receptor. The primary groupings are Very High, High, Medium, Low, and Not Discernible. A standardized summary report structure, referred to as an Evaluation Template, is used to present the resulting information about each EU.
3. **Risk Ratings.** Potential receptors that may be at risk are characterized and rated using a defined rating scale derived from the evaluation methodology developed for each receptor type. The rating scale for each type of receptor are determined from the specific methodology developed

[3] The Hanford Site-wide Risk Review Project Interim Progress report can be found on the CRESP website: www.cresp.org/hanford/.

[4] The Hanford Site has been divided into more than 2500 individual contaminated areas (i.e., operable units) and RCRA permitted facilities for regulatory purposes.

[5] A "rough order of magnitude grouping" refers to drawing distinctions between groupings that are approximately a factor of 10 different when based on quantitative information (or substantially different for qualitative assessments) recognizing the inherent uncertainties and data gaps which exist.

for that receptor using recognized thresholds, if they exist, as screening levels, as well as other factors. The receptors being rated using a defined scale are facility workers, co-located people, public, groundwater and the Columbia River, and ecological resources. This approach is intended to provide relative risk ratings *within* receptor categories (i.e., relative binning of risks to the Columbia River, groundwater, ecology, etc.) that will be used to inform the urgency of addressing specific hazards. An overall risk rating will not be provided for cultural resources; however, information about cultural resources within or near (with 500 m) each EU will be gathered, described, and analyzed as a planning guide or tool for future activities. Although the integration across receptor categories is considered inherently driven by individual and collective values, the Risk Review Project will provide examples that illustrate how grouping or binning that integrates the ratings across receptor categories (e.g., integrated risk binning that combines risks to human health with risks to ecology and groundwater) could be carried out.[6]

4. **Initiating Events.** The likelihood of initiating events, both localized and regional in scale, which may occur during any or all of the evaluation periods, including operational events such human error and external episodic events such as fire, volcanic eruptions, and loss of power, is described. This is to establish a consistent basis for identifying and categorizing phenomena that may remove or degrade barriers, placing receptors at risk from contaminants. Nuclear safety is considered in the context of potential initiating events and risks to receptors and is described in more detail in Chapter 4. Furthermore, contaminants in environmental media (e.g., soils, vadose zone, groundwater) will flow, move, diffuse, and disperse under long-term prevailing conditions without the presence of specific episodic initiating events.
5. **Temporal Evaluation Periods.** Risks are evaluated based on distinct timeframes or evaluation periods. The evaluation periods are 1) active cleanup period (or until 2064), including the current status of the EU prior to cleanup, where applicable, and during active cleanup (or until 2064); 2) near-term post-cleanup (until 2164, or assuming a 100-year duration for institutional controls associated with areas transferred from federal control); and 3) long-term post-cleanup (or until 3064). Each EU and selected EU components are evaluated as if cleanup were not to occur for 50 years to provide insights into the potential risks of delay to help inform sequencing of cleanup actions. However, this is not to infer that delay of cleanup for 50 years is recommended. Section 2.4 provides additional assumptions relative to each evaluation period. Using the specific methodology to rate risks for each receptor (described in Chapters 5 through 8), each EU will receive a rating for each applicable receptor during the active cleanup period (including current status and as a result of cleanup actions where applicable) and the near-term post-cleanup period[7]. The long-term post-cleanup period will be considered for the remaining contaminant inventory and physical/chemical form, engineered and natural containment barriers to contaminant release, and potential risk pathways. However, a rating for specific receptors will not be assigned to the long-term post-cleanup period.
6. **Economic Assets.** The Hanford Site and its vicinity include a range of economic assets that may be impacted by cleanup activities at the Hanford Site. DOE economic assets include the Hanford Site infrastructure. Commercial activities on the Hanford Site include the US Ecology low level waste disposal facility, Energy Northwest nuclear power generation, and multiple PNNL research laboratories. Furthermore, the regional economy may be impacted by public perceptions of cleanup activities at the Hanford Site. EU evaluations indicate when the current status, delay or

[6] This will be included in the final report but not the interim progress report.
[7] The human health risks associated with potential failure of institutional controls during the near-term post-cleanup period will be evaluated in the final report but not the interim progress report.

cleanup activities may have direct impact on DOE and non-DOE economic assets. Economic assets are described briefly at the end of this chapter, but identified economic assets are not evaluated individually in detail in this document.

The overall methodology is illustrated in Figure 2-1 and the key assumptions are discussed later in this chapter.

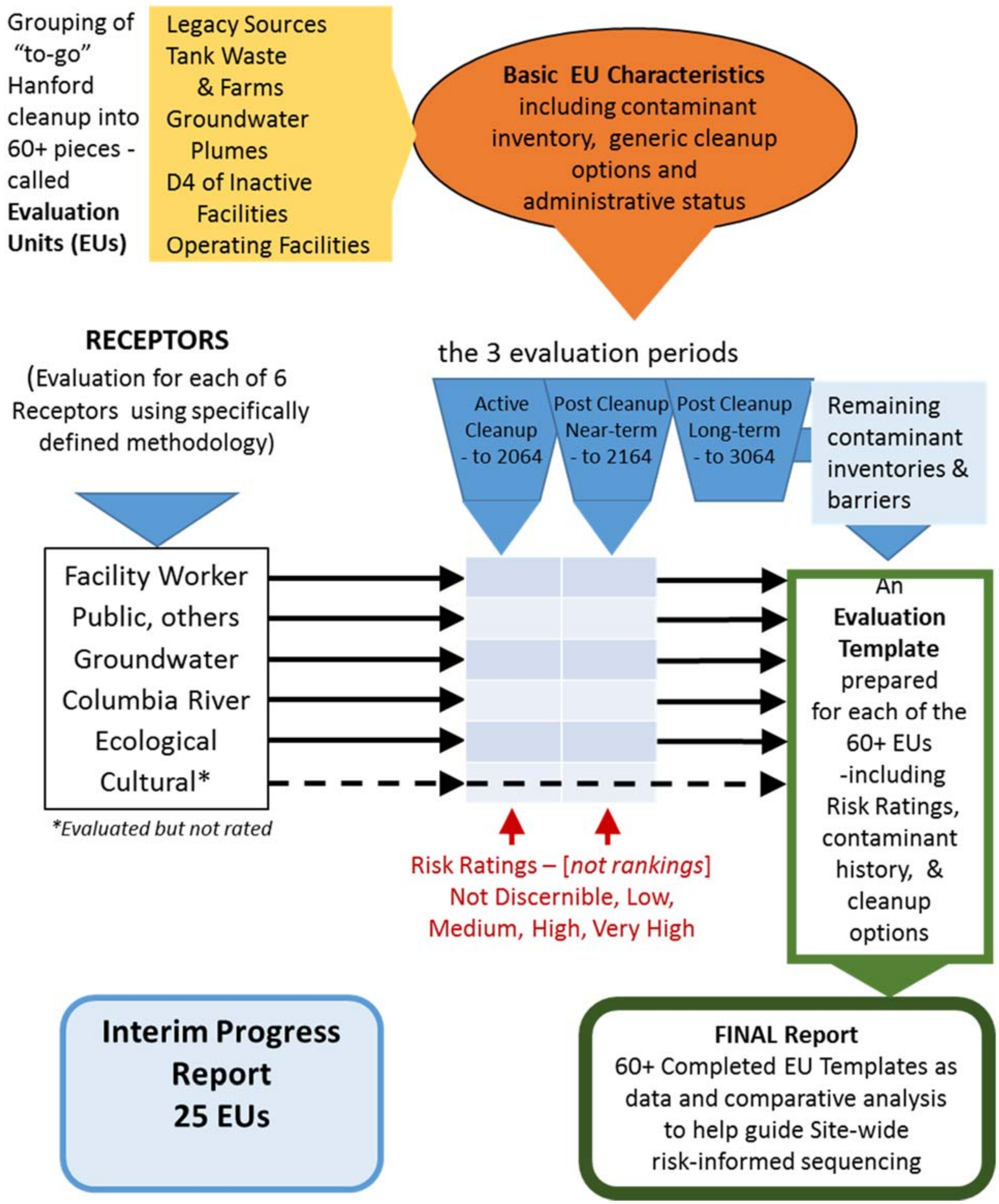

Figure 2-1. Methodology overview for the Hanford Site-Wide Risk Review Project.

2.2. RADIONUCLIDES AND OTHER CONTAMINANTS CONSIDERED

The Risk Review Project focuses on radionuclides and contaminants that have been of large, site-wide significance and public concern or are the major contributors to receptor risks at specific EUs (i.e., risk drivers). Collectively, the set of radionuclides and contaminants being considered are referred to as primary contaminants (PCs) and may differ for specific EUs (because of the presence or absence of specific radionuclides and contaminants and different risk and impact drivers)[8]. In most cases, the list of PCs for each EU will be more limited than the regulatory list of contaminants of potential concern. The radionuclides and other contaminants that are considered to have site-wide significance and are of concern to the public at the Hanford Site are:

- Radionuclides:[9] cesium-137 (Cs-137); iodine-129 (I-129); isotopes of plutonium (Pu) including Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242; strontium-90 (Sr-90); technetium-99 (Tc-99); and tritium (H-3, or ^3H_2O)
- Other contaminants – carbon tetrachloride (CT or CCl_4), trichloroethylene (TCE), hexavalent chromium [Cr(VI)], total chromium [Cr(total)], total uranium [U(total)], and nitrate (NO_3)

Examples of additional primary contaminants that are of interest at specific or limited EUs are

- Cyanide (CN), which was discharged to the BY Cribs and is present in the B-Complex as a groundwater plume (0.4 km^2) within the Central Plateau;
- Diesel as total petroleum hydrocarbons (TPH-diesel), which is present as a relatively small plume (0.016 km^2) in the 100-NR Operable Unit;
- Lead (Pb), mercury (Hg), and tributyl phosphate (TBP), which were discharged into the environment (e.g., 300 Area waste sites for TBP) but are not currently present in the groundwater;
- Carbon-14 (C-14), which was discharged primarily to the 116-KE-1 and 116-KW-1 gas condensate cribs and is present as a relatively small plume (0.03 km^2) in 100 K Area groundwater (100-KR-4 Operable Unit);
- Americium-241 (Am-241) was discharged into a number of EUs (e.g., 26,000 Ci into the Pu-contaminated waste sites); however, is not currently in groundwater in measured concentrations exceeding standards and is expected to be relatively immobile in the Hanford subsurface;
- Chlorine-36 (Cl-36) is primarily associated with the 100 Area reactor facilities (e.g., 100-KE and 100-KW Reactors) but has not been measured in groundwater;
- Cobalt-60 (Co-60), which was discharged to various EUS (e.g., 27 Ci to BC Cribs and Trenches), is not present as a groundwater plume, is expected to be immobile in the Hanford subsurface, and

[8] The terminology of "primary contaminants" is specific to the Hanford Risk Review Project, with the specific radionuclides and contaminants included based on Hanford history and prior evaluations, and with input from the Core Team.

[9] Radionuclides included as primary contaminants are selected plutonium isotopes (i.e., Pu-238, -239, -240, -241, and -242). Uranium isotopes (U-232, -233, -234, -235, -236, and -238) were also considered; however, risks related to uranium were typically driven by chemical toxicity and not specific activity (TC&WM EIS) and thus total uranium was the focus for the Review. Note that inventories and effects from both the plutonium and uranium isotopes were typically aggregated in the source material (e.g., TC&WM EIS) and the Risk Review Project maintained a similar convention.

will rapidly decay (half-life of 5.3 years) so that the only likely health risk is from direct exposure to workers over the next 50 years (i.e., 10 half-lives).

- Selected isotopes of nickel (i.e., Ni-59 and Ni-63) and europium (i.e., Eu-152 and Eu-154) were discharged into various EUs including 110 Ci of Ni-59 and -93 in the waste sites associated with the C Tank Waste and Farms EU and 130 Ci of Eu-152 and -154 in the BC Cribs and Trenches; however, these isotopes are not in groundwater at measured concentrations exceeding standards and are expected to remain relatively immobile in the Hanford subsurface.

Other chemicals (including mercury and PCBs) and radionuclides (including Np-137) were considered as part of the Interim progress report process but did not rise to the level of what were considered primary contaminants for the Interim progress report. The inventory for mercury has been summarized for each of the EUs where present in significant quantities; however, the potential exposure pathway has not been evaluated in this Interim Report but will be considered in the Final Report. EUs The CRESP team will consider these and other contaminants of potential concern for inclusion as primary contaminants for the Final Hanford Risk Review Report based on review of the additional EUs.

2.3. DURABILITY OF INSTITUTIONAL CONTROLS

Institutional controls are assumed to be effective for the duration of federal control of designated land areas and the EUs contained therein. Furthermore, institutional controls are assumed only to be effective for 100 years after the transfer of land areas from federal to non-federal control. Some areas of the Hanford Site are currently planned to be under federal control for very long periods (e.g., greater than 300 years for permitted disposal areas in the Central Plateau). Periods of planned federal control may change over time in response to changes in public policy or other decisions. Changes in assumptions of institutional controls may necessitate future changes in the end-states of an EU (i.e., changes in final barriers or physical-chemical forms or amounts of remaining contaminants).

2.4. EVALUATION PERIODS

Three evaluation periods are considered for each EU in this Risk Review Project:

- Active cleanup (50 years or until 2064), including during the current status and during cleanup actions
- Near-term post-cleanup (100 years after cleanup or 2064 to 2164)
- Long-term post-cleanup (1000 years after cleanup or 2164 to 3064, although longer-term risks are noted when available from prior analyses)

The rationale and description for each of these evaluation periods are provided below.

2.5. ACTIVE CLEANUP

The active cleanup period for Hanford is defined as 50 years (i.e., until the year 2064). During this timeframe, all currently planned cleanup is assumed to be completed, except groundwater cleanup; natural attenuation processes, when selected as a remedy (for vadose zone and groundwater); and final disposition of entombed reactors and facilities along the Columbia River Corridor. The current designated actions for the entombed reactors specify an evaluation of the final timeline and removal of these facilities to the Central Plateau in the future, with approximately 75 years for reactor entombment to allow for radioactive decay and therefore increased safety associated with future actions.[10] Final on-site disposal units may require very long-term monitoring.

The goal of the Risk Review Project is to help inform DOE and regulator decisions concerning future sequencing of cleanup activities, including which areas should be given priority earlier for additional characterization and analysis. Thus, the Risk Review Project does not assume a fixed sub-interval in time for cleanup of any specific EU or EU component. Rather, each EU and selected EU components are evaluated as if cleanup were not to occur for 50 years to provide insights into the potential risks of delay to help inform sequencing of cleanup actions. However, this is not to infer that delay of cleanup for 50 years is recommended.

Cleanup activities at Hanford are ongoing and are not static. Since the Risk Review Project is being completed in a short timeframe, this means that 1) risks to receptors may change as a result of changing contamination distributions, 2) risks to receptors may change as a result of nearby cleanup activities, and 3) currently undetermined cleanup methods or timing may affect risk in EUs or adjacent EUs. Although characterization of each EU will include the risks posed by the current and projected contamination, the risk profile for each EU's sources may also change significantly during, or as a result of, cleanup activities. Changes in the risk profile may include increases in risks to workers, accidental or consequential dispersion of contaminants, disruption of biota and ecosystems, disruptions to or exposure of cultural resources, and impacts to nearby operating facilities. By definition, the final approach and timing for cleanup of each source area, where there has not yet been a regulatory decision, is not known at this time. Therefore, for EUs where regulatory determinations have not been made, a range of cleanup approaches is examined for each generic type of source, when considering risks and impacts from cleanup.

The primary distinctions among different cleanup approaches are the amount of contaminant inventory remaining, barriers that prevent dispersion of residual contamination, and the types of activities required to achieve cleanup (potentially impacting worker safety and surrounding ecological and cultural resources). The range of possible cleanup approaches for any EU will emerge from information on the sources and risks/impacts at specific EUs. Hence, a list of probable cleanup approaches reflects how the sources might be addressed. The list below provides several examples of the types of different remedial options for the major contaminant sources.

Legacy Source Sites

- Removal (excavation), transport, and on-site disposal
- *In situ* immobilization (e.g., grouting or injections to form low solubility minerals)
- *In situ* treatment resulting in contaminant removal (e.g., *in situ* biodegradation or natural attenuation)
- *In situ* phytoremediation (e.g., use of plants to remove contaminants)
- Capping and restoration

Tank Waste and Farms

- Retrieval of waste
- Grouting of tanks and ancillary equipment

Groundwater and Deep Vadose Contamination

[10] The EIS (DOE/EIS-0119D 1989) and its Addendum (DOE/EIS-0222-F 1992) addresses the disposition of eight surplus Hanford reactors.

- Natural attenuation (e.g., by radioactive decay or biodegradation processes)
- *In situ* immobilization (e.g., grouting, desiccation, or injections to form low solubility minerals)
- Capping (i.e., to limit infiltration and recharge)
- Groundwater recovery with or without active flushing ("pump and treat")

D4 of Inactive Facilities

- Decommissioning and demolition, including *in situ* deactivation (decontamination) and decommissioning (D&D)
- Full or partial permanent entombment
- Interim entombment followed by further decommissioning and demolition (i.e., allowance for radioactive decay to reduce worker risks and potential impacts)

Operating Facilities

- The Environmental Restoration Disposal Facility (ERDF) continues to accept certain categories of waste, contaminated soil, equipment, and construction debris.
- Permanent federal control with surveillance and maintenance of institutional controls, etc.

In addition, disposition of materials and wastes to an off-site federal or commercial disposal site or a national geologic repository is the disposition pathway for several sources of contamination (e.g., high-level waste).

For those sources where the cleanup plan has been determined by a final remedial action record of decision (EPA 2013), such as for the 300 Area (EPA 2013), or EIS (DOE/EIS-0391 2012), such as for the tank farms, the selected remedy will be considered the baseline cleanup scenario in the Risk Review Project risk ratings. For sources where there has not been a final remedial decision, the DOE planning basis assumption for each EU is considered as a baseline reference for the range of potential cleanup approaches for each EU and is summarized in Appendix C.

Since EU categories and components are diverse and may include multiple sources and types of hazards, contaminant inventories and existing environmental contamination, the current status, potential initiating events, and pathways that cause or exacerbate risks also are diverse. Conceptual site models (CSMs) are provided for each EU category to help explain the potential initiating events and pathways to relevant receptors (Section 2.8).

Initiating events can result in movement or migration of contaminants. However, it is possible to describe and anticipate the major aspects of different scenarios for key sources. Nuclear safety analysis, which is embodied in the documented safety analysis (DSA) process, including hazards analysis (HA), preliminary DSA, and final DSA, provides a detailed evaluation of external and operational initiating events and scenarios that can result in risks to human health from existing hazards. In addition to episodic events, evaluated as part of nuclear safety analysis, prevailing conditions, including infiltration and subsurface contaminant transport with groundwater flow, are considered as mechanisms for dispersion of existing environmental contamination and for potential impacts to receptors.

2.6. NEAR-TERM POST-CLEANUP

The near-term post-cleanup period is for 100 years after cleanup is completed (until the year 2164). This period was selected because it is the interval over which institutional controls are assumed to be in effect for land areas no longer maintained under federal control. During this period, maintenance activities also are assumed to occur, as necessary, to maintain the integrity of the remaining engineered systems (landfill caps, liners, entombment, etc.), along with active monitoring to detect any new releases and confirm the efficacy of remaining remedial activities (natural attenuation, groundwater containment, etc.). Periodic regulatory reviews are also required by federal law to be continued as long as institutional controls are in place.

Post-cleanup does not mean that all contamination has been removed from the Hanford Site. Thus, a diversity of states will constitute "completion" at the EUs. The following examples illustrate the range of end-states for units of characteristic "sources" to be achieved at the completion of the active cleanup period, which is also the beginning of the near-term post-cleanup period.

> Legacy Source Sites - cleanup to unrestricted use; cleanup to industrial use standards; cleanup consistent with other land use designations
>
> Tank Waste and Farms - removal of 99% of the waste contained in tanks followed by grouting of tanks and ancillary equipment and capping of the tank farm[11]
>
> Groundwater and Deep Vadose Zone Contamination - natural attenuation (e.g., by radioactive decay or biodegradation processes); removal by pump-and-treat or immobilization of a certain percent of the initial inventory; capping (i.e., to limit infiltration and recharge)
>
> D4 of Inactive Facilities - D&D completed; final permanent entombment achieved

The presence of residual contaminants in remediated areas and engineered disposal facilities typically is evaluated through performance assessments under DOE Order 435.1.

2.7. LONG-TERM POST-CLEANUP

The long-term post-cleanup period is assumed to extend for 900 years after the near-term post-cleanup period (until the year 3064), for a total post-closure assessment period of 1000 years. This interval was selected to be consistent with current DOE Order 435.1 for performance assessments and the basis of prior contaminant transport modeling information, as well as the recently adopted 1000-year period of compliance for commercial low-level waste (LLW) disposal facilities regulated by the Nuclear Regulatory Commission (NRC).[12] The same end-states associated with the end of the active cleanup period are assumed to apply until the year 3064, where reasonable. Associated uncertainties, uncertainty ranges, and impacts that may occur beyond this timeframe will be clearly identified, where possible.

For many remaining sources, the only reasonable characterization for EUs will be 1) the remaining contaminant inventory along with the physical state and location; 2) the degradation, prevailing natural processes (contaminant transport and dispersion associated with recharge and groundwater flow, etc.), or failure modes that can result in dispersal or migration of contaminants from the remaining engineered systems or subsurface contamination; and 3) the probability of significant initiating events. The assumed set of infiltration and recharge rates for the long-term post-cleanup period will be the same as for the near-term, post-cleanup period because they bracket very low to very high infiltration rates that may be possible under a range of land cover and climate conditions.

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[11] According to the Hanford Tri-Party Agreement (TPA), retrieval limits for residual wastes are 360 ft^3 and 30 ft^3 for 100-Series and 200-Series tanks, respectively, corresponding to the 99% waste retrieval goal as defined in TPA Milestone M-45-00.

[12] The Commission approved the staff requirements memorandum on February 12, 2014.

2.8. A PRESUMPTIVE SET OF POTENTIAL PATHWAYS FROM CONTAMINANT RELEASE TO RECEPTORS

Despite the diversity of sources and receptors, there is a limited set of potential contaminant release mechanisms and pathways from source areas to receptors that constitute the focus of the Risk Review Project. The list below identifies the relevant contaminant release and impact pathways of primary importance for each source type. Hence, the following may be considered a “checklist” for evaluating sources within each EU:

Pathways

Risks from Contaminated Near-Surface Soils – the primary pathways are 1) direct human exposure through land use; 2) transport to the subsurface and groundwater through infiltration; 3) contaminant transport through erosion, biotic processes, or atmospheric dispersion; 4) biota exposure and biotic transport; and 5) exposure to cultural resources.

Risks from Vadose Zone Contamination – infiltration-induced transport through the subsurface to groundwater and the Columbia River.

Risks from Engineered Waste Management Facilities (either currently operational or inactive) – initiating events (external or operational) that cause loss of waste/contaminant containment followed by either 1) direct human exposure, 2) atmospheric dispersion, 3) near-surface soil contamination, 4) impaired or precluded use of other resources and facilities, 5) damaged biota or ecosystems, or 6) damaged or destroyed cultural resources.

Risks from D4 Facility Activities – occur primarily from unanticipated facility conditions and accidents during cleanup and maintenance activities. Accidents or other initiating events prior to completion of decommissioning may cause loss of waste or contaminant containment followed by combinations of 1) direct human exposure, 2) atmospheric dispersion, 3) near-surface soil contamination, 4) impaired or precluded use of other resources and facilities, or 5) damaged biota, ecosystems, or cultural resources.

Risks from Groundwater Contamination – only may occur when there is active or projected use and/or consumption of contaminated groundwater, uptake by biota, or as a consequence of contaminant discharge to the Columbia River. However, groundwater is a protected resource under Washington State and federal regulations, so risks or impacts to groundwater are also considered.

Risks from Biota – tumbleweed that rumbles over the land, snakes that hibernate in buildings and carry contamination out, birds that fly from place to place, etc.

Receptors

Worker Health Risks – occur primarily from unanticipated circumstances and accidents during cleanup and maintenance activities. Occupational health exposures and traumas may occur as a consequence of existing conditions, maintenance, monitoring, or cleanup activities. These include releases, chronic undetected exposure, and industrial-type accidents.

Public Health Risks – occur from exposures to contaminants in air, water, near-surface soils, or consumption of food grown or harvested from contaminated soils. Potential exposure due to routine excavation or other activities is considered to a depth of 5 m. Groundwater contamination is evaluated separately from other pathways because groundwater use can be (and often is) managed separately from land use.

Risks to Groundwater – either from waste currently in engineered facilities, near-surface contaminated soils, vadose zone contamination, or through the movement, diffusion, and dispersion of contaminants already present in groundwater. Sources, currently in engineered facilities, require an initiating event (e.g., cover or liner failure, corrosion or other induced leakage, infrastructure failure causing large water release, large precipitation event, earthquake, accident) to release contaminants to the soil surface or subsurface. Contaminants in near-surface soils and the vadose zone are transported to the groundwater as a function of prior moisture conditions and infiltration rate (location and surface condition dependent), individual contaminant sorption/transport characteristics (subsurface stratigraphy and contaminant dependent), and the distance to groundwater (location dependent). Further spreading of contaminants in the groundwater is dependent on contaminant concentration, groundwater flow rate and dispersion, and the individual contaminant sorption/transport characteristics.

Risks to the Columbia River – either from current or projected discharge of contaminated groundwater through the riverbed (upwellings or seeps), direct waste discharges, or overland flow and erosion that discharges to surface water. Physical erosion also needs to be considered (e.g., soil). Risks from contaminant exposure in the riparian zone (through seeps) and benthic zone (through groundwater upwellings) originating from the Hanford Site are considered. Human health risks associated from potential surface water contamination originating from the Hanford Site are considered in the context of Columbia River use.

Risks to Biota and Ecosystems – from physical disruption of an ecosystem, contaminant dispersion and uptake, fragmentation of habitats, or introduction of invasive species resulting from contaminant releases or cleanup activities (either in proximity to sensitive ecosystems or as a result of transit pathways to/from remediation activities). Physical disruptions, such as soil compaction, introduction of obstacles for wildlife (e.g., roads), and soil removal, have major impacts on plant and animal species distribution and ecosystems.

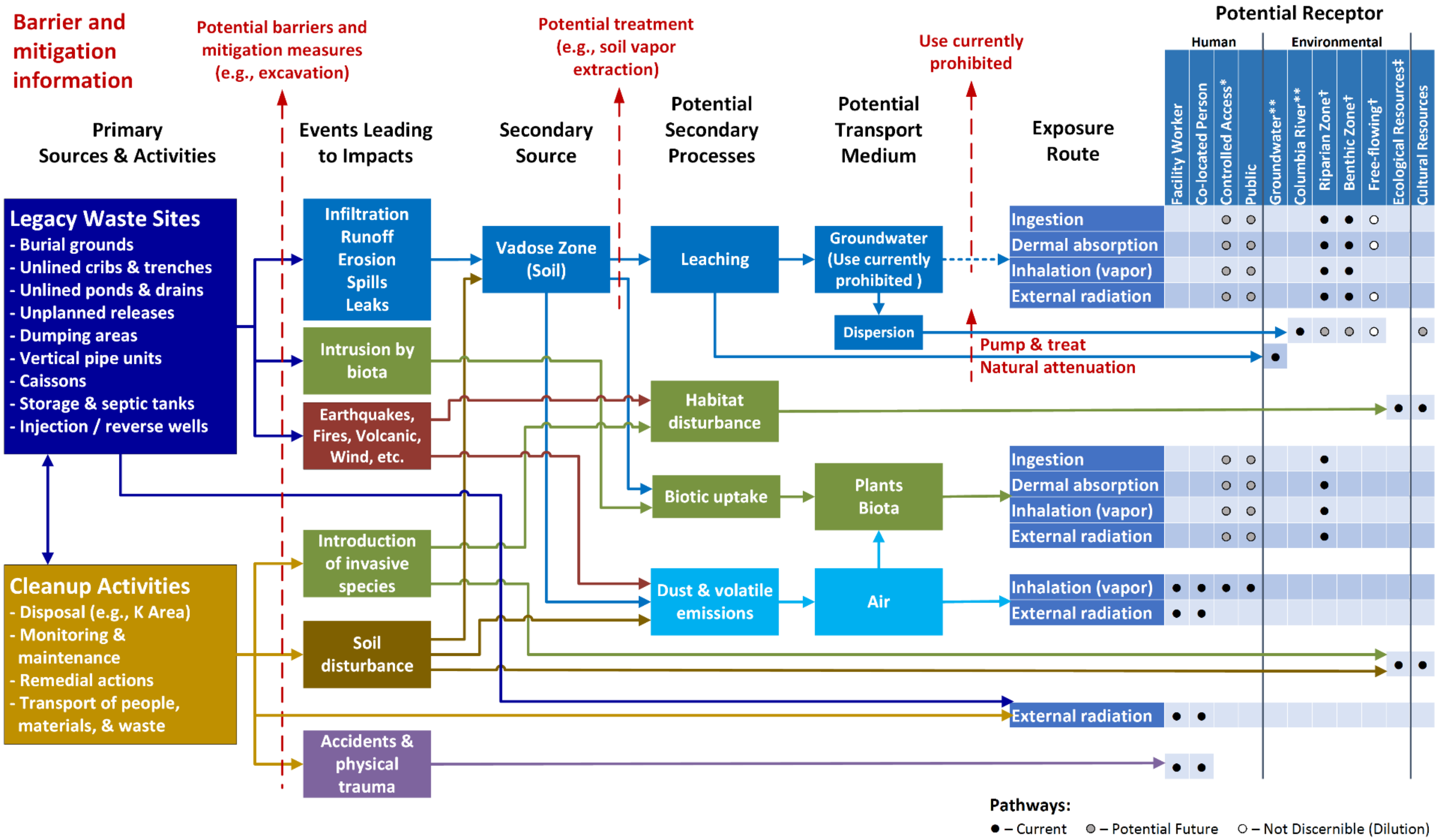
Risks to Cultural Resources – from physical disruption, destruction, exposure, impaired access or precluded access resulting from contaminant releases or cleanup activities. Indirect impacts are also considered such as impairment of view sheds. Risks to cultural resources will be described but not rated.

There are also potential risks to economic assets as a consequence of cleanup activities, but they are limited to EUs where either the presence of contamination or cleanup activities may directly impact other DOE or non-DOE facilities. Thus, the consideration of economic assets will be constrained to 1) the intersection of specific EUs with specific facilities, and 2) a description of the general economic context of the Hanford Site.

Many EUs may have multiple sources that are aggregated to provide a clearer picture of the risks associated with a geographic area. Evaluations of risks to certain receptors then lend themselves to consideration in the context of individual EUs. These include risks to human health, impacts to groundwater, and risks to the Columbia River. In addition, some receptors require consideration from broader perspectives: 1) a site-wide perspective and 2) the potential risk or impact based on the geographic location of the EU and surrounding areas. These broadly geographically defined receptors include sensitive biota and ecosystems, cultural resources (notably indirect impacts), and economic assets.

Furthermore, cumulative risk assessments are often performed to evaluate the combined fate and effects of multiple contaminants from multiple sources through multiple exposure pathways (MacDonell et al. 2013). However, the purpose of this Review is very different than that of a baseline risk assessment or performance assessment. First, it is already assumed that there are unacceptable risks associated with contamination on the Hanford Site that must be addressed. Second, focusing on individual contaminants for EUs through each exposure pathway (e.g., groundwater) allows identification of the most urgent risks to be addressed and helps inform sequencing of remedial actions across the Hanford Site.

A convenient representation of how sources are linked to potential receptors is a conceptual site model (CSM) (ASTM 1995; Brown 2008). For an environmental system, a CSM represents (often in block form) the biological, physical, and chemical processes that determine contaminant transport from sources through environmental media to potential receptors. Examples of CSMs for each of the five EU types were developed (i.e., Figure 2-2 through Figure 2-6) to help elucidate the sources, pathways, and receptors considered in this Review. For example, legacy sources (and associated cleanup activities) are common to three of the five EU types, including the Tank Waste and Farms and Inactive Facilities (D4) EUs, and as shown in Figure 2-2, typically include sources such as burial grounds, unlined cribs and trenches, and unplanned releases, events such as infiltration leading to further contamination of the vadose zone, and other pathways leading to exposure via ingestion and other routes of both human and ecological receptors. The Groundwater EU CSM (Figure 2-5) only deals with contaminants already in the saturated zone (and potential impacts to groundwater, the Columbia River, and related receptors). The Operating Facilities EU CSM (Figure 2-4) only deals with the facilities that do not include legacy sources although many of the pathways and receptors are common amongst all EU types.



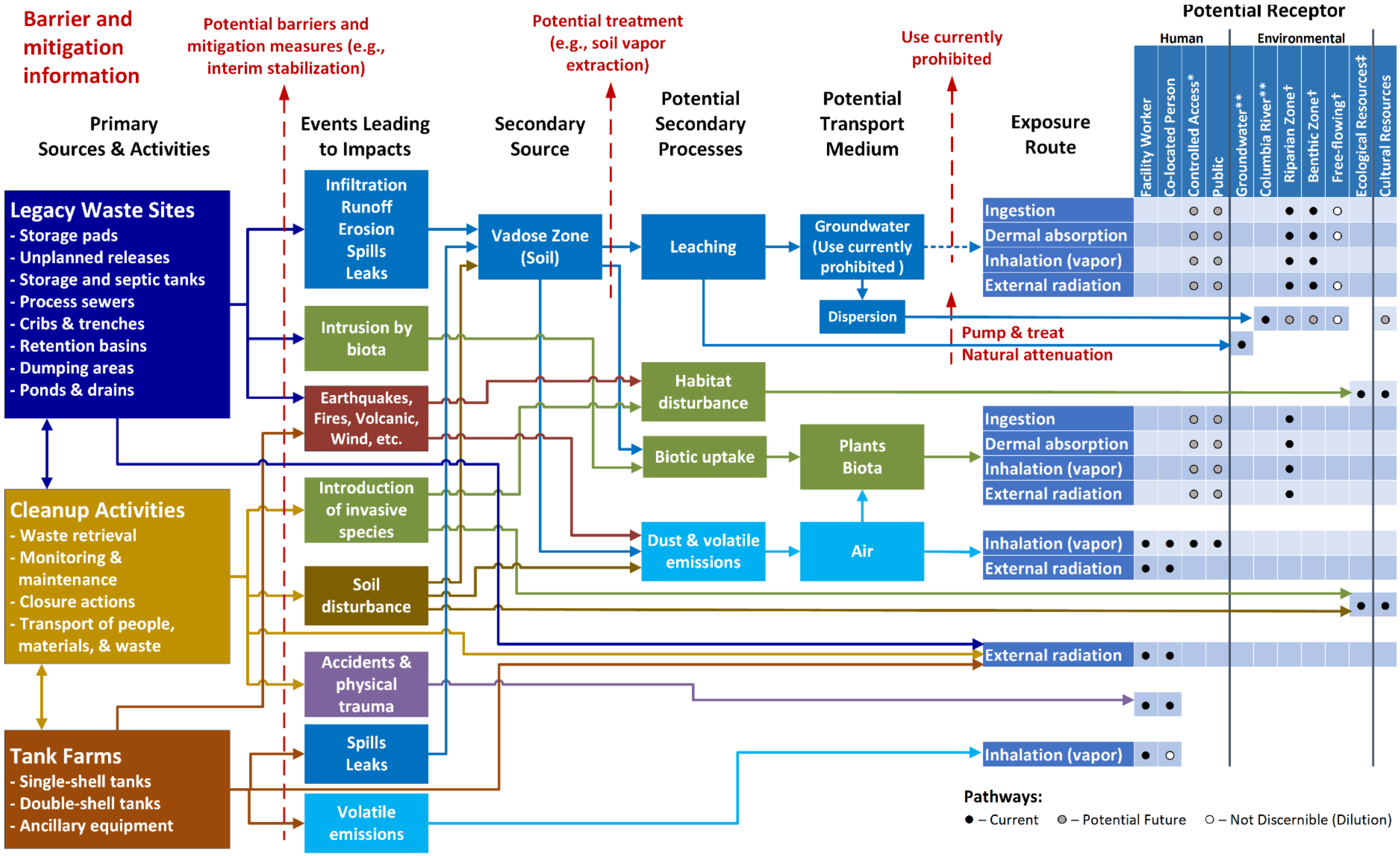
* Activities by members of Tribal Nations are considered a Controlled Access group within human health, recognizing the potential for different exposures as a result of specific cultural practices.

** These are evaluated as protected resources, independent of use.

† Threats to the Columbia River specifically include potential contaminant impacts to the ecology of the Riparian Zone, Benthic Zone, and Free-Flowing River component.

‡ Threats indicated within Ecological Resources focus on habitant disruption and potential impacts to endangered and sensitive species.

Figure 2-2. Legacy Source Evaluation Unit Conceptual Site Model.



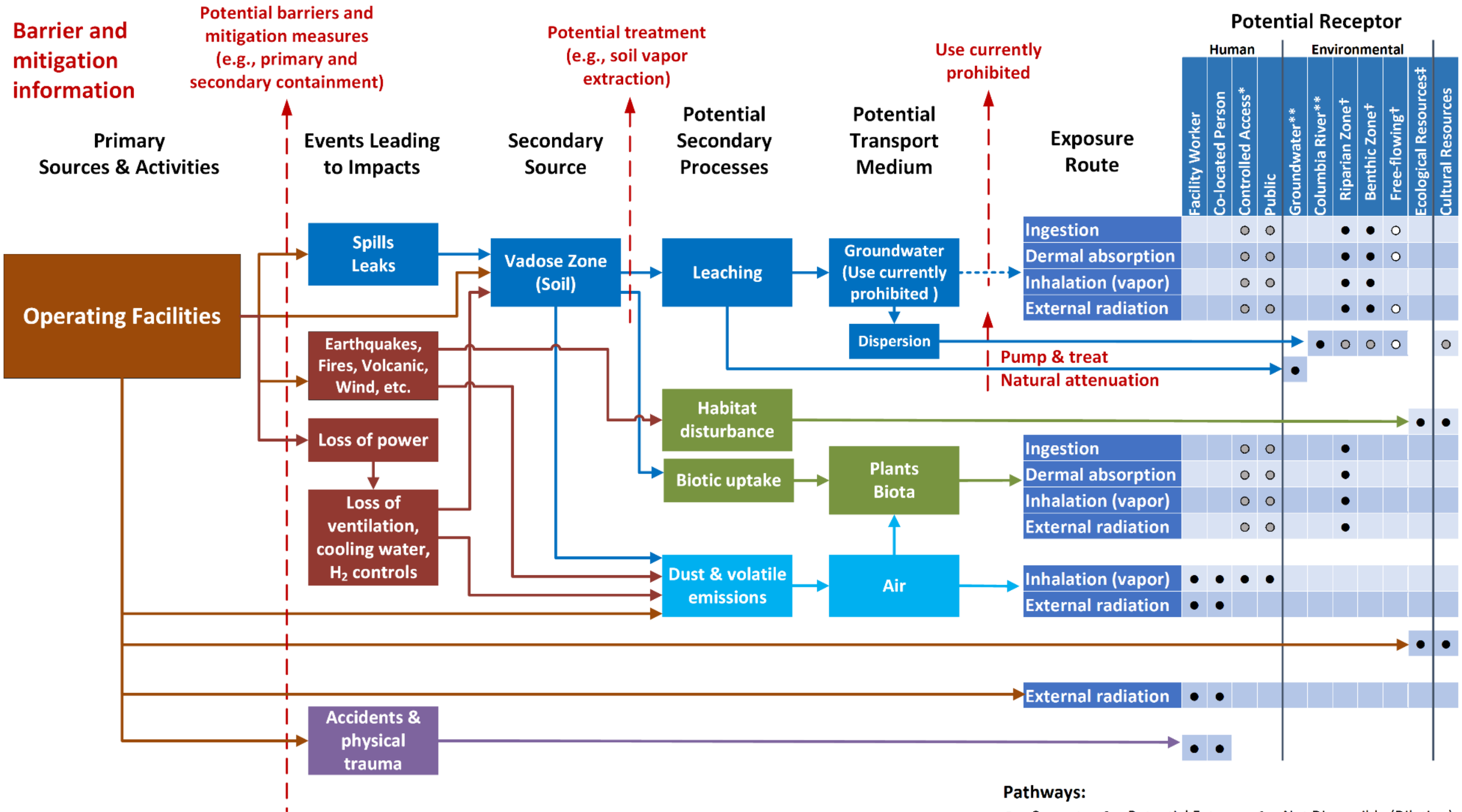
* Activities by members of Tribal Nations are considered a Controlled Access group within human health, recognizing the potential for different exposures as a result of specific cultural practices.

** These are evaluated as protected resources, independent of use.

† Threats to the Columbia River specifically include potential contaminant impacts to the ecology of the Riparian Zone, Benthic Zone, and Free-Flowing River component.

‡ Threats indicated within Ecological Resources focus on habitant disruption and potential impacts to endangered and sensitive species.

Figure 2-3. Tank Waste and Farms Evaluation Unit Conceptual Site Model.



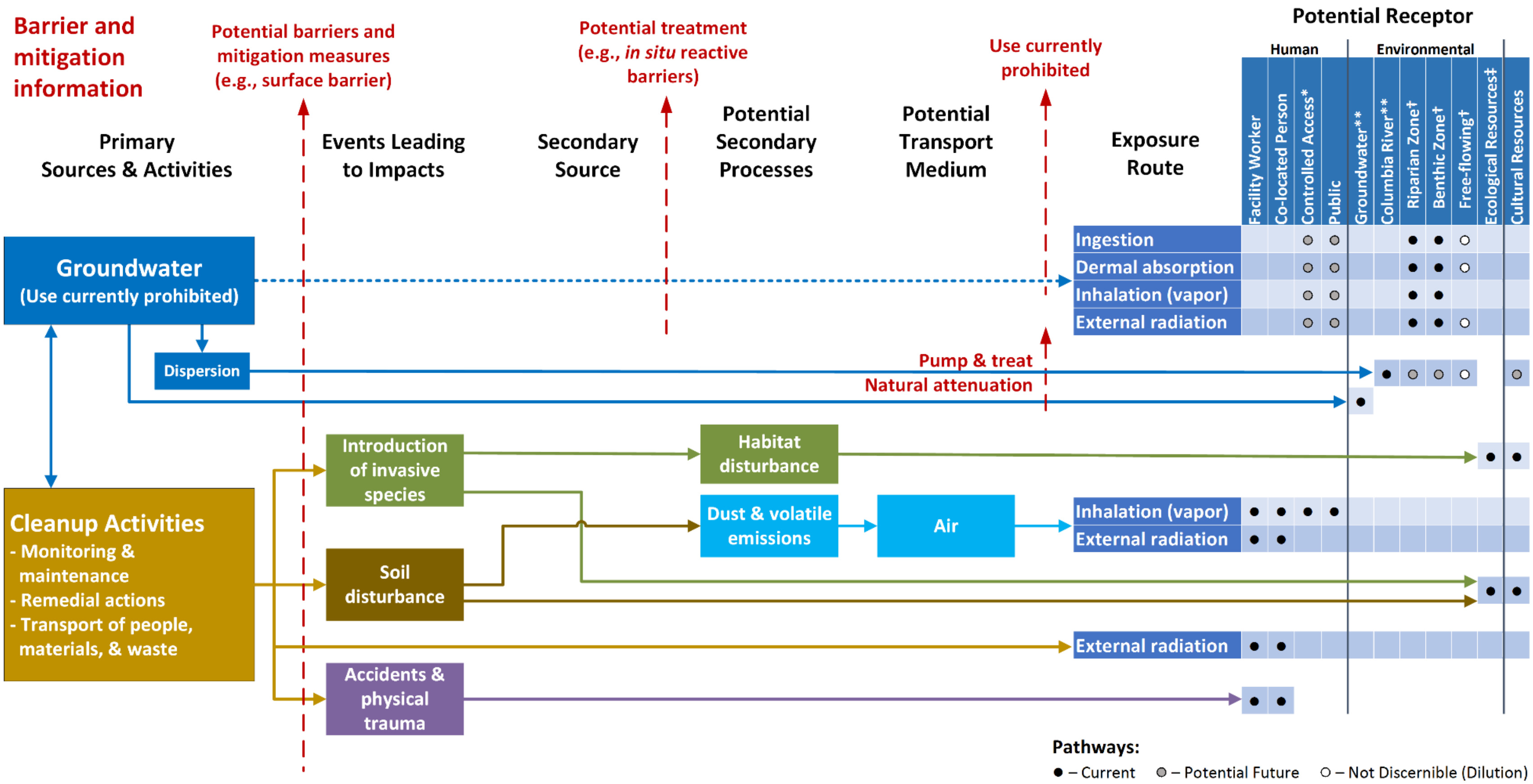
* Activities by members of Tribal Nations are considered a Controlled Access group within human health, recognizing the potential for different exposures as a result of specific cultural practices.

** These are evaluated as protected resources, independent of use.

† Threats to the Columbia River specifically include potential contaminant impacts to the ecology of the Riparian Zone, Benthic Zone, and Free-Flowing River component.

‡ Threats indicated within Ecological Resources focus on habitant disruption and potential impacts to endangered and sensitive species.

Figure 2-4. Operating Facilities Evaluation Unit Conceptual Site Model.



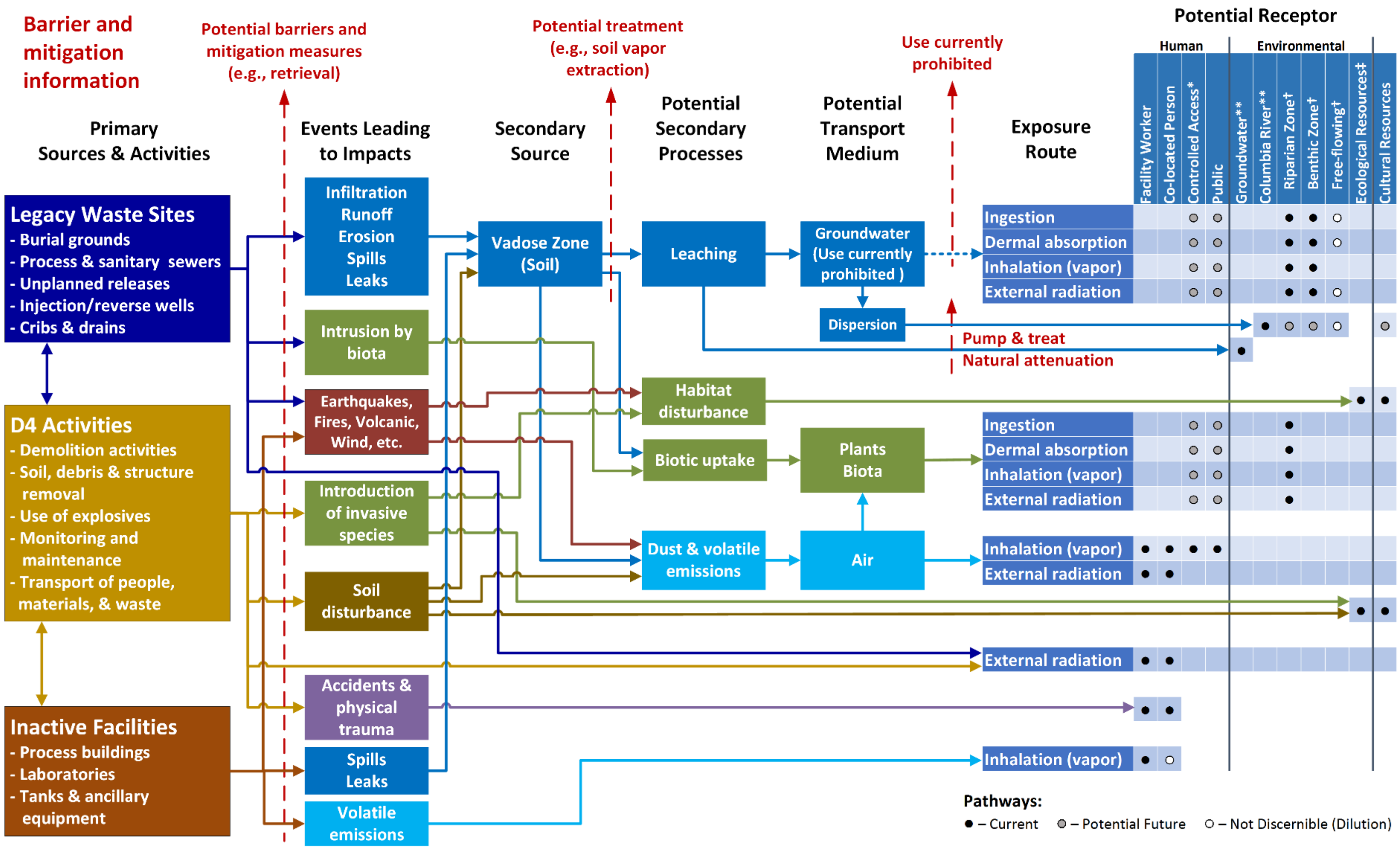
* Activities by members of Tribal Nations are considered a Controlled Access group within human health, recognizing the potential for different exposures as a result of specific cultural practices.

** These are evaluated as protected resources, independent of use.

† Threats to the Columbia River specifically include potential contaminant impacts to the ecology of the Riparian Zone, Benthic Zone, and Free-Flowing River component.

‡ Threats indicated within Ecological Resources focus on habitant disruption and potential impacts to endangered and sensitive species.

Figure 2-5. Groundwater Evaluation Unit Conceptual Site Model.



* Activities by members of Tribal Nations are considered a Controlled Access group within human health, recognizing the potential for different exposures as a result of specific cultural practices.

** These are evaluated as protected resources, independent of use.

† Threats to the Columbia River specifically include potential contaminant impacts to the ecology of the Riparian Zone, Benthic Zone, and Free-Flowing River component.

‡ Threats indicated within Ecological Resources focus on habitant disruption and potential impacts to endangered and sensitive species.

Figure 2-6. Inactive Facilities (D4) Evaluation Unit Conceptual Site Model.

2.9. LAND USE AND GROUNDWATER USE

For the Risk Review Project, it is assumed that all reasonably available land uses at the Hanford Site will have been realized when the near-term post-cleanup period begins or by 2064. This means that land use will be considered as part of the evaluation for each EU for two periods: near-term post-cleanup (until 2164) and long-term post-cleanup (until 3064). However, while future land use is an important consideration for determining the extent of cleanup, it is not a direct factor in the urgency or sequencing of cleanup activities from a risk perspective (although it may be for other factors, including community preferences). Additionally, in this Risk Review Project, the human health risks associated with land use have been separated between 1) surface (i.e., facilities, soils and waste disposal sites) and near-surface exposures associated with the land use scenario, and 2) use of groundwater. This separate consideration is important because 1) cleanup of facilities and surface and near-surface contamination is most frequently a separate effort from groundwater remediation, 2) treatment or alternate forms of water supply can be provided to facilitate desired land use when the groundwater within the unit being evaluated is not suitable, and 3) groundwater remediation timeframes may be much longer than required to achieve near-surface remediation and alternative land uses.

Direction for the Risk Review Project states, "The review should place Hanford environmental and nuclear safety hazards and risks in context with currently designated future uses of the Hanford site and nearby land uses and activities that have a potential to impact risks, natural resources and cultural resources." (Appendix A). The established federal basis for future land use at the Hanford Site is defined in the preferred land use alternative under the Comprehensive Land Use Plan EIS and record of decision (land use EIS) (DOE/EIS-0222-F 1999, DOE/EIS-0222 1999). See Figure 2-7 and Table 2-1 for more specific information on each designation. However, specific exposure scenarios that correspond with the EIS land use categories have not been developed through past Tri-Party efforts and therefore are not currently available for evaluating risks under those future land use designations.

The State of Washington currently recognizes only "unrestricted use"[25] and "industrial use" as standard land use designations with established exposure scenarios (WAC 173-340-200 2007). The EPA has recognized the following land uses as available following completion of remedial actions: any combination of unrestricted uses, restricted uses, and use for long-term waste management (OSWER Directive No. 9355.7-04, p. 2).

The Core Team has requested one other designation called "unrestricted use," which also has been referred to as "residential land use," to serve as a second basis for assessment, along with the primary designation from the land use EIS. This would apply whenever or wherever the primary future land use in the EIS is neither "unrestricted use" nor "industrial." The alternative land use designation or "unrestricted use" does not apply to EUs located within the Central Plateau.[26]

The Risk Review Project is using "unrestricted use" and "industrial use" scenarios and cleanup levels to understand the risks when land is cleaned up to a less restrictive standard but then failure of

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[25] "...has determined that residential land use is generally the site use requiring the most protective cleanup levels and that exposure to hazardous substances under residential land use conditions represents the reasonable maximum exposure scenario." [WAC 173-340-740(1)(a)]

[26] It should be noted that the T Plant Canyon Building (221-T) has been specifically identified as one of the buildings eligible to be protected under the legislation that establishes a Manhattan Project National Historical Park (see Chapter 8). The B Reactor has been identified for inclusion as well. This designation may require additional considerations with respect to cleanup requirements.

institutional controls leads to land usage consistent with a more restrictive exposure scenario (e.g., areas cleaned up to industrial land use and then used for a residential use scenario).

Results from a limited set of additional alternative land use exposure scenarios also are being used for comparison.

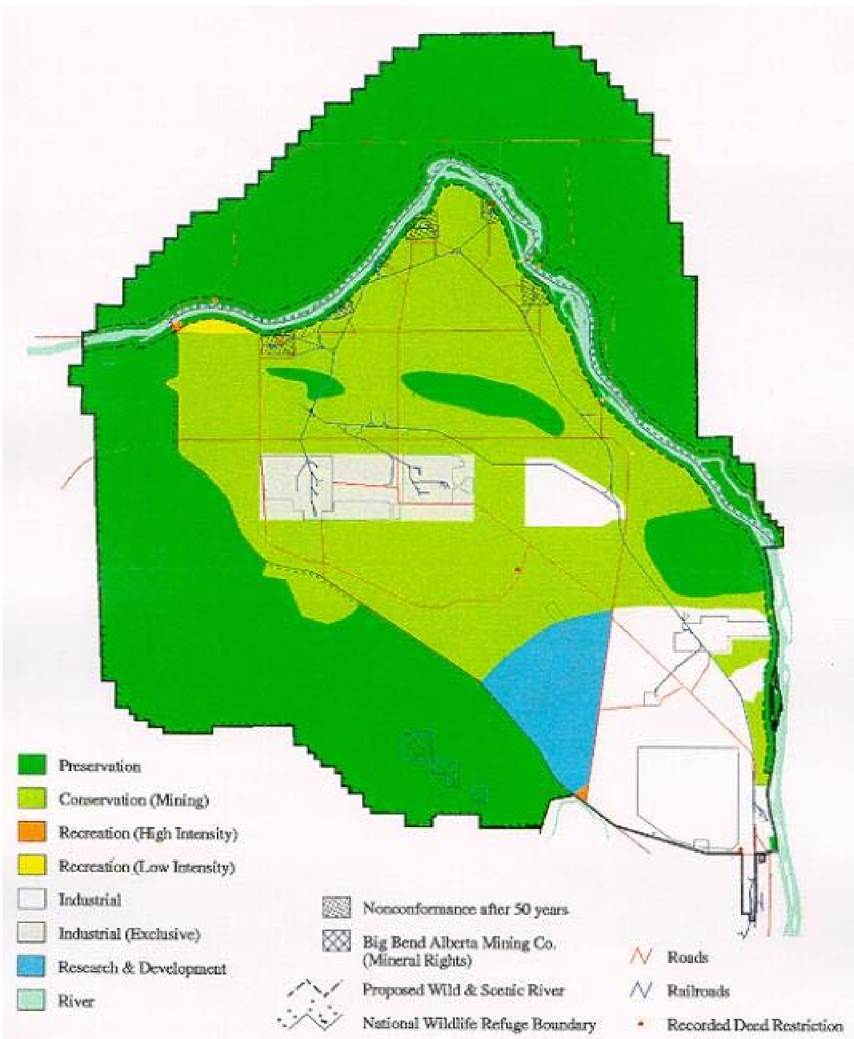

Figure 2-7. Methodology overview for the Hanford Site-Wide Risk Review Project. Future land use designations from the land use EIS (DOE/EIS-0222-F 1999, Figure 3.3).

Table 2-1. Definitions of land use designations in the EIS (DOE/EIS-0222-F 1999).

Industrial Exclusive	An area suitable and desirable for treatment, storage, and disposal of hazardous, dangerous, radioactive, and nonradioactive wastes. Includes related activities consistent with Industrial Exclusive uses.
Industrial	An area suitable and desirable for activities, such as reactor operations, rail, barge transport facilities, mining, manufacturing, food processing, assembly, warehouse, and distribution operations. Includes related activities consistent with Industrial uses.
Research and Development	An area designated for conducting basic or applied research that requires the use of a large-scale or isolated facility, or smaller scale, time-limited research conducted in the field or within facilities that consume limited resources. Includes scientific, engineering, technology development, technology transfer, and technology deployment activities to meet regional and national needs. Includes related activities consistent with Research and Development.
High-Intensity Recreation	An area allocated for high-intensity, visitor-serving activities and facilities (commercial and governmental), such as golf courses, recreational vehicle parks, boat launching facilities, Tribal fishing facilities, destination resorts, cultural centers, and museums. Includes related activities consistent with High-Intensity Recreation.
Low-Intensity Recreation	An area allocated for low-intensity, visitor-serving activities and facilities, such as improved recreational trails, primitive boat launching facilities, and permitted campgrounds. Includes related activities consistent with Low-Intensity Recreation.
Conservation (Mining)	An area reserved for the management and protection of archeological, cultural, ecological, and natural resources. Limited and managed mining (e.g., quarrying for sand, gravel, basalt, and topsoil for governmental purposes) could occur as a special use (i.e., a permit would be required) within appropriate areas. Limited public access would be consistent with resource conservation. Includes activities related to Conservation (Mining), consistent with the protection of archeological, cultural, ecological, and natural resources.
Preservation	An area managed for the preservation of archeological, cultural, ecological, and natural resources. No new consumptive uses (i.e., mining or extraction of non-renewable resources) would be allowed within this area. Limited public access would be consistent with resource preservation. Includes activities related to Preservation uses.

2.10. EVALUATION TEMPLATE

Each Evaluation Template provides a consistent, cohesive, and useful portrayal of the multiple source types within each EU considered (Appendix B). The Evaluation Template contains the following sections:

Part I – Executive Summary provides an overview of the EU and its risk evaluations.

Part II – Administrative Information allows cross-walking of EUs used in this Risk Review Project with regulatory operable units.

Part III – Summary Description includes location and layout maps, primary EU components, and land use information.

Part IV – Unit Description and History, including former and current uses, current extent of environmental contamination, ecological resources setting, and cultural resources setting.

Part V – Waste and Contamination Inventory summarizes the inventory and physical-chemical form of contaminants present.

Part VI – Potential Risk Pathways and Events provides a summary of the current conceptual model, cleanup approaches, initiating events and pathways that can result in risks to receptors over the three evaluation periods.

Part VII – Supplemental Information and Considerations may include co-location of facilities, sequencing considerations, linkages to other required facilities or unique skills, loss of facility integrity, etc.

2.11. USE OF METRICS AND ASSIGNMENT OF RISK RATINGS

A categorization system for considering the magnitude and likelihood of risks to each receptor forms the basis for assigning risk ratings to receptors for each EU, within each evaluation period. The risk rating assumes that nuclear safety hazards are assessed based on unmitigated dose estimates because the unmitigated dose integrates across the radionuclide inventory as a *relative* risk metric and acknowledges that some mitigation measures may be subject to failure. However, the Risk Review Project recognizes that typical DOE/contractor mitigation actions substantially reduce most risks, typically to Low or Not Discernible. Specific metrics for each receptor type that provide the basis for the risk ratings are identified in Chapters 5 through 8. Risks and potential impacts are categorized into five ratings: Not Discernible (ND), Low, Medium, High or Very High, where Very High is used only for exceptional cases. Further, for many receptors, the risk rating for an equivalent impact during the active cleanup period is higher than in the near-term post-cleanup period. This rating reduction is considered appropriate for most cases because additional response time would be available before preventative action would be required, and therefore addressing the risk or potential impact is less urgent. In addition, within similar types of EUs, the risk ratings are expected to differ. Risks that are rated higher, therefore, should suggest that remediation should proceed more quickly.

A final listing of the risk ratings for each receptor group, except cultural resources as discussed earlier, will be provided with the final report for the Risk Review Project. For example, a final set of tables will provide the risk ratings by receptor for all of the EUs. There is no scientifically accepted method for normalizing ratings between and among receptors. That is, high risk may mean different things for human health, ecological resources, and groundwater. The final risk ratings will include an explanation of the meaning of the risk rating designation with respect to each receptor.

Risks to receptors will not be integrated across different receptor types. The balancing and relative importance of risks to different receptors are driven by individual and collective values, which vary considerably and therefore make integration across different receptor types the domain of DOE and its regulators, with input from their constituencies. However, the Risk Review Project will provide, as part of the Final report, examples that illustrate how difficult grouping or binning that integrates the ratings across receptor categories (e.g., integrated risk binning that combines risks to human health with risks to ecology and groundwater) could be carried out.

The methodologies for evaluating risk to receptors are described in separate chapters of this document (5-8). Descriptions or characterizations of the receptors vary somewhat depending on the receptor. For example, ecological receptors are examined in terms of both species and ecosystems of value, cultural receptors include several key periods (Native American [10,000 years ago to present], pre-Hanford Era [1805-1943], and the Manhattan Project/Cold War Era [1945-1990]), and the Columbia River is described with groundwater because it is the groundwater that has the potential to discharge radionuclides and other contaminants to the river. The characterization of resources at risk forms an important basis for developing the methodology for each resource, as well as the basis for determining the risk rating.

The methodology for evaluating each receptor varies because the nature of the receptors varies (e.g., groundwater vs. facility workers). For example, worker and public include only people, while ecological receptors include thousands of species and many different kinds of ecosystems, and cultural receptors include many kinds of cultural resources (e.g., artifacts, traditional cultural places, and historic buildings). Further, the Risk Review Project recognizes that risk to any individual is important, while for ecosystems the important consideration is the population of a given species (except in the case of federally or state-listed species).

2.12. ECONOMIC ASSETS

The Hanford Site and its vicinity include a range of economic assets that may be impacted by cleanup activities at the site. DOE economic assets include the Hanford Site infrastructure. Commercial activities on the Hanford Site include the US Ecology LLW disposal facility, Energy Northwest nuclear power generation, and multiple PNNL research laboratories. Furthermore, the regional economy, which includes substantial agricultural production, may be impacted by public perceptions of cleanup activities at the Hanford Site.

The Risk Review Project will indicate when the current status, delay, or cleanup activities may have a direct impact on DOE and non-DOE economic assets.

2.13. CONTEXT WITHIN THE REGION AND OTHER LARGE REMEDIATION EFFORTS

The Hanford Site needs to be viewed in the context of the regional ecology, economy, important on-site or adjacent economic assets, and the multiple relevant sources of human health risks and impacts to resources near the Hanford Site. Examples include the Energy Northwest nuclear generating station and PNNL facilities in the Hanford 300 Area, the US Ecology waste disposal site in the 200 East Area, and discharges from non-Hanford sources to the Columbia River of contaminants found on the Hanford Site. The Risk Review Project will also seek to put the Hanford risks, potential impacts, and cleanup in context with other large cleanup efforts in the region. In addition, the Risk Review Project Final report will provide a regional context for the relationships between the Hanford Site cleanup and the regional economy.

2.14. CONSIDERATION OF UNCERTAINTY IN THE HANFORD RISK REVIEW

The Risk Review Project is not a regulatory risk assessment; however, the Project has many elements in common with regulatory risk assessment especially in terms of the uncertainties in the information used, including that from prior assessments. For example, each step in the risk assessment process incurs several types of uncertainties, and these uncertainties encumber discussions of risk and communication of risk. Uncertainty is inherent in the process even when using the most accurate data and the most sophisticated models (EPA 2005). Sources of uncertainty include 1) intrinsic variability in the processes or variables being studied or analyzed, 2) model variability (parameter estimates), 3) decision-rule variability (choices of processes or variables for inclusion and standards for comparison), and 4) residual variability due to random errors, systematic errors, and inadequate sampling or data. In some cases uncertainties can be estimated or bounded, while in other cases they are unknown. Some information is unknown, and some is unknowable, although more data points can reduce these uncertainties (EPA 2005). For the Risk Review Project, a central uncertainty results from the unevenness in terms of extent and detail, and frequently very limited or incomplete (and in some cases inconsistent), information available for individual EUs. This variability in available data is a direct result of the long time period and step-wise process being taken for cleanup of the Hanford Site. Thus, different EUs are at different stages of investigation and cleanup.

The Risk Review Project has developed a screening process to help inform sequencing of future cleanup actions at the Hanford Site; the screening process uses *existing information* to identify, characterize, and rate potential risks to the public, facility workers, co-located people, groundwater, the Columbia River, and ecological and cultural resources. Potential risks may be posed by hazards from contaminant inventories in various physical-chemical forms including existing environmental contamination, structural integrity, vulnerability to initiating events, and cleanup actions (including mitigation measures intended to offset or reduce risk associated with existing contamination and cleanup). The conditions and cleanup at the Hanford Site are highly complex, and there are often large and unknown uncertainties associated with the factors needed to understand the potential risks to receptors and efficacious cleanup. Since the Risk Review Project is using existing information to rate potential risks, the ratings are only as accurate and complete as the existing information used in the process. However, identifying key data gaps is also an important part of characterizing risk.

There is also a wide range of completeness, quality, and uncertainties associated with the information used in the Review. There are also uncertainties in the natural chemical, hydrologic, and biological systems themselves, as well as the waste characterization and distribution of current environmental contamination. The Risk Review Project has used consistent sources of information wherever possible and has selected a rough order-of-magnitude (ROM) basis for comparing risks (i.e., ratings for different receptors[27]) as a way of managing the large uncertainties and differing states of information as described below. However, there are approximately 2500 individual contaminated areas identified on the Hanford Site; it was considered prohibitive for the purpose of this Risk Review Project to attempt to

[27] For example, ratings of Not Discernible to Very High for impacts to groundwater as a protect resource *or* ecological impacts are intended to represent the same comparative ratings; however, ratings are not intended to represent the same results across impacts (e.g., a Low rating for potential impacts to groundwater as a protected resources does not have the same meaning as a Low rating for ecological impacts).

characterize and rate each individual contaminated area. The major contaminated sites are thus grouped into approximately 60 EUs composed largely of geographically co-located sites, rather than using regulatory groupings such as operable units, considering commonality among source types and the overlapping of impacts and risks to receptors. There is an inherent trade-off between grouping contaminated areas into EUs (with the concomitant loss of information, specificity, and variability due to aggregation of source information) and the ability to complete the Risk Review Project and provide sufficient information to support decision making in a timely and efficient manner. Contaminated areas are grouped in a way to minimize the loss of information and to not mask major risk factors (considering the ROM basis used for comparison). Where found necessary, evaluations are focused on a much finer gradation, including consideration of individual Operable Units for potential groundwater impacts and individual Tank Farms (and individual waste tanks and constituents) for evaluating impacts from Hanford tanks.

TANK WASTE AND FARMS

Managing the wastes in the Hanford tanks likely represents the most complex and expensive part of cleaning up the Hanford Site. The best-basis inventory (BBI) obtained from the Tank Waste Information Network System (TWINS) is used for tank waste inventories[28]. The BBI utilizes sample data, process knowledge, surveillance data, and waste stream composition information from the Hanford Defined Waste model (Agnew, et al. 1997) to estimate inventories for 25 chemical and 46 radionuclide components representing over 99% of the mass or activity in a given tank, respectively. The tank waste inventory estimates contain large uncertainties based the number and quality of the available measurements (with uncertainties due to limited samples, complex tank contents, chemical reactions and physical interactions, and impacts of the waste management process itself) and the estimation procedures used (e.g., based on samples or process knowledge used in lieu of measurements). Estimated relative standard deviations for Tc-99 and I-129 (i.e., primary threats to groundwater) in Hanford tank wastes range from 70-231% and 44-231%, respectively, and others (i.e., U-238 and Np-237) by a factor of up to five (TC&WM EIS, Appendix D, p. D-12). Uncertainties for all constituents tend to be larger tank-to-tank than totals and when using process-based rather than sample-based estimates. Thus a ROM basis for comparison of ratings developed from tank waste inventory information is appropriate[29].

The information regarding the input (e.g., radioisotopes related to the separations processes) to the Hanford tank farms appears reliable; however, the current locations of the primary tank waste contaminants result from various tank transfers, as well as intentional and unintentional discharges to the environment over the several decades and are highly uncertain. This uncertainty is compounded by the highly complex nature of the Hanford subsurface and increases dramatically for projections of contaminant spatial distributions in the environment over many decades or longer into the future. The Soil Inventory Model (SIM) Rev. 1 (RPP-26744, Rev. 0) was used to estimate current inventories and uncertainties (Monte Carlo) for 46 radionuclides and 29 chemicals for legacy waste sites including from liquid-waste disposal sites, unplanned releases, and tank leaks from 1944 to 2001. For these data, the uncertainties (expressed as percent relative standard deviations, which is the percent standard

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[28] Best Basis Inventory (BBI) Summary (March 24, 2014) provided in spreadsheet form by Mark Triplett. The current version of the BBI is stored online and can be accessed using the Tank Waste Information Network System (TWINS) at: https://twinsweb.labworks.org/ (July 2015).

[29] From a personal communication from D. Bernhard (Nez Perce Tribe), there may be additional uncertainties based on the version of the Hanford Defined Waste (HDW) used; however, these additional uncertainties do not obviate the ROM basis used in this Review.

deviation of the distribution divided by the mean) range up to 300% for all constituents and up to 160% for those with significant vadose zone inventories. Thus the ROM basis for comparing ratings developed from the SIM inventories again appears to be reasonable.

HUMAN HEALTH

For human health risks to workers and the public, the primary bases for evaluating human health risks include documented safety analyses and hazard analyses that provide detailed evaluations of external and operational initiating events and scenarios that can result in risks to human health from existing hazards. The Risk Review Project is not performing an independent risk assessment as input to remedial action selection, but rather an order-of-magnitude rating or binning of potential risks to human health based on hazards, accident or exposure scenarios, and consequences to different categories of people who may be present on or adjacent to the Hanford Site. This order of magnitude basis for binning, rating, and comparing potential impacts and risks to not only human but other receptors (as described above) allows identification of the most urgent risks to be addressed and helps inform sequencing of remedial actions across the Hanford Site.

GROUNDWATER

Past legacy sites are the primary sources of existing groundwater contamination at the Hanford Site. Inventories for groundwater contamination were estimated using the process outlined in the Interim Remedial Action Record of Decision for the Hanford 200-UP-1 Operable Unit (EPA 2012) and demonstrated in Chapter 6 of this Report. Groundwater plumes are primarily defined using well data where newly installed wells are sampled quarterly for the first year, semi-annually the second year, and annually after that. If trends appear, sampling frequencies are adjusted accordingly. Differences in sampling frequencies and locations (relative to contamination) likely create uncertainties in data and may underestimate concentrations and potential risk. To attempt to bound the inventories, well data and applicable aquifer tube[30] data for CY 2013 were downloaded from PHOENIX (http://phoenix.pnnl.gov/). The downloaded data were used to estimate the 95% upper confidence interval (UCL) about the log-transformed means[31] and corresponding inventories as described in Appendix G for the five groundwater EUs.

The groundwater plume and the SIM vadose zone source inventories are used to estimate (by difference) remaining vadose zone inventories to help evaluate threats to groundwater as a protected resource. These estimates carry very large uncertainties, especially because the depth of the plume is unknown for most of the plumes[32]. Note that only three of the 26 remaining vadose zone inventory estimates (both radionuclides and chemicals) were negative indicating that the method was not

[30] Aquifer tubes are small-diameter, flexible tubes that are screened on one end that have been installed in the aquifer along the Columbia River shoreline from just upstream of the 100-B/C Area to downstream at the 300 Area. Water is withdrawn from the tube using a peristaltic pump. Most aquifer tube sites include two or three individual tubes monitoring groundwater along the shoreline at depths ranging from ~1 to 8 meters.

[31] The method in the Interim Remedial Action Record of Decision for the Hanford 200-UP-1 Operable Unit used the 90th-percentile on the individual measurements (EPA 2012), and EPA Superfund Guidance recommends using the 95% UCL on the arithmetic mean (OSWER 9285.6-10) for estimating exposure point concentrations (EPCs). However, since many of the measurement distributions had arithmetic means proximate to the origin (in terms of relative standard deviations), the 95% UPC on the log-transformed data appeared to be a more reasonable basis for the EPC for this Review.

[32] For those areas where plume depths are not known, either the depths provided in the Interim ROD for the 200-UP-1 Operable Unit (EPA 2012) or the unconfined aquifer thickness in the area is used, which likely results in much larger uncertainties than associated with the estimates for the 200-UP-1 OU contaminants (EPA 2012).

unreasonable despite the large uncertainties involved. Furthermore, the primary bases for ascribing risks to contamination is the use of established thresholds (primarily drinking water standards for human health and Biota Concentration Guide (radionuclides) or Ambient Water Quality Criteria (chemicals) for ecological receptors). Despite large uncertainties in plume and remaining vadose zone inventory estimates and the thresholds used (EPA/540/1-89/002; Cook 2003), the use of a common method, data sources and set of thresholds provides a consistent and reasonable basis for comparing potential threats to groundwater in the form of relative risk ratings within receptor categories.

ECOLOGICAL RESOURCES

Ecological Resources (i.e., the living component of the ecosystem) as functions of exposure to contamination, ecological accessibility, remedial actions, and temporal and spatial scales were evaluated to provide an overview of resources on site and in-depth information about the level of resources that are at risk in specific EUs. Species and ecosystems are dynamic, leading to difficulties and corresponding uncertainty in assessing vulnerabilities. The uncertainties inherent in ecological data are of two types: those as a result of data collection or timing (e.g. birds and other vertebrates are not present at all times of the year for evaluation), and those related to variability in the biological system. Nearly all ecological parameters vary, and while the variability can be quantified, it still can be greater than predicted. Uncertainties increase when two or more variable ecological processes are considered together (e.g. percent of pairs breeding in a given year and clutch size for birds). Further, ecosystems change with time, perturbations, and climate factors, making assessments less reliable as a function of the time since assessment. Unlike other parts of the Risk Review Project, it was found necessary to acquire new field data on resource level values for the EUs evaluated and surrounding buffer areas to complement previous studies and to help reduce uncertainties. Furthermore, risk ratings are defined based on the degree of physical disruption and exposure from remedial activities. The combination of additional field data and ecological risk ratings has provided a reliable methodology for evaluating and comparing risks to ecological resources.

CULTURAL RESOURCES

The Risk Review does not include an overall risk or impact rating or binning for Cultural Resources because 1) risks to these resources cannot be characterized in the same way as for other risks (e.g., to groundwater) and 2) federal law requires that a cultural resources review be completed before any project activity may begin (16 U.S.C. 470 et seq.; 36 CFR Part 800 [2004]). A similar mandate is not imposed for other receptors being evaluated. While not rated, cultural resources are evaluated primarily by relying on surveys and other information gathered from these cultural resources reviews. Data on what is known about the presence of cultural resources within any EU can vary greatly depending on the number of projects that have occurred at the EU, which would have triggered a cultural resources review. Additionally, subsurface surveys are not conducted at Hanford Site, so in any given EU, cultural resources may be present but their location is not known because they are below the ground surface. The purpose of the cultural resources evaluations for this Risk Review Project is to provide guidance to DOE and regulatory agencies as remediation alternatives are considered.

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PART 2. CONTAMINATION SOURCES

CHAPTER 3. METHODOLOGY FOR GROUPING CONTAMINANT SOURCES FOR EVALUATION

ABSTRACT

The risk and impact methodology developed for the Risk Review Project is applied to groups of Hanford cleanup sites defined as "evaluation units". The cleanup sites under consideration include solid and liquid waste sites, surplus facilities and infrastructure, and various operating facilities, including treatment, storage, and disposal (TSD) facilities. The focus of the Risk Review Project is on cleanup sites remaining to be addressed as of October 1, 2015, and does not include sites that have already been cleaned up. A primary goal of the grouping methodology is to assemble EUs that not only illuminate distinctions between the various EUs, but also provide insight into the contributions to risks and impacts from discrete sources within a single EU.

EUs are composed of geographically co-located sites to the extent possible, with additional consideration given to commonality amongst the types of sources and the potential for geographically overlapping impacts and risks to receptors (ecological resources, groundwater, etc.). Such a construct will allow for the grouping of sites that have had common waste management operational practices and similar contaminant sources. A total of approximately 60 EUs have been defined for this effort and binned into categories of 1) legacy waste; 2) D4; 3) tank waste and farms, including co-located legacy contamination sources; 4) groundwater plumes; and 5) operating facilities.

3.1. OBJECTIVE

In order to perform a comprehensive, meaningful, and efficient risk review, it is necessary to group the various "to-go" cleanup sites (i.e., solid and liquid waste sites, surplus facilities and infrastructure, and various operating facilities, including TSD facilities) into a manageable collection of evaluation units. The term "evaluation units" is used to describe these groupings. The risk and impact methodology developed for this effort is then applied (as appropriate) to each resulting EU (Chapter 2). A primary goal of the grouping methodology is to assemble EUs that not only illuminate distinctions between the various EUs, but also provide insight into the contributions to risks and impacts from discrete sources within a single EU.

3.2. GROUPING CONSTRUCT

A sound organizing construct is needed to describe the human health risks and impacts to resources, under current conditions, during active cleanup operations and during various post-cleanup evaluation periods. Historically, waste disposal has been geographically located near the associated major operation facilities (e.g., the 100 B and C Reactors; T Plant). Waste disposal was generally segregated by media and waste stream; for example, high-level liquid waste associated with T Plant went to underground storage tanks (e.g., 241-T tank farm), intermediate-activity liquid wastes went to underground infiltration facilities (collectively termed cribs, e.g., 216-T-5 and -6 cribs), low-activity liquid wastes went to ditches and ponds (e.g., 216-T-4 Pond), and solid waste went to landfills (termed burial grounds, e.g., 218-W-3A). EUs are composed of geographically co-located sites to the extent possible, with additional consideration given to commonality amongst the types of sources and the potential for geographically overlapping impacts and risks to receptors (ecological resources, groundwater, etc.).

Such a construct allows for the grouping of sites that have had common waste management operational practices and similar contaminant sources. For example, geographically co-located sources (such as a tank farm, proximate and underlying legacy sources, contaminated soils, vadose zone and groundwater) that may have overlapping impacts to groundwater may be grouped into a single EU. This also allows for the integration and the evaluation of possible interactions of contaminant sources as various initiating events, contaminant exposure pathways, and common receptors are considered as part of this risk review. In addition, close geographic proximity likely is an important consideration in the selection and timing of potential remedial and closure actions, since physical cleanup actions at one site could impact adjacent sites. As EUs are identified and described, a crosswalk to the existing regulatory basis (operable units [OUs], TSD designation, etc.) also is provided.

Sources, or cleanup elements, that form the EUs are grouped into the following major categories: legacy source units, groundwater plumes, tank waste and farms, operating facilities, and D4 of inactive facilities. For the Interim progress report, 25 EUs across each of these categories have been assembled. Table 3-1 which can be found at the end of the chapter, lists the EUs identified for the Interim Progress Report.

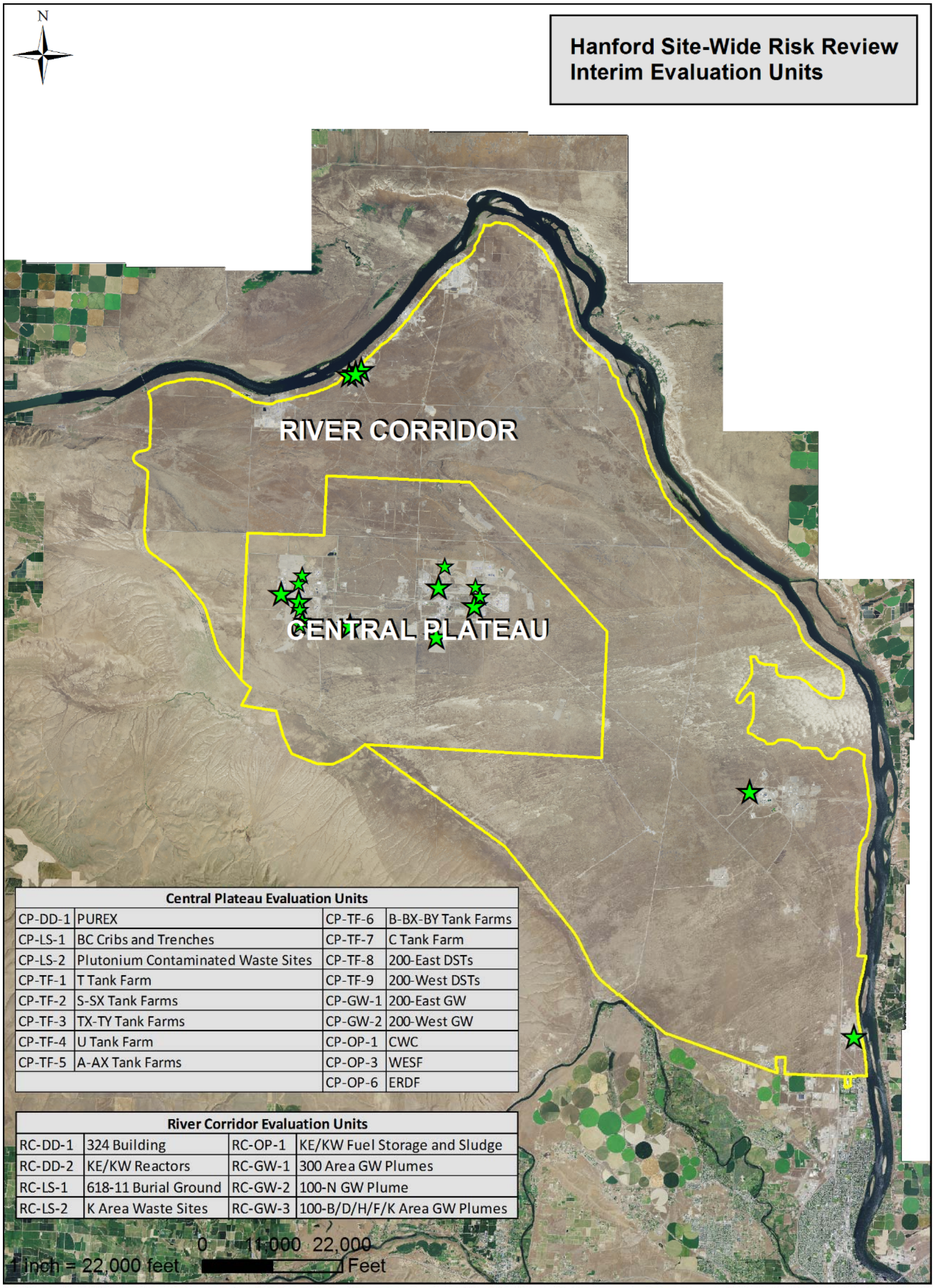

Figure 3-1. Overall Hanford Site map with EUs listed for the Interim Progress Report (groundwater EUs not shown).

3.3. LEGACY SOURCE SITES

Legacy source sites include all past practice liquid waste disposal sites (e.g., cribs, ponds, and ditches), buried solid waste sites (including retrievably stored transuranic [TRU] waste sites), unplanned releases, and associated underground piping and infrastructure. This also includes associated near-surface and vadose zone contaminated sediments associated with these sites. The evaluation of these sites includes, to the extent that information is available and clearly identifies uncertainties, a summary of the amount and physical-chemical-radiological nature of contamination and all relevant pathways (including the potential to impact groundwater resources) using a conceptual site model for the combined inventories within the EU. In evaluating potential impact to groundwater, important distinctions are whether the EU is currently releasing contaminants (and the type and nature of the contaminants) to the groundwater, has a potential to impact groundwater in the future (and when), and is likely to contribute to new or expanded areas of groundwater impact. Risks to human health and impacts to ecological and cultural resources from the EUs during maintenance and cleanup operations are a function of the ongoing operations, range of potential remedies, potential initiating events, and pathways to receptors (direct exposure, atmospheric dispersion, physical disruption, etc.).

3.4. TANK WASTE AND FARMS

The tank waste and farms units include all underground single-shell and double-shell high-level waste tanks and associated infrastructure. The tank EUs also include related and co-located legacy waste sites (such as cribs, trenches, and unplanned releases) as well as any near-surface and vadose zone contaminated sediments associated with these sites. Similar to the legacy source units, the evaluation of these sites includes, to the extent that information is available and clearly identifies uncertainties, a summary of the amount and physical-chemical-radiological nature of contamination and all relevant pathways (including the potential to impact groundwater resources) using a conceptual site model for the combined inventories within the EU. In evaluating potential impact to groundwater, important distinctions are made regarding whether the EU is currently releasing contaminants (and the type and nature of the contaminants) to the groundwater, has a potential to impact groundwater in the future (and when), and is likely to contribute to new or expanded areas of groundwater impact. Risks to human health and impacts to ecological and cultural resources from the EUs during maintenance and cleanup operations are a function of the ongoing operations, range of potential remedies, potential initiating events and pathways to receptors (direct exposure, atmospheric dispersion, physical disruption, etc.).

3.5. GROUNDWATER PLUMES

Groundwater plume EUs are based on areas of the site where there are existing groundwater plumes (with one or more contaminants above maximum contaminant levels). In many of these cases, interim or final remedial actions are underway. A description of the nature and extent of contamination, ongoing and potentially contributing contamination sources (e.g., Are plumes growing or likely to grow?), and current remedial actions underway provides the foundational information for the risk review. The description and risk evaluation for potential contributing sources are included as part of other EUs (legacy sources, tank waste and farms, etc.) and are referenced in the development of the risk review for the specific groundwater plumes. These units include the operation of above ground pump and treat systems, including reinjection / hydraulic control schemes for treated water. Figure 3-2 illustrates the principal Hanford Site groundwater contamination plumes. It is envisioned that the EUs would closely align to the existing groundwater OUs.

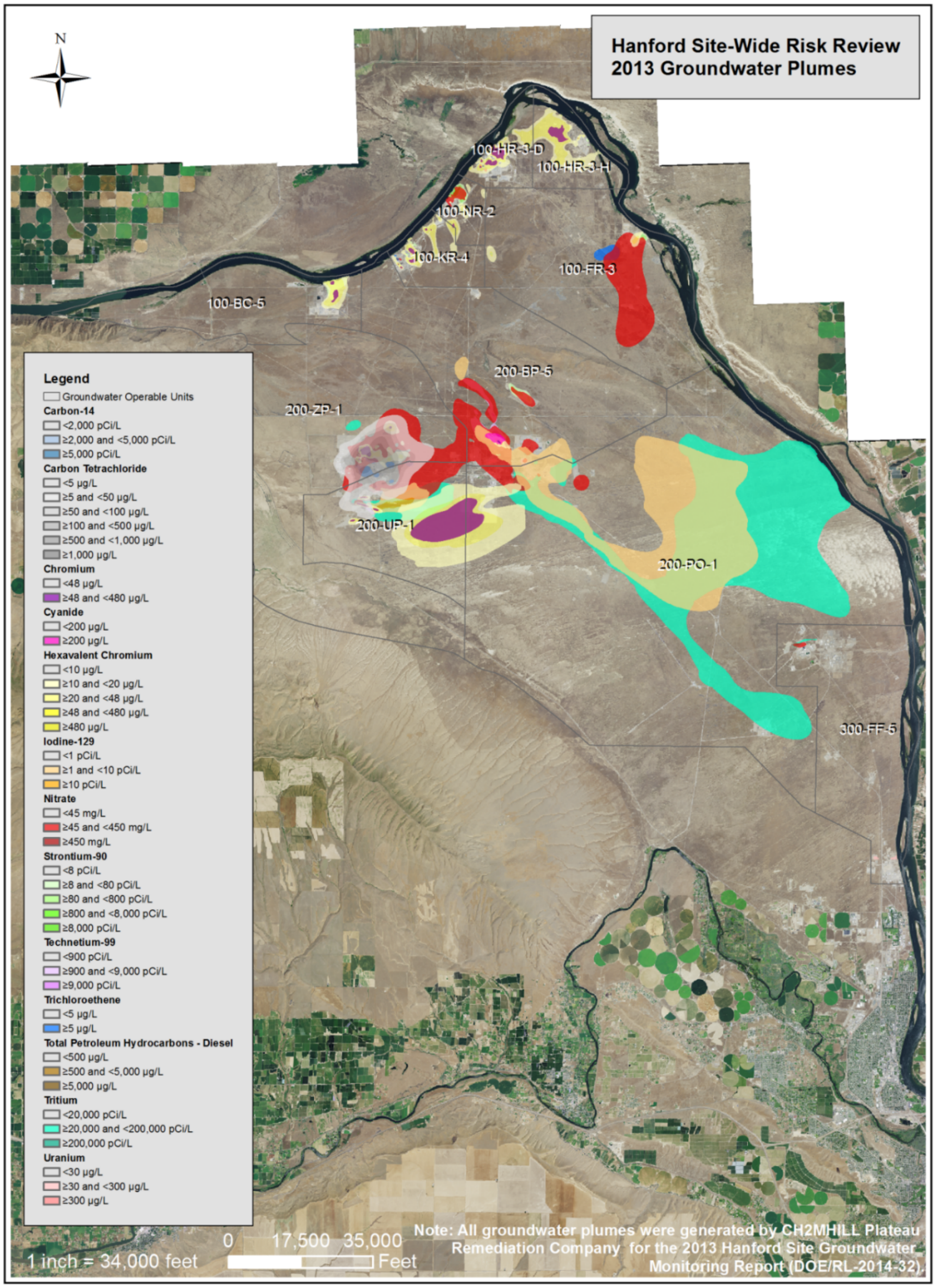

Figure 3-2. The Hanford Site groundwater plume map.

3.6. D&D OF INACTIVE FACILITIES

A set of inactive facilities EUs is assembled based on major processing complexes or facilities with a common history of operations and close geographic proximity. Examples of EUs are the Plutonium Finishing Plant (PFP) complex, 324 Building, the Fast Flux Test Facility, 100-K Basins, the reactors along the river, and the five processing canyons. T Plant is the only canyon facility at Hanford that remains in operation. The historical mission of chemical separation at the Hanford Site was terminated in the late 1980s. Currently, the mission of T Plant is to support decontamination; headspace sampling; and repackaging, remediation, and verification of containerized waste as noted below. The other four canyon facilities at Hanford—the B Plant, Reduction-Oxidation Plant (REDOX; S Plant), U Plant, and the Plutonium Uranium Extraction Plant (PUREX; A Plant)—have long been shut down. However, as also discussed below, the Waste Encapsulation and Storage Facility (WESF; adjacent to B Plant) is an operational facility used for underwater storage of strontium and cesium capsules. The current capsule storage operations and the possible move to dry cask capsule storage may be considered in the operating facility EU portion of the risk review. In addition, the specified EU includes soils contaminated as a result of facility operations or unplanned releases underneath or in the immediate vicinity of the facility (such as the 324 Building).

3.7. OPERATING FACILITIES

The operating facilities EUs are organized around three principal operating functions: 1) solid waste TSD, 2) liquid waste processing and disposal, and 3) supporting infrastructure facilities. Considerations of the operating functions, interactions of waste processing functions, and geographic proximity are used in assembling the EUs for the operating facilities. A brief description of the overall process flow for each of these functional areas is provided as context for the roles these facilities play in the cleanup efforts and to provide insight into the hazards present. In addition, a description of the off-site facilities that are important elements of Hanford Site cleanup are referenced as part of the overall cleanup context. They include such facilities as the Waste Isolation Pilot Plant (WIPP), where TRU waste is disposed; various commercial waste treatment and disposal facilities; and the yet to be established high level waste geologic repository.

SOLID WASTE TREATMENT, STORAGE, AND DISPOSAL

The Solid Waste Operations Complex (SWOC) facilities are permitted TSD units that manage LLW, mixed low-level waste (MLLW), TRU, transuranic mixed (TRUM) waste, and Toxic Substances Control Act (TSCA) polychlorinated biphenyl (PCB) waste at Hanford, as illustrated in the process flow diagram (Figure 3-3) and described as follows:

1. **Store, package, certify, and ship TRU, hazardous, and mixed wastes**. The SWOC consists of four facilities: the Central Waste Complex (CWC), two Resource Conservation and Recovery Act (RCRA) permitted disposal trenches, T Plant, and the Waste Receiving and Processing Facility (WRAP). Collectively, these four facilities enable the storage, packaging, and certification of TRU, mixed, and hazardous waste. This waste results from the retrieval of stored waste and from TRU-contaminated materials that are newly generated as a result of cleanup operations. The CWC accepts LLW/MLLW with no identifiable disposition path and the TRU and TRUM waste that has to be certified for shipment to WIPP in New Mexico throughout cleanup. Once generated, the TRU waste is stored in the CWC. In addition, LLW, MLLW, hazardous waste, and

other materials are also stored at CWC while awaiting treatment or final disposition. Trenches 31 and 34 are permitted disposal units for certain MLLW and LLW and certain types of TSCA PCB waste.

TRU waste is packaged and certified for shipment in the WRAP facility adjacent to the CWC. WRAP is a multipurpose facility for processing and treating LLW and TRU waste, including mixed and TSCA PCB waste. It can also perform nondestructive assay (NDA) and nondestructive examination (NDE) of waste containers. Some mixed waste is shipped off-site for treatment at commercial facilities and returned to the site for disposal. WRAP is being maintained in an operational status, even though it has been several years since TRU waste was sent to WIPP. The CWC and WRAP facilities, both located in the 200 West Area, will be maintained and operated until site cleanup operations are completed, at which time all inventory will be removed and the facilities closed.

T Plant Complex is currently used by SWOC for storage, repackaging, treatment, and decontamination of radioactive waste. T Plant can accept LLW and TRU waste, including mixed and TSCA PCB waste. T Plant can also perform NDA/NDE analysis, including the sampling of gases trapped inside drums of waste. Radioactive and mixed wastes are processed and packaged to meet state and federal regulations as well as criteria associated with transporting waste to certain specific waste disposal facilities. The T Plant Complex is also being evaluated for receiving, storing, and treating the radioactive sludge that has been containerized within the K-West Basin. T Plant has been identified as a potential historic site as part of the Manhattan Historic District National Park proposed legislation, and as such, for the purpose of risk review, T Plant operations will need to be partitioned from any potential D&D activities (including possible preservation as a historic landmark).

2. **Safely store used fuel and nuclear materials**. Hanford will continue to operate the Canister Storage Building (CSB) and the adjacent interim storage area for management of used fuel and nuclear materials that will eventually be moved to off-site locations. In addition, nearly 2000 cesium and strontium capsules are currently stored under water inside WESF adjoining the B Plant canyon facility. For the purpose of the risk review, the disposition of the capsules will need to be partitioned from the D&D of the B Plant canyon, yet their schedules are linked. Some of these materials are yet to be generated (e.g., immobilized high-level waste from Hanford's tanks) and to date the final disposition pathway, schedule, and location for off-site disposal is uncertain. Therefore, safe management of these materials (for interim storage and preparation for shipment) may be required for decades in new facilities similar to the CSB.
3. **Operate solid LLW and MLLW disposal facilities**. Waste disposal facilities including solid waste burial grounds (two mixed waste trenches in the 200 West Area), the Integrated Disposal Facility (IDF), and the ERDF will continue to operate and receive inventory well into the future, and will be closed when no longer needed. The ERDF receives bulk low-level radioactive, hazardous, and mixed wastes generated during environmental remediation and building demolition activities. The mixed waste trenches received containerized mixed-waste generated during various cleanup operations. The IDF is designed to hold the immobilized low-activity waste and other low-level and mixed wastes generated during the tank waste processing mission. Strictly hazardous wastes and municipal solid wastes are packaged and shipped off-site for disposal at commercial facilities.

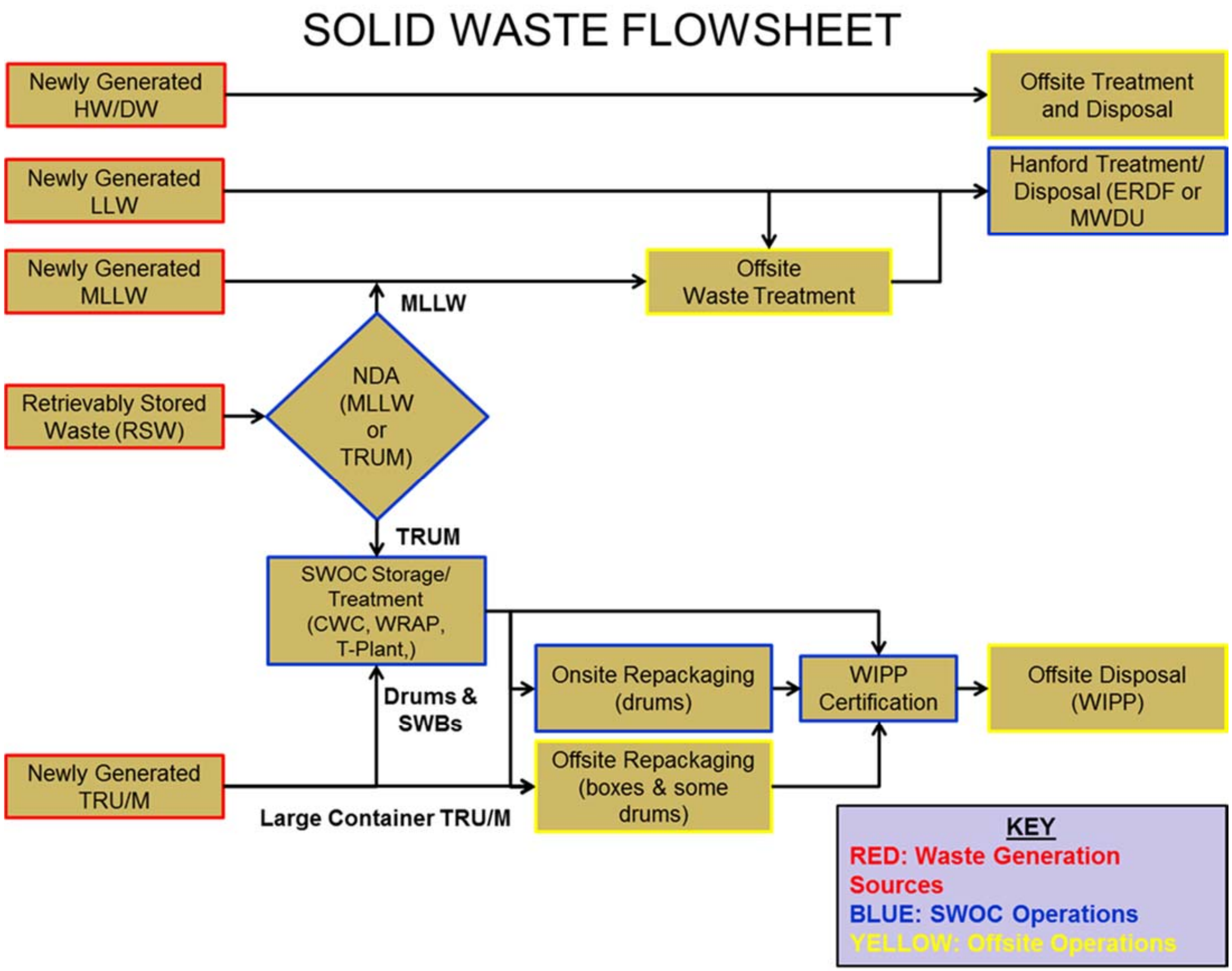

Figure 3-3. Hanford solid waste operations flow sheet.

LIQUID WASTE TREATMENT AND DISPOSAL FACILITIES

Liquid effluents are generated by numerous processes and facilities at Hanford. Treatment of these effluents is provided by the Evaporators, the Effluent Treatment Facility, and the Liquid Effluent Retention Facility. Treated effluents are discharged to the State Approved Land Disposal Site in the 200 East Area. Modifications to facilities, permits, or operational conditions may be required to support future operation of the Waste Treatment and Immobilization Plant (WTP). The tank waste treatment flow diagram (Figure 3-4) illustrates both the existing and future liquid and solid waste processing and disposal facilities associated with the tank waste cleanup mission.

The WTP consists of five facilities/complexes: 1) the Analytical Laboratory (LAB), 2) Balance of Facilities (BOF), 3) Low-Activity Waste (LAW) Vitrification Facility, 4) High-Level Waste (HLW) Vitrification Facility, and 5) Pretreatment (PT) Facility. The WTP is being designed to process the tank farm waste during a roughly 40-year period. The current design requires waste to be processed through the PT Facility, where it will be separated into a low-activity waste stream to be vitrified in the LAW Facility and a high-level waste stream to be vitrified in the HLW Facility. The LAB and BOF support these vitrification activities. In September 2013, DOE published the Hanford Tank Waste Retrieval, Treatment, and Disposition Framework, which described a phased approach designed to accomplish the following objectives (DOE, Rev. 0 2013):

- Begin immobilization of the tank waste as soon as practicable through Direct Feed to LAW (DFLAW).
- Process selected tank wastes for potential disposal at WIPP, should those wastes be reclassified as TRU and be permitted for disposal at WIPP[33].
- Resolve technical issues for the PT and HLW Facilities, including determining how to adequately mix and sample the waste prior to processing, to enable design completion, and the safe completion of construction, startup, and operations of these facilities.

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[33] There may be as many as 11 Hanford tanks (in the 241-T and 241-B Tank Farms) that contain wastes that potentially could be reclassified as contact-handled TRU (CH-TRU) waste (Tingley, et al. 2004). It has been estimated that processing these 11 tanks for disposal at WIPP could shorten WTP operation by up to 1 year and save as many as 100 canisters of HLW glass. These tanks are undergoing a classification analysis to determine whether the waste may be properly and legally classified as CH-TRU. To change the classification from HLW to TRU, DOE would have to follow the appropriate steps in DOE 435.1.

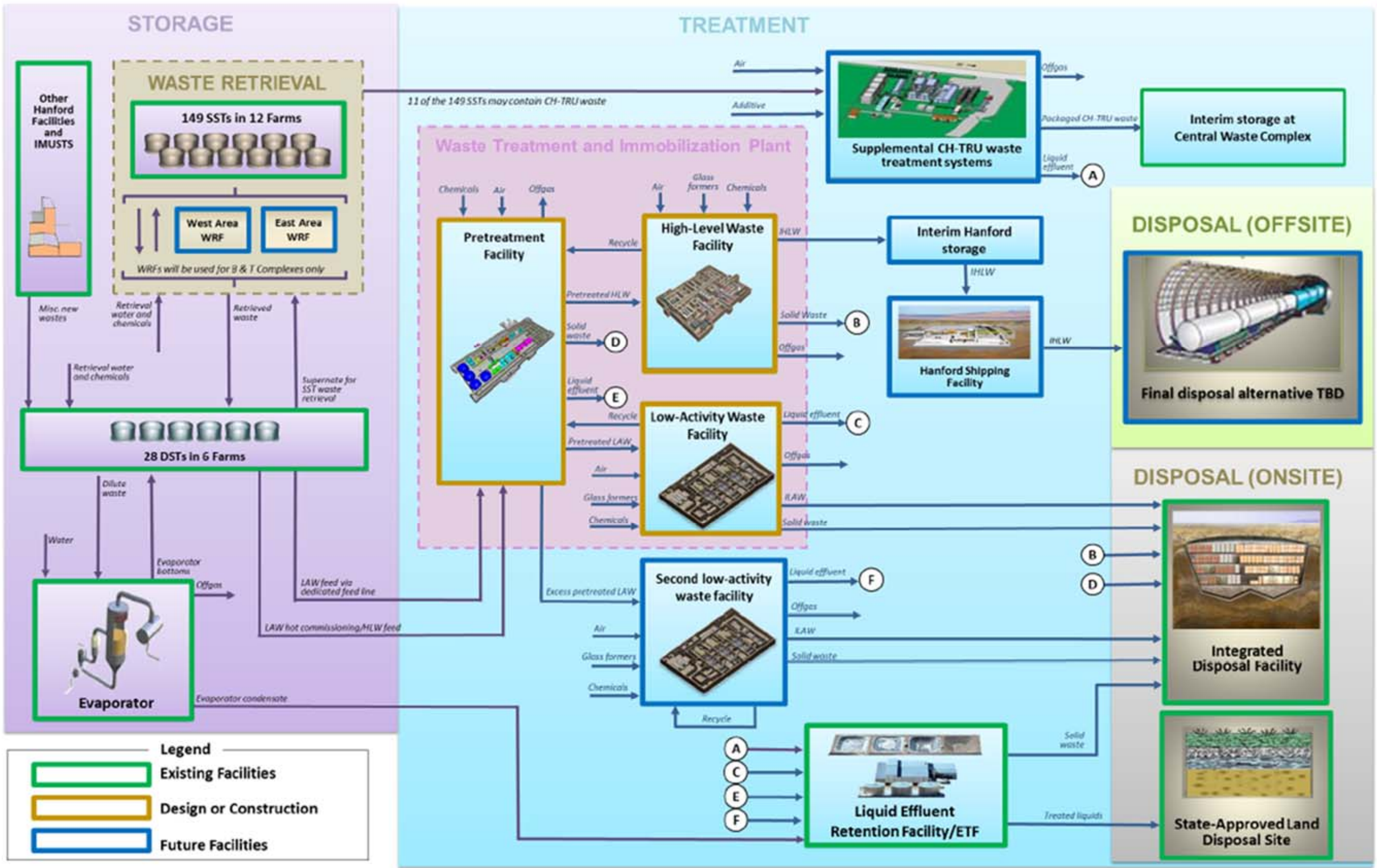


Figure 3-4. Tank waste treatment flow diagram (from ORP-11242, Rev. 6 2011).

The specific phases of the Hanford Tank Waste Retrieval, Treatment, and Disposition program (indicated in Figure 3-5) envision sequential completion and startup of the individual WTP facilities.

Phase 1 key activities include:

- Current Activities
    - Completion, commissioning, and startup of BOF and the LAB
    - Completion of the ongoing C Farm retrievals
- DFLAW Activities
    - Completion of the tank farm infrastructure and an interim pretreatment capability (for removal of cesium and miscellaneous solids) needed to directly feed the LAW Facility
    - Completion, commissioning, and startup of the LAW Facility
    - Final permitting of the on-site IDF for low-activity waste
- Contact-Handled TRU Activities
    - Retrieval and shipment of any contact-handled TRU waste from the single-shell tanks to WIPP, pending the proper and legal reclassification of the waste as CH-TRU and obtaining the necessary permits
- Direct Feed HLW (DFHLW) Activities
    - Initiation of a tank waste characterization and staging capability in the tank farms to support DFHLW
- Technical Issue Resolution
    - Completion of full-scale vessel testing and resolution of technical issues in the PT and HLW Facilities

Phase 2 key activities include:

- DFHLW Activities
    - Completion of the HLW Facility
- Completion of a tank waste characterization and staging capability
- Completion and commissioning of the Interim Hanford Storage Facility
- PT Facility
    - Continued construction of the PT Facility

Phase 3 key activities include:

- Full WTP completion
- PT Facility commissioning
- Initiation of integrated WTP operations
- Possible additional preconditioning capability for the harder-to-process waste

This phased approach—with individual but integrated paths for each of the three primary waste streams—is intended to provide optionality, flexibility, and redundancy for completing the tank waste cleanup mission.

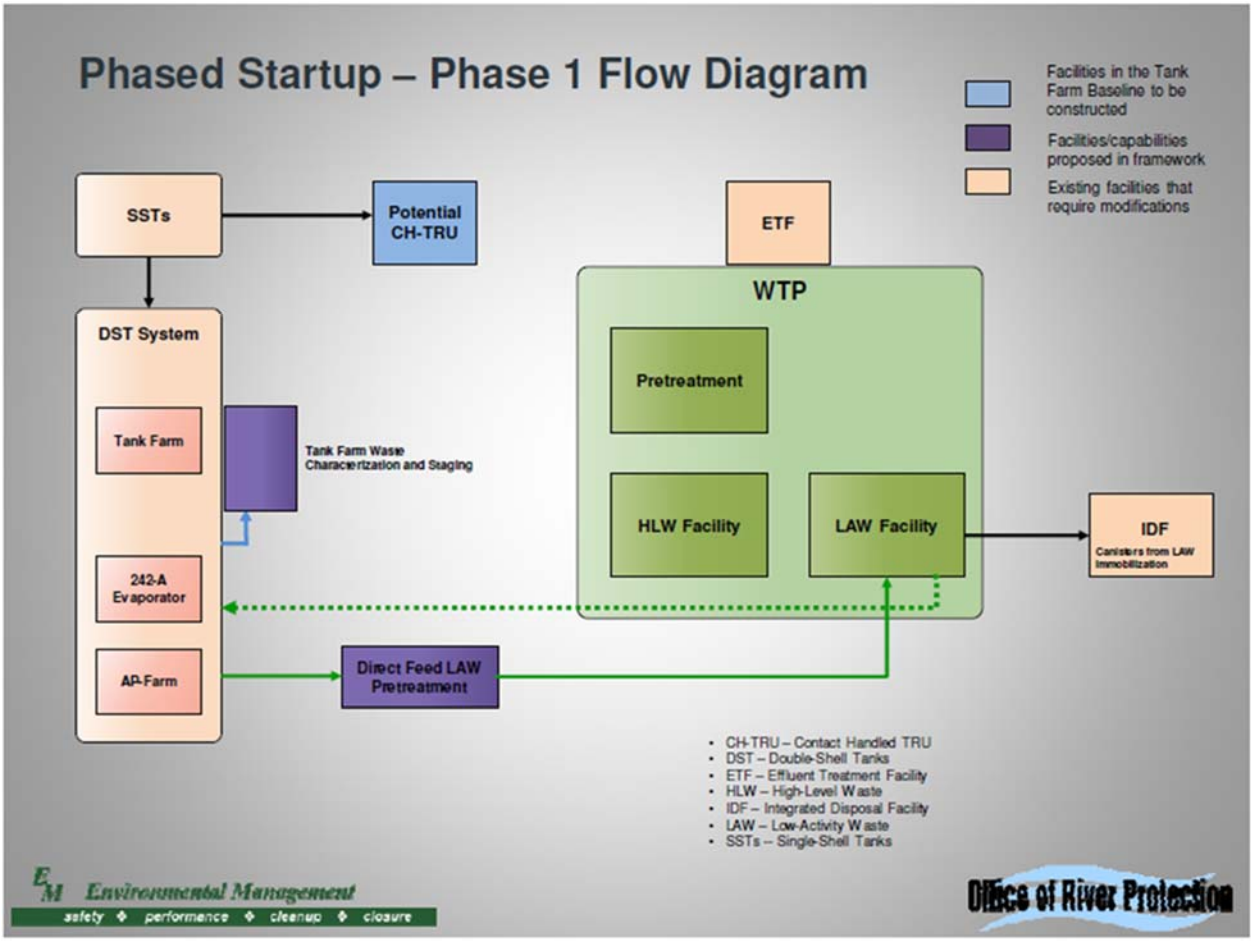


Figure 3-5. Direct-feed low-activity waste: interim pretreatment system facility flow diagram.

3.8. INFRASTRUCTURE FACILITIES SUPPORTING CLEANUP

Cleanup support facilities include analytical laboratories (such as the 222-S Laboratory and the WTP LAB); maintenance shops and equipment storage facilities; office complexes (including mobile offices); meteorology station and towers; fire houses and security complexes; training and testing facilities (such as Volpentest Hazardous Materials Management and Emergency Response Federal Training Center [HAMMER] and the Cold Test Facility); and water, energy (gas and electric), and telecommunications infrastructure. As these facilities complete their missions, some will undergo final remediation through RCRA TSD unit closure, or deactivation/decommissioning per DOE or CERCLA requirements. Some of these infrastructure support facilities likely will be needed to support the long-term stewardship mission following the completion of cleanup. For completeness, a separate discussion describing the operations and issues associated with the infrastructure will be included in the Final Report, but will not undergo the risk ranking. For those facilities (such as 222-S Laboratory) where a significant D&D effort following operations is likely, due to radiological and chemical inventories, a separate EU has been proposed.

3.9. NON-DOE-EM HANFORD SITE FACILITIES

Activities on the Hanford Site that are not part of the EM cleanup mission are not included in the Risk Review Project as EUs. Rather, they are considered in a site-wide context with the other Hanford Site sources and activities and included as potential receptors/impacted resources. These include the US Ecology commercial LLW burial ground, the Energy Northwest Columbia Generating Station, and the Laser Interferometer Gravitational Wave Observatory (LIGO). In addition, the PNNL facilities, stewarded by the DOE Office of Science, are not included as EUs. This includes the four facilities maintained by PNNL in the 300 Area (Buildings 318, 325, 331, and 350) as well as the rest of the PNNL campus located in north Richland. However, these facilities, and their associated workforces, are included as potential receptors and potential accident initiators.

3.10. PRIMARY INFORMATION SOURCES

Each EU has been described using existing information, including regulatory documents, maps, and studies. Information gathered on each EU includes the unit description and history, an inventory of waste and contamination history, and the selected or potential range of cleanup approaches.

For example, as described in Attachment 6-3, tank inventories for the nine Tank Waste and Farms EUs (including all single-shell and double-shell tanks) are taken from the March 2014 Best Basis Inventory (BBI)[34]. Inventories for ancillary equipment associated with the Tank Waste Farms and leaks[35] are taken from the Appendix D of the TC&WM EIS (DOE/EIS-0391 2012). Inventories for the legacy source sites (i.e., cribs, trenches, unplanned releases, ponds, etc.), including those waste sites associated with the Tank Waste Farm EUs, were estimated from the Soil Inventory Model Rev. 1 (RPP-26744, Rev. 0) to be consistent with the information in the TC&WM EIS. The inventories for the five groundwater (GW) EUs were based on the sample data from the 2013 Hanford Site Groundwater Monitoring Report for the individual GW Operable Units and the method described in the Interim Remedial Action Record of Decision for the Hanford 200-UP-1 Operable Unit (EPA 2012).

Other important sources of information include:

- Current and future land-use scenarios are primarily taken from the Comprehensive Land Use Plan Environmental Impact Statement (DOE/EIS-0222-F).
- Risks to human health (including facility workers, co-located persons, and the public) are typically evaluated using hazard analyses, and/or preliminary or final documented safety

[34] Best Basis Inventory (BBI) Summary (March 24, 2014) provided in spreadsheet form by Mark Triplett. The current version of the BBI is stored online and can be accessed using the Tank Waste Information Network System (TWINS) at: https://twinsweb.labworks.org/ (July 2015).

[35] The single-shell tank leak information in Appendix D of the TC&WM EIS (DOE/EIS-0391 2012) was used for this Review because it was reconciled with the other inventory information used. Updated estimates of the SST leak volumes are available (in Leak Assessments Reports) for various SST Farms (e.g., A-AX, BX-BY, C, SX, and TY) that include both increases (e.g., 70,000 to <140,000 gallons for BX-102) and decreases (e.g., 10,000-277,000 to 2,000-40,000 gallons for A-105) in leak volume estimates. Because the corresponding radionuclide and chemical inventories are needed for the Risk Review Project's evaluation and these are not provided in the Leak Assessments Reports, the leak inventory estimates from the TC&WM EIS (DOE/EIS-0391 2012) are used. The overall impacts of using the revised leak estimates on an EU basis would likely not increase ratings because these are based on a rough order of magnitude type of analysis.

analyses that provide evaluations of external and operational initiating events and scenarios that can result in risks to human health from existing hazards.

- Ecological resource evaluations are conducted using 2014 – 2015 field-collected data, in addition to an evaluation process previously developed by DOE with state regulators and other stakeholders that resulted in a ranking of ecological resources from 0 to 5 (very high; unique resources and habitats) (DOE/RL-96-32 2013).
- For evaluations of impacts to cultural resources, primary information sources are obtained and analyzed by a professional archaeologist that are from: the DOE Hanford cultural resources database; DOE Cultural and Historic Resources database and records room; and Washington State Department of Archaeology and Historic Preservation records room cultural resources and survey data. Records include, but are not limited to: GIS data and associated records, cultural resources surveys and archaeological site forms, historic maps, and PHOENIX 2012 aerial imagery.

3.11. LISTING OF EVALUTION UNITS

Table 3-1 lists the proposed EUs for this effort. The table is organized into the following major categories: legacy source units, groundwater plumes, tank waste and farms, operating facilities, and D&D. Units in the light blue rows will be part of the Interim Progress Report. The remaining EUs will be included in the final report. Following Table 3-1 are example maps (Figure 3-6 through Figure 3-9) illustrating the locations and boundaries of the EUs. Maps for each EU will be included in both the interim and final reports prepared for the Risk Review Project. Additionally, Evaluation Templates completed for each EU will include similar maps depicting the location and setting of the unit being evaluated.

Table 3-1. Listing of evaluation units.

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
			Legacy Sites		
RC-LS-1	Legacy Source	618-11 Burial Ground	618-11 Burial Ground	300-FF-2	CP-GW-1
RC-LS-2	Legacy Source	K Area Waste Sites	Legacy waste sites within the fence at 100-K, where remediation is post 2015	100-KR-1, 100-KR-2	RC-DD-2
RC-LS-3	Legacy Source	Orchard Lands	Pre-Hanford orchard lands	100-OL-1	
RC-LS-4	Legacy Source	618-10 Burial Ground	618-10 Burial Ground	300-FF-2	
CP-LS-1	Legacy Source	BC Cribs and Trenches	Cribs, trenches, and tank located to the south of the 200 E Area	200-BC-1	CP-LS-17, CP-GW-1
CP-LS-2	Legacy Source	Plutonium Contamin-ated Waste Sites	Plutonium (Pu) contaminated cribs and trenches associated with the Plutonium Finishing Plant (PFP) in central part of 200 W Area	200-PW-1,3,6 200-CW-5	CP-DD-5, CP-GW-2
CP-LS-3	Legacy Source	U Plant Cribs and Ditches	Liquid waste discharges in the central part of 200 W Area associated with U Plant operations	200-DV-1, 200-WA-1	CP-LS-7, CP-DD-3, CP-GW-2
CP-LS-4	Legacy Source	REDOX Cribs and Ditches	Liquid waste discharges in the southern part of 200 W Area associated with Reduction-Oxidation Plant (REDOX) (S Plant) operations	200-WA-1, 200-DV-1	CP-DD-4, CP-GW-2
CP-LS-5	Legacy Source	U and S Pond	Liquid waste discharges in the southern part of 200 W and outside the fence of 200 W associated with U and S ponds and closely related trenches, ditches, and cribs	200-CW-1, 200-OA-1	CP-GW-2
CP-LS-6	Legacy Source	T Plant Cribs and Ditches	Liquid waste sites on the northern end of 200 W Area (associated with T Plant operations)	200-WA-1, 200-DV-1	CP-GW-2
CP-LS-7	Legacy Source	200 Area HLW Transfer Pipeline	High-level waste (HLW) pipelines outside of tank farm EUs. Includes 200 East-West transfer lines, IMUSTS, catch tanks, diversion boxes, etc.	200-IS-1	CP-TF-1 through -9
CP-LS-8	Legacy Source	B plant Cribs and Trenches	Liquid waste sites on the west side of 200 E (associated with B Plant operations)	200-EA-1, 200-DV-1, 200-OA-1	CP-DD-2, CP-GW-1

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
CP-LS-9	Legacy Source	PUREX Cribs and Trenches (inside 200 E)	Liquid waste sites on the east side of 200 E (associated with PUREX (Plutonium Uranium Extraction Plant) operations and immediately surrounding PUREX)	200-EA-1, 200-PW-3	CP-DD-1, CP-GW-1
CP-LS-10	Legacy Source	PUREX and Tank Farm Cribs and Trenches (outside 200 E)	Liquid waste sites on the east side of 200 E (associated with PUREX and tank farm operations, but outside the 200 E Area fence)	200-EA-1	CP-GW-1
CP-LS-11	Legacy Source	B Pond	B Pond and associated ditches, where liquid wastes were discharged in the northern and western part of 200 E and outside the fence of 200 E	200-EA-1, 200-CW-1, 200-OA-1, 200-IS-1	CP-LS-7, CP-GW-1
CP-LS-12	Legacy Source	200 West Burial Grounds	Past practice radioactive waste burial grounds, including retrievable stored transuranic (TRU) trenches	200-SW-2	
CP-LS-13	Legacy Source	200 West Miscel-laneous Waste Sites	Waste sites, buildings, and structures associated with maintenance operations, laundry, and coal power plant in the west/central portion of 200 W	200-QA-1, 200-WA-1, 200-IS-1	CP-LS-7
CP-LS-14	Legacy Source	200 East Burial Grounds	Past practice radioactive waste burial grounds	200-SW-2	
CP-LS-15	Legacy Source	200-East Miscel-laneous Waste Sites	Waste sites, buildings, and structures associated with maintenance operations and coal power plant in the southern portion of 200 E	200-OA-1, 200-EA-1	
CP-LS-16	Legacy Source	Grout Vaults	Grout vaults located west of the Hanford Waste Treatment and Immobilization Plant (WTP)	NA	
CP-LS-17	Legacy Source	BC Control Zone	Surface contamination area to the south of 200 E (excluding the BC Cribs and Trenches)	200-OA-1	CP-LS-1
CP-LS-18	Legacy Source	Outer Area Sites	Outer area solid waste disposal sites (e.g., NRDWL, SWL, etc.) and other outer area waste sites, miscellaneous buildings, and structures	200-CW-1, 200-CW-3, 200-OA-1, 200-SW-1	

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
RC-LS-4	Legacy Source	618-10 Burial Ground	618-10 Burial Ground	300-FF-2	
Tank Farms					
CP-TF-1	TF	T Tank Farm	T tank farm, ancillary structures, associated liquid waste sites, and soils contamination	200-DV-1, WMA T, 200-WA-1	CP-LS-7, CP-GW-2
CP-TF-2	TF	S-SX Tank Farms	S-SX tank farms, ancillary structures, associated liquid waste sites, and soils contamination. Includes 242-S Evaporator	WMA S/SX, 200-DV-1, 200-WA-1	CP-LS-7, CP-TF-9, CP-GW-2
CP-TF-3	TF	TX-TY Tank Farms	TX-TY tank farms, ancillary structures, associated liquid waste sites, and soils contamination. Includes 242-T Evaporator	WMA TX/TY, 200-DV-1, 200-WA-1	CP-LS-7, CP-GW-2
CP-TF-4	TF	U Tank Farm	U tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA U, 200-WA-1	CP-LS-7, CP-GW-2
CP-TF-5	TF	A-AX Tank Farms	A-AX tank farms, ancillary structures, associated liquid waste sites, and soils contamination	WMA A/AX, 200-EA-1, 200-PW-3	CP-LS-7, CP-TF-8, CP-GW-1
CP-TF-6	TF	B-BX-BY Tank Farms	B-BX-BY tank farms, ancillary structures, associated liquid waste sites, and soils contamination	WMA B/BX/BY, 200-DV-1, 200-EA-1	CP-LS-7, CP-GW-1
CP-TF-7	TF	C Tank Farms	C tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA C	CP-LS-7, CP-GW-1
CP-TF-8	TF	200 East Double-Shell Tanks (DSTs)	AN, AP, AW, AY, AZ tank farms, ancillary structures, associated liquid waste sites, and soils contamination	NA	CP-LS-7, CP-TF-5
CP-TF-9	TF	200 West DSTs	SY tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA S/SX	CP-LS-7, CP-TF-2
Groundwater					
RC-GW-1	GW	300 Area Ground-water (GW) Plumes	300 Area uranium and associated contaminant plumes	300-FF-5	RC-DD-1
RC-GW-2	GW	100-N GW Plume	100-N strontium and associated contaminant plumes	100-NR-2	

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
RC-GW-3	GW	100-B/D/H/F/K Area GW Plumes	100-B/D/H/F/K Area chromium and associated contaminant plumes, includes pump and treat systems	100-BC-5, 100-KR-4, 100-HR-3, 100-FR-3	
CP-GW-1	GW	200 East Ground-water	Existing groundwater plumes emanating from 200 E Area	200-BP-5, 200-PO-1	CP-LS-1, -8, -9, -10, -11, CP-TF-5, -6, -7
CP-GW-2	GW	200 West Ground-water	Existing groundwater plumes emanating from 200 W Area, includes pump and treatment systems	200-ZP-1, 200-UP-1	CP-LS-2 through -6, CP-TF-1 through -4
Deactivation (Decontamination) and Decommissioning (D&D)					
RC-DD-1	D&D	324 Building	324 Building and associated soil contamination under the building	300-FF-2	RC-GW-1
RC-DD-2	D&D	KE/KW Reactors	KE/KW Reactors, basin, ancillary buildings, sludge, associated soil contamination	TBD, 100-KR-1, 100-KR-2	RC-LS-2, RC-GW-3
RC-DD-3	D&D	Final Reactor Disposition	C, D, DR, F, H, KE, KW, and N Reactors	TBD	
RC-DD-4	D&D	FFTF	Fast Flux Test Facility and ancillary buildings and structures	NA	
CP-DD-1	D&D	PUREX	PUREX Canyon, tunnels, ancillary buildings, structures, and associated near-surface contaminated soils	200-CP-1	CP-LS-9
CP-DD-2	D&D	B Plant	B Plant Canyon, ancillary buildings (e.g., 224-B), structures, and associated near-surface contaminated soils, includes the D&D of the Waste Encapsulation Storage Facility (WESF) after the capsules are moved into dry storage	200-CB-1	CP-LS-8
CP-DD-3	D&D	U Plant	U Plant Canyon, ancillary buildings, structures, and associated near-surface contaminated soils	200-CU-1	CP-LS-3
CP-DD-4	D&D	REDOX	REDOX Canyon (S Plant), ancillary buildings, except 222-S laboratory, structures, and associated near-surface contaminated soils	200-CR-1	CP-LS-4

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
CP-DD-5	D&D	PFP	PFP ancillary buildings, structures, and associated near-surface contaminated soils	200-WA-1	CP-LS-2
Operating Facilities					
RC-OP-1	Ops	KW Basin Sludge	KW sludge, basin, and ancillary buildings	100-KR-1, 100-KR-2	RC-DD-2, RC-LS-2
RC-OP-2	Ops	Retained Facilities	Retained Office of Science facilities including the 318, 320, 325, 331, and 350 buildings	300-FF-2	RC-GW-1
CP-OP-1	Ops	CWC	Central Waste Complex (CWC) operations, closure, and D&D	NA	
CP-OP-2	Ops	T Plant	T Plant Canyon, ancillary buildings, structures. Evaluate through operations, then will be preserved as a historical site or undergo D&D	NA	
CP-OP-3	Ops	WESF (only Cs/Sr capsules)	WESF – Evaluate for the storage and removal of Cs/Sr Capsules. D&D included with B Plant EU	NA	CP-DD-2
CP-OP-4	Ops	WRAP	Waste Repackaging and Processing (WRAP) facility operations, closure, and D&D	NA	
CP-OP-5	Ops	CSB	Canister Storage Building (CSB) operations and closure (including adjacent spent fuel dry storage pad)	NA	
CP-OP-6	Ops	ERDF	Environmental Restoration Disposal Facility (ERDF) operations and closure	NA	
CP-OP-7	Ops	IDF	Integrated Disposal Facility (IDF) operations and closure	NA	
CP-OP-8	Ops	Mixed Waste Trenches	Mixed waste trenches (Trenches 31 and 34, next to WRAP) operations and closure	200-SW-2	CP-LS-14
CP-OP-9	Ops	Naval Reactors Trench	Naval reactors disposal trench operations and closure	200-SW-2	CP-LS-14
CP-OP-10	Ops	242-A Evaporator	Operations and D&D of the 242-A Evaporator	NA	CP-TF-5
CP-OP-11	Ops	LERF	Operations and closure of the Liquid Effluent Retention Facility (LERF)	NA	
CP-OP-12	Ops	TEDF	Operations and closure of the Treated Effluent Disposal Facility (TEDF)	NA	

EU ID	Group	EU Name	Description & Comments	Operable Unit Crosswalk	Related EUs
CP-OP-13	Ops	SALDS	Operations and closure of the State Approved Land Disposal Sites (SALDS)	NA	
CP-OP-14	Ops	WTP	WTP operations and D&D. Includes new tanks (if needed), preconditioning, four major facilities, and interim storage elements	NA	
CP-OP-15	Ops	222-S Laboratory	Operations and D&D of the 222-S Laboratory	NA	
CP-OP-16	Ops	ETF	Effluent Treatment Facility	NA	CP-OP-11 CP-OP-12 CP-OP-13
CP-DD-17	Ops	WSCF	Waste Sampling and Characterization Facility and ancillary buildings and structures	200-ZP-1	CP-GW-2

Notes for River Corridor: Includes Energy Northwest, PNNL, HAMMER, and LIGO as a comparator – but not as an EU. Includes infrastructure discussion as context, but not as an EU. Source remediation and D&D (RTD) being completed in FY15 are not included.

Notes for Central Plateau: Includes U.S. Ecology as a comparator – but not an EU. Include infrastructure discussion as context, but not as an EU. T Plant is an operating facility and an historic site that is eligible for inclusion in the Manhattan Project National Historical Park Act that establishes the park at Hanford Site (S.1847, section 3039 (2014)).

Figure 3-6. Hanford Site-Wide Risk Review Project: K Area waste sites evaluation units.

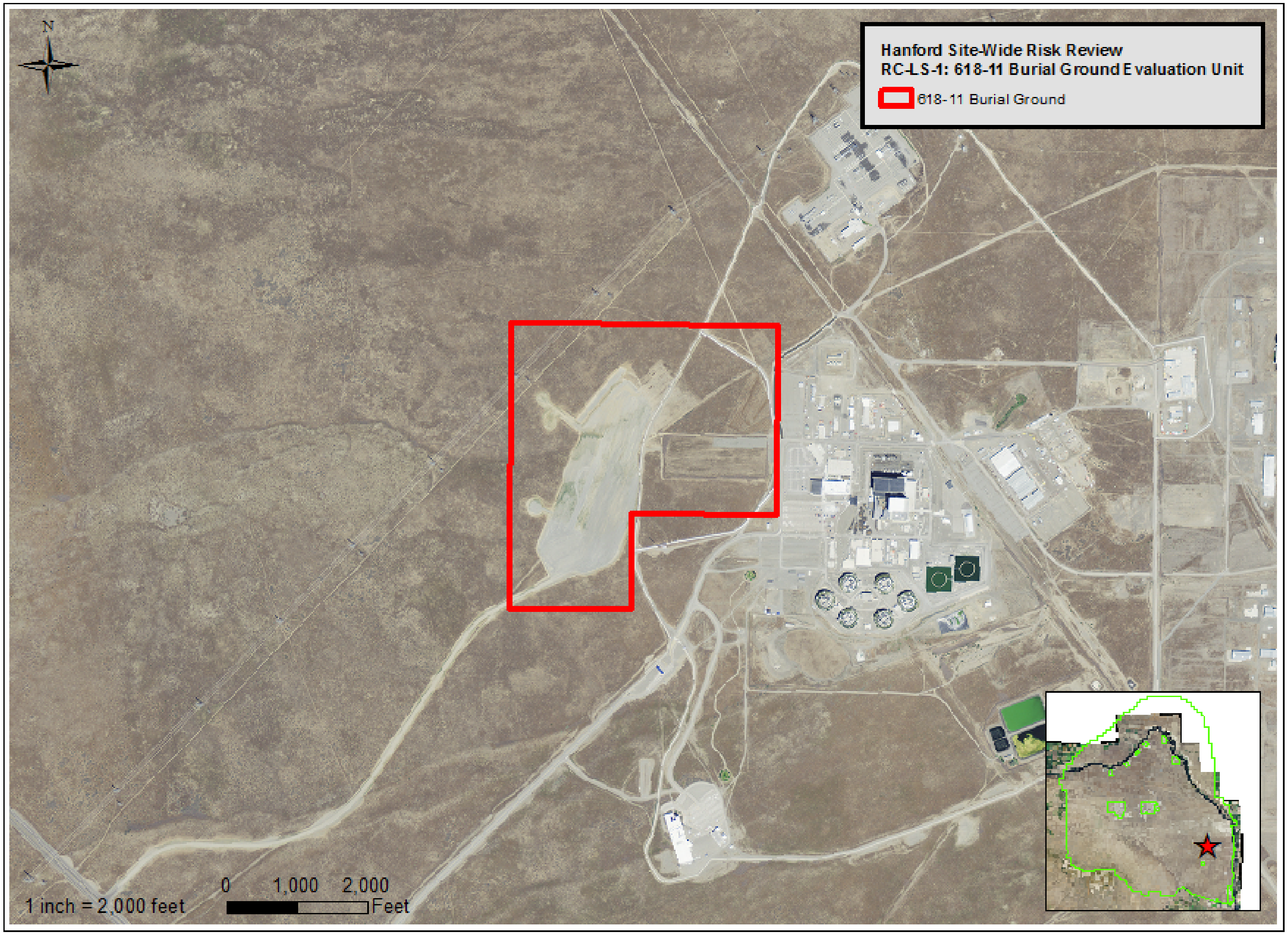
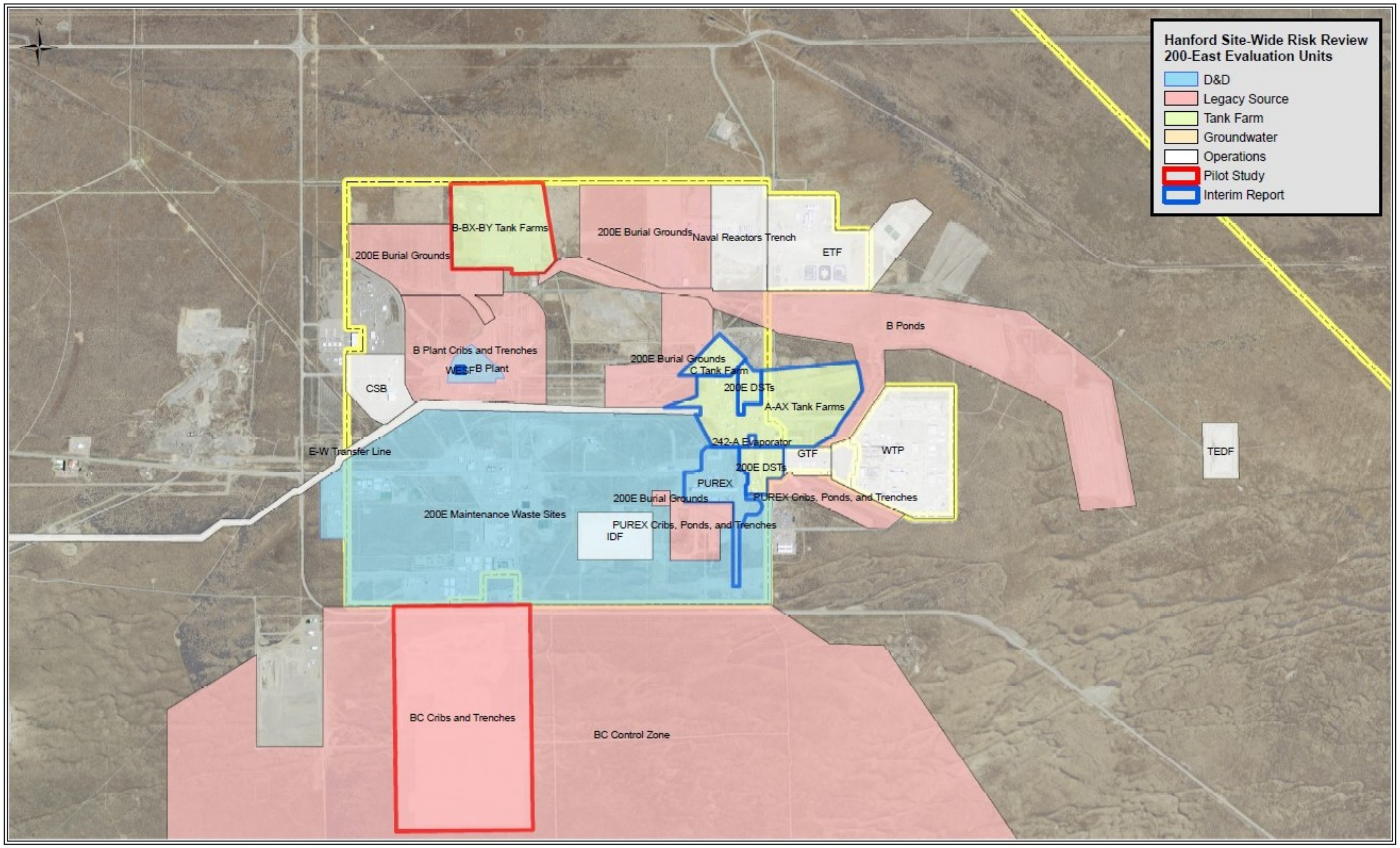


Figure 3-7. Hanford Site-Wide Risk Review Project: 618-11 burial ground evaluation unit.



1 inch = 2,100 feet

Figure 3-8. Hanford Site-Wide Risk Review Project: 200 East Area evaluation units.

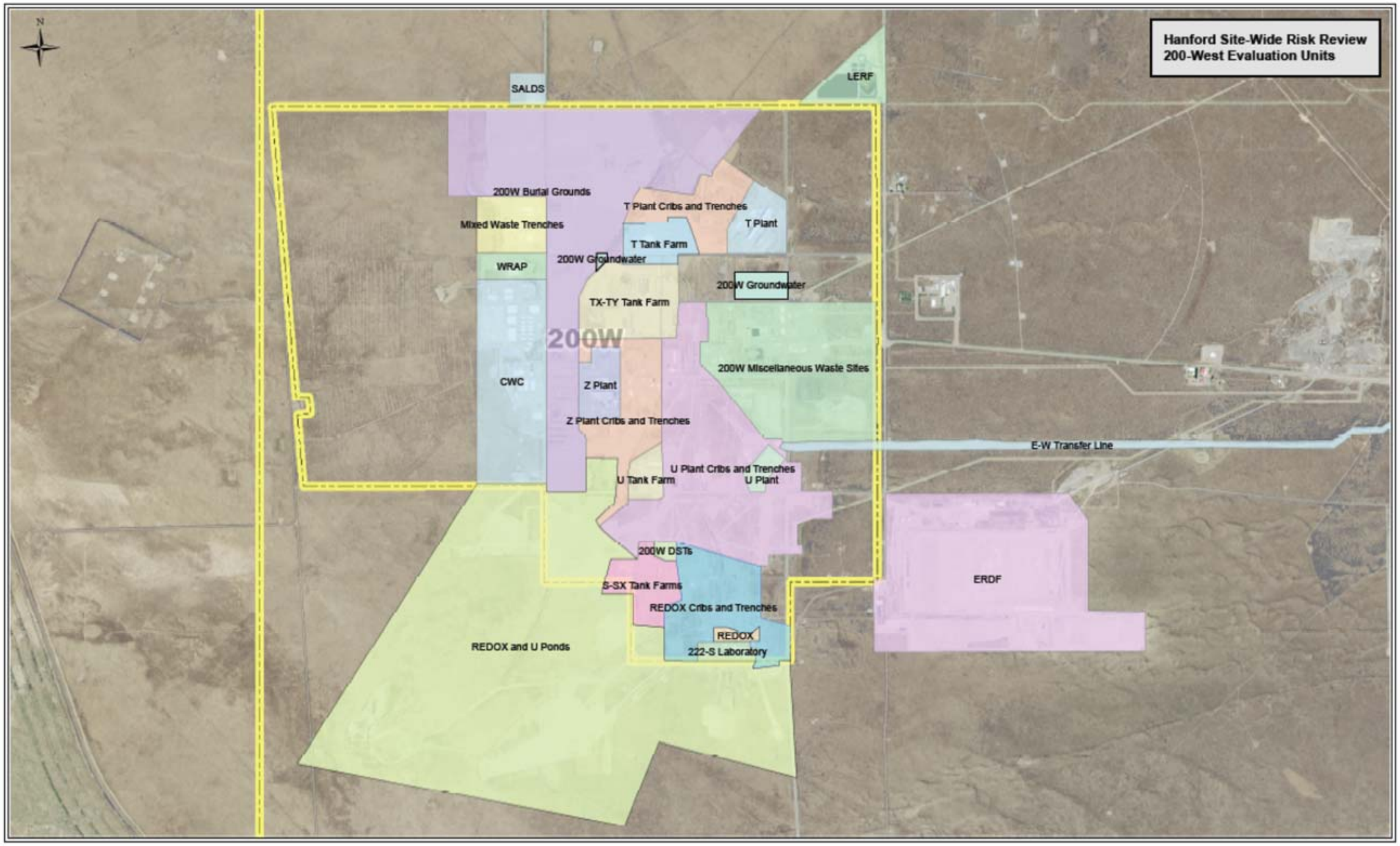


Figure 3-9. Hanford Site-Wide Risk Review Project: 200 West Area evaluation units.

3.12. REFERENCES

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CHAPTER 4. METHODOLOGY FOR CONSIDERING INITIATING EVENTS USED IN EVALUATIONS

ABSTRACT

As part of the Risk Review Project methodology, it is important to establish a consistent basis for identifying and categorizing phenomena that may remove or degrade barriers to completed pathways. The term "initiating events" is used herein for these phenomena. The initiating event methodology described in this chapter provides a basis for assigning the likelihood of loss or degradation of barriers and guidance for assigning impacts (consequences) due to the loss of barrier based on the event being considered. The risk and impact methodology developed for this effort and also described in this chapter are applied as appropriate to each category of evaluation unit, utilizing this basis.

4.1. OBJECTIVE

In order to perform a meaningful and efficient risk review at the Hanford Site, it is necessary to establish a consistent basis for identifying and categorizing phenomena that may remove or degrade barriers to completed pathways. The term "initiating events" is used herein for these phenomena. The primary goal of the initiating event methodology is to provide a basis for assigning the likelihood of loss or degradation of barriers and guidance for assigning impacts (consequences) due to the loss of barrier based on the event being considered. The risk and impact methodology developed for this effort and also described in this chapter is applied as appropriate to each EU, utilizing this basis. Initiating events are episodic events that may occur over short or long timeframes (from less than a day to years) and are considered in addition to natural prevailing processes (i.e., groundwater flow) that may result either by themselves or in combination with initiating events, in risks to receptors from contaminants already in environmental media (e.g., soils, vadose zone, groundwater).

4.2. GENERAL CONSTRUCT

In the context of this Risk Review Project, initiating events will be grouped into anthropogenic and natural events. Anthropogenic events include events directly attributed to human initiators (e.g., human error leading to accidents, loss of institutional control), failure of engineered systems, and external events from man-made sources (aircraft impacts, events at other EUs). Natural events include episodic natural hazards phenomena (earthquake, high winds, volcanic ashfall, and wildfires) consistent with guidance in DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*. This category of events also includes natural processes such as structural decay of barriers and facilities (landfill covers, storage tanks, buildings, etc.) exposed to the environs, changes in water table, and drought/climate change.

4.3. INITIATING EVENT LIKELIHOOD DESIGNATIONS

Each initiating event will be associated with an event likelihood or likelihood range. The likelihood ranges are generally expressed as a function of estimated annual likelihood of occurrence (event/yr) (DOE-STD-3009), but may also be assigned based on qualitative estimate (e.g., the likelihood of experiencing structural decay for barriers exposed to the environment during the long-term post-cleanup phase). Table 4-1 identifies the quantitative likelihood ranges and descriptions for use in the evaluation of initiating events. The frequencies associated with anthropogenic events (human and system failures) are based on facility lifespans and are judged to apply to the active cleanup evaluation period (50 years, through 2064) without additional modification. For the post-cleanup evaluation periods, additional considerations of human and system failures may be warranted when considering the activities and controls expected during these intervals.

For EUs where there is a DSA, HA, or other document that provides initiating event frequencies developed specifically for the facilities and activities occurring within the EU, these documents should be used.

In all cases, these initiating frequencies should only be considered for use in a relative risk sense and not for the determination of an absolute risk value. See Table 4-2.

Table 4-1. Likelihood estimates for initiating events (DOE-STD-3009, HNF-8739).

Likelihood Designation		Quantitative Range/yr	Qualitative Descriptions (HNF-8739)
Anticipated	(A)	> 10^{-2} (a)	Events that are expected to happen in the evaluation period (typically the lifetime of a facility for operational facilities).Typically this includes human errors and failure of active systems, short-term loss of power.
Unlikely	(U)	10^{-2} to 10^{-4} (b)	Events that are not anticipated to occur during the evaluation period. Natural phenomena events in this range include design basis events such as earthquakes, probable maximum flood, maximum wind gust, maximum flood, maximum wind gust, and other extreme phenomena. For engineered systems, failures of passive systems and multiple failures of active systems, events resulting in long-term loss of power usually fall within this range.
Extremely Unlikely	(EU)	10^{-4} to 10^{-6} (c)	Events that will probably not occur during the evaluation period. This typically includes severe natural phenomena hazards (NPH) exceeding the design basis of the facility that have the potential for significant regional impacts (see Section 4.4), and rare external events, e.g., aircraft crashes, random dam failures.
Beyond Extremely Unlikely	(BEU)	< 10^{-6} (d)	Events that are not expected to occur. Usually events requiring multiple independent failures or very rare phenomena (e.g., asteroid impacting the Hanford Site).

a. An event that has a likelihood of occurrence between 0.01 and 1 (10^{-2} to 1).
b. An event that has a likelihood of occurrence between 0.0001 and 0.01 (10^{-4} and 10^{-2}).
c. An event that has a likelihood of occurrence between 0.000001 and 0.0001 (10^{-6} to 10^{-4}).
d. An event that has a likelihood of occurrence of less than 1 in a million (< 10^{-6}).

Human-initiated events (intentional destructive acts [IDAs]) are not included in the above frequencies. Facilities/locations with enough radioactive material to result in potentially severe impacts are protected by numerous physical, procedural, and operations-based systems that minimize the probability of a successful IDA. In the unlikely event of an actual IDA, physical features associated with the facilities' locations would reduce potential impacts for most IDA scenarios. DOE security and response teams are trained and prepared to respond to an IDA to further reduce potential impacts.

4.4. EVENT DAMAGE ASSESSMENT

An event also must be related to the damage to a barrier it is expected to cause. The following guidance is provided to assist in assigning damage estimates and resulting consequences for the initiating events.

For EUs where there is a DSA, HA, or other document that provides consequence estimates developed specifically for the events postulated to occur within the EU, these documents should be used. The consequence determinations within HAs and DSAs and the hazardous material exposures are usually limited to short durations (e.g., less than 8 hours) and do not include food or water pathways. In contrast, for the Risk Review Project, longer-term consequences and the additional receptor pathways are also considered.

(LOW) LOCALIZED IMPACTS

These events are associated with damage to individual (single) barriers (release of material) that may result in release of material and immediate impact to the nearby worker but are not expected to have impacts outside the facility/area boundary (HNF-8739). Environmental impacts would be expected to be limited and able to be mitigated and remediated. For determining radiological impacts, these are events associated with less than Hazard Category 3 (DOE-STD-1027 CN1) quantities of material.

Examples include the following:

- Container retrieval, handling, and storage events impacting one to a few drums or containers
- Liquid waste handling events (leaks, spills, overflows) resulting in the release of a few gallons of material
- Uncontained inadvertent criticality events (single pulse)

Within a DSA or HA, these events are identified as having high consequences to the facility worker and low consequences to a co-located person (< 5 rem total effective dose [TED]) (see Terminology) and the public (< 5 rem total effective dose [TED]).

(MODERATE) FACILITY IMPACTS

These events are associated with damage to many barriers or entire facility/systems (e.g., an entire tank farm or operating plant) that may result in release of material and have immediate impact to receptors outside the EU site or facility/area boundary but not the overall Hanford Site boundary (HNF- 8739).

Environmental impacts would be expected to be limited to the Hanford Site boundary but could include potential impacts to groundwater.

Examples include the following:

- Container retrieval, handling, and storage events driven by mechanical failures (e.g., crane drops) impacting several pallets or rows of storage containers
- Liquid waste handling events (large leaks, mis-transfers) resulting in the release of a hundreds of gallons of material
- Low-pressure spray leaks of high-activity waste material
- Deflagrations or explosions within a single waste tank
- Contained inadvertent criticality events (multiple pulses)

Within the DSA or HAs, these events are identified as having high consequences to the facility worker, moderate or high consequences (5 to 100 rem TED) to a co-located person, and low (<0.1 rem TED) consequences to the public. However, in the context of the Risk Review Project, these events may also have consequences to other receptors outside the facility/area boundary (i.e., groundwater, ecological and cultural resources).

(HIGH) OFF-SITE IMPACTS

These events are associated with damage to multiple facilities/systems that may result in release of material and have an immediate impact on receptors outside the Hanford Site boundary (HNF-8739).

Environmental impacts would be expected off-site and could include potential impacts to groundwater and surface water (Columbia River).

Examples include the following:

- Facility-wide events, such as fire or building collapse, impacting the entire inventory of stored (in-process) containers
- Liquid waste handling events (large leaks, mistransfers) resulting in the release of a hundreds gallons of material
- High-pressure sprays leaks of high-activity waste material
- Deflagrations or explosions within multiple waste tanks resulting in airborne contamination reaching beyond Hanford boundary

Within the DSA or HAs, these events are identified as having high consequences to the facility worker and co-located person and moderate (0.1 to 5 rem TED) or high (≥5 rem TED) consequences to the public.

In addition to immediate impacts to barriers resulting in the release of radioactive or hazardous material, certain events such as severe NPH can result in site-wide or regional impacts, which can then lead to additional or worsening release and limit the availability and capability to respond to the event. The following are examples of these types of events and their potential impacts.

Seismic Events: In addition to direct failures of barriers, severe seismic events can result in loss of support systems (long-term loss of power, water) and damage to access roads normally available to support recovery activities (emergency generator refueling). Seismic events are also noted as a leading cause of dam failures (PUD 2012) (discussed further below). When considering the risk associated with these events, the assessment should include an evaluation of active systems and whether these systems will be readily available post event. HNF-SD-GN-ER-501, *Natural Phenomena Hazards, Hanford Site, Washington,* and PNNL-23361, *Hanford Sitewide Probabilistic Seismic Hazard Analysis*, provide additional seismic hazard information for the Hanford Site.

Dam Failure (Flooding): Dam failure can impact significant portions of the Hanford Site and disrupt electric power generation and transmission throughout the region, resulting in loss of power in non-flooded areas (e.g., 200 Area Plateau). For flooded areas, equipment damage may be sufficient to preclude repair upon recession of floodwaters. Severe flood events would also impact downstream communities to a great extent (RLO-76-4) and could limit the capability of emergency response. When considering the risk associated with these events, the assessment should include an evaluation of active systems and whether these systems will be readily available post event. HNF-SD-GN-ER-501, *Natural Phenomena Hazards, Hanford Site, Washington,* and RLO-76-4, *Evaluation of impact of Potential Flooding Criteria on the Hanford Project,* provide additional flood hazard information for the Hanford Site.

Ashfall: In addition to direct failures of barriers due to structural loads, ash fallout is also expected to plug ventilation systems (filter plugging) and may result in electrical shorting and other failures of active systems. Ashfall can also impact the capability to support emergency response activities (e.g., generator refueling) due to road closures and vehicle impacts. When considering the risk associated with these events, the assessment should include an evaluation of active systems and whether these systems will be readily available post event.

Note: As discussed in HNF-SD-GN-ER-501, snow loading (15 lb/ft^2) is the dominant structural load contributor for events with annual exceedance probability of 5E-04/yr or less. For events with an annual exceedance probability of 1E-04/yr, ash loading is 23 lb/ft^2. When considering the risk associated with these events, the assessment should include an evaluation of active systems and whether these systems will be readily available post event. HNF-SD-GN-ER-501, *Natural Phenomena Hazards, Hanford Site, Washington*, and WHC-SD-GN-30038, *Volcanic Ashfall Loads for the Hanford Site*, provide additional ashfall hazard information for the Hanford Site.

Geomagnetic Disturbance: Solar storms or geomagnetic disturbance events have demonstrated the potential to disrupt normal operations of the power grid. Severe events may result in regional loss of power and communication events with significant recovery times. When considering the risk associated with these events, the assessment should include an evaluation of active systems and whether these systems will be readily available post event. NERC Project 2013-03, *Benchmark Geomagnetic Disturbance (GMD) Event Description*, provides additional information on geomagnetic disturbance hazards.

4.5. EVENT LIKELIHOOD AND IMPACTS

Table 4-2 identifies typical initiating event classes expected to be relevant to the Hanford Risk Review Project for the three evaluation periods. Additional initiating events may be added for individual EUs based on review of the HAs and DSAs. This table identifies the expected likelihood range of the events (see Table 4-1) and provides a qualitative estimate of the expected consequences (Low, Moderate, High) from releases due to those initiators, which are then integrated to form a Risk Review Project risk rating to a receptor from ND to High. These can be used to aid in binning EU-specific events according to frequency and consequences. For longer post-cleanup evaluation periods, the impacts of the initiating events have been adjusted as necessary based on the nature of the remaining hazards and activities expected on-site.

Key assumptions applied to the specific EU groupings (i.e., Legacy Source Sites, Tank Waste and Farms, Groundwater Plumes, D&D of Inactive Facilities, Operating Facilities) for each evaluation period area are identified below.

Active cleanup (Active): Defined as 50 years (i.e., until 2064).

- All groupings are assumed to include human activities and various types of engineered systems, administrative controls (e.g., health and safety plans), and maintenance efforts.
- There will be no active operations for facilities in D&D (or transferring to D&D) during the Surveillance and Maintenance Phase. Human activities are limited to monitoring and maintenance to ensure necessary systems remain functional.

Near-term post-cleanup (Near): Lasts 100 years after cleanup is completed (until 2164).

- No active-engineered systems are required to maintain integrity of barriers.
- Passive barriers including canyons and engineered covers are addressed assuming no active-engineered systems are required to maintain integrity of barriers.
- Passive barriers including canyons and engineered covers are addressed as “Structures” versus “Systems.”
- Institutional controls are in place.
- Loss of monitoring and support infrastructure does not lead to the failure of a barrier.
- For groundwater and surface water, it is necessary to address consequences of released water or failure of a barrier (intrusion into groundwater or river). Impacts to the groundwater from the vadose zone are addressed as appropriate for the individual EUs.

Long-term post-cleanup (Long): Extends for 1000 years after cleanup is complete (until 3064).

- No institutional controls are in place, although federal control may extend beyond the year 2164 in some areas of the Hanford Site.
- No protective actions or repair of barriers are assumed.

Table 4-2. Typical initiating events and impacts for the Hanford Site Risk Review Project.

EVENT (reference)	Likelihood[i]/Impact[j]			Discussion
	Active[a]	Near[b]	Long[c]	
Human Errors	A/L	--/NA	--/NA	Includes events involving mechanical movements—drops or impacts involving nuclear or chemical material and contamination. Misroutes of material (feed) resulting in spills or overflows. Exposure to "unknown material."
	U/M	--/NA	--/NA	Typically these errors would be associated with failure of a formal regulatory or safety management program (e.g., Criticality Safety Program).
Fires	A/L	--/NA	--/NA	Local fires prior to initiation of suppression. Range fires impacting barriers or isolated units (e.g., exposed waste containers or contaminated areas would also be exposed waste containers or contaminated areas) would also impact ventilation and power systems.
Failures of Industrial Grade Active Systems	A/M	--/NA	--/NA	Loss of motive force (pumps, compressed air, ventilation). Usually restricted to one shift. Pressure boundary (gaskets, pumps) failure. Drum over-pressurizations (non-vented).
Loss of Power	A/L	--/NA	--/NA	(Short duration.) Active failures (breaker trips, off-site power). Can initiate loss of multiple active systems (normal operating systems). Loss of monitoring not assumed to lead to failure of barrier.
	U/L, M, H	--/NA	--/NA	(Long duration.) Failure in switchgear substations, regional loss of power events (blackouts). May challenge robust engineered systems even with backup power available. Loss of monitoring not assumed to lead to failure of barrier.
Explosions	A/L	U/L	U/L	Accumulation in unvented container (drum, inactive system diversion box). Unlikely that accumulation (flammable mixture) would occur in stabilized waste.
Failures of Robust System	A/L	--/NA	--/NA	Pressure boundary failures resulting in leaks and spills for non-maintained systems.
	U/L, M	--/NA	--/NA	Failure of active redundant (safety) systems. Pressure boundary failures resulting in large leaks and spills for maintained systems or catastrophic failure of systems.

EVENT (reference)	Likelihood[i]/Impact[j]			Discussion
	Active[a]	Near[b]	Long[c]	
Loss of Institutional Controls and Human Intrusion	EU/L	U/L	A/L	For long -term post-cleanup period, assumes no controls are in place for repair of barriers or prevention of intrusion.
Loss of Engineered Systems	U/L	--/NA	--/NA	For post-cleanup evaluation periods, see Structural Decay discussion below.
Significant Dam Failure (flooding)[d]	EU/ L	EU/L	U/L	Impacts to barriers near Columbia River (100 Area, 300 Area). Significant widespread flooding through Columbia River Basin. Assumes River Corridor has only residual contamination after active cleanup period. For other flooding, see River Flood. Note: The Central Plateau is above maximum flood levels.
Plane Crash[f, g]	EU/M	EU/L	EU/L	EU (light aviation). Significant damage to single system.
	BEU/H	EU/L	EU/L	(Commercial carriers.) Significant damage to facility/multiple systems.
Structural Decay	U/L	A/L	A/M	Failure of barrier exposed to environs assumes human intervention (maintenance and repair) during active cleanup phase and no/minimal human intervention in the post-cleanup periods.
Earthquake[e]	A/M	U/M	U/M	Failure of normal ("non-safety") structures/systems exposed to seismic loads.
	U/MH M H	--/NA	--/NA	Failure of robust ("safety") structures/systems during active remediation. Off-site impact would require multiple failures.
Winds[e]	A/M	A/L	A/L	Failure of normal ("non-safety") structures/systems exposed to 91 mph peak, 115 mph ultimate-peak wind speeds. For post-cleanup evaluation periods, can include soil erosion resulting in loss of barrier with subsequent water infiltration.
	U/L	--/NA	--/NA	Failure of robust ("safety") structures/ systems exposed to 100 mph peak, 129 mph ultimate-peak wind speeds during active remediation.
Tornado[e]	EU/H	--/NA	--/NA	Failure of facilities and exposed structures. Loss of power. Not included in Hanford Site Design Criteria.
Snow Load/Icing[e]	U/M	--/NA	--/NA	Failure of barriers from structural loading >15 lb/ft^2.

EVENT (reference)	Likelihood[i]/Impact[j]			Discussion
	Active[a]	Near[b]	Long[c]	
Ash Fall (Volcanic)[e]	U/M EU/H	--/NA	--/NA	Failure of barriers from structural loading (12 - 23 lb/ft^2) and from airborne concentration leading to plugging, electrical shorting, loss of power (1325 - 2650 mg/m^3). Off-site impact would require multiple failures.
Flood(Local Storm-rainfall)[e]	A/L	A/L	A/L	Failure of barriers due to potential intrusion/accumulation for 100-yr rainfall (2 inches).
	U/L	U/L	U/L	Failure of barriers due to potential intrusion/ accumulation for 1000-yr rainfall (2.7 inches).
River Flood[e]	U/L	--/NA	--/NA	100 Area elevations < 426 ft 200 Area (southwestern) Cold Creek Drainage area, for elevations < 640 ft. 300 Area elevations < 380 ft.
Land Slide[e]	U/M	--/NA	--/NA	To be evaluated on specific site basis—typically associated with steep slopes/water saturation.
Land Movement: Subsidence/ Uplift[e]	A/L	--/NA	--/NA	To be evaluated on specific site basis—typically associated with groundwater removal/injection.
Severe Drought/ Precipitation	A/L	A/L	A/L	Migration of contamination in soil or groundwater.
Geomagnetic Disturbance[f] (solar flare)	A/L	--/NA	--/NA	Localized loss of power disturbances. See Loss of Power events discussion above.
	U/L, M, H	--/NA	--/NA	Potential for regional loss of power disturbances. Associated with beyond design basis events affecting the grid. See Loss of Power events discussion above.

a. Active cleanup period (until 2064).
b. Near-term, post-cleanup period (until 2164).
c. Long-term, post-cleanup period (until 3064).
d. RLO-76-4, *Evaluation of Impact of Potential Flooding Criteria on the Hanford Project* (ERDA 1976)
e. HNF-SD-GN-ER-501, *Natural Phenomena Hazards, Hanford Site, Washington*, Rev. 2.
f. *Benchmark Geomagnetic Disturbance (GMD) Event Description*, NERC Project 2013-03 GMD Mitigation, Draft: October 27, 2014.
g. RPP-11736, *Assessment of Aircraft Crash Frequency for the Hanford Site 200 Area Tank Farms*, Rev. 0.
h. PRC-STP-00815, *Aircraft Crash Evaluation for 105-KW Basin/ECRTS Modified Annex Operations*, Rev. 1.
i. Likelihoods: A – Anticipated (> 10^{-2}/yr); U – Unlikely (10^{-2} – 10^{-4}/yr); Extremely Unlikely (10^{-4} – 10^{-6}/yr); and BEU – Beyond Extremely Unlikely (<10^{-6}/yr).
j. Impacts: L – Low (Single barrier with localized impacts); M – Moderate (Single facility or system with on-site impacts); and H – High (Multiple facilities or systems with potential off-site impacts). (NA) – Not applicable (For NA events the likelihood is not evaluated reflected by “- -“).

4.6. REFERENCES

DOE-STD- 1020, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities, U.S. DOE.

DOE-STD-1027, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports Change Notice 1, U.S. DOE.

DOE-STD-3009, Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses, U.S. DOE.

HNF-8739 Rev. 2 2012, *Hanford Safety Analysis and Risk Assessment Handbook (SARAH,)* CH2M HILL Plateau Remediation Company, Richland WA.

HNF-SD-GN-ER-501 Rev. 2 2012, *Natural Phenomena Hazards, Hanford Site, Washington,* Washington River Protection Solutions LLC, Richland, WA.

NERC Project 2013-03 GMD Mitigation, *Benchmark Geomagnetic Disturbance (GMD) Event Description*, North America Reliability Corporation, Draft: October 27, 2014.

PNNL-23361 2014, *Hanford Sitewide Probabilistic Seismic Hazard Analysis,* Pacific Northwest National Laboratory, Richland, WA.

PRC-STP-00815 Rev. 1 2013, *Aircraft Crash Evaluation for 105-KW Basin/ECRTS Modified Annex Operations*, CH2M HILL Plateau Remediation Company, Richland, WA.

Public Utility Districts (PUD) of Chelan, Douglas, and Grant Counties 2012, *Probabilistic Seismic Hazard Analyses Project for the Mid-Columbia Dams.*

RLO-76-4, *Evaluation of Impact of Potential Flooding Criteria on the Hanford Project*. ERDA, 1976.

RPP-11736 Rev. 0 2003, *Assessment of Aircraft Crash Frequency for the Hanford Site 200 Area Tank Farms*, CH2M HILL Hanford Group Inc., Richland WA

WHC-SD-GN-30038 Rev. 2 2012, *Volcanic Ashfall Loads for the Hanford Site*, Washington River Protection Solutions LLC Richland, WA.

PART 3. HANFORD CONTEXT AND METHODOLOGIES FOR EVALUTING RISKS TO HUMAN HEALTH AND RESOURCES

CHAPTER 5. EVALUATING RISKS TO HUMAN HEALTH

ABSTRACT

This chapter provides an overview of potential risks to human health from the Hanford Site and the methodology used to rate individual EUs with respect to human health for the Risk Review Project. The following categories of potentially exposed persons or populations are defined for evaluation purposes: 1) facility worker, 2) co-located person, 3) controlled access persons, and 4) public. Assumptions and methodology are described for relative rating of each category of potentially exposed persons during 1) the active cleanup period, including the current status of the EU prior to cleanup, where applicable, and during active cleanup; and 2) the near-term post-cleanup (until 2164, or assuming a 100-year duration for institutional controls associated with areas transferred from federal control).

The evaluation approach for potential risks during the long-term post-cleanup evaluation period (or until 3064) associated with the failure of institutional controls is also discussed. In the post-cleanup period, some land may be owned and controlled by DOE or another federal agency, may have controlled access, or may be transferred from federal control for other uses (e.g., recreational, industrial, or other forms of development) or preservation. Many of the EUs evaluated will likely be remediated in place or have some residual contamination inventory. These are considered part of the "industrial-exclusive" or core zone of the Central Plateau, and are expected to remain under federal control. Groundwater is evaluated separately from land use (Chapter 6) because 1) groundwater use can be, and often is, managed separately from land use; 2) groundwater is considered a protected resource by the State of Washington, with a goal of restoration to the highest potential use; and 3) there is potential in the short term for provision of alternate or treated water supply commensurate with the anticipated uses, until groundwater quality can meet relevant water quality standards.

5.1. OVERVIEW OF HUMAN HEALTH CONSIDERATIONS

People who work on, visit, or live near[36] contaminated or formerly contaminated sites with residual contamination have the potential to be exposed to a variety of site-specific hazards: chemical, radiologic, biologic, and physical. Hazards may be in the form of contaminants in structures or containers or in air, water, soil, or food, and may include direct radiation exposure as well as physical trauma, including blast injury. Contaminants may enter the body through inhalation, ingestion, dermal absorption, or direct radiation penetration. This chapter considers people who work at, may visit, or use facilities or land within or adjacent to a Hanford EU now or in the future. People considered include those who may be exposed to current or residual contamination on or from the Hanford Site as site workers, controlled-access visitors, recreational users, and employees of current and future non-DOE industries, as well as potential residents, farmers, Tribal members and the general public.

For many sites on the National Priorities List, there are residential communities nearby. Risk assessments guide decisions about occupancy versus evacuation, mitigation measures (e.g., providing alternate water supplies), and remediation versus no action. A different situation exists at the Hanford Site, where public occupancy is currently prohibited, current non-worker exposure is minimal, and access is highly controlled (however, substantial resources are needed annually to maintain this condition). The mosaic of planned future land uses depends in part on existing contamination, cleanup

[36] The large land area and buffer zones associated with the Hanford Site currently preclude "nearby" residential use.

objectives, and potential future exposure pathways. Specifically, future land use of various parts of the Hanford Site and associated institutional controls (WAS 2001a) depend in part on the extent of contamination of particular EUs, the proposed remediation alternatives, the planned post-remediation residual contamination, and potential exposure pathways.

There is a reflexive relationship between land use and cleanup. Where unrestricted land use is desired (WAC 2007), cleanup levels must be set to very low values to prevent future impacts on health or other resources. If these low cleanup levels cannot be achieved safely or practically by current technologies and available resources, then future land use must be restricted. For the purposes of the Risk Review Project, near-surface contamination is considered to be within the uppermost 5 m of soil or the depth of the constructed facility if it is deeper than 5 m. The remediation of groundwater contamination to achieve groundwater quality suitable for "highest beneficial uses" (WAC 2001), such as drinking water and irrigation, is considered separately (Chapter 6).

Large areas of uncontaminated landscape at Hanford may be made available for use under control of the U.S. Fish and Wildlife Service as part of the National Monument, although some areas of the monument may require remediation. Indeed, Hanford can be considered as multiple entities: large areas of uncontaminated or minimally contaminated landscape, and a mosaic of former industrial lands and disposal areas subject to cleanup. In addition, some areas have near-surface contamination from non-DOE uses (e.g., former orchard lands contaminated from agricultural use of arsenic). Release of certain areas from federal control may occur after cleanup, and residual contamination may limit future land use options as "Brownfields" or as exclusion zones, and may require future risk assessments to deal with uncertainties in current modelling (Scott et al. 2005) or additional cleanup actions if land use changes.

The Risk Review Project considers potential exposures (and their associated risks/impacts) prior to remediation, during remediation, and after completion of remediation. Following cleanup of specific areas, land associated with some EUs may be released for designated uses with or without associated institutional controls, while others (such as the ERDF and other areas, and portions of or the entire 200 Area) are assumed to be maintained by the federal government in perpetuity with controlled access consistent with residual contamination and hazards, intended uses, and mitigation measures to protect human health.

The Risk Review Project is not performing an independent risk assessment, but rather an order-of-magnitude rating or binning of potential risks to human health based on hazards, accident or exposure scenarios, and consequences to different categories of people who may be present on or adjacent to the Hanford Site.

5.2. CATEGORIES OF PEOPLE WHO MAY BE PRESENT ON OR ADJACENT TO THE HANFORD SITE (HUMAN RECEPTORS)

At Hanford, there are many types of site-employed workers (construction, rad-workers, maintenance, administrative, engineering, etc.), non-site-employed workers (visiting contractors, regulatory personnel, researchers, etc.), and other people present for variety of reasons (educational visits, cultural practices, recreation, etc.). Before, during, and after remediation, access to some areas of Hanford is or will be controlled. Access by non-workers to high hazard areas is restricted and escorted. Controlled access to other parts of Hanford is allowed for designated purposes along with appropriate mitigation measures to protect human health (activity limitations, access to limited areas, monitoring, etc.). Parts of the Hanford Site are accessible from the Columbia River and from public highways. For the purposes of HAs, DOE divides workers into "facility workers," who are located at the facility being analyzed, and "co-located workers," who are located 100 m from the facility boundary for the event being analyzed. However, the term "co-located worker" can be confusing because of different perceptions of what constitutes a "worker" and other people who may be present for reasons other than work (e.g., educational visitors). Thus, for clarity, within the Risk Review Project, specific categories of people are defined for evaluation purposes. The definition of each category reflects the location of the person and the constraints imposed (or not imposed) on the individuals within the specific category. The following categories of people are defined:

Facility Worker – any worker or person within the facility or activity geographic boundary as established for DSA and located less than 100 m from the potential contaminant release point. This definition is consistent with the SARAH definition of a facility worker (HNF-8739 2012 and DOE-STD-3009).

Co-located Person – a hypothetical on-site person located at the distance from the point of potential contaminant release at which the maximum dose occurs (at a point equal to or greater than 100 m from the point of release, the boundary of the facility *or the activity boundary)*. If the release is elevated, the co-located person is assumed to be at the location of greatest dose, which is typically where the plume touches down. This definition is consistent with the SARAH definition of a co-located worker, but also is expanded to represent any person at the postulated location, independent of that person's activity or employer.

Controlled Access Person – a person who is granted limited access to the Hanford Site, within the current site security boundary, for a specific purpose or set of activities. This definition is one that has been developed for the purpose of the Risk Review Project. Specific controlled access groups may include 1) people granted access for work-related visits, 2) people granted access for educational activities (e.g., site tours or visiting the B Reactor museum), 3) people granted access for different forms of recreational activities, and 4) Tribal members granted access for practicing designated Tribal activities. Site access for practicing designated Tribal activities represents a unique controlled access group that will require clear definition of safety and mitigation measures including biomonitoring of collected flora and fauna and should consider unique Tribal use and consumptive practices. Recommending specific controls and mitigation measures for any of the controlled access groups, including for Tribal cultural activities, is beyond the scope of the Risk Review Project.

The general location of the site security boundary is indicated in Figure 5-1 and is demarcated as the area between Highways 240 and 24 and the towns of Richland and West Richland on the south and west and the south bank of the Columbia River on the north and east. Conspicuous signs discourage intrusion away from this zone. Individuals or groups of people within these boundaries are assumed to be granted access with restrictions (e.g., badging, escorts).

The restrictions on co-located persons include risk mitigation measures that are necessary to protect human health such that resultant risks for these visitors would be ND to Low. Depending on the nature of the access purpose or activities, the restrictions may include any of the following: location or age (i.e., "no children" restrictions; activity restrictions (no hunting, fishing or other consumptive practices, excavation, etc.); training, personal protection equipment, escort, communications, and/or notification requirements.

Public - The word "public" has multiple meanings in common parlance. In most Hanford-related documents and discussions, the term "public" refers to people residing or present at the fence line of the Hanford Site. However, currently the public has open access along the river and public highways. For the Risk Review Project, "public" refers to people present for any purpose or residing at or beyond the Hanford Site security boundary (see Figure 5-1), where access to the surface soil to a depth of 5 m is not restricted. The current site security perimeter is defined as the south bank of the Columbia River on the north and east and the public highways such as Rts. 240 and 24 on the west and south.

The maximally exposed individual (MOI) is a hypothetical member of the public located at or outside the Hanford site security boundary at the distance and in the direction from the point of the contaminant release at which the maximum postulated dose occurs.

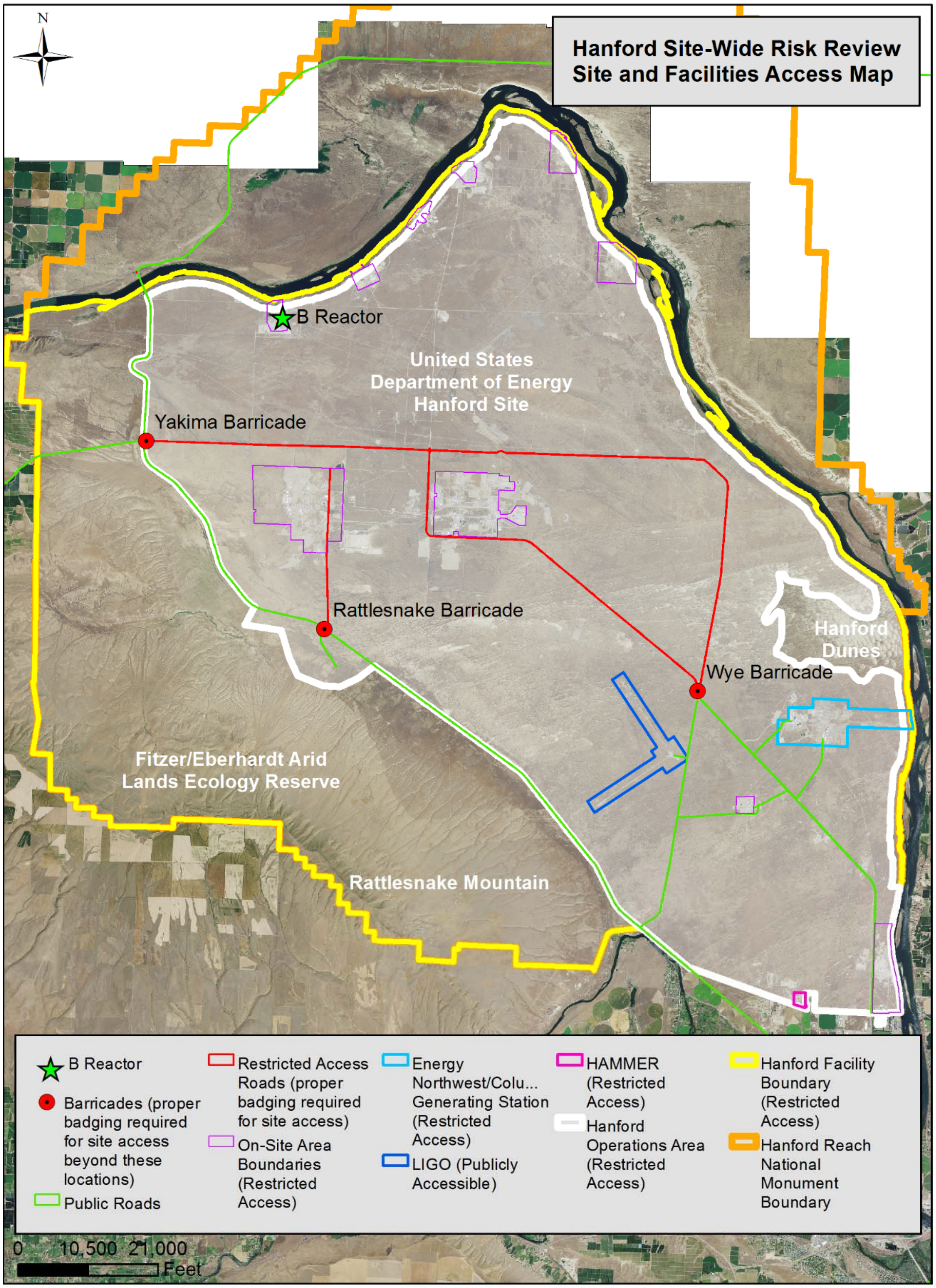

Figure 5-1. The Hanford Site boundaries, public roads, and access control points. The shaded area between the river and the highways indicates the controlled access portion of the site. People outside of the shaded area would be considered "public."

As cleanup progresses and after the cleanup is completed, the Site's security boundaries may be revised allowing for controlled access to other areas of the Hanford Site for specific uses including designated Tribal activities, recreational users in appropriate locations, and businesses that may be allowed to operate on the industrial/commercial use areas. Public health risks also need to consider the potential for failure of institutional controls and the potential for a "stealth" intruder before, during, and after cleanup activities.

Public health risks are considered by the Risk Review Project in the context of potential exposure from a radiological event (e.g., accident scenario or other form of release) and from exposure to soil, flora, and fauna. Public risks associated with water usage are also considered in the context of the groundwater evaluation. Groundwater evaluation is not aggregated with the other potential exposure routes for several reasons[37]. First, separate screening evaluation of groundwater against regulatory established thresholds that are risk informed (e.g., drinking water standards or aquatic water quality standards) allows for more explicit evaluation without needing to determine whether the water will actually be used. Thus, the groundwater is evaluated as a protected resource, *per se*, and therefore greater clarity is provided on the impacts to and from groundwater. Second, land use is often managed separately from groundwater use because of potentially longer time horizons associated with groundwater remediation and because alternative water supplies may be available.

5.3. WORKER SAFETY

People who work on contaminated sites have the potential to be exposed to a variety of hazards: radiologic, chemical, biologic, and physical, particularly if they work directly with the hazardous materials, as in the case of remediation or "cleanup" workers on DOE nuclear legacy sites such as Hanford (Martin and Gochfeld 2000). For this review, worker risk is considered with respect to the specific facilities in which or near which they work. A worker in the bounds of a facility or activity that is being evaluated for a possible event or release is designated a "facility worker." Workers who are 100 m or more from the facility or activity boundary are identified as "co-located." Worker exposure to site-specific radiologic or chemical hazards or blast injury may be acute (Type 1) due to some initiating event (e.g., a natural disaster or an anthropogenic accident), or subacute or chronic (Type 2) due to proximity, inhalation, ingestion, or contact exposure to some undetected radioactive agent or toxic chemical. The latter may occur during investigation or remediation of an inadequately characterized site. Workers also incur a more general risk (Type 3) of accident and injury unrelated to site-specific contamination (identified here as "industrial accidents"). HAs and DSAs estimate the likelihood and consequences of Type 1 and some Type 2 events, but specifically exclude Type 3 from analysis, except when these serve as initiating events. These documents also identify controls to prevent or mitigate consequences. At Hanford, a safety culture emphasizing radiation protection, industrial hygiene, and safety reduces Type 2 and 3 events to a low level. DOE and its contractors have accident rates about one-third those of comparable non-DOE workforces. This section provides an overview of occupational health and safety and the specific methodology to be used in developing worker risk ratings for each EU. The resulting risk

[37] Cumulative risk assessments are performed to evaluate combined fate and effects of multiple contaminants from multiple sources through multiple exposure pathways (MacDonell et al. 2013). However, the purpose of this Review is very different than that of a baseline risk assessment or performance assessment and thus a cumulative risk assessment is not needed. Instead, isolating on single contaminants for EUs through a single exposure pathway (in this case, groundwater) allows identification of the most urgent risks to be addressed and helps inform sequencing of remedial actions across the Hanford Site.

ratings are relative to worker ratings for other EUs and are neither absolute nor normalized with respect to other types of receptors.

OCCUPATIONAL HEALTH AND SAFETY

An underlying principle of occupational health and safety is that ***all*** work-related illness and injury is preventable. Industrial hygiene, radiation protection, and industrial safety are the professions that focus on the "anticipation, recognition, evaluation, and control" of workplace hazards (NSC 2012). This principle, derived in the context of the industrial factory with its fixed walls and defined processes, has proven more challenging in the context of hazardous materials management, stabilization, demolition, and remediation or "cleanup." Nonetheless, the prevention of illness or injury related to work hinges on the identification of current or potential hazards, the anticipation of accidents, and the controls to prevent accidents or mitigate their consequences. The *Hanford Safety Analysis and Risk Assessment Handbook* (HNF-8739 2012) provides a detailed methodology for considering the probability and consequences of accidental events and exposures (Type 1) and for designing and implementing controls.

DOE has been proactive in defining worker safety as a priority of its environmental management activities. DOE and its prime contractors endorse a safety culture through numerous orders, standards, contracts, and training programs. For example, 10 CFR 851 and DOE Order 440.1 require that the same safety standards be incorporated into all contractual activities for all tiers of contractors. As a result, the overall safety performance at DOE legacy environmental management sites is significantly better than the performance of comparable tasks in the "private sector" in terms of lost time injuries and illnesses, at about one-third the comparable rates (i.e., two-thirds less) at non-DOE sites (Duncan 2005).

However, work that requires several tiers of subcontractors, performing highly specialized jobs, challenges the safety culture, requires close oversight, and creates opportunity for accidents and injury, particularly as the contractors encounter sites and facilities that are incompletely characterized with respect to sources and hazards (Gochfeld & Mohr 2007). The risk of exposure or industrial accident increases with the duration of the job, the number of workers involved, the nature of the hazards, and the complexity of the work, including the span of supervision overseeing performance and safety.

A program for detailed evaluation of risks to workers and prevention of exposures and disease (in contrast to the screening assessment being carried out in Risk Review Project) needs to distinguish DOE employees, prime contractors, and remediation subcontractors who have the required training, expertise, and safety equipment and protocols, from workers in support capacities who have only general site safety training. Workers in the latter category may have no prior experience with the site and its hazards, and their work may be incidental to the hazards of a particular site. However, because of unfamiliarity, these support workers may be at greater risk through accidental intrusion or even by triggering an event (fire, explosion, release). Subcontractor employees are generally at greater risk than prime contractor workers or federal employees, and the more complex the subcontracting arrangements, the greater the opportunity for accidents (Gochfeld & Mohr 2007).

In the EU summaries, facility workers (with direct exposure to an event) are distinguished from a co-located person (more than 100 m from an event or the facility in which it occurs). For this methodology, workers at a canyon (>100 m in length) where an event occurs would all be considered facility workers, even if they were >100 m from the event. As another example, an employee of Energy Northwest, adjacent to the 618-11 burial ground, would be considered a co-located person for any event occurring at the burial ground.

Evaluation Units and Time Periods

The EUs addressed in the Risk Review Project risk-rating fall into the following general categories:

- Legacy source sites
- Tank waste and farms
- Groundwater plumes
- D&D of inactive facilities
- Operating facilities

For each EU, the following temporal phases are considered with respect to worker risk (Chapter 2): active cleanup period (including the current status and remediation activities) and near-term post cleanup period. At different stages, the cadre of workers involved may be different. Worker safety issues are mainly considered before and during remediation, while public health considerations are primarily addressed after remediation is completed and in the context of future land use activities.

Prior to remediation, work mainly involves characterization, surveillance, and maintenance. If sites are unstable or have initiating events during the pre-remediation phase, there may be a range of conditions resulting in worker injury. The recognition of such vulnerable sites is factored into remediation sequencing. Once remediation is complete, there will be relatively few surveillance and maintenance workers remaining at the site. If future land use includes industrial or commercial development, those employees, as well as their customers, may be considered members of a future "public" or may be considered co-located persons depending on the definition of the site security boundary at that time.

Therefore, this section focuses mainly on the current period of active remediation, when most worker risk will occur.

Methodology for Rating Worker Risk

This section describes an approach to linking the information contained in the Evaluation Templates and DOE HAs to the binning of risk for workers, i.e., worker risk ratings. For each EU, an Evaluation Template is completed (Chapter 2 and Appendices B to E) that includes a description of the hazards, sources, and conditions of the site, its current status, and a proposed or a range of potential remediation option(s). Specifically for workers, the evaluation steps in the methodology include 1) identifying site-specific worker hazards, 2) identifying worker risk issues found in remediation options, and 3) reviewing final or draft HAs or DSAs if available.[38] For EUs where cleanup planning is at early stages and HAs do not yet exist for anticipated cleanup activities, HAs or DSAs from one or more analogous facility or cleanup activity will be used in carrying out the evaluation.

The Risk Review Project considers three types of worker risk:

> Type 1 - acute events or upset conditions (i.e., from explosions, fires, earthquakes, structural failures) resulting in blast injuries, fires, collapses, and sudden radiation and chemical releases. These are low probability, high consequence events that may result in death, injury, or exposure of large numbers of facility workers, co-located persons, controlled access persons, or potentially the public. These events or scenarios range greatly in probability and are captured in HAs or DSAs, which should be available (at least in draft) for most of the EUs. The initiating events may be natural disasters or anthropogenic (including deliberate events; see Chapter 4).

[38] A primary reference, where available for an EU, is the DSA implementing the requirement of 10 CFR 830 and described in the *Safety Analysis and Risk Assessment Handbook* (HNF-8739, 2012).

Type 2 - Potential threats from subacute or chronic exposure (hours to days) to undetected or unsuspected site-specific radioactive or chemical hazards (intermediate probability and consequence). These will not occur under "normal" operating conditions, and they may be predicted in the course of an HA and thereby prevented. Specific types of hazards in addition to radiation and chemical hazards exist in many Hanford facilities (e.g., asbestos, beryllium, PCBs) and are considered as part of analyses. Examples of potential Type 2 exposure pathways are given in the exposure matrix below. The recurrent events at the tank farms, where workers have repeatedly reported irritating gas exposures, is a Type 2 event, captured in the air x inhalation pathway in Table 5-1.

Type 3 - industrial accidents and injuries include, for example, transportation accidents, falls, persons struck by objects, crush injuries, machinery injuries, and heat stress. These are relatively frequent events, particularly in construction activities, that may result in death or injury, but usually to one or a few individuals, and can be considered higher probability and lower consequence events compared to Type 1 (above). Although risk for Type 3 events typically is measured as a function of worker hours on the job (Brown 2008), it is not a simple function since contractor or worker experience with particular jobs or sites, along with task complexity and environment, influences safety and safety behavior. The SARAH Handbook (DOE 2012) indicates that industrial accidents and injuries for which standard industrial safety procedures, training, and equipment are in place should be excluded from the HA unless they initiate the release of or exposure to "process hazards'" (radiological and hazardous material).

The three types of worker risk must be considered individually to develop a risk rating, since the risks are not additive.

Table 5-1 provides an exposure matrix for Type 2 risks, identifying potential pathways by which a worker may be exposed to a radiologic or chemical hazard, over a period of hours or days, before the hazard is detected and identified.

Table 5-1. Exposure matrix for Type 2 for facility worker.

Exposure Matrix for Facility Worker with Potential Exposure to Unsuspected Hazard				
	Contaminated Matrix			
	Air	**Water**	**Soil**	**Containers**
Inhalation	Volatiles at tank farms Airborne radiation releases Asbestos			Release during sampling, repackaging and preparing containers for transport
Ingestion			Inadvertent ingestion of soil	
Dermal				Surface contamination
Direct radiation			Direct radiation or vapor intrusion	Direct radiation during handling

Mitigated Versus Unmitigated Risk

There is variability in the definitions and categorization of both likelihood and consequences across the DOE complex (CSTC 2003). At Hanford, DOE mainly uses four categories of likelihood and three categories of consequences as defined in the SARAH for Hanford (HNF-8739 2012 and DOE-STD-3009-2014); see Chapter 4. This approach is used in DOE HAs to identify and control acute events such as natural or anthropogenic disasters that may involve Type I risks to workers. Consequence estimates range from ND from every day background to High (meaning serious injury to multiple persons or a fatality) and are integrated into the overall ratings.

The DSA and other HAs identify unmitigated, worst-case, "what if" scenarios for Type 1 consequences to workers and to the public. The documents also identify the prevention and mitigation strategies used to reduce the risks to within acceptable levels. Nuclear safety engineering plays a primary role in anticipating, evaluating, preventing, and mitigating the Type 1 hazards. As a result, the mitigated risks are usually Low or even ND. Some facilities are intrinsically hazardous due to the inventory and condition of the site. Some tasks are intrinsically hazardous due to the inventory and the activities that must be conducted. For each EU, the scenarios that result in the highest unmitigated dose (including the dose estimate) and the primary mitigation measures are summarized in the EU template.

For Type 2 hazards, the same approach applies. Subacute or chronic exposure to hazards can occur if workers encounter inadequately characterized or newly exposed radiation or chemical hazards. Although DOE and its contractors have extensive safety programs intended to permeate all levels of contracting and all activities on the site, the project assumes that a breakdown could occur, resulting in exposure and increased risk. The professions of industrial hygiene and radiation protection are tasked with the anticipation, evaluation, and control of such hazards, thereby reducing the mitigated risks to Low or ND for most EUs. This is in accord with the OSHA Hazardous Waste Operations Standard (OSHA 1910.120).

For Type 3 industrial accidents and injuries, the project assumes that conditions common to construction activities will apply to many of the remediation alternatives. This project begins by rating the intrinsic, unmitigated hazards for each EU in its current state and during remediation by the preferred (and occasionally by the alternative) option. Some mitigation measures will need to be in place to protect any future surveillance and maintenance workers from remaining hazards, whether federal or private. This is the domain of industrial safety and is part of the safety culture emphasized in DOE's Integrated Safety Management. As a result, fatalities have been rare in DOE's environmental management program, and lost-time injuries (per job-hours) occur at a rate about one-third that of comparable outside work.

Rating Type 1 Risks and Radiation Dose Considerations

The methodology for a summary risk rating will employ the following approach. A basic assumption is that worker risk only exists when work is actually occurring. For remediation projects and/or operating facilities that have HAs or DSAs, the rating for Type 1 risks will rely on the unmitigated dose estimates to the co-located person as the primary differentiating characteristic. This is because dose estimates usually are not directly calculated for facility workers, and the unmitigated dose to the co-located person considers all significant radiological and chemical hazards present in a facility. *The scenarios that result in significant unmitigated doses are the result of initiating events that may occur with a high uncertainty with respect to probability of occurrence, and therefore the consequence rating is assumed to be the risk rating.* Scenarios with the greatest unmitigated dose to the co-located person are summarized (including the dose estimates) and the mitigation measures are described.

For projects that do not yet have an HA or DSA completed, a surrogate evaluation (such as a preliminary HA) will be used based on analogous prior projects to determine the following:

1. How many of the hazards normally analyzed will be present?
2. Is there a novel remediation strategy projected?
3. How extensive is the project (long in duration/broad in impact)?

The limitations of the available information and key uncertainties will be noted in the completed template, with important data gaps relative to risk screening identified.

Table 5-2 summarizes various dose limits, standards, guidelines, benchmarks and recommendations regarding human exposure to radiation. The discussion that follows only refers to whole body doses. The exposures being considered in the Risk Review Project are from Type I events, with ***theoretical scenarios constructed for safety analysis causing postulated exposures*** lasting hours or days. The dose limits and standards provided in the following table refer most frequently to the dose delivered over a year – referred to as the annual dose. The doses are expressed as 'total effective dose' (TED). This consists of summing the dose from all external exposures with the dose from oral or respiratory intakes during the year. This distinction is made between internal and external radiation exposure because internally deposited radionuclides deliver their dose over time following the intake. The total dose that will be received from the intake is calculated, and then assigned in the year of exposure. This is the standard method of accounting for radiation dose that will be received by the individual as a consequence of the long term decay and elimination of the radioactive material from their body.

Doses from natural background, therapeutic and diagnostic medical radiation, and participation as a subject in medical research programs are not included in dose records or in the assessment of compliance with the occupational dose limits.

The values in

Table 5-2 are provided to provide context and include the regulatory levels such as dose limits set by the DOE (DOE 10 CFR 835), the NRC (NRC 10 CFR 20) and standards set by the U.S. Occupational Safety and Health (OSHA). Two advisory bodies, the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) make recommendations regarding allowable or excessive exposure for consideration by regulatory authorities. Some of their recommendations are noted.

These doses are (or would be if an event occurred) superimposed on a background signal of radiation from cosmic rays, terrestrial sources (primarily radon), and internal radionuclides. The average U.S. background radiation (excluding medical uses) was estimated at 360 mrem/year (BEIR 1990). More recent estimates place the average at 310 mrem/year (NRC 2014). Background radiation in radon-rich areas can exceed 1000 mrem per year.

The primary applicable DOE document for controlling radiation exposure of workers at DOE installations is *Occupational Radiation Protection* (10 CFR 835) which defines the radiation protection standard "applicable to DOE, its contractors, and persons conducting DOE activities" and includes equivalent dose limits. In addition to radiation protection limits, DOE establishes 'administrative control levels'. These are below the dose limits, and the intent of the administrative control levels is to ensure that the DOE limits and control levels are not exceeded. They also help reduce the collective dose to individuals and the worker population. The DOE dose-limits take into account information provided by the ICRP, NCRP, and EPA. The whole body dose limit is 5 rem per year (5 rem=5000 mrem=0.05 Sv = 50 mSv). The DOE administrative level is 2 rem per year. The DOE also has a dose limit applicable to the public of 0.1 rem (=100 mrem) per year.

Similar standards are found with the NRC that limits maximum radiation exposure to individual members of the public to 100 mrem (1mSv) per year above background, and limits occupational radiation exposure to adults working with radioactive material to 5 rem (50 mSv) per year (NRC 10CFR 20). The OSHA worker standard is also 5 rem per year.

Table 5-2. Criteria, Standards, Guidelines, Benchmarks and Recommendations from various U.S. and international agencies for human exposure to radiation. (Note: 1 mSV=100 millirem)

Estimated Total effective dose equivalent (TED[39])	DOSE Limits, Standards, Guidelines, Benchmarks and Recommendations
0.012 rem (12 mrem or 0.12 mSv)	EPA recommends a 12 mrem/yr dose (effective dose equivalent), corresponding to an estimated 3 x 10^{-4} excess lifetime cancer risk (incidence) for 30 yr residential land use at CERCLA sites.[a]
0.025 rem (25 mrem or 0.25 mSv)	NRC's License Termination Rule (LTR) specifies 25 mrem/yr dose (TED) for unrestricted use from all exposure pathways combined to an average member of the critical group. (http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html#part020-1402
0.1 rem (100 mrem or 1mSv)	Expressed as an annual dose limit for public. (DOE 10CFR835.207) It is set at 0.1 rem (100 mrem or 1 mSv) per year above background. Other Federal agencies (OSHA, NRC 10CFR 20) use the same limit for public exposures.
0.3 rem (300 mrem[a] or 3 mSv)	Average annual U.S. background radiation from natural sources is about 0.3 rem per year (NRC 2014) NOT including medical uses[a]. An individual's dose depends on many factors including location, altitude, geology, and lifestyle.
2 rem (or 2,000 mrem or 20 mSv)	Occupational dose as recommended by the ICRP[b] is 2 rem (or 0.02 Sv or 20 mSv) per year. US DOE establishes an Administrative Control at an occupational dose of 2 rem per year
5 rem (or 5,000 mrem or 50 mSv)	Annual occupational dose limit as set by the DOE (10 CFR 835 DOE *Occupational Radiation Protection)* rule for radiation workers specifies a dose-limit of 5 rem (or 5,000 mrem or 50 mSv) per year. This is equivalent to both the US NRC and the OSHA Occupational radiation exposure standard of 5 rem per year for non-DOE workplaces.
25 rem (or 25,000 mrem or 250 mSv)	If from *a single short-term event*, the 25 Rem DOE dose limit applies to a worker who is protecting large populations or critical infrastructure or performing life-saving efforts in emergency circumstances. This one-time qualified worker dose requires DOE prior authorization to proceed
100 rem (or 100,000 mrem or 1000 mSv)	A 100 rem dose, occurring from a single short-term event, may cause acute symptoms (nausea and vomiting with 4 h) in 5 - 30 percent of the exposed population. The risk of fatal cancer is increased by up to 8% (the lifetime risk of fatal cancer without radiation exposure is approximately 24% (NCRP, 2005)). A 100 rem dose, accumulated over a working lifetime yields the ICRP[b] recommended maximum lifetime dose for a radiation worker: 1 Sv (or 100 rem). This dose, accumulated over a long period of time, will not cause acute symptoms in the exposed population. Because the dose is spread out over time, the estimated risk of cancer is cut in half to approximately 4 % (In contrast, the NCRP[b]=National Council on Radiation Protection recommends a maximum permissible dose of 0.65 Sv (or 65 rem – which is 10 mSv x age).

a=Average background varies with elevation up to about 500 mrem
b=ICRP= International Council on Radiation Protection=consensus body with no regulatory authority
NCRP=National Council on Radiation Protection

[39] The term TED, which is replacing the earlier TEDE, reflects current international, industry and federal standards and reflects DOE STD 3009-14. Some of the documents cited in this report specify doses using TEDE. For most circumstances, the differences between TED and TEDE are not substantial.

Table 5-3 presents the Risk Review Project ratings for Facility Workers and Co-located Persons that are based on *unmitigated* dose estimates from DSA or hazard assessments using the estimated unmitigated dose to the co-located worker as the metric Risk Review Project rating. Similarly, Table 5-4 presents the Risk Review Project ratings for the Public. Rating categories for the Public are more stringent than for Facility Workers and Co-located Persons than for the Public because of increased training and informed consent associated with worker and on-site activities. Note that rating definitions used by the Risk Review Project are different from SARAH risk rating assignments. These differences were to facilitate more effective risk communication with a general audience in context with information provided in

Table 5-2.

Table 5-3. SARAH and Risk Review Project "Worker" and "Co-located Person" Risk Rating Basis for Unmitigated Type 1 Design Basis Events (single event unmitigated dose estimates).

Unmitigated Estimated Total Effective Dose Equivalent (TED)[b]	**SARAH Rating** (corresponding to DSA or HA ratings)	**Risk Review Project Rating**
≤0.1 rem		ND[a]
>0.1 rem to ≤5 rem	Low	Low
>5 rem to ≤25 rem	Low	Medium
>25 rem	Medium	High
>100 rem	High	

[a] "ND" or "not discernible" does not exist in the DOE nuclear safety risk or consequence levels (DOE-STD-3009-2014 or SARAH). This rating is added for binning purposes.

[b] The term TED, which is replacing the earlier TEDE, reflects current international, industry and federal standards and reflects DOE STD 3009-14. Some of the documents cited in this report specify doses using TEDE. For most circumstances, the differences between TED and TEDE are not substantial.

Table 5-4. SARAH and Risk Review Project "Public" Risk Rating Basis for Unmitigated Type 1 Design Basis Events (single event unmitigated dose estimates).

Unmitigated Estimated Total Effective Dose Equivalent (TED) [b]	**SARAH Rating** (corresponding to DSA or HA ratings)	**Risk Review Project Rating**
≤0.1 rem		ND[a]
>0.1 rem to ≤1 rem	Low	Low
1 to ≤5 rem	Medium	Medium
>5 rem	Medium	High
>25 rem	High	

[a] "ND" or "not discernible" does not exist in the DOE nuclear safety risk or consequence levels (DOE-STD-3009-2014 or SARAH). This rating is added for binning purposes.

[b] The term TED, which is replacing the earlier TEDE, reflects current international, industry and federal standards and reflects DOE STD 3009-14. Some of the documents cited in this report specify doses using TEDE. For most circumstances, the differences between TED and TEDE are not substantial.

RATING TYPE 2 AND TYPE 3 RISKS

The following approach supplements the information that may be obtained from HA documents for each EU. Sites with large amounts or concentrations of radioactive or chemical materials, particularly in vulnerable containers, or in geologically vulnerable or physically unstable situations, will have higher likelihoods of acute releases with high consequence ratings (Type 1). Inadequately characterized sites may result in higher subacute to chronic exposure to radiation or chemicals. The likelihood of an industrial accident/injury depends on the number of workers, the duration of the job(s), and the nature of the workforce (high injury rates in some construction trades and truck operations). Moreover, some types of work (e.g., demolition) offer greater opportunities for industrial-type accidents (Chapter 4).

The methodology, summarized in Table 5-5 that will be used to arrive at risk ratings for each type of EU, taking into account site-specific conditions, the source inventory, physical status of containers and structures, the type and size of workforce, and their activities is as follows. For each of the five categories of EU there are starting estimates of Type 2 and Type 3 exposures to workers. These starting values are modified in the EU templates, taking into account inventory, status, and proposed remediation.

The following information may be incorporated into assessments of the unmitigated risks to workers:

- Sources range from negligible quantities, or concentrations with minimal exposure opportunity as in groundwater plumes, may be considered insignificant when compared to large amounts of highly radioactive or toxic and potentially pyrophoric chemicals (such as subsurface at Building 324 and the 618-11 burial grounds, vertical pipe units and casions).

- Situations range from readily accessible sites with well-contained contaminants, with adequate documentation of the inventory, to vulnerable hazards in deteriorating containers, in unstable buildings, or inaccessible locations and poorly documented inventory.
- Workforce involvement ranges from few workers involved in surveillance and maintenance to large numbers of workers, equipment operators, or construction workers employed by multiple contractors, involved in large-scale excavations, demolition, or operating facilities.
- Activities range from low hazard with only indirect exposure potential, for example well-drilling, to direct hands-on involvement with contaminated soil, containers, or structures.

In summary, information derived from the EU templates and the corresponding HA, DSA, or other documents will be used to develop a facility worker rating with respect to Type 1 (acute events) and Type 2 (subacute and chronic exposures) hazards, while Type 3 (industrial accidents) hazards will be inferred from the nature and scope of particular remediation approaches.

Hanford remediation workers will face unmitigated Type 3 industrial-type injuries comparable in type to those experienced at non-DOE sites, but at a lower frequency due to mitigation by Integrated Safety Management. The Type 3 risks are intrinsic to the type of work being done, worker locations and proximity, confined space, elevated workplace, and crane or equipment operations. Potential exposure to radiation and some chemical hazards is higher on the Hanford Site than off-site. In general, unmitigated construction/excavation/ demolition hazards at DOE sites are similar to those elsewhere (Gochfeld 2004), although the event and injury rate is lower (Duncan 2005). The potential risks from these hazards must be considered for DOE remediation projects. The larger the scope of the project or activity, the greater the contractual and oversight complexity, and/or the longer the duration, the greater the likelihood that an accident of this type will occur.[40] In some cases, cleanup is being delayed to learn from earlier cleanups (U-Canyon, 618-10) as well as from simulation studies (Building 324), specifically because of recognition of high potential for some Type 1 along with Type 2 and Type 3 risks and the need to gain experience in risk mitigation approaches.

[40] Type 3 risk scenarios may or may not differentiate among remediation projects. Furthermore, DOE safety analyses assume that standard safety training, procedures, and equipment should prevent such events.

The following table provides an overview of unmitigated hazards to workers, related to the five types of EUs considered in the risk rating. The rating may vary for specific EUs and most are expected to be mitigated to low levels.

Table 5-5. Overview of unmitigated Type 2 and 3 risks to workers.

Type of Evaluation Unit	Activities	Type 2 Subacute To Chronic Exposure	Type 3 Unmitigated Industrial Accident Risk
Legacy waste sites	Sampling and characterization, surface construction activities, soil excavation, recovery of buried containers, operations with heavy equipment, manual operations	Low to Medium	Low to Medium
Tank waste and farms	Maintenance, transfer, remediation, repair, leaks, some soil removal (many operations may lead to vapor releases and exposure)	Medium (current reports of exposure with medium health consequences)	Low to Medium (current exposure to irritating vapors)
Groundwater	Well-drilling, maintenance, water treatment, in situ treatment	ND to Low	Low
D&D	Decontamination and demolition activities (may lead to collapse or falls), heavy equipment use; confined space entries	Low to High	Medium to High
Operating facilities	Heavy equipment operations, transfers and monitoring of drums and containers, loading and unloading trucks	Low to Medium	Low to Medium

5.4. PUBLIC HEALTH AND RISK

HAZARD, EXPOSURE, AND RISK

This section presents the methodology to be used for rating risks by identifying potential exposure pathways to the public under various current and future scenarios, considering likelihood and consequence. The hazard at any EU is represented by its inventory of radioactive and chemical materials; their physical-chemical form; potential exposure pathways; barriers to exposure that may be engineered systems, natural systems, mitigation measures or institutional controls; and initiating events that may cause partial or complete failure of one or more of the barriers. Exposure may be in the form of inhalation, ingestion, contact with hazardous materials, or external radiation dose. Completed exposure pathways result in human health risk. Potential or future completion of pathways results in potential risk. Further, for risks to human health, the level or magnitude of exposure and duration are important factors that lead to a risk rating ranging from ND to High. Thus, exposure scenarios are discussed in detail, including likelihood of exposure and consequences. A scenario with no current completed exposure pathways and with all future potential pathways effectively interdicted will have a rating of Low, compared to scenarios with currently completed or unblocked future pathways (potentially a rating up to High). The potential failure of barriers (engineered or natural) and the waning of institutional controls are of major concern to stakeholders.

Some EUs will be cleaned up completely to industrial or unrestricted land-use levels with the removal of contaminated structures, containers, equipment, and soil. The formerly used nuclear reactors along the river corridor, for example, temporarily cocooned, are slated to be demolished and removed to ERDF, with extensive cleanup and source removal of the former sites. For various waste sites with soil contamination, the soil may be cleaned up to industrial or to unrestricted use levels. Some facilities within other EUs will be entombed in place. For example, current planning for PUREX considers stabilization, grouting, and entombment of contamination in place for both the processing cells within the main canyon building and disposal tunnels. The entire EU or at least a large portion of it may be capped and fenced, and access will be restricted in perpetuity by barriers and institutional controls. There is no plan for the federal government to relinquish control of many EUs, and the federal government retains responsibility in perpetuity for maintaining barriers and controls.

Thus, for the D&D sites, the tank farms, and permitted waste disposal sites within the Central Plateau, there is no reasonable potential for future public use or intrusion, except as part of the Manhattan Era National Historical Park. The future of the currently operating and planned operating facilities is uncertain. Future access and uses of the remaining areas, including legacy waste sites, and minimally impacted areas as well as future access to groundwater, are part of land-use planning.

PUBLIC AND NON-WORKER CONTROLLED ACCESS

Public

"Public" typically encompasses several categories of people. However, for the purposes of the Risk Review Project, "public" is narrowly defined as people having unrestricted access to areas at or beyond the security perimeter of the Hanford Site, or boundaries at which access controls are maintained. The Risk Review Project considers the security perimeter as the south bank of the Columbia River on the north and east and the public highways such as Routes 240 and 24 on the west and south (see shaded area in Figure 5-1). Route 240 practically bisects Hanford, with former industrial 200 areas to the north and east and the Arid Lands Ecology Preserve (also controlled access) occupying much of the area to the southwest. Access to the former industrial sites (mainly the 200 Area) is strictly controlled by entrance barricades requiring badges and escorts. Signage, fencing, and patrols limit access even within these areas. Likewise, the Columbia River and the beaches or littoral zone on both sides of the river are open to public boating access, although large "keep out" signs discourage trespassing beyond the beach area into the Hanford 100 and 300 Areas, where active cleanup is ongoing. Thus, in effect, the highway and river provide boundaries relevant to the public. Currently and prior to transfer from DOE or other federal control, areas of the Hanford Site, access to most of the Hanford Site within these boundaries, is controlled. Nonetheless, some unauthorized intrusion may occur, exposing people to hazards.

As cleanup progresses and in the post-cleanup period, the boundaries for public access may be revised, allowing for controlled access to parts of the remaining Hanford Site for specific uses and maintaining parts of the site for ecological preservation. Future uses may include traditional Tribal activities, recreational users in appropriate locations, and businesses that may be allowed to operate on the "industrial/commercial use" areas. Unauthorized intrusion may also occur with the breakdown of institutional controls. For the Risk Review Project, institutional controls are assumed to remain effective for at least 100 years following the transfer of land from federal control to state, local, or private agencies. For the industrial-exclusive zone, the federal government will need to maintain the barriers and institutional controls in perpetuity.

Controlled Access Populations

Prior to or during cleanup, access including by escorted visitors, tourists and others, is restricted from unremediated or active remediation areas with hazardous conditions, such as burial grounds or contaminated facilities to be decommissioned.

Various groups of people may be allowed controlled access to areas within the Hanford Site security boundary for specific purposes and activities. These may include traditional cultural activities, educational visits, national monument and museum visits, and recreational uses, among other activities. Each controlled access use will be accompanied by a set of controls and mitigation measures considered appropriate to the use. Controls may include escorts, access limited to only parts of the site, limitations on specific activities, duration of visits, and monitoring, among other controls. Within the Risk Review Project, controlled access is assumed to include controls and mitigation measures that provide appropriate protection of human health for the given population of visitors and activities. However, such individuals may be close to a facility at the time of an event, thereby incurring some risk of type 1 exposure.

For the post-cleanup period, people present as future employees of businesses constructed on land designated for industrial or industrial-commercial land-uses are considered public.

Tribal Activities

Several Native American tribes have treaty rights that affect access to and activities on the Hanford Site and have expectations to camp, hunt, fish, gather, and pursue cultural activities on the Site. The Yakama identify their historic cultural connection to the lands occupied by Hanford (R. Jim personal communication). Two Tribal comprehensive exposure assessment documents (Harris & Harper 2004; Ridolfi 2007) develop cumulative exposure scenarios for various uses of the Hanford Site. The most complete scenario corresponds to a rural farmer scenario coupled with consuming large amounts of fish and the daily use of sweat lodges by adults and youths. The latter is a unique activity with multiple direct pathways (ingestion, inhalation dermal) as well as indirect pathways (activities in support of sweat lodge use), and thus represents a maximally exposed individual.

Any use of Hanford lands prior to release from federal control is considered part of controlled access, with appropriate controls and mitigation measures in place. Biomonitoring (e.g., of collected flora and fauna) is considered important to ensuring safety during use that involves consumptive practices.

STEALTH INTRUDERS

The NRC distinguishes deliberate intrusion (so-called stealth visitors or trespassers who knowingly violate access controls) from inadvertent or lost intruders. The consequences will vary with the hazards encountered, and by route, duration, and the period of exposure (before and during remediation, and future land users). A stealth intruder might include a thrill-seeker, a political demonstrator, a saboteur, or a hypothetical stealth farmer family (Antonio et al. 2002). "Stealth" (unauthorized) or inadvertent intruders may enter areas where they are exposed to radiologic, chemical, or structural hazards. For example, a visitor on a guided tour might wander away from the group to take photographs. A stealth farmer as used by EPA is a family of four that climbs a fence or by passes access controls, sets up a residence, farms and consumes crops, and potentially spends 365 days a year on the site cleaned up only to industrial levels. During active remediation, a stealth farmer is precluded by site security controls. The waste sites like the ERDF and some entombed sites will be controlled by DOE or its successor in perpetuity. For other EUs, the post-federal control period may see institutional controls or barriers fail, the potential for completed exposure pathways will increase, and "stealth" may become a moot point.

PUBLIC HEALTH EXPOSURE SCENARIOS

General approaches

The SARAH for Hanford (HNF-8739, 2012 and DOE-STD-3009-2014) estimates no significant exposure resulting in safety and health consequences to the off-site public during active cleanup, even during site "accidents" once mitigation measures are considered.

Controlled access to non-contaminated areas of Hanford would result in ND exposure and ND-to-Low risk. Controlled access to EUs prior to completion of cleanup would require badging and chaperoning; hence, exposure should be ND to Low, or access would not be allowed. Disastrous (Type 1) events occurring during such visitation would affect both facility workers and co-located persons, as well as controlled-access people. These Type 1 events are addressed in DSAs and HAs, and the controlled-access person may experience exposure at levels similar to or less than the co-located person, depending on their location relative to the event. In DSAs, attention particularly focuses on facilities with large inventories of highly hazardous material, such as plutonium at PUREX or the cesium and strontium capsules at WESF. Intruder actions that result in exposure to these radiation sources, would be a low probability occurrence and therefore are rated as Low.

Because exposure is central to determining risk and consequences to individuals from on-site contamination and remediation, and after completion of remediation, it is discussed next. Table 5-6 provides a generalized exposure matrix that can be used to determine whether there are completed or potential exposure pathways. This matrix can be applied to the land uses designated for individual EUs as part of the Risk Review Project. Each cell in the matrix represents a potential exposure pathway. This general exposure scenario forms the basis for the risk rating for each type of person that is not part of the facility worker category. When engineered barriers, natural barriers, and/or institutional controls are successful, there should be no completed pathways to any members of the public.

As with workers, initiating events causing sudden releases of energy, radiation, and/or chemicals (Type 1 events) can impact the public, even those located miles from the source of the event. The unmitigated risks are captured in HAs and/or DSAs. During the active remediation period, when access is restricted to the site and the EUs, this is the main source of risk to the public. This chapter provides a methodology for relative rating of exposure to the public from the EUs in the active remediation period (2015‑2064), including before and during remediation. After remediation is complete, future land uses may begin. If land uses are consistent with the cleanup levels achieved for residual contamination, risk to the public should be ND. Many EUs may be remediated in place, potentially leaving a significant, but secured, inventory of radioactive materials and chemicals, especially in the Central Plateau. The grouted conditions coupled with security and access barriers (fences, cover materials) and institutional controls, should deter future intrusion and exposure. Even if engineered barriers are not maintained and institutional controls fail, the residual contamination should be in a form that remains relatively inaccessible.

During the active remediation period, the greatest risk to the public is from a Type 1 event extending from the source facility to the controlled access boundaries, the public highway, or the Columbia River. Remediation is expected to remove, stabilize, and/or contain the inventories that could be released in a Type 1 event. Thus, the probability and consequences of Type 1 events are greatly reduced or eliminated upon completion of an EU remediation. Therefore, the risks to the public in the post-remediation period would be Type 2 risks, from chronic exposure to residual contamination, due to a disconnect between projected land use (and corresponding cleanup levels) and actual land use.

However, some stakeholders are concerned that land uses entailing higher-level exposure scenarios than “industrial” may occur in areas designated for “industrial” use only. Failure of engineered barriers and institutional controls may occur, allowing future occupants to encounter contamination, completed exposure pathways, and risks. The Risk Review Project assumes that during the 2064‑2164 period barriers and institutional controls will be intact. Human health risks presented by failure of institutional controls will be considered in the Final report but are not included in the analysis as part of the Interim progress report.

If barriers or controls break down prematurely, public risk may occur. If consumptive recreation (fishing, hunting, gathering) or residential uses intrude on land cleaned up to industrial land-use levels, exposure and excess risk to the public may occur. This is a concern voiced by the Tribes and stakeholders who reviewed the draft methodology. Risk assessments (DOE 2010) using Tribal exposure scenarios did identify significantly elevated non-cancer and cancer risks, including the potential impacts should institutional controls fail now or in the near-term post-remediation period (2064‑2164). The most challenging and controversial issues for public exposure and health occur in the long-term period (2164‑3064), when federal control may be in jeopardy, engineered barriers may require maintenance, and institutional controls may wane or fail entirely.

Table 5-6. Generalized exposure matrix. Each cell represents a potential exposure pathway that may occur during the different evaluation periods. Some potential exposure pathways and some receptors are not applicable during specific evaluation periods.

		Contaminated Environmental Media			
		Air	**Water**	**Soil**	**Food**
Route of Uptake	**Ingestion**		Drinking water is major pathway for GW or SW[(a)]	Toddlers[(b)], gardeners and some construction workers may ingest soil that contains contaminants	Major route for home gardens, rural farms, tribal members consuming fish, game, and plants
	Inhalation	Major pathway for airborne contaminants	Volatiles and aerosols during cooking and showering and some traditional Tribal activities (i.e., sweat lodges)	Fine dusts generated during construction, transport or natural dust storms; Vapor intrusion	Not applicable[(c)]
	Dermal	Not applicable	Some organics when showering or bathing	Some contaminants in muds and slurries, and contained on clothes	Not applicable
	Direct	Direct radiation exposure or vapor intrusion from soil, containers, structures			

a. GW = groundwater, SW = surface water or Columbia River water.
b. The inadvertent or deliberate ingestion of soil by toddlers is often the main driver of residential or recreational (playground) risk assessments.
c. Not an applicable pathway.

EPA Land Use Scenarios

The Risk Review Project is not conducting new or independent risk assessments, but rather is providing several land use and exposure scenarios for context.

The EPA guidance documents (EPA 2003) and memoranda for CERCLA sites identify two main categories of future land use. These are variously referred to as "industrial" or "industrial/commercial" on the one hand and "residential" or "unrestricted" on the other. The latter may include either groundwater or surface water as appropriate to the site (EPA 2003, Chapter 3). There may be many site-specific variations and additional land use categories. Many parts of the United States that have CERCLA sites are already urban industrial, relying on treated public water supplies rather than groundwater. These are residential but not unrestricted uses (Gochfeld et al. 2015). Urban communities may have apartment complexes with no soil contact, eliminating the most sensitive exposure pathways present in rural and suburban use scenarios. Various additional scenarios include the "stealth farmer," the "avid angler," Tribal multimedia exposure (e.g., from sweat lodges), and others that reflect use or avoidance of particular exposure pathways. Potential recreational scenarios vary based on the frequency of visitation and the intensity of resource use, including whether hunting and fishing are allowed. At Hanford, Tribal scenarios, including on-site residence, fishing, hunting, gathering, and particularly daily sweat lodge use, have the highest potential exposure through multiple pathways. Recreational use scenarios need to consider that some forms of recreation, such as intensive off-road vehicle use, can both harm the ecology and disrupt the soil surface integrity, thus potentially creating secondary exposure pathways.

For many CERCLA risk assessments, ingestion of soil, particularly by toddlers, is the "driver" of the risk assessment (Moya and Phillips 2014). In general, soil access can be interdicted by removing contaminated near-surface soil or hazardous materials followed by at least 5 m of clean soil cover. This would prevent both residential and agricultural contact with residual contamination in the soil (very deep rooted plants may pose an exception). This mitigation may convert a high risk to a low risk. Residential use without groundwater access may be allowed, where external water sources can be provided. The "suburban residential" scenario is consistent with local experiences, since part of the City of Richland, for example, relies on surface water for drinking.

At the opposite end of the spectrum from unrestricted future land use is a completely restricted, no access zone, sometimes referred to as a "sacrifice zone," which includes areas destined for long-term disposition of hazardous and radiologic waste, either too hazardous to remediate or aggregated at an on-site permanent disposal area, monitored in perpetuity by the federal government (e.g., ERDF at Hanford). These disposal sites rely on a combination of engineered barriers (e.g., fences, caps and liners), natural barriers (e.g., contaminant retention in the vadose zone), and institutional controls to prevent intrusion, contaminant dispersion, and human exposure. The DOE or its successors have perpetual responsibility for these sites. The land use EIS designation "Industrial: Exclusive" (DOE/EIS-0222-F 1999) is a "no access" waste disposal and storage designation.

Commercial-industrial sites can be occupied by adults up to 40 hours per week over a 25 to 40 year working lifetime. Residual soil contamination precludes residential use, and it is assumed that there are no airborne contaminants that would require the future workers to use respiratory protection. Dust suppression, typically by paving (capping) or vegetative land cover, prevents access to soil contamination. Commercial facilities also have clients or customers who are not employees. Their time on the site and opportunity for exposure is lower than for the 40 hour per week employee.

It is usually assumed that if groundwater is contaminated (as it is in most of the regions that have sites on the National Priorities List), use of groundwater for drinking will be restricted until all contaminant levels meet drinking water standards, even while the surface is released for use. The Risk Review Project methodology considers groundwater as a separate receptor from other potential exposure pathways (Chapter 6). Although future users and occupants of the site are most likely to rely on surface water for most uses, several exposure scenarios for future land use contemplate domestic reliance on groundwater for drinking water. Moreover, the Tribal scenarios assume that a failure of institutional controls may allow current use of contaminated groundwater prior to remediation (Ridolfi 2007; DOE 2010), although it is unlikely that groundwater could be accessed anywhere other than at springs along the riverbank during low water periods.

The near-surface soil cleanup levels for a residential land use are typically 5 to 15 times lower than for industrial use, to preclude significant exposure to a toddler or gardener.

Hanford Comprehensive Land Use Plan and Future Exposure Scenarios

The Comprehensive Land-use Plan for Hanford (CLUP; DOE/EIS-0222-F 1999) designates near-term, post-cleanup land uses, as well as a process for periodic review and revisions. Notwithstanding the land use EIS and subsequent record of decision, future land use at Hanford is a topic of considerable disagreement. The Core Team has requested that an "unrestricted release" scenario, also known as "residential land use," be considered as an alternate assessment scenario for areas outside of the Central Plateau and for parts of the 100 and 300 Areas, even though it is not included in the land use EIS. Additional land uses have been described elsewhere (e.g., PNNL 1998; Richland 2008). Additional land use scenarios also are being considered in response to input from the Tribes and the broader set of stakeholders as part of public comment on this document. Post-cleanup, public exposure to contaminants may occur if barriers or institutional controls fail, resulting in unplanned contaminant dispersion or human exposures, or if higher-level land use (e.g., residential occupancy of industrial-designated land) occurs.

The primary land uses defined in the EIS (1999), are described below.

- **Industrial exclusive:** This is a core zone within the Central Plateau designated for long-term waste management.
- **Industrial:** Much of these areas had substantial surface and subsurface contamination from DOE activities. After remediation, future commercial and industrial uses as Brownfields would be allowed, based on a 40-hour work week and a 40-year working lifetime.
- **Research and development:** This land use is an economic designation that appears to correspond to an industrial use scenario.
- **Conservation (Mining):** This is mainly a preservation area, but DOE can use some areas for surface mining in conjunction with its waste management activities (i.e., soil borrow pit areas for backfilling and capping remediated land areas). This designation may allow future public access.
- **Preservation:** This is land designated for protection of ecological and cultural resources. These areas will be open for public visitation under the auspices of the U.S. Fish and Wildlife Service.
- **High-intensity recreation:** These are areas along the Columbia River where extensive infrastructure development will attract tourism and various forms of recreation (swimming, boating, hiking, etc.). There currently is no explicit limit on visitation frequency or intensity of use.
- **Low-intensity recreation:** These are areas of limited infrastructure development and support (i.e., picnic tables). There currently is no explicit limit on visitation frequency or intensity of use.

The DOE land use EIS designations provide broad land use categories and descriptions of potential associated activities, but do not provide exposure scenarios to serve as the basis for risk comparisons. The industrial and research and development designations are assumed here to correspond to the industrial use exposure scenario category. For public access areas, the land use EIS does not specify the frequency or duration of allowable visitation, nor is there a statement for the conservation and preservation areas regarding whether extractive uses (harvesting and consuming roots, fruits, fish, and game) would be specifically allowed or precluded.

There has not been a follow-up delineation by DOE of specific exposure scenarios to be used in risk assessments that provide a one-to-one correspondence with the EIS land use designations. However, several different exposure scenarios are discussed in the other DOE, state, Tribal, and EPA documents, and some of these are discussed below to illustrate the different assumptions and pathways.

The generalized exposure matrix (Table 5-6) is useful in considering specific public exposure scenarios with regard to potentially completed exposure pathways.

Exposure Scenarios from the Hanford 300 Area RI/FS

In addition to the land use designations in the EIS and the Columbia River Comprehensive Impact Assessment, CRESP reviewed scenarios from the 300 Area River Corridor Remedial Investigation/Feasibility Study (RI/FS; DOE 2013b, EPA 2013) including (in descending order of residual contamination) 1) industrial, 2) casual recreational visitor, 3) residential monument worker, 4) residential, and 5) tribal. This document provides more useful hazard and exposure information than the land use EIS. These are described briefly in Attachment 5-1. The City of Richland Comprehensive Land Use Plan (Richland 2008) also includes residential development on parts of the 300 Area.

Risk Review Project Methodology for Rating Risks to the Public

The generalized exposure scenario (route of exposure by media type, e.g., food or water; Table 5-6), the Hanford Site land use types, were used to develop a methodology for rating risks and impacts to the public. The Washington Department of Ecology scenarios for unrestricted use and industrial use were taken as reasonable limit cases for allowable post-cleanup contaminant levels because specific exposure scenarios have not been developed that correspond with the EIS land use designations. The Risk Review Project methodology includes the following steps for evaluating public health with respect to each EU and evaluation period:

1. Review the likelihood and unmitigated consequence categorizations for the EU-specific postulated acute events from the EU HA or DSA[41] when available or from analogous documents or approaches. An HA or DSA may exist for a specific EU such as a building or for a grouping such as tank farms. For remediation projects and/or operating facilities that have HAs or DSAs, the rating for Type 1 risks will rely on the unmitigated dose estimates to the public as the primary differentiating characteristic. This is because the unmitigated dose to the public considers all significant radiological and chemical hazards present in a facility in combination with the potential initiating events. *The scenarios that result in a significant unmitigated dose are the result of initiating events that have high uncertainty with respect to probability of occurrence, and therefore the consequence rating is assumed to be the risk rating.* Scenarios with the greatest unmitigated dose to the public are summarized (including the dose estimates) and the mitigation measures are described. Table 5-4 provides the unmitigated dose estimate range for Type 1 exposures, corresponding Risk Review Project rating, and notes providing context for the dose range and rating.
2. Identify the proposed alternative remediation options for the EU. For post-remediation exposure, refer to Table 5-7 as a starting point and modify risks according to site-specific conditions. This may be an iterative process as conditions or information change. Evaluate the likelihood and consequences of a reasonable maximally exposed individual scenario before and after remediation based on the designated land use.
3. Evaluate the potential for the public reasonable maximally exposed individual to violate engineered or institutional controls during the selected evaluation period (Table 5-7).
4. Evaluate the likelihood and consequences of a scenario involving a stealth intruder who enters the EU during remediation activities (Table 5-8). Stealth access would be possible along the river into the 100 Area, with a very low probability in the 200 Area.
5. Summarize the risk ratings.

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[41] HAs and DSAs typically are not developed for specific remediation activities until the early stages of work plan development.

Table 5-7. Near-term post-cleanup likelihood, consequence, and risk rating table for violation or failure of engineered and institutional controls for each designated land-use type. The areas are assumed to be under federal control.

Land Use Designation	Comments	Likelihood of Occurrence	Consequence	Risk Rating
Industrial exclusive hazardous waste management	Engineered and institutional controls will limit access to authorized personnel.	Unlikely	Medium	Low
Industrial	Institutional controls will limit hours on-site to 40 hours per week for industrial or commercial facilities until failure.	Anticipated	Pre-failure: Low Post-failure: Medium	Pre-failure: Low Post-failure: Medium
Research and development	Institutional controls will probably limit hours on-site to 40 hours per week.	Anticipated	Pre-failure: Low Post-failure: Medium	Pre-failure: Low Post-failure: Medium
High-intensity[a,b] recreation	Frequent visitation with some resource extraction (i.e., fishing) to uncontaminated land.	Anticipated[d]	ND	ND
Low-intensity[a,c] recreation	Infrequent visitation with no resource extraction from uncontaminated land.	Anticipated[d]	ND	ND
Conservation/ mining	Public access may be allowed to most of this area.	Anticipated[d]	ND	ND
Preservation	Public access allowed for recreation.	Anticipated[d]	ND	ND

a. The land use designation refers to the extent of infrastructure, not the type of activities.
b. The Risk Review Project uses this term to refer to frequent visitation with some resource extraction.
c. The Risk Review Project uses this term to refer to infrequent visitation with no resource extraction.
d. Prolonged camping and extractive/consumptive use.

Several of these EU types can be viewed as active construction sites with the main intruder risk related to hazards other than site-specific radiation or toxic materials (e.g., traffic, equipment, falls, or other reasons that the public is excluded from any construction site). This table can be used for each potential remediation option for each EU, with consequences modified according to site-specific conditions. The likelihood of an intruder at any EU is influenced by the EU's distance from public roads and/or the Columbia River and by signs, fences, other barriers, and patrolling. At the request of a public comment, Tribal use following failure of barriers and institutional controls also will be addressed.

Table 5-8. Consequence to stealth intruder and Tribal member. During the active cleanup period, consequence to a stealth intruder who bypasses access controls and enters an active remediation area, perhaps deliberately approaching a work area where a particular remediation is in process.

Remediation Process or Activity	Consequence to Stealth Intruder during Remediation	Consequence to Tribal Member if Controls Failed Now
Natural attenuation	ND	Medium to High if contaminated GW were accessed
In situ containment (capping)	Low to Medium	Medium to High if contaminated soil were accessed
Pump and treat	ND to Low	Medium to High if contaminated GW were accessed
In situ treatment (grouting, barriers)	ND to Low	Low
D&D	Medium to High	High
Excavation, trucking, disposal	Medium to High	Medium to High

Table 5-9. Post-cleanup intruder and Tribal rating. Risk-rating matrix for land use designations, for reasonably maximally exposed individuals such as a stealth farmer intrusion on land, after completion of remediation. For the purpose of this rating, assume farmer does not rely on groundwater. For worst case, assume the intrusions are actually occurring (i.e., Likelihood = 1). Tribal exposure assessment does assume that groundwater may be used for all purposes.

Land Use Designation	**Post-cleanup Intruder Risk Rating** (allowed rural farmer, stealth farmer or resident on-site, irrigates crops, hunts, fishes, but no groundwater use)	**Post-cleanup Tribal (**comprehensive exposure assessment including use of groundwater for drinking, bathing, irrigation, and sweat lodges)
Industrial exclusive	Not applicable	Not applicable
Industrial	High	High
Research and development	Insufficient information	Insufficient information
High-intensity recreation	ND Low for the avid angler scenario	Low to Medium based on very high level of fish consumption
Low-intensity recreation	ND	Low to Medium based on very high level of fish consumption
Conservation	ND	ND
Preservation	ND	ND
Unrestricted	ND	ND

5.5. CONCLUSION

The Risk Review Project's rating process focuses on identified EUs that are expected to require remediation. Although many EU's have medium to high unmitigated risks, these should be substantially reduced by a variety of maintenance, engineering, training, and other processes that block exposure pathways or diminish the likelihood or consequence of release. Access to the EUs or their proximity is controlled by DOE, and DOE or federal control will continue beyond 2064 for some areas with residual contamination on the Hanford Site. DOE or its successors will have responsibility for waste sites to be maintained in perpetuity, including entombed facilities.

During the active cleanup period there should be a low probability of public approaching or entering an unremediated EU. Harm from Type 1 catastrophic events or releases may occur. With regard to Type 2, subacute to chronic exposures, the public either is far away or is under controlled access and risks should be ND to Low. The exception would be the failure of a barrier or institutional control, allowing an inadvertent or stealth intruder to encounter a hazardous condition. During the post-cleanup period, land-uses are subject to change. Under the land use EIS and ROD there are no residential uses envisaged for the Hanford Site, with a variety of recreational scenarios possible. Under other land-use plans and assumptions by the State of Washington, City of Richland, and Tribal users, a variety of higher level uses with more extensive exposure scenarios and potential pathways are desired.

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ATTACHMENT 5-1

SUMMARY OF EXPOSURE SCENARIOS INCLUDED IN THE 300 AREA RI/FS

Industrial Scenario

For many parts of the Hanford Site, an industrial (or industrial/commercial) scenario is considered as a reasonably anticipated future land use (assuming cleanup and institutional controls are sufficient to protect future on-site employees and their clients). The industrial scenario is also based on EPA guidance (EPA 2003). Anticipated exposure to contaminants in soil includes direct contact radiation, dust and vapor inhalation, and incidental soil ingestion. A detailed description of the industrial exposure scenario is provided in *Calculation of Radiological Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario* (DOE 2013a). Table 5-10 indicates that although there are several potential exposure pathways, most if not all pathways can be interdicted by layers of soil and capping, leading to very low exposure potential to any residual contamination (however, special controls may still be needed for construction/excavation activities).

Whereas a residential scenario assumes that a homebound person may be on-site 365 days a year for a 70-year lifetime, the industrial scenario is based on assumed on-site activities of 40 hours per week for a 25-year working lifetime. Moreover, any occupational hazards that may be encountered in these future workplaces are presumed to be controlled with negligible impact and no additivity to any exposure to residual legacy radiologic or non-radiologic contaminants.

Table 5-10. Potential exposure pathways to future industrial/commercial employees under the industrial land use scenario. Each cell in the exposure matrix represents a potential pathway.

Exposure Pathway ↓	Contaminated Environmental Media			
	Air	**On-Site Groundwater**	**Soil** (Minimized By Capping Or Paving)	**On-Site Food**
Ingestion		Not allowed	Incidental ingestion	Not allowed
Inhalation	Vapors and dusts emanating from soil		Dust inhalation minimized by capping Vapor intrusion	
Dermal			Direct contact or direct external radiation exposure	

CASUAL RECREATIONAL VISITOR

The conservation/preservation land use areas will be open for "recreation" in the broadest sense (CLUP; DOE/EIS-0222-F 1999). The casual recreational visitor is considered a "reasonably anticipated future land use" for areas along the river, excluding some restricted or otherwise categorized areas (e.g., the 300 Area industrial zone, burial ground, entombed reactors in parts of the 100 Area). These lands and activities would be under the jurisdiction of the U.S. Fish and Wildlife Service. Recreation covers a spectrum of potentially exposed activities. This could range from a single day use hiking and picnic visit to overnight camping (duration unspecified, typically for up to 14 days). Collection of plants (roots, berries) is typical of some Tribal visitation scenarios. Hunting and fishing with consumption represents a further exposure pathway for both avid non-Tribal and Tribal visitors. The avid angler and Tribal scenarios include very high levels of fish consumption, mainly of salmon. Truly casual visitors may be exposed to inhalation of airborne contaminants if present in near surface soil, but will have minimal contact with soil and will not consume groundwater. The exposure assessment in the RI/FS (DOE 2013b) was limited to walking and picnicking along the river, entirely outdoors.

For soil, the exposure pathway included direct contact with surface soil (no digging) and inhalation of dust as well as vapors. Incidental ingestion, particularly for toddlers, would be an important pathway. Groundwater contamination is not considered since groundwater use is not envisioned in this scenario.

RESIDENT MONUMENT WORKER

"Future land use within the River Corridor's 100 and 600 Areas is predominantly conservation/ preservation" (DOE 2013b, p. 6-44). Consistent with the land use EIS, the Hanford Reach National Monument, managed by DOE in conjunction with the U.S. Fish and Wildlife Service, was created in 2000. Establishment of the monument specifically precluded future residential or commercial development. DOE noted that, "For the purposes of the RI/FS, the resident monument worker represents [a] reasonably anticipated future land use (DOE 2013b, p. 6-43)." Areas specifically excluded are the 300 Area industrial zone and the 618-10 and 618-11 burial grounds.

The resident monument worker scenario was originally designed to reflect an occupationally exposed worker who was present on-site for more than 40 hours per week, including living on-site on a remediated waste site and working outdoors (tour leader) in the River Corridor for 40 hours per week. It is identified as an adult scenario (DOE/RL-2007-21 2007). As with a residential scenario, the resident monument worker scenario includes domestic well water access to groundwater. It differs from the residential scenario in that no food chain pathways are included.

The resident monument worker scenario considers exposure to soil, inhalation and direct contact with the volatile materials in the vadose zone, and airborne vapors and dust. "Adults could potentially be exposed to site contaminants in shallow vadose zone material at their residence through direct external exposure to radiation, inhalation of intruding vapors, incidental ingestion, and dermal absorption. During working activities, these adults may also be potentially exposed to contaminants in shallow vadose zone material by direct external exposure, incidental ingestion, dermal absorption, and inhalation" (DOE 2013b). Children are excluded from this scenario; hence, surface soil ingestion by toddlers is not a pathway.

The resident monument worker scenario represents a group of people that is too narrowly defined to be useful for the specific objectives of the Risk Review Project, and it will not be considered further.

RESIDENT

The residential scenario represents an unrestricted land use scenario including children and assumes 365 days/24 hours for some individuals with use of water and gardens. Table 5-11 is an exposure matrix for residential occupancy, which could include either surface or groundwater. With the exception of the on-site food consumption and soil ingestion by toddlers, it applies to the resident monument worker as well. A separate Tribal scenario is given in Table 5-12. In many risk assessments, the ingestion of contaminated surface soil by toddlers is the "driver" or predominant pathway of concern.

Table 5-11. Residential exposure matrix. All pathways are potentially complete for surface water or public water supply.

	Contaminated Environmental Media			
	Air	**Groundwater**	**Soil**	**Food**
Ingestion		Domestic wells Onsite groundwater use may be restricted	Incidental ingestion by toddlers	Homegrown produce and meat Fish (wild or in home ponds)
Inhalation	Vapors and dusts emanating from soil	Showering	Dust inhalation	
Dermal		Bathing	Direct contact	
			Direct external radiation exposure mitigated by capping	

Tribal Exposure Scenarios

Hanford differs from most sites on the National Priorities List and most other DOE sites because of potential exposure scenarios of the Native Tribes that assert treaty rights to access the land, and expect to use the Hanford Site in the future for traditional activities. DOE (2010) has recognized Tribal exposure scenarios from the Yakama Nation (Ridolfi 2007) and the Confederated Tribes of the Umatilla (Harris & Harper 2004). Both Tribes have performed independent risk assessments for parts of the Hanford Site. The Wanapum and Nez Perce tribes also express interest in traditional and future access to Hanford. The Tribal risk assessments use exposure assessment approaches that follow EPA guidance, but make extensive modifications to account for activities regularly or historically practiced by Native Americans. A major departure is in the frequent use of sweat lodges, for which Harris & Harper (2004) and Ridolfi (2007) developed detailed exposure estimates based on 1 to 2 hours per day for adults. The Tribal risk assessments are driven by the groundwater consumption pathway, and represent maximally exposed individuals. These risk assessments identify excess cancer and non-cancer risks from pursuing traditional lifeways on the Hanford Site related to current contamination levels and exposure assumptions (Harris & Harper 2004; Ridolfi 2007).

Unrestricted Land Use

The Core Team has requested that the Risk Review Project consider "unrestricted land use" as an alternate evaluation basis for the 300 Area, exclusive of the 618-10 and 618-11 burial grounds, and the approximately 1 square mile industrial area in the southeast corner of the 300 Area, as well as other areas outside of the Central Plateau.

Table 5-12. Tribal exposure scenarios emphasize the daily use of sweat lodges and the use of groundwater for drinking and sweat lodges. (Harris & Harper 2004; Ridolfi 2007).

	Contaminated Environmental Media			
	Air	**Water**	**Soil**	**Food**
Ingestion		Inadvertent or deliberate drinking, surface or groundwater	Toddler ingestion, adult ingestion incidental to gathering and other activities	Groundwater used to water crops or livestock Collection and preparation of fruits, roots, vegetation Daily fish and weekly game ingestion
Inhalation	Contamination of ambient air by dust and volatiles	Steam and volatiles in sweat lodge	Surface soil as dust	Not applicable
Dermal		Sweat lodge may allow organics to penetrate skin	Some organics may penetrate skin	Poultices
Direct Exposure		Radon or other radioactivity or volatile chemical intrusion from soil, water, or structures		

CHAPTER 6. EVALUATING RISKS TO THE COLUMBIA RIVER AND GROUNDWATER

ABSTRACT

Many of the evaluation units being considered involve discharges of contaminants into the environment that either have resulted in current groundwater contamination or may in the future impact groundwater or the Columbia River. This chapter focuses on the methodology for evaluating primary contaminants that either are currently present in the vadose zone or groundwater or have the potential to be released to the subsurface and subsequently impact groundwater or the Columbia River, including riparian and benthic zones. The approach described is to be used in the context of the large and often highly variable degrees of uncertainty and information gaps in contaminant distributions and subsurface contaminant transport at the many contamination sources within the Hanford Site. Thus, this methodology focuses on groundwater evaluation metrics that may lead to rough-order of magnitude differences and thereby allow relative binning of potential impacts and risks from EUs. This focus is in contrast to the information needed for a performance assessment or baseline risk assessment, or as the basis for remedial process selection and design.

The major steps of the process are 1) identifying EUs that either are or may impact groundwater; 2) compiling relevant information concerning the source, vadose zone, and saturated zone for each EU; 3) defining the evaluation metrics for each EU; and 4) comparing the evaluation metrics. Information gaps, uncertainties, and data gaps will be described for each EU. The methodology considers the three evaluation periods defined for the Risk Review Project: active cleanup (50 years, to 2064), near-term post-cleanup (100 years post cleanup, to 2164), and long-term post-cleanup (1000 years post-cleanup, to 3064 or beyond where indicated). Three possible recharge rates (i.e., surface barrier [0.5 mm/yr], undisturbed plant communities [5 mm/yr], and disturbed soil [50 mm/yr]) are considered to reflect uncertainties and a range of potential local surface conditions over the three evaluation periods as a result of ground cover, closure covers, climate variation, and localized surface hydrologic effects.[42]

The evaluation metrics for risks to groundwater from current groundwater plumes and near-surface or vadose zone sources are as follows:

1. The estimated time interval (active cleanup; near-term, post-cleanup; or long-term, post-cleanup) until groundwater would be *impacted* by a PC where a current plume does not exist[43]. Groundwater is considered *impacted* in this Review when a PC concentration exceeds a threshold value, e.g., a drinking water standard (DWS) or maximum contaminant level (MCL).
2. The estimated amount of groundwater (e.g., areal extent) currently *impacted* by the PCs with existing plumes[44].
3. The *groundwater threat metric (GTM)*, defined as the volume of groundwater potentially contaminated at the reference threshold concentration (e.g., DWS or MCL) based on the estimated contaminant inventory over the three evaluation periods[45].

[42] A value of 100 mm/yr will be used when needed to reflect specific conditions (e.g., gravel cover).
[43] If no PCs are expected to *impact* groundwater during the evaluation periods, then the EU does not have potential GW-related issues (Figure 6-8, Step 3).
[44] The estimated plume areas (areal extent above a threshold, often the drinking water standard) are taken from the 2013 Annual Groundwater Monitoring Report (DOE/RL-2014-32 Rev. 0). See Figure 6-9, Step a1.
[45] For current plumes, see Figure 6-9, Step a3. For vadose zone threats, see Figure 6-10, step b5.

The selected evaluation metrics for risks to the Columbia River from near-surface, vadose zone, and groundwater contamination sources are as follows:

1. The evaluation period(s) that the Columbia River would be impacted[46]. The Columbia River is considered *impacted* when a PC concentration from EU sources exceeds a benthic, riparian, or free-flowing threshold value.
2. The ratio (R1) of the maximum PC concentration within the plume to the reference threshold screening value (e.g., Biota Concentration Guide [BCG] for radionuclides or Ambient Water Quality Criterion for chemicals[47]).
3. The ratio (R2) of the upper 95th percentile upper confidence limit on the log-mean plume concentration to the reference threshold screening value.
4. For benthic impacts, the length of river shoreline estimated to be impacted by the plume above a reference threshold.
5. For riparian zone impacts, the area of the riparian zone estimated to be impacted by the plume above a reference threshold.

An example is presented using the 200-UP Operable Unit (OU) groundwater plumes in the 200 West Area.

6.1. AN OVERVIEW OF THE COLUMBIA RIVER, VADOSE ZONE, AND GROUNDWATER CONDITIONS AT THE HANFORD SITE

THE COLUMBIA RIVER

The Columbia River is part of a large, dynamic watershed that dominates the Pacific Northwest and also is important to Native American culture. Many Native American tribes, including the Nez Perce, Umatilla, Wanapum, and Yakama, have depended on the Columbia River for over 10,000 years (Landeen & Pinkham 1999). The Columbia River supports commercial and recreational fishing, hydroelectric power, industry, agriculture, and residential communities. It also supports a diverse and important ecosystem. Although there are more than 40 species of fish in the river, salmon are the keystone species in the river ecosystem. The fall run Chinook (*Oncorhynchus tshawytscha*) is probably of greatest importance to the Hanford Reach within the Columbia Basin. A significant portion of the fall-spawning Chinook salmon construct their nests (redds) in the Hanford Reach, with a significant concentration near Locke Island and thus alongside reactor areas 100 D through F. The salmon are important bioindicators of river health because of their tribal, cultural, and economic importance to the Pacific Northwest (NRC 1996; Landeen & Pinkham 1999; Williams 2006; Dauble 2009; Burger et al. 2013; CRITFC 2013).

The length and width of the Columbia River and its tributaries, and the size of the Columbia River basin watershed, have resulted in its use by people for thousands of years (Landeen & Pinkham 1999), and consequently it has experienced intense development, including factories, towns, agriculture, and construction of hydroelectric dams along its banks. One widely held view among technical analysts and Tribal observers alike is that the Columbia River should be returned to conditions of natural water flows,

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[46] This metric is captured in the framework in three places: Steps c1 and c7 (Figure 6-11) for plumes in contact with the Columbia River and Step c11 (Figure 6-11) for potential future impacts.

[47] For radionuclides, the Biota Concentration Guide (BCG) consistent with DOE Technical Standard DOE-STD-1153-2002 is used. For chemical PCs, the AWQC from the Columbia River Component Risk Assessment (CRCRA) (DOE/RL-2010-117, Rev. 0) Volume I: Screening Level Ecological Risk Assessment are used.

habitats, and biotic and human communities (Williams et al. 1999). However, Hobbs et al. (2013) caution that given global and demographic changes, it is unrealistic to assume that any ecosystem, much less one experiencing ongoing energy, agricultural, and industrial impacts, can be restored to pristine conditions. Natural water flow and native habitats, however, can be restored without returning to historical "natural conditions," including maintaining healthy salmon populations (NRC 1996).

Over geologic time, the Columbia River has shifted course and deepened its gorges, but its current course and water quality are controlled by anthropogenic forces. Water is withdrawn or added; nutrients, chemicals, and radionuclides were either discharged or flowed into the river; and in some cases water temperatures were changed because the water was used for cooling purposes. The species that live in the Columbia River are a function of the geographic, physical, and chemical conditions, which in turn are a result of natural and anthropogenic forces. The amount of water flowing in the river, as well as flow rate and water level, are a function of natural conditions (headwaters, snow melt, and runoff from rainfall) and anthropogenic factors, such as withdrawal for agricultural, industrial, and residential uses, and control by hydroelectric dams (Figure 6-1). For example, the runs of salmon and other species on the Columbia River have been severely impacted by dams that impede access to their traditional upstream spawning areas (Hanrahan et al. 2005), and a significant proportion of fish fall back when attempting to overcome obstacles when moving upstream (Boggs et al. 2004). Likewise, many juvenile fish migrating downriver are killed in turbines. Thus, habitat quality has been affected by altering water levels, water quality, and current characteristics.

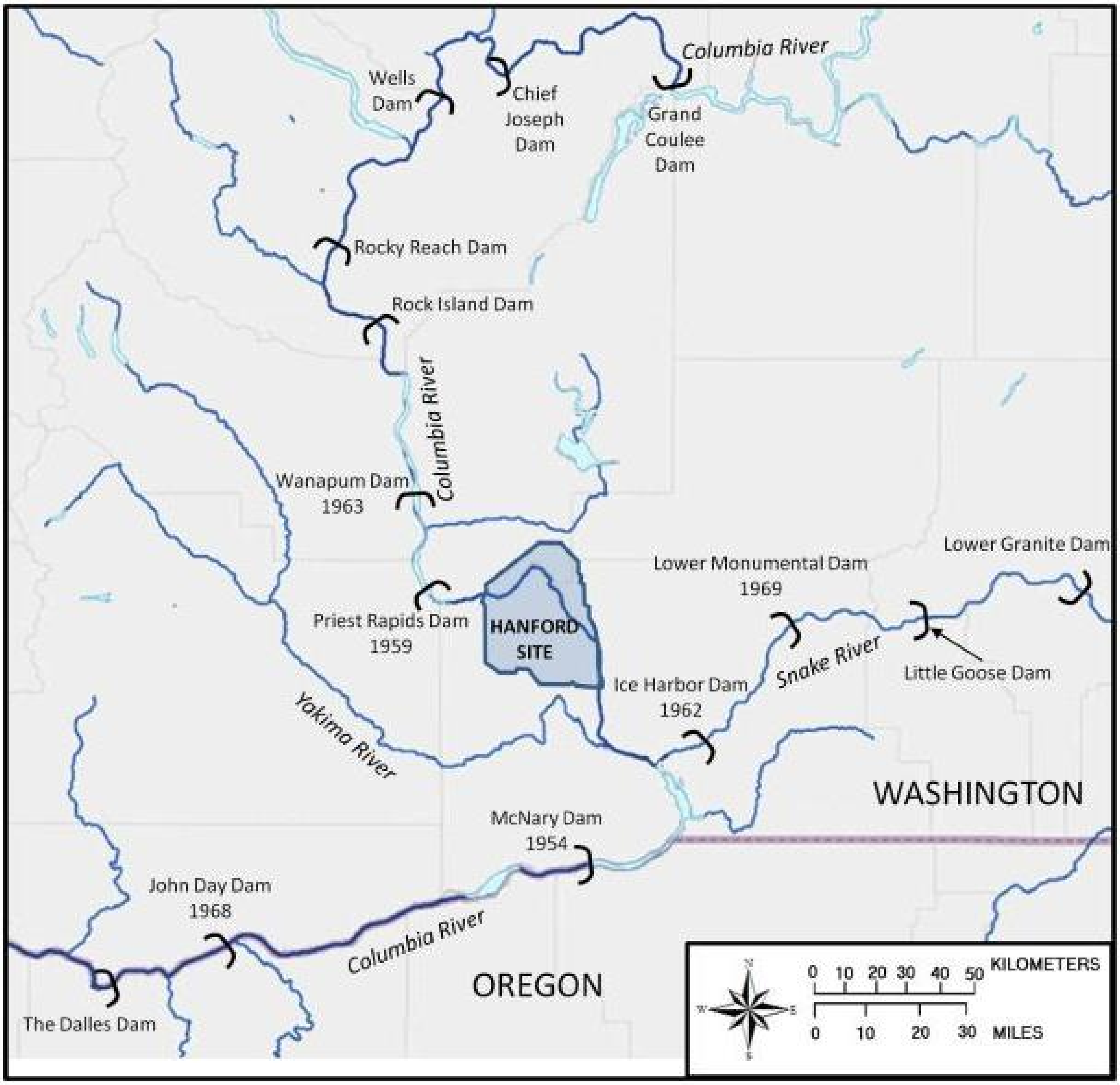

Figure 6-1. Map of the Columbia and Snake Rivers showing dams. The dates of the major dams affecting the Hanford Reach and the confluence of the two rivers are also shown.

The Hanford Reach is one of only two sections of the Columbia River that is free-flowing. Although the Hanford Reach was affected by past activities on the Hanford Site, at present it is subject to surface runoff and incursions of water from seeps and upwellings on the riverbed. There is a direct pathway from the Hanford Site to the river through run-off and potentially future deliberate releases[48]—and some Tribal observers note that run-off could be increased by remediation (such as massive digging to remove contaminated soil, R. Jim, pers. comm.). Since the geology of the river is ever changing, the exact locations of seeps and upwellings can shift over time. Upwellings and seeps can be contaminated

[48] Deliberate releases refer to surface water discharges permitted by the State of Washington as part of a federal surface water quality protection program. As of the writing of this document, no permitted or intentional discharges directly to the Columbia River remain from the Hanford Site operations. One permitted discharge to the Columbia River is from the PNNL Aquatic Research Laboratory.

by groundwater contaminant plumes originating from the Hanford Site. The very high quantity and speed of water flow in the river relative to groundwater discharge results in rapid dilution. Potential problems occur for organisms that live in the sediment and gravel of the riverbed (e.g., salmon eggs) when upwelling water moves through the gravel to meet the fast-flowing river water. However, salmon biologists believe that "pollutants …generally are not considered a major factor in salmon declines, nor are they particularly problematic for recovery" (Stanford et al. 2006, p. 211).

In summary, the Columbia River is a large watershed that is subject to a complex matrix of natural and anthropogenic factors. Its banks have been occupied by people for over 10,000 years, and since the arrival of settlers of European origin it has seen massive agricultural, industrial, and residential development. It has experienced large-scale disruption and pollution from a variety of sources. The river section flowing through the Hanford Site has experienced far less physical disruption than the rest of the Columbia River but is still potentially subject to contamination from groundwater contaminant plumes that discharge into the river.

VADOSE ZONE AND GROUNDWATER

Groundwater underlying the Hanford Site is important because it is both a valued natural resource subject to protection by the State of Washington and under federal regulations and a pathway for contaminant transport to the Columbia River. Potential sources of contamination at Hanford currently are present either near or above ground surface (i.e., processing facilities, waste storage tanks, legacy disposal sites) or in the vadose zone (a complex assemblage of unsaturated geologic layers and formations between the ground surface and underlying groundwater) as a result of past intentional or unintentional releases. After near-surface releases, contaminants pass through the vadose zone, where contaminants are subject to complex physical-chemical transport, retention, and attenuation processes prior to entering the groundwater. Contamination currently is present in the groundwater, delineated as groundwater contamination plumes[49]. Once in the groundwater, contaminants are subject to a further set of complex physical-chemical transport, retention, and attenuation processes as they are transported along with the groundwater through multiple geologic formations. Contaminants entering an aquifer may (and in most cases do) flow or diffuse in part into less permeable parts of the aquifer, remaining there for long periods, and feed contaminants into flowing groundwater in more permeable surrounding materials. These low-permeability materials within an aquifer thus form secondary contaminant sources for the same aquifer and serve as long-term reservoirs of contamination during remediation. Contaminants in the groundwater ultimately discharge to the Columbia River, unless they are subject to natural attenuation (e.g., radioactive decay or bio/chemical degradation) or are irreversibly bound to the subsurface solid phase.

Hydrogeologic conditions beneath the Hanford Site are controlled by the basalt bedrock (Columbia River Basalt Group), the consolidated to semi-consolidated sediments of the Ringold Formation and Cold Creek unit, and the unconsolidated sediments of the Hanford formation (Figure 6-2). The site is capped by a discontinuous veneer of Holocene alluvium, colluvium, and/or eolian sediment. Groundwater lies at a depth of up to 100 m beneath the Central Plateau (200 West and 200 East Areas).

[49] Plumes represent the areal extent that a contaminant exceeds a threshold (e.g., drinking water standard or maximum contaminant level).

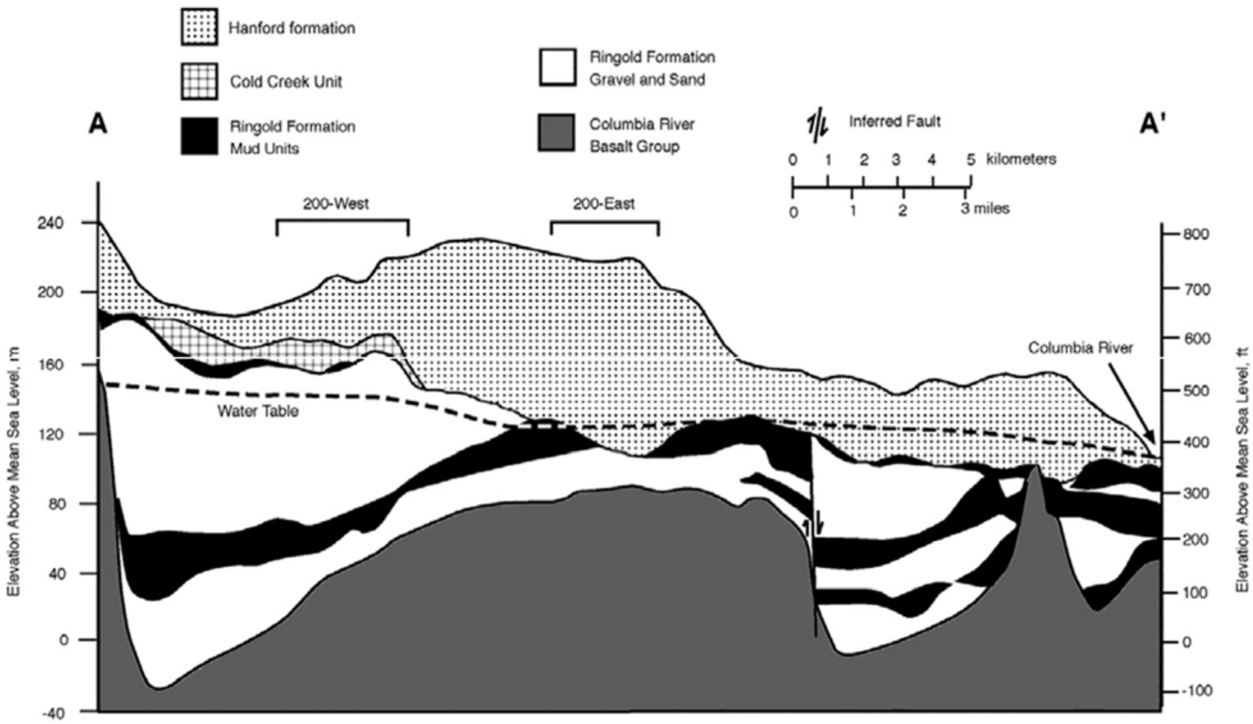

Figure 6-2. Generalized west-to-east geologic cross-section through the Hanford Site (Last et al. 2006). The vadose zone is the vertical cross-section from the ground surface to the water table (as indicated by the dashed line).

Past waste disposal practices (e.g., direct liquid waste disposal to the ground via engineered facilities) and unplanned releases (e.g., spills and tank leaks) contaminated hundreds of discrete waste areas across the Hanford Site, impacting the vadose zone and creating large contaminant plumes within the uppermost aquifer system.

Vadose Zone Stratigraphy

The vadose zone beneath the Hanford Site ranges in thickness from less than 1 m along the Columbia River to more than 100 m on the Central Plateau. The geologic framework of the vadose zone is very complex. It is dominated by Holocene and Hanford formation sediments and to a lesser extent the Cold Creek unit and upper Ringold Formation. The sediments impart high heterogeneity and anisotropy in the physical, hydrologic, and geochemical properties of the vadose zone (Last et al. 2006).

The complex hydrogeochemical framework, together with wastewater and meteoric water fluxes, has led to complex three-dimensional movement of moisture and contaminants through the vadose zone. Flow within the vadose zone is dynamic and characterized by periods of unsaturated flow punctuated by episodes of preferential, saturated flow in response to hydrologic events or releases of liquids (Wilson et al. 1995).

Many parts of the vadose zone still contain residual wastewater and associated contamination from past Hanford activities that may continue to drain into the groundwater. Perched water[50] conditions are still

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[50] Perched water is a saturated area of the subsurface where water has accumulated above a low permeability zone (e.g., a localized clay lens) but is still above the water table (thus, there exists an unsaturated zone between the saturated area where the water has accumulated and the water table).

present in parts of the 200 East and 200 West Areas (Hartman 2000; Truex et al. 2013; Oostrom et al. 2013).

Unconfined Aquifer System

The unconfined aquifer system is contained in the unconsolidated Hanford formation and semi-consolidated to consolidated Ringold Formation, overlying the basalt bedrock (Figure 6-2). Coarse-grained facies of the Hanford formation make up the most permeable zones of the unconfined aquifer system. Hydraulic conductivities of these Hanford formation sediments are 10 to 100 times greater than that of coarse-grained facies of the Ringold Formation (Hartman 2000). In some areas, low-permeability mud layers within the Ringold Formation form aquitards that create local confined hydraulic conditions in the underlying sediment. Collectively, the aquifers within the suprabasalt sediment are referred to as the Hanford/Ringold aquifer system (Hartman 2000). Saturated thickness of the Hanford/Ringold aquifer system exceeds 180 m in areas near the center of the Hanford Site and north of the Gable Mountain-Gable Butte anticline, but pinches out along the flanks of the basalt ridges (Hartman 2000). Groundwater in the unconfined aquifer system generally flows eastward from points of natural recharge along the Hanford Site's western boundary to points of discharge along the Columbia River (Figure 6-3).

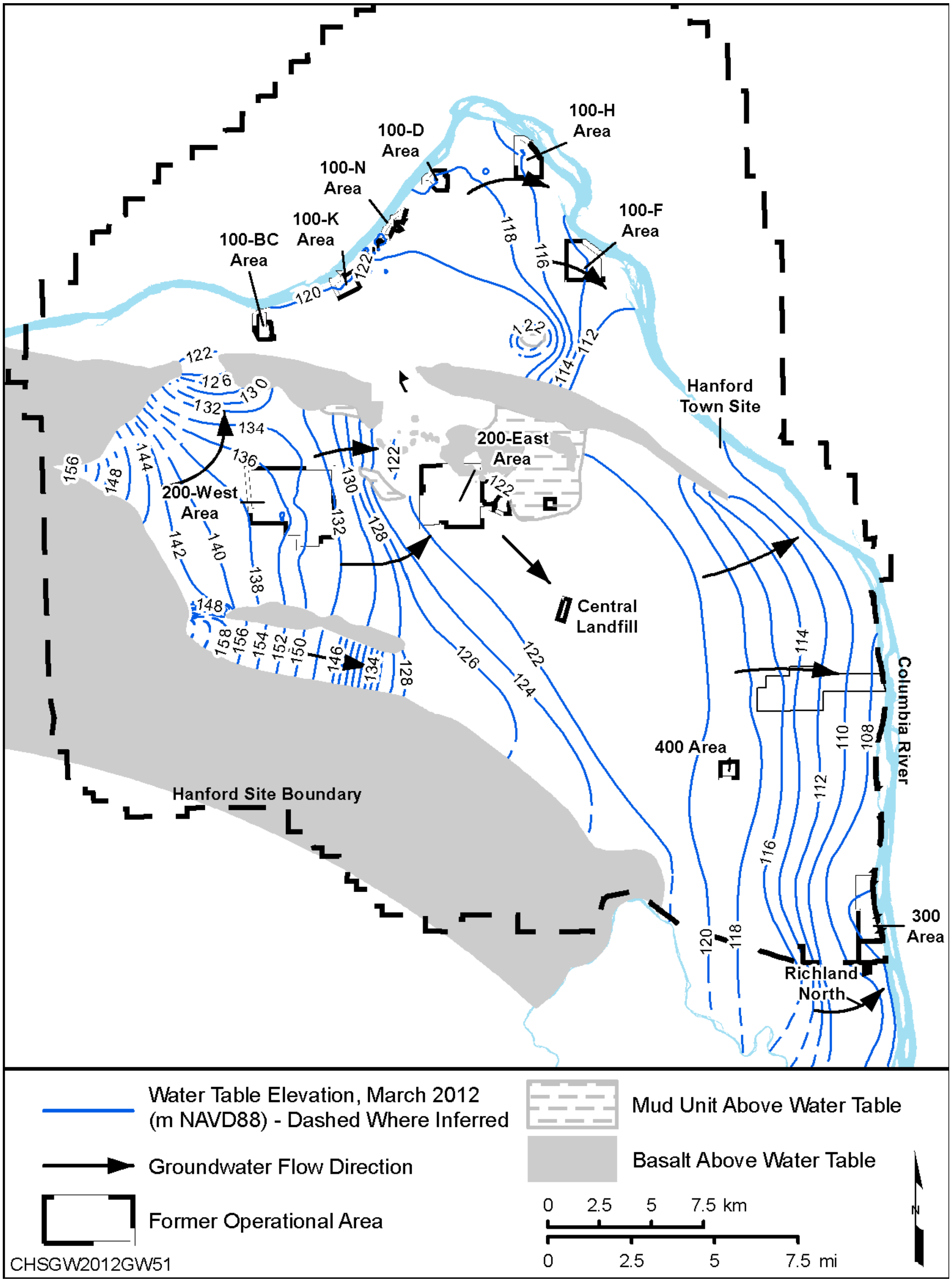


Figure 6-3. Water table map of the Hanford Site, March 2012 (from DOE/RL-2013-22 Rev. 0 2013).

Recharge from precipitation and snow melt is highly variable, both spatially and temporally, across the Hanford Site. It ranges from near zero to greater than 100 mm per year for gravel-covered areas, depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer & Walters 1995).[51] Recharge from precipitation is highest in coarse-textured soil with little or no vegetation or areas with gravel cover.

Artificial recharge from wastewater disposal operations has dramatically affected the Hanford/Ringold aquifer system. Since the start of Hanford Site operations in the mid-1940s and during the Hanford production period, estimated wastewater discharges greatly exceeded the estimated recharge from natural sources (Hartman 2000). These discharges caused groundwater mounds to form beneath major wastewater disposal facilities and increased water table elevations over much of the Hanford Site. The largest of these groundwater mounds developed beneath the 216-U-10 Pond in the 200 West Area, where water levels increased by at least 22 m (Hartman 2000). In 1988, production activities on the Hanford Site began to close, resulting in dramatic decreases in wastewater disposal and subsequent decreases in water table elevation over much of the site.

Groundwater flow is generally to the east and southeast across the Hanford Site to the Columbia River, with groundwater travel times estimated at a few decades from 200 East Area to perhaps a century or more from the 200 West Area (Gephart 2003; PNNL-6415 Rev. 18). Groundwater flow has been locally interrupted by residual groundwater mounds and pump-and-treat systems. Water levels have changed over time due to variations in the volume and location of wastewater discharges or pump-and-treat systems, and so too has the movement of groundwater and its associated constituents. Some localized backflow of water from the Columbia River into the ground may also occur along the banks of the river in response to changes in river elevation.

Groundwater in the unconfined aquifer system primarily discharges to the Columbia River through springs and areas of upwelling. These points of discharge are the primary exposure pathways for contaminants to reach human, environmental, and ecological receptors. Discharge along the Columbia River varies both spatially and temporally—strongly controlled by variations in river stage and bank storage.

Wastewater discharges (including unplanned releases) have resulted in both chemical and radioactive contamination of the uppermost aquifer system (the Hanford/Ringold aquifer system), with an estimated 152 km^2 exceeding drinking water standards (DOE/RL-2013-22 Rev. 0 2013). The most noteworthy contaminants (and their estimated aerial extent exceeding drinking water standards) include tritium (88.8 km^2), iodine-129 (47.8 km^2), nitrate (38.2 km^2), carbon tetrachloride (13.4 km^2), technetium-99 (2.7 km^2), strontium-90 (2.0 km^2), uranium (1.7 km^2), hexavalent chromium (1.2 km^2), trichloroethene (0.9 km^2), and cyanide (0.2 km^2). Figure 6-4 illustrates the distributions of groundwater contaminants in the River Corridor and 300 Area, as well as those emanating from the Central Plateau.

[51] Higher recharge rates (up to 100 mm/yr) will be considered for those areas with known gravel cover.

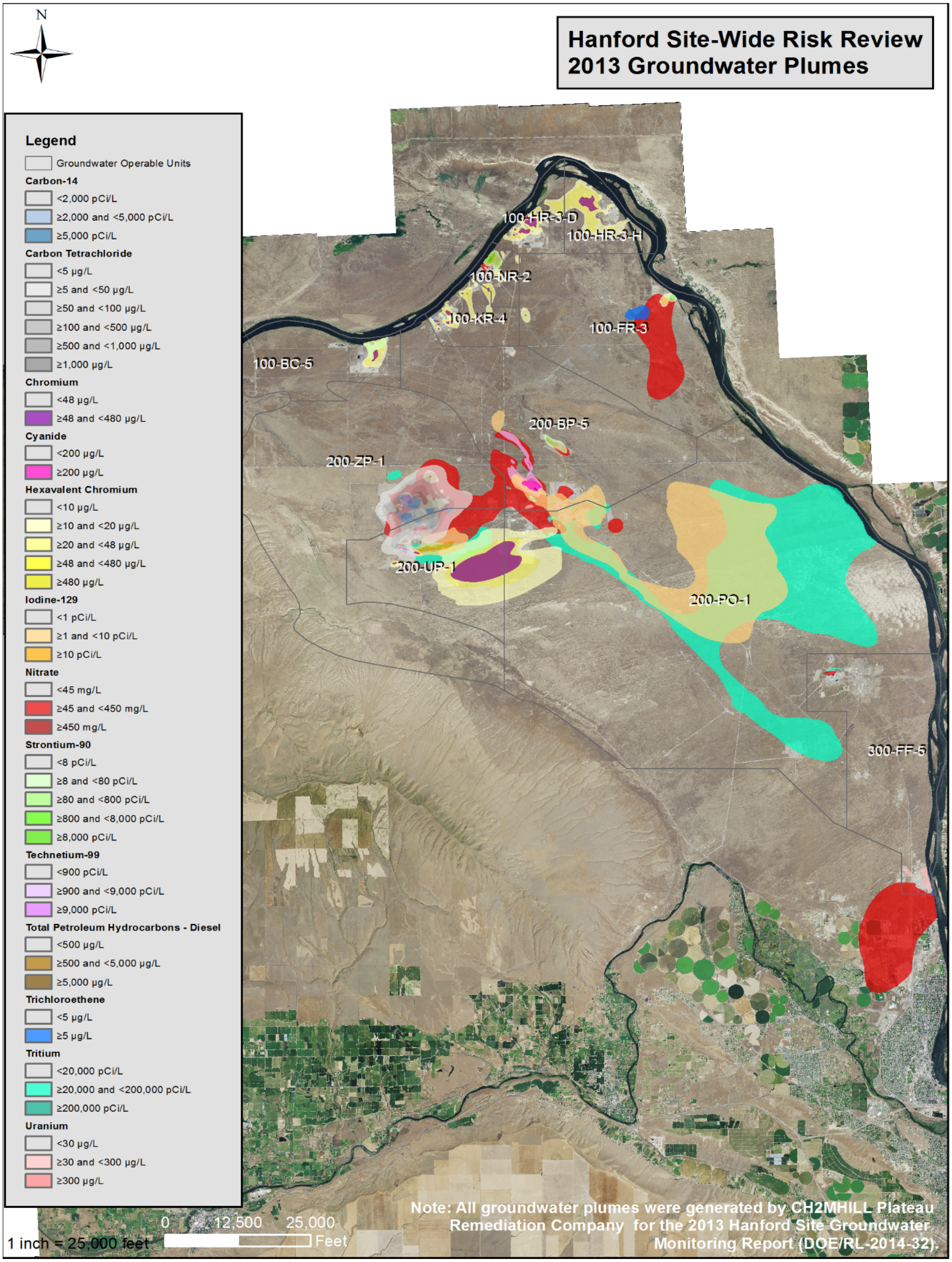


Figure 6-4. Groundwater contaminants in the River Corridor and Central Plateau.

Since the curtailment of production activities, DOE has been working to remediate soil and groundwater contamination (DOE/RL-2013-22 Rev. 0 2013). Current interim groundwater remedial actions in the River Corridor vary from active pump-and-treat systems at the 100-K Area (100-KR-4) and the 100-D and 100-H Areas (100-HR-3) to removal of hexavalent chromium through excavation (Figure 6-5). *In situ* treatment of strontium-90 is underway at the 100-N Area (100-NR-2) using apatite sequestration as an interim action. In the 300 Area, a persistent uranium plume in the groundwater originates from sediments in the vadose zone, as well as in the aquifer. Passive management strategies being considered are institutional controls and monitored natural attenuation, whereas active technologies are selective excavation to the water table and stabilization via application of polyphosphate.

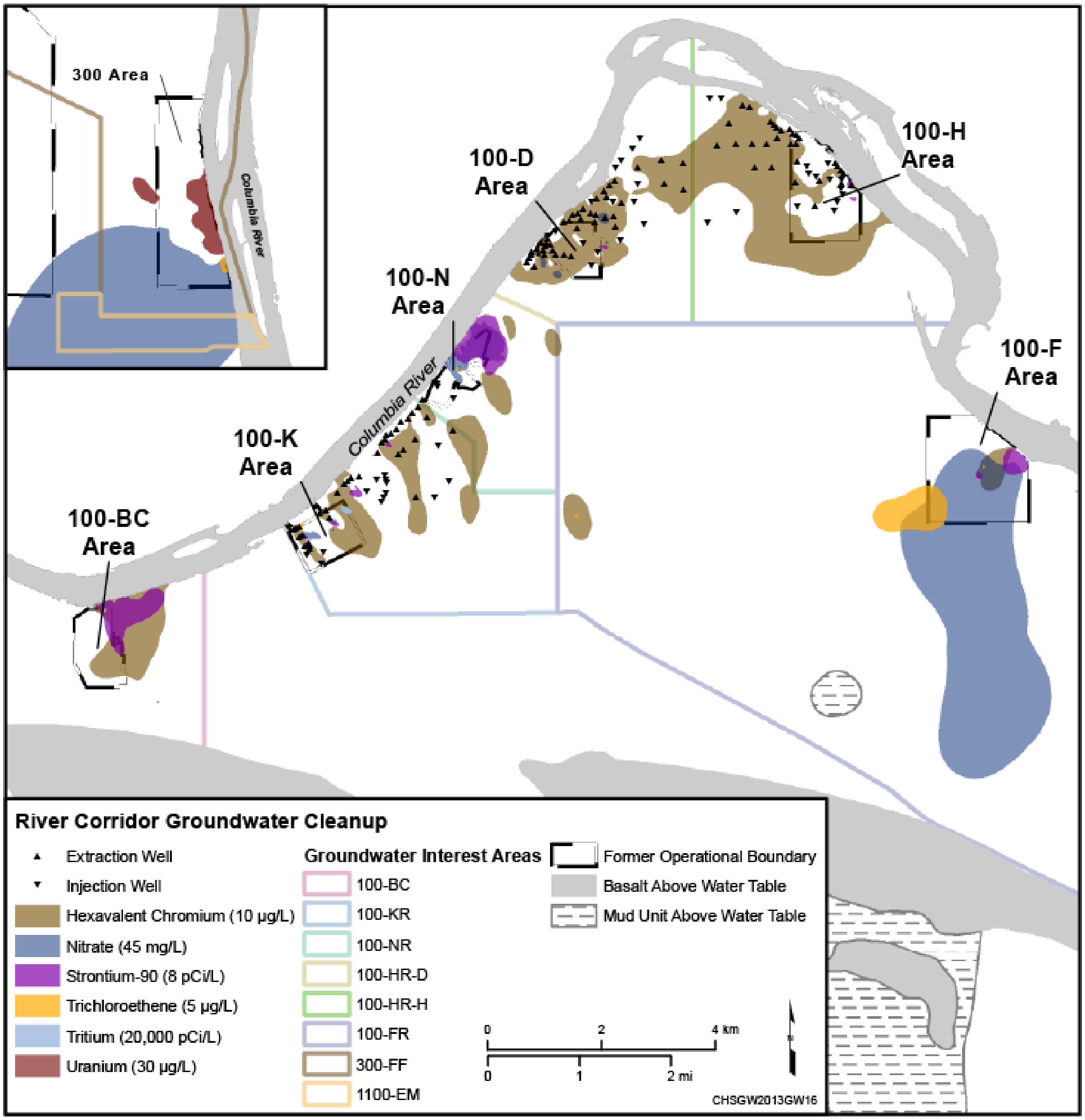


Figure 6-5. Hanford Site River Corridor Groundwater Cleanup (DOE/RL-2013-22 Rev. 0 2013).

In the Central Plateau, a final action pump-and-treat system is being expanded for the 200-ZP-1 OU (in the northern portion of the 200 West Area) to remove and treat carbon tetrachloride and nitrate contamination. An interim action pump-and-treat system is also underway to remove technetium-99, carbon tetrachloride, chromium, trichloroethylene, and nitrate from a smaller area near the 241-T, 241-TX, and 241-TY Tank Farms (Waste Management Areas [WMAs] T and TX-TY). In the southern portion of 200 West Area, another interim action pump-and-treat system is operating for the 200-UP-1 OU near the 241-S and 241-SX tank farms (WMA S-SX) to recover and treat technetium-99, nitrate, and chromium.

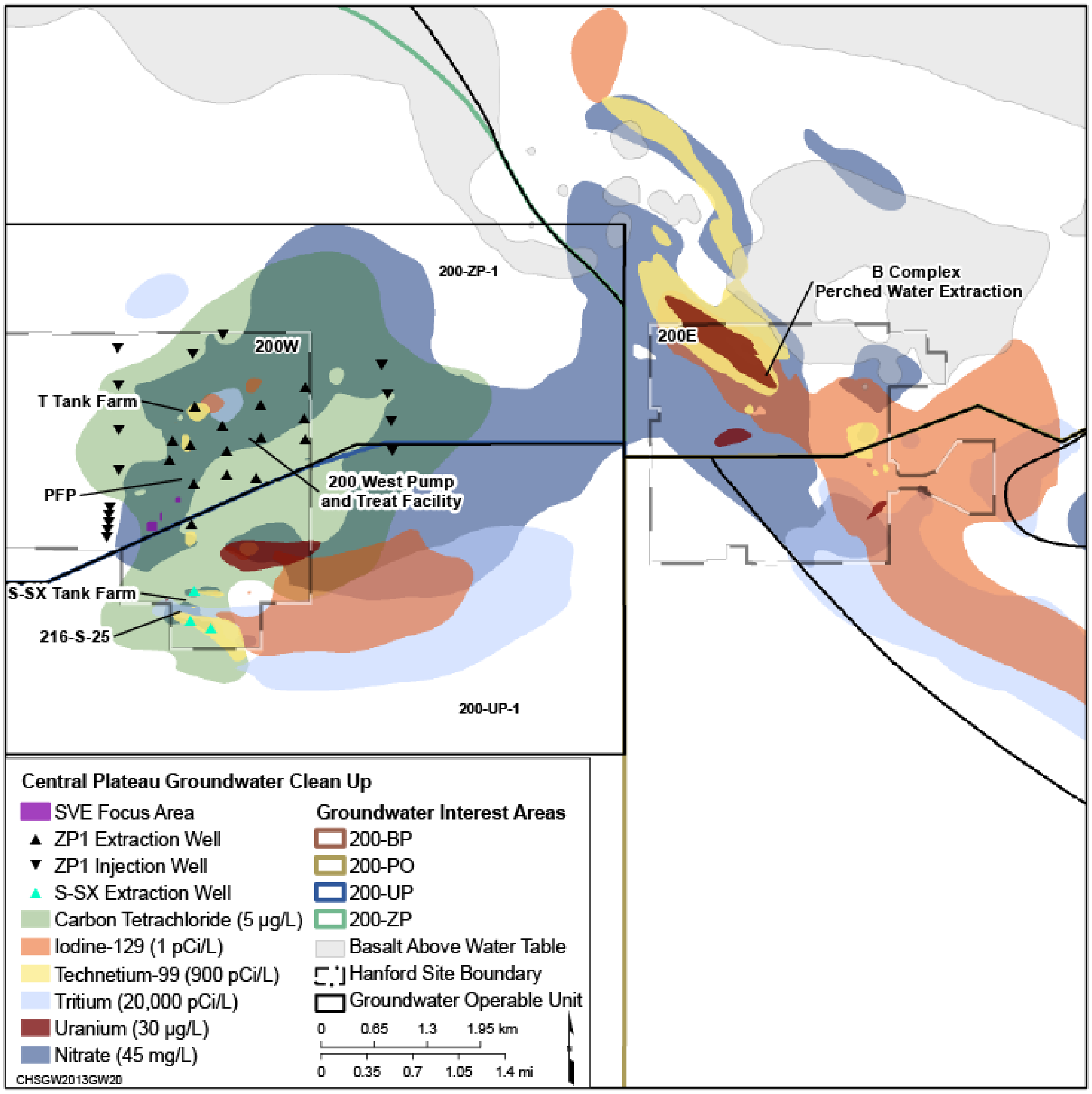


Figure 6-6. Hanford Site Central Plateau Groundwater Cleanup (DOE/RL-2013-22 Rev. 0 2013).

Confined Aquifer System

A sequence of confined aquifers is present within the Columbia River Basalt Group beneath the Hanford Site. These aquifers are composed of sedimentary interbeds and the relatively permeable tops of basalt flows. The dense interior sections of the basalt flows form confining layers. Groundwater in the basalt-confined aquifers generally flows from elevated regions at the edge of the Pasco Basin toward the Columbia River (Hartman 2000). No significant contamination has been detected in the basalt-confined aquifer system, except in the northwestern portion of the 200 East Area, where poorly constructed wells and temporary drilling effects allowed local migration of groundwater contamination from the overlying unconfined aquifer (DOE/RL-2013-22 Rev. 0 2013).

6.2. METHODOLOGY FOR EVALUATING IMPACTS TO AND BY GROUNDWATER AND TO THE COLUMBIA RIVER

A General Framework for Evaluation

Many of the EUs to be considered involve past, current, and potential future intentional or unintentional discharges of PCs into the subsurface as well as areas of current saturated zone contamination. A framework is presented for determining and comparing evaluation metrics to estimate rough-order of magnitude differences in potential impacts from PCs on groundwater at Hanford (i.e., groundwater as a protected resource) and discharge to the Columbia River as a protected resource (i.e., groundwater as a pathway) and the potential impact to benthic and riparian ecology because these are considered more sensitive indicators than free stream ecology. The potential for primary and secondary (vadose zone) sources to impact groundwater and the Columbia River in the future is also considered.

The Hanford subsurface is a highly complex formation and contains both significant vadose (unsaturated) and saturated zones of varying thicknesses and characteristics at different geographic locations within Hanford (Figure 6-7). Significant effort has been applied over many decades to characterize the subsurface and the location and movement of PCs, although substantial data gaps and uncertainties remain. This effort has produced a large amount of information pertinent to the Hanford Site, including borehole and well data and subsurface zone property estimates. Models also have been developed in varying detail describing the fate and transport of PCs in the Hanford subsurface. It is recognized that the information available is not perfect, contains varying levels uncertainty, and is not available at the same level of detail across the EUs and related subsurface and receptor areas. The underlying complexity and uncertainty necessitates that analyses be tailored to the objectives and intended use of the specific evaluation.

Analysis of the Hanford subsurface is also complex. In addition to the hydrogeological complexity of a very heterogeneous subsurface, biogeochemical interactions add complexity. To make the analysis tractable for this Risk Review Project, prior work is being leveraged to provide an analysis to a rough-order of magnitude sufficient to compare risks to groundwater and the Columbia River related to the different EUs and inform future cleanup sequencing. Development of new primary data is beyond the scope of this review.

The specific objectives of the methodology described here are as follows:

1. Provide a basis for characterizing and binning current and potential future risks (over the three evaluation periods) from PCs to groundwater resources.

2. Provide information necessary for characterizing the risks from groundwater contamination to the Columbia River, including riparian and benthic zones, over the three evaluation periods.
3. Provide information needed for estimating risks to human health and potential impacts to other resources.

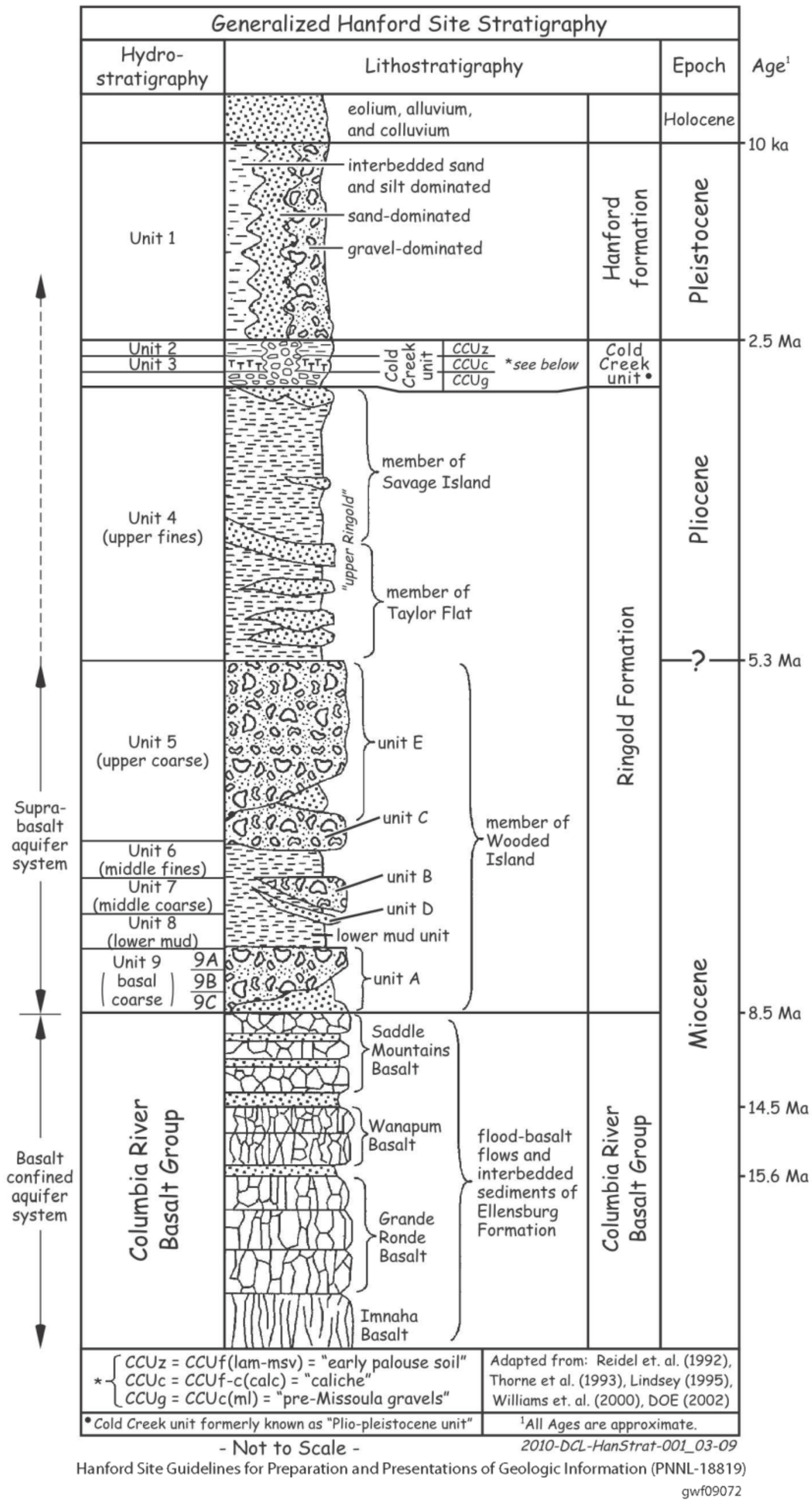


Figure 6-7. A generalized representation of subsurface stratigraphy for the Hanford Site showing nomenclature (DOE/RL-2010-11 Rev. 1 2010, p. 3.0-12).

A process has been developed as a general framework for binning EUs using the evaluation metrics considering three distinct potential impacts: 1) groundwater as a protected resource, 2) groundwater as a pathway to impact the Columbia River, and 3) impact from potential future sources (e.g., tank leaks) and current vadose zone contamination on groundwater and the Columbia River. The focus on the evaluation metrics allows for differentiation between potential groundwater-related risks from the EUs. This process does not concern itself directly with highly uncertain point estimates of risks and impacts often used for other analyses (e.g., performance or baseline risk assessments). The uncertainties associated with the analyses related to EUs become more tractable when evaluation metrics are considered in relative rather than absolute terms. It is understood, nonetheless, that sufficient information may not be available for certain EUs to meet the objectives of this evaluation and that additional characterization and modeling would be required; the likelihood of these information gaps and uncertainties has been accounted for in developing the framework presented here.

An analysis that allows comparison of available evaluation metrics for EUs, provides a rating of the EUs evaluated, and informs decision making, including the sequence of addressing specific sources and plumes as well as the needs for additional subsurface characterization, must necessarily consider the following:

1. The inherent complexity of the Hanford subsurface and its evaluation;
2. The difficulty and time required to determine accurate, point estimates out to a specified (i.e., long) time horizon;
3. The lack of equivalent information across all EUs;
4. The large uncertainties that are necessarily associated with much of the extant information (e.g. vertical concentration profiles associated with contaminant plumes); and,
5. The uncertainties and biological variability in benchmarks for biota.

The overall approach to characterizing and comparing EUs is presented in Figure 6-8. Since this framework can be applied across EUs in a well-defined manner, it provides a straightforward process to compare EUs on a relative basis.

After selecting units for evaluation (Steps 1-2 in Figure 6-8) as described in Chapter 3, the first question (Step 3) to address is whether or not each EU has existing or likely potential groundwater impacts based on prior evaluations (e.g., National Environmental Protection Act, records of decision, risk or performance assessments) and the presence, form, and amounts of contaminants present. If the EU does not pose potential groundwater impacts (e.g., there is no inventory for the PC for this EU, then no further inquiry is made (i.e., the rating for this PC for this EU is *Not Discernible*) and the next EU on the list is selected (Step 2), if any EUs remain to be evaluated (Step 6). If there is potential for groundwater impacts based on previous evaluations, a list of PCs to be evaluated is identified from previous evaluations (Step 4) from the contaminants of potential concern and iconic contaminants. The reason for retaining the constituent as a PC (e.g., of site-wide interest or EU specific risk-driver) as well as the source and reliability of the information used is documented as part of the selection process.

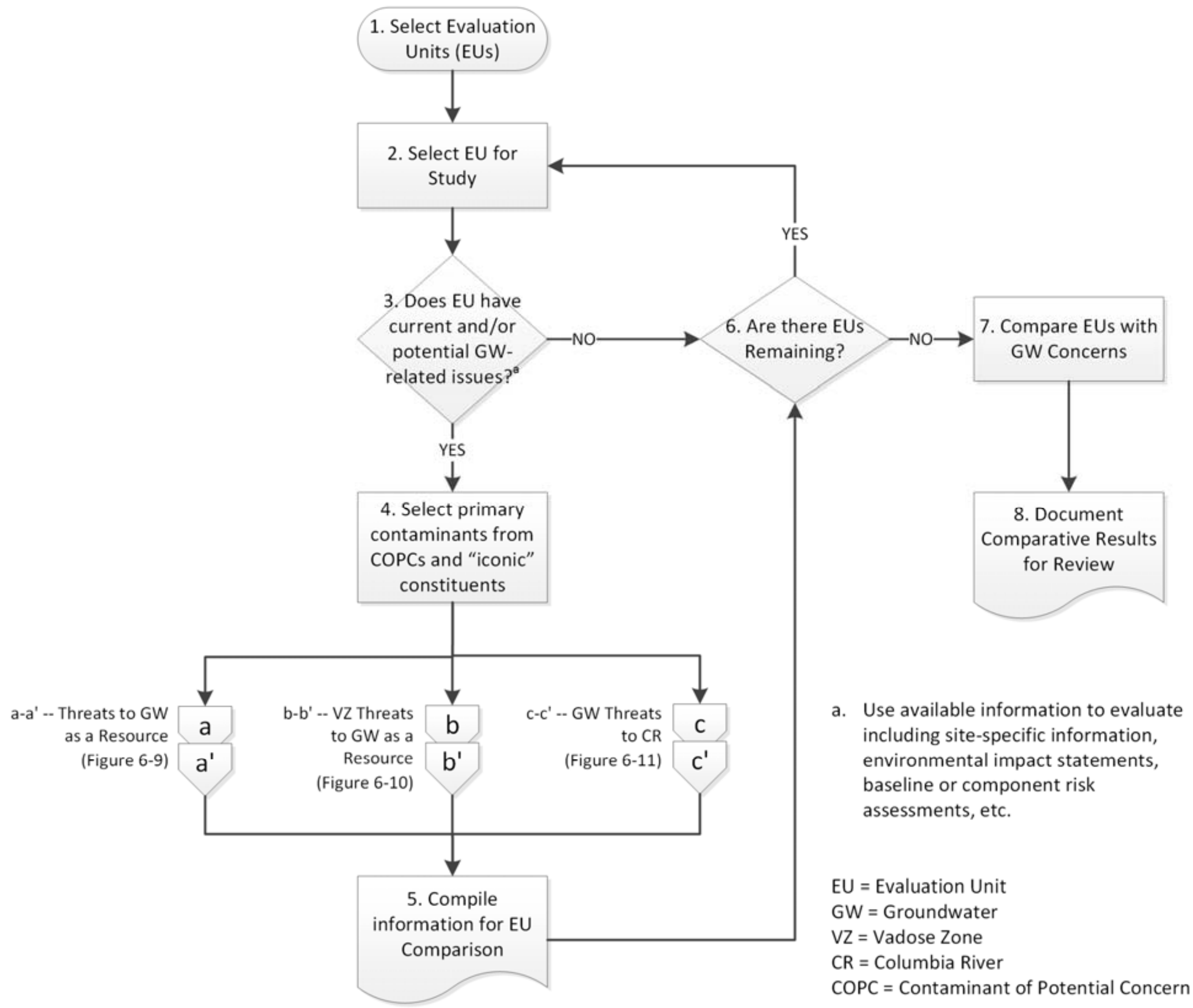


Figure 6-8. Overall process steps for evaluating potential groundwater-related threats. Process flow steps a-a', b-b', and c-c' are provided in Figure 6-9, Figure 6-10, Figure 6-11, respectively.

PRIMARY CONTAMINANT GROUPS

The primary contaminants (PCs) described in Section 2.2 were grouped to help simplify their evaluation. The PC groups used in this review are described in Table 6-1, which categorizes them according to their mobility and persistence in the Hanford environment. The categorization was done on a relative basis among the PCs. Mobility relates to the relative ability of the PC to be transported in the subsurface environment (as represented by the contaminant transport retardation factor, R) and is mainly a function of the contaminant’s chemistry and sorption with the Hanford subsurface geology. For the radioactive contaminants, the persistence category is based on the radionuclide’s half-life. The persistence category for the organic and inorganic contaminants is based on their chemical degradation and biodegradation potential. For example, chromium, being non-degrading and not radioactive, is classified as having a high persistence in the subsurface. For this site-wide review, the PCs were divided into four groups based on their persistence and mobility. Group A contains technetium-99 (Tc-99), iodine-129 (I-129), carbon-14 (C-14), chlorine-36 (Cl-36), hexavalent chromium (Cr^{6+}), and carbon tetrachloride. Group B contains strontium-90 (Sr-90), trichloroethylene (TCE), uranium ($U^{(tot)}$), total chromium ($Cr^{(tot)}$), and cyanide (CN). Group C contains tritium (^3H_2O), nitrate (NO_3), and TPH-diesel.

Group D contains cesium-137 (Cs-137), americium-241 (Am-241), and isotopes of plutonium (Pu), europium (Eu), and nickel (Ni). Additional contaminants may be added to the groupings based on review of the final set of EUs. The groups are ranked relative to each other with respect to groundwater impacts, with Group A being the highest (highly mobile and highly persistent) and Group D being the lowest (low mobility and highly persistent) for the purpose of this study.

Table 6-1. Primary contaminant groups used in this review.

		Mobility*		
		Low (R>500)	Medium (5<R<500)	High (R<5)
Persistence	Low		TPH-diesel	^3H_2O, NO_3
	Medium	Cs-137, Am-241	Sr-90	Cyanide, TCE
	High	Pu, Eu, Ni (all isotopes)	$U^{(total)}$, $Cr^{(total)}$	Tc-99, I-129, C-14, Cl-36, Cr^{6+}, Carbon Tetrachloride

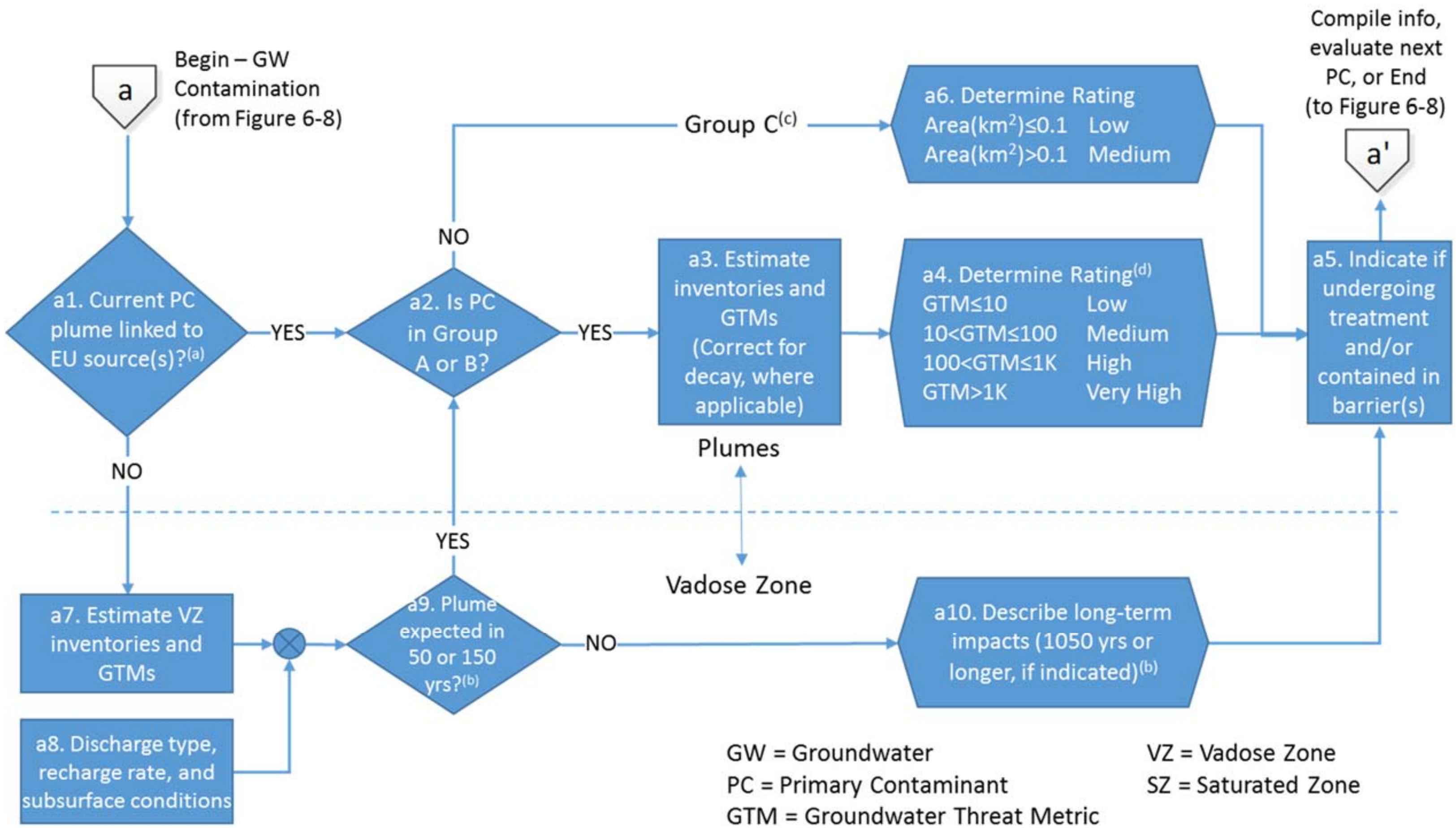
Group A Primary Contaminants (red)
Group B Primary Contaminants (orange)
Group C Primary Contaminants (green)
Group D Primary Contaminants (blue)

* Assume most mobile form of contaminant
R = retardation factor

As indicated in Figure 6-8, an EU will be characterized using the following steps:

- a-a' – Threats to Groundwater as a Protected Resource from existing groundwater contamination (Figure 6-9).
- b-b' – Vadose Zone Threats to Groundwater as a Protected Resource (Figure 6-10) where steps b1 through b9 are the same as steps a2 through a10 in Figure 6-9.
- c-c' – Groundwater (Pathway) Threats to the Columbia River (including Benthic, Free-flowing, and Riparian Ecology) as indicated by the steps in Figure 6-11. Note that the red box in the figure distinguishes between current (inside the box) and potential future (outside the box) impacts to the Columbia River.

The resulting groundwater and Columbia River metrics are compiled (Step 5) for subsequent comparison (Steps 7 and 8 in Figure 6-8). Some of the information may not apply to every specific EU being characterized. However, working through the framework provides the characterization information needed to subsequently compare EUs based on potential for groundwater impacts.



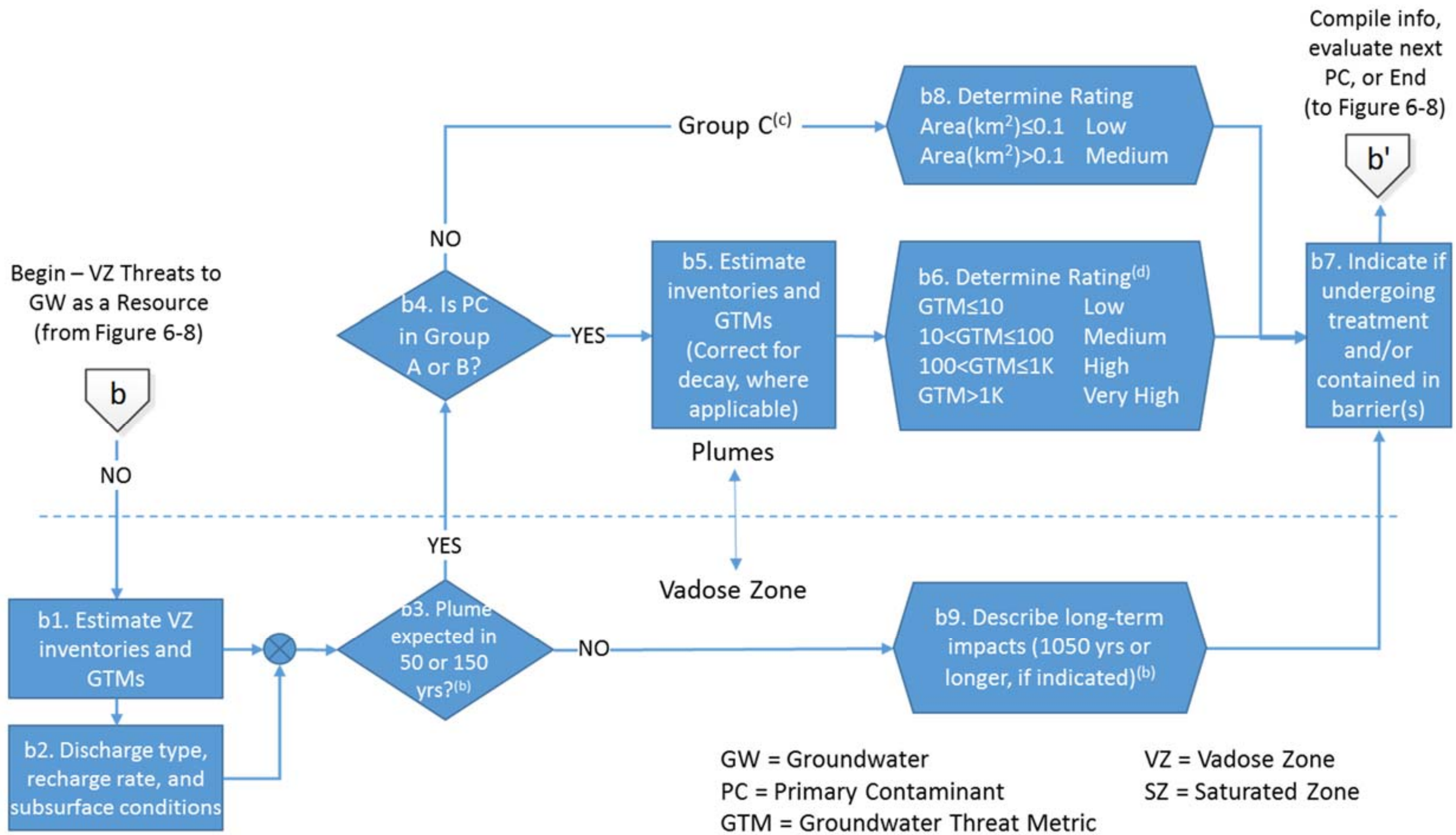
a. Based on plume area above a threshold (e.g., Water Quality Standard (WQS) from 2013 Annual GW Monitoring Report (DOE/RL-2014-32 Rev. 0)). Note plume areas and corresponding estimated plume volumes are (highly) positively correlated.

b. Use available information (e.g., environmental impact statements, risk assessments) to evaluate.

c. Note, no Group D contaminants have been identified as groundwater threats.

d. GTM Rating Table for Group A and B PCs (Table 6-3).

Figure 6-9. Framework steps a-a' (refer to Figure 6-8) for characterizing an evaluation unit for threats to groundwater as a protected resource.



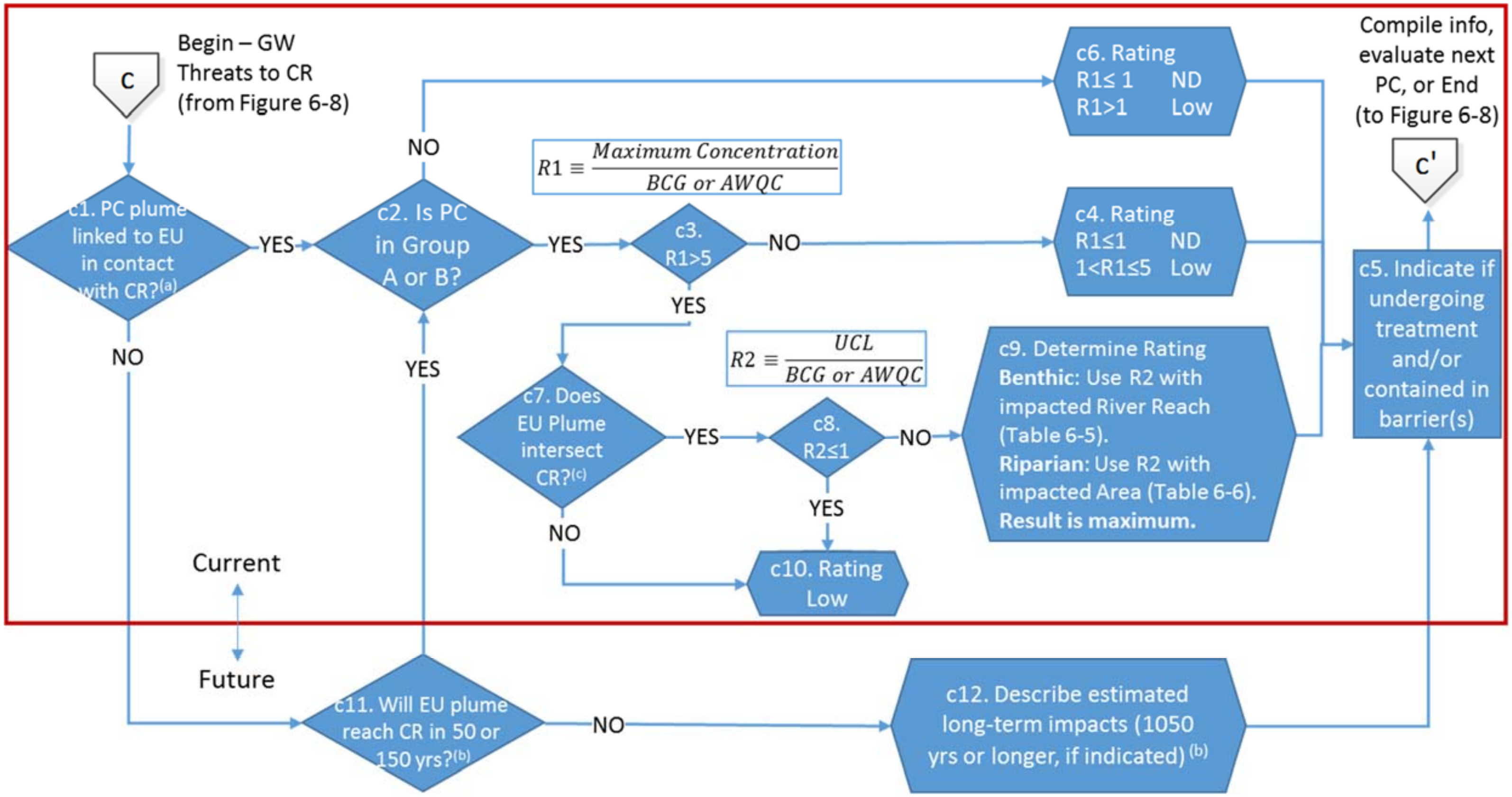
a. Based on plume area above a threshold (e.g., Water Quality Standard (WQS) from 2013 Annual GW Monitoring Report (DOE/RL-2014-32 Rev. 0)). Note plume areas and corresponding estimated plume volumes are (highly) positively correlated.

b. Use available information (e.g., environmental impact statements, risk assessments) to evaluate.

c. Note, no Group D contaminants have been identified as groundwater threats.

d. GTM Rating Table for Group A and B PCs (Table 6-3).

Figure 6-10. Framework steps b-b' (refer to Figure 6-8) for characterizing an evaluation unit for vadose zone threats to groundwater as a protected resource. Note that these steps correspond to steps a2 through a10 in Figure 6-9).



PC = Primary Contaminant
GTM = Groundwater Threat Metric
UCL = Upper 95% confidence limit (log-mean)
VZ = Vadose Zone
CR = Columbia River
AWQC = Ambient Water Quality Criterion (chemicals)
BCG = Biota Concentration Guide (radionuclides)
ND = Not discernible

a. Based on plume area above a threshold (e.g., Water Quality Standard (WQS) from 2013 Annual GW Monitoring Report (DOE/RL-2014-32 Rev. 0)). Note plume areas and corresponding estimated plume volumes are (highly) positively correlated.
b. Use available information (e.g., environmental impact statements, risk assessments) to evaluate.
c. Based on either aquifer tube data or contours exceeding the threshold (e.g., from PHOENIX at http://phoenix.pnnl.gov/).

Figure 6-11. Framework steps c-c' (refer to Figure 6-8) for characterizing an evaluation unit for threats to the Columbia River (where steps in red box are for current impacts and those below are for potential future impacts to the river).

Threats to Groundwater as a Protected Resource

As indicated in Figure 6-9, the first step in determining whether a PC poses a threat to groundwater (as a resource) is to determine if there is a current plume (i.e., area exceeding a water quality standard, often the drinking water standard (DWS) or maximum contaminant level (MCL)) associated with the contaminant from sources associated with the EU. The suggested reference to identify existing groundwater plumes and identify major sources for the plumes is the 2013 Hanford Annual Groundwater Monitoring Report (DOE/RL-2014-32 Rev. 0 2013)[52]. If there is not a current plume associated with the PC or the current plume is not associated with EU sources, then any vadose zone threats related to the PC are assessed as outlined in the next section (Figure 6-10).

If there is a current plume associated with the PC related to EU sources, then the PC group (Table 6-1) is queried. If the PC is in Group C,[53] then the plume area is used to rate the PC as either Low (where area $\leq 0.1\ km^2$) or Medium (area $> 0.1\ km^2$). This determination is made because the Group C contaminants are either frequently present in groundwater from a range of sources and readily treated or would not impair many uses (e.g., nitrate) or are subject to relatively rapid natural decay (e.g., tritium). Alternatively, if the PC is in Group A or B, then saturated zone inventories are estimated for each PC using a method similar to that outlined in the Hanford 200-UP-1 OU Interim Record of Decision (ROD) and described below (EPA 2012).

Estimating Saturated Zone Inventories

The method of estimating saturated zone inventories for the 200-UP OU as an example is outlined in Table 6-2. These inventory estimates necessarily have large associated uncertainties and are intended to be bounding. Furthermore, use of the method outlined in Table 6-2 for other OUs will result in even larger uncertainties because, for example, the depth of a given plume in the saturated zone is not known for these other OUs.

Using the 2013 groundwater monitoring data obtained from PHOENIX (http://phoenix.pnnl.gov/) for the 200-UP OU, the 95% upper confidence level (UCL) on the log-mean of the contaminant data that exceed the water quality standard (WQS) from the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0)[54] is calculated. An upper-bound estimate of the 2013 saturated zone inventory for a chemical contaminant plume (Table 6-2) is given (using 2013 parameter estimates):

$$M^L[kg] = C_{95}^L \left[\frac{\mu g\ X}{L\ soln}\right] V_{WQS}^L[L\ soln] \times \frac{1}{10^9}\left[\frac{kg\ X}{\mu g\ X}\right] \quad [6\text{-}1]$$

$$V_{WQS}^L[L] = \theta A_{WQS}^L[km^2]\tau_{WQS}^L[m] \times 10^6 \left[\frac{m^2}{km^2}\right] 1000 \left[\frac{L}{m^3}\right] \quad [6\text{-}2]$$

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[52] Another source of information for current Hanford groundwater plumes is PHOENIX (http://phoenix.pnnl.gov/).
[53] No current groundwater plumes contain Group D PCs (Table 6-1).
[54] The analysis in the Hanford 200-UP-1 Operable Unit Interim ROD instead used the concentration representing the 90% values for the individual groundwater measurements to estimate the inventory (EPA 2012). Note that the concentrations used in the 200-UP-1 ROD (and thus the resulting plume volumes and inventories) were generally higher than the 95% UCL estimates used in this Review although both were intending to bound the actual plume volume. If insufficient data were available in PHOENIX to estimate the 95% UCL for a PC in the GW OU, then the average value (log-space) of the maximum measured concentration and limit (used to draw the DWS contour) was used. If the 95% UCL exceeded the maximum measured concentration, the average value (log-space) of the measured concentrations exceeding the limit was used.

where

- τ is plume thickness; *A* is area; *V* is volume; *C* is concentration; θ is porosity
- Superscript (*L* or *S*) indicates phase (liquid or solid, respectively) or Total (*Tot*)
- Subscript 95 indicates the upper 95% percentile confidence limit on the log-mean value
- Subscript *WQS* indicates the water quality standard

An equation analogous to Eq. 6-1 is used to provide 2013 saturated zone estimates for radionuclides. For contaminants in other areas, the plume thicknesses were not typically available; thus the minimum of either 1) the thickness from Table 6-2 for the same or related contaminant or 2) the unconfined aquifer thickness in the area is used for the contaminant depth interval and the inventory is estimated as shown. This use leads to likely much larger uncertainties in the plume volumes and inventories in these other areas.

Table 6-2. 200-UP-1 Operable Unit (OU) pore volume and groundwater inventory estimates (based on Table 3 in the Hanford 200-UP-1 OU Interim Record of Decision (EPA 2012))

Contaminant	WQS	Porosity[a]	Area (km^2)	Thickness (m)	Plume Pore Vol. (x $10^6 m^3$)	95% UCL[b]	Estimated Inventory[e]
Uranium	30 µg/L	0.23	0.34	15	1.2	188 µg/L	220 kg
Nitrate, as NO_3	45 pCi/L	0.23	5.80	24	32	116 mg/L	3700000 kg
Total chromium	100 µg/L	0.23	0.37	24	2.0	294 µg/L	600 kg
Hexavalent chromium	48 µg/L	0.23	3.85	24	21	118 µg/L	2500 kg
Tritium (H-3)	20000 pCi/L	0.23	5.50	30	38	57600 pCi/L	2200 Ci
Technetium-99	900 pCi/L	0.23	0.29	20	1.3	6340 pCi/L	8.5 Ci
Iodine-129	1 pCi/L	0.23	3.10	30	21	3.59 pCi/L	0.077 Ci
Carbon tetrachloride	3.4 µg/L[c]	0.23	13.3	55	170	322 µg/L[d]	54,000 kg

a. The porosity is obtained from the analysis described in Attachment 6-1 instead of the value (0.2) used in the 200-UP-1 OU calculation.
b. 95% UCL on the mean of the natural logarithms of those groundwater measurements exceeding the WQS for the primary contaminant.
c. The drinking water standard for carbon tetrachloride is 5 µg/L.
d. The carbon tetrachloride plume covers areas in both the 200-UP-1 and 200-ZP-1 operable units. Measurements from both areas were used to estimate the 95% UCL.
e. Some 2013 inventory estimates are significantly different than those in the 200-UP-1 OU Interim ROD. For example, the 2013 Tc-99 inventory estimate (8.5 Ci) is significantly less than that (20.5 Ci) in the 200-UP-1 OU Interim ROD. This difference is primarily a function of the much smaller plume area in 2013. One the other hand, the 2013 carbon tetrachloride inventory estimate (54,000 kg) is significantly higher than that (9500 kg) in 2012, which is a function of both a ~3× higher plume area and a ~2× higher 95% UCL concentration used to estimate the inventory. Relative differences for the other inventory estimates fall between those for Tc-99 and carbon tetrachloride.

Estimating the Groundwater Threat Metric for Current Plumes

The next step in evaluating risks to groundwater (Step a3 in Figure 6-9) is to estimate the GTM for the current plumes associated with the Group A and B PCs. The GTM represents the maximum volume of water that *could* be contaminated by the inventory of a PC from a source (be it a groundwater plume, remaining vadose zone contamination, tank contents, etc.) if the contaminant was found in the saturated zone at the WQS and in equilibrium with the soil. The GTM accounts only for 1) source inventory, 2) partitioning with the surrounding subsurface, and 3) the WQS. The GTM is based on a snapshot in time (assuming only decay of short-lived radionuclides to the beginning of the evaluation period) and does not account for differences in groundwater mobility or bulk groundwater flow.

For an existing groundwater plume, the GTM is defined (Attachment 6-2 provides the derivation of the GTM) as (where the numerator in the far right-hand expression represents the contaminant mass estimate in the plume):

$$GTM = V_{WQS}^{L} = \theta V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L}}{C_{WQS}^{L}} \qquad [6\text{-}3]$$

where

- V is volume; C is concentration; θ is porosity
- Superscript (L or S) indicates phase or Total (Tot)
- Subscript 95 indicates the upper 95% percentile confidence limit on the log-mean value
- Subscript WQS indicates the Water Quality Standard

For example, the GTM (Eq. 6-3) for the uranium plume in the 200-UP-1 OU would be:

$$GTM = V_{WQS}^{L} = \theta V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L}}{C_{WQS}^{L}} = \frac{(0.23)(5.1 \times 10^{6} m^{3})(188 \mu g/L)}{30\ \mu g/L} = 7.35 \times 10^{6} m^{3} \qquad [6\text{-}4]$$

An analogous equation is used to provide the saturated zone estimates for the radionuclides. The rating for each PC is then defined using Table 6-3 (where the uranium rating, for example, corresponding to the GTM in Eq. 6-4 would be *Low*). Finally, it is indicated if the current plume is undergoing treatment. For example, a pump-and-treat system is being used to treat the plume in the 200-UP-1 OU (Table 6-2). For EUs with multiple PCs, the highest rating is used as the overall summary rating.

Table 6-3. GTM rating table for Group A and B primary contaminants.

GTM (1E6 m^3)	Rating
GTM ≤ 10	Low
10 < GTM ≤ 100	Medium
100 < GTM ≤ 1K	High
GTM > 1K	Very High

VADOSE ZONE THREATS TO GROUNDWATER AS A PROTECTED RESOURCE

The vadose zone threats to groundwater as a protected resource are represented (ultimately as ratings) using the process described in Figure 6-10. The first step (Step b1 in Figure 6-10) is to estimate the vadose zone inventories for the PCs. The basic concept is, using a mass balance approach, that the vadose zone inventory for a PC is the difference between the estimated initial source inventory and the estimated saturated zone inventory (and any contamination removed via treatment processes). Because of the uncertainties involved in the estimates used, the vadose zone inventory is necessarily also a high uncertainty estimate.

Estimating the Source Inventory

The method for estimating the 2013 source inventories is provided in Attachment 6-3 and is based on using data from the Best Basis Inventory for tank wastes (BBI, March 2014 update[55]), the Soil Inventory Model, Rev. 1 (SIM; RPP-26744, Rev. 0) for legacy sites, and the Tank Farm Closure and Waste Management (TC&WM) EIS (DOE/EIS-0391 2012) for tank leaks and ancillary equipment (Table 6-16, Attachment 6-2). Note that for the radionuclides, these information used may have different decay dates; however, any impact of these decay rates for the Group A and B PCs (e.g., Sr-90) is relatively small compared to the large uncertainties in both the saturated zone and remaining vadose zone inventory estimates.

Estimating the Remaining Vadose Zone Inventory and GTM

The inventory estimated in Table 6-2 represents an upper-bound of the amount of the contaminant in the pore water within the plume (in 2013). The corresponding bounding amount of contaminant adsorbed to the sediment phases is estimated using:

$$M^S = K_d \left[\frac{\mu g\ X/g\ solid}{\mu g\ X/mL\ soln}\right] C_{95}^L \left[\frac{\mu g\ X}{L\ soln}\right] (1-\theta) \left[\frac{L\ solid}{L\ total}\right] V_{WQS}^L [L\ soln] \frac{\rho_{bulk}}{1-\theta} \left[\frac{kg\ solid}{L\ solid}\right] \times \frac{1}{10^9} \left[\frac{kg\ X}{\mu g\ X}\right] 1000 \left[\frac{g\ solid}{kg\ solid}\right] \frac{1}{1000} \left[\frac{L\ soln}{mL\ soln}\right] \quad [6\text{-}5]$$

where

- *M* is mass; *V* is volume; *C* is concentration; θ is porosity; ρ is density
- Superscript (*L* or *S*) indicates phase or Total (*Tot*)
- Subscript 95 indicates the upper 95% confidence limit on the log-mean value
- Subscript *WQS* indicates the Water Quality Standard
- Subscript *bulk* indicates the bulk density from Attachment 6-1

An analogous equation is used to provide the sediment estimates for radionuclides. The estimated total mass (solution and sediment) in the saturated zone (SZ) for the current plume is given by $M^{SZ} = M^L + M^S$ from Eq. 6-1 and Eq. 6-5. An estimated amount of a contaminant remaining in the vadose zone is given by the difference of the source mass, M^{Source}, described in Attachment 6-3, and the total plume mass, M^{SZ}, representing the current plume and any removed by treatment, M^{Treat}, or $M^{Tot} = M^{Source} - M^{SZ} - M^{Treat}$.[56] Because of the large uncertainties in the various estimates used in the previous expression for M^{Tot}, the remaining vadose zone estimates also have very high associated uncertainties. Furthermore, because the saturated zone estimate, M^{SZ}, is intended to be an upper bound estimate, the remaining vadose estimate will tend to be biased low.

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[55] From Best Basis Inventory (BBI) Summary (March 24, 2014) provided in spreadsheet form by Mark Triplett (PNNL). The current version of the BBI is stored online and can be accessed using the Tank Waste Information Network System (TWINS) at: https://twinsweb.labworks.org/ (July 2015).

[56] There are additional contaminant sinks (e.g., losses to the atmosphere, biological process, or hydrolysis) that may apply to contaminants such as tritium, carbon tetrachloride, etc. However, sinks apart from treatment have been largely ignored in prior analyses that serve as input to the Risk Review Project because these estimates tend to have very high associated uncertainties and their omission provides higher vadose zone estimates. The exception is for carbon tetrachloride where estimates of total losses (21-38% of the amount disposed) to the atmosphere have been made (DOE/RL-2007-22 2007, p. 4-3). For carbon tetrachloride source mass should be decreased by a factor of 0.21; however, inspection of the results indicates that decreasing the source mass by a factor of 0.38 would not change the resulting ratings.

The corresponding vadose zone GTMs are then computed by substituting the remaining vadose zone mass estimate, M^{Tot}, into the numerator of Eq. 6-3 and converting to a liquid phase volume (Attachment 6-2):

$$GTM = \frac{M^{Tot}}{\left[1 + \frac{\rho_{bulk} K_d}{\theta}\right] C_{WQS}^{L}} \qquad [6\text{-}6]$$

where the saturated zone parameter estimates are described in Attachment 6-1.

As illustrated in Steps b2 and b3 in Figure 6-10, existing information concerning the original discharge type(s), recharge rates, subsurface conditions, and available modeling results (EISs, baseline risk assessments, records of decision, etc.) are then used to determine if a plume is expected in the next 150 years (representing the near-term post-cleanup evaluation period). If a plume is not anticipated based on existing information, then available modeling results from prior studies are used to describe potential long-term impacts (1050 years or longer, if appropriate) as indicated by Step b9 (Figure 6-10). If a plume is anticipated in the 150-yr period, then the process described for the threats from existing plumes to groundwater (a-a' in Figure 6-8 and Steps b4 through b8 in Figure 6-10) is followed, including rating the vadose zone threats using Table 6-3 for Group A and B contaminants (Step b6 in Figure 6-10). Any vadose zone sites that are being treated (e.g., excavation or barriers) are indicated (Step b7 in Figure 6-10).

GROUNDWATER-RELATED THREATS TO THE COLUMBIA RIVER

The final assessment related to PCs is to assess threats to the Columbia River and the riparian zone ecology (c-c' in Figure 6-8 and Figure 6-11). The steps related to evaluating benthic and riparian zone impacts are detailed in the sections that follow. Impacts to benthic and riparian zones were considered a more sensitive evaluation basis than free-stream concentrations because of the very high dilution of groundwater discharges within the Columbia River (as explained below).

Threats to the Columbia River Benthic Ecology

The first step (Step c1 in Figure 6-11) in the threat determination process for impacts to the Columbia River is to determine if a plume associated with sources from the EU is in contact with the Columbia River at concentrations exceeding the WQS. For example, the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) or the aquifer tube data from PHOENIX (http://phoenix.pnnl.gov/) can be used to determine if the near-river concentrations exceed the corresponding WQS. If the plume is not in contact with the Columbia River, then available information (environmental impact statements, baseline risk assessments, records of decision, etc.) can be used to determine if a plume related to sources in the EU can be expected to intersect the Columbia River in the next 150 years (Step c11 in Figure 6-11). If not, then available modeling results are used to describe potential long-term impacts (1050 years or longer, if appropriate, as indicated in Step c12 in Figure 6-11) and then proceed to the next threat assessment (Figure 6-8).

If the plume linked to EU sources either is in contact with the Columbia River or is expected to intersect the river in 150 years, then the threat to the Columbia River is evaluated in the multi-step process (i.e., Steps c2 through c10) shown in Figure 6-11.

First, the ratio (R1) of the maximum concentration to the appropriate benthic screening value is computed (Step c3 in Figure 6-11), where the screening values are as follows:

- For radionuclides, the BCG consistent with DOE Technical Standard DOE-STD-1153-2002[57] is used.
- For chemicals, the Ambient Water Quality Criteria (AWQC) from the Columbia River Component Risk Assessment (CRCRA) (DOE/RL-2010-117, Rev. 0) Volume I: Screening Level Ecological Risk Assessment are used (where the Tier II Screening Risk Values are used when the AWQC is unavailable, which is also consistent with the CRCRA). The only exception is (total) uranium where the AWQC (5 µg/L) from the CRCRA is less than the background uranium concentration (~5-12.8 µg/L) (PNNL-17034, p. 6.9). A value of 12.9 µg/L was selected for total uranium beneath the 300 Area to identify those areas contaminated by the Hanford Site (PNNL-17034, p. 6.9); this value is also used in this Review.[58]

Table 6-4 summarizes the thresholds considered in this review for the Group A and B PCs.

[57] The values used are taken from RESRAD BIOTA (https://web.evs.anl.gov/resrad/home2/biota.cfm), which is consistent with DOE Technical Standard DOE-STD-1153-2002 and the Columbia River Component Risk Assessment (DOE/RL-2010-117, Rev. 0) Volume I: Screening Level Ecological Risk Assessment.

[58] The selected value of 12.9 µg/L represents between the 90th and 95th percentile for site-wide background uranium concentration (DOE/RL-96-61, 1997). Note that there also is a large uncertainty relative to the No Effects level for total uranium. As stated in the CRCRA, "Effect levels span nearly three orders of magnitude (3 µg/L to 900 µg/L), reflecting considerable uncertainty in selection of a no-effect concentration. The value selected is a probable no effect concentration and is the 5th percentile of the toxicity data set" (DOE/RL-2010-117 Rev. 0, p. 6.2).

Table 6-4. Thresholds considered in the Risk Review for the Group A and B primary contaminants. The primary thresholds used in the analysis are indicated in the red boxes.

PC	Grp	WQS[a]	DWS	DOE DCS[b]	BCG[c]	AWQC[d]/SCV[e]
Tc-99	A	900 pCi/L	900 pCi/L	44000 pCi/L	667000 pCi/L	---
I-129	A	1 pCi/L	1 pCi/L	330 pCi/L	38500 pCi/L	---
C-14	A	2000 pCi/L	2000 pCi/L	62000 pCi/L	609 pCi/L	---
Cr-VI	A	10-48 ug/L[f]	---	---	---	10 ug/L[f]
CCl_4	A	3.4 ug/L[g]	5 ug/L	---	---	9.8 ug/L
Sr-90	B	8 pCi/L	8 pCi/L	1100 pCi/L	279 pCi/L	7 ug/L (Sr)
U(tot)	B	30 ug/L	30 ug/L	750 pCi/L (U-238)	224 pCi/L (U-238)	12.9 ug/L[h]
Cr(tot)	B	48 ug/L[f]	100 ug/L[f]	---	---	55 ug/L
CN	B	200 ug/L	200 ug/L	---	---	5.2 ug/L
TCE	B	4[g]-5 ug/L	5 ug/L	---	---	47 ug/L

Human Health ⟷ Benthic/ Riparian

a. Water Quality Standard (WQS) from 2013 Annual GW Report (DOE/RL-2014-32, Rev. 0). Some values vary by Operable Unit.
b. DOE Derived Concentration Standard (Ingested Water DCS from Table 5 in DOE-STD-1196-2011).
c. Biota Concentration Guide (BCG) from RESRAD-BIOTA v1.5 (consistent with DOE Technical Standard DOE-STD-1153-2002).
d. Ambient Water Quality Criterion (AWQC) (Table 6-1 in DOE/RL-2010-117, Rev. 0).
e. Tier II Screening Concentration Value (SVC) (http://rais.ornl.gov/documents/tm96r2.pdf) when AQWC not provided.
f. Different values tabulated for different GW Operable Units. 10 ug/L is the surface water standard for Cr-VI. 20 ug/L is the groundwater cleanup target for Cr-VI identified for interim remedial action. 48 ug/L is the MTCA groundwater cleanup standard. 100 ug/L is the drinking water standard for total chromium.
g. Risk-based cleanup value from the record of decision as reported in the 2013 Annual GW Report (DOE/RL-2014-32, Rev. 0).
h. Uranium (total) screening values were 0.5 ug/L (DOE/RL-2007-21 2012) and 5 ug/L (DOE/RL-2010-117, Rev. 0, 2010). Background uranium levels of 0.5-12.8 µg/L were detected near the 300-F Area with a value of 12.9 µg/L selected (Peterson et al, 2008, p. 6.9). No effect levels span 3-900 µg/L reflecting considerable uncertainty (DOE/RL-2010-117, Rev. 0, 2010).

The rating process for benthic threats under current conditions (Figure 6-11) proceeds as follows:

- If the ratio R1 ≤ 1 (i.e., the maximum concentration is less than the screening threshold as indicated in Steps c3 and c4), then the rating for benthic threats is ND and then proceed to the next threat assessment (below).
- If the PC is in Group C (Table 6-1), then the rating for benthic impacts is Low (Step c6) and then proceed to the next threat assessment (below).
- If the PC is in Group A or B (Table 6-1), then the rating is Low if the ratio R1 ≤ 5 (Step c4) and then proceed to the next threat assessment (below).
- If the ratio R1 > 5, then rating is Low if the plume is not currently intersecting the Columbia River as indicated in Step c7 (using aquifer tube data or contours exceeding the threshold). Then proceed to the next threat assessment (below). If the plume is currently intersecting the river, then the ratio R2 of the 95% UCL estimate to the screening value (BCG or AWQC) is computed.
- If the ratio R2 ≤ 1 (i.e., the mean concentration is less than the screening threshold in Step c8), then the rating is Low if the ratio R1 ≤ 5 (Step c10) and then proceed to the next threat assessment (below).
- If the ratio R2 > 1, then the matrix represented in Table 6-5 is used to determine the rating (Step c9) based on the ratio R2 and the Shoreline Impact provided in the 2013 Hanford Annual

Groundwater Report (DOE/RL-2014-32 Rev. 0). Then proceed to the next threat assessment (below).

Table 6-5. Benthic zone ratings for contaminants based on the estimated length of potentially impacted river reach and the ratio R2 (i.e., [log-mean concentration, 95th UCL]/(BCG or AWQC)).

	(Log-Mean Concentration, 95th UCL)/(BCG or AWQC)			
River Reach (m)	< 1	1 to < 5	5 to < 10	> 10
<50	ND	Low	Medium	Medium
50 to < 500	ND	Medium	Medium	High
500 to < 1500	ND	Medium	High	High
> 1500	ND	Medium	High	Very High

ND = Not discernible
BCG = biota concentration guide for radionuclides
AWQC = ambient water quality criterion for chemicals

Threats to the Columbia River Riparian Zone Ecology

The threat determination process for the riparian zone (C-C' in Figure 6-8 and Figure 6-11) proceeds along the same lines as that for threats to benthic receptors unless the ratio R2 exceeds unity, in which case the final step in the threat assessment process is as follows:

- If the ratio R2 > 1, then the matrix represented in Table 6-6 is used (again in Step c9) to determine the rating based on the ratio R2 and the Riparian Zone impact area.[59] Then proceed to the next threat assessment (below).

[59] The intersection area between the groundwater plume and the riparian zone was provided by PNNL based on the 2013 Hanford Site Groundwater Monitoring Report (DOE/RL-2014-32 Rev. 0).

Table 6-6. Riparian zone ratings for contaminants based on the area of the potentially impacted riparian zone and the ratio R2 (i.e., [log-mean concentration, 95th UCL]/(BCG or AWQC)).

	(Log-Mean Concentration, 95th UCL)/(BCG or AWQC)			
Area (hectares)	< 1	1 to < 5	5 to < 10	> 10
<0.5	ND	Low	Medium	Medium
0.5 to < 5	ND	Medium	Medium	High
5 to < 15	ND	Medium	High	High
> 15	ND	Medium	High	Very High

ND = Not discernible
BCG = biota concentration guide for radionuclides
AWQC = ambient water quality criterion for chemicals

Threats to the Columbia River Free-flowing Ecology

The threat determination process for the free-flowing Columbia River ecology was evaluated in a manner similar to that described above for benthic receptors (c-c' in Figure 6-8 and Figure 6-11). However, because of the river has a large dilution effect on the contamination from the seeps and groundwater upwellings,[60] the differences from EU to EU were not found distinguishing and the potential for groundwater contaminant discharges from Hanford to achieve concentrations above relevant thresholds is very remote[61]. If additional information becomes available (e.g., based on concentration measurements or bioaccumulation in certain areas of the Hanford Reach) that would lead to significant differentiation among EUs based on potential free-flowing river impacts, then the framework will be revised for the Final Report of the Risk Review Project.

[60] "Groundwater is a potential pathway for contaminants to enter the Columbia River. Groundwater flows into the river from springs located above the water line and through areas of upwelling in the river bed. Hydrologists estimate that groundwater currently flows from the Hanford unconfined aquifer to the Columbia River at a rate of ~ 0.000012 cubic meters per second (Section 4.1 of PNNL-13674). For comparison, the average flow of the Columbia River is ~3,400 cubic meters per second" (DOE/RL-2014-32 Rev. 0). This represents a dilution effect of more than eight orders of magnitude (a dilution factor of greater than 100 million).

[61] Bioaccumulation and biomagnification of some contaminants in aquatic biota may be possible, however, these effects typically are considered in the development of surface water quality standards, and insufficient information exists at the Hanford site to use potential consideration of these effects in the screening process for the Risk Review Project.

6.3. DEMONSTRATION OF THE GROUNDWATER EVALUATION FRAMEWORK

The capability of the framework is demonstrated in this section by characterizing the 200-UP-1 OU that lies within the CP-GW-2 EU. Note that the vadose zone sources associated with the 200-UP OU include those associated with the S-SX (CP-TF-2) and U (CP-TF-4) WMAs[62]. The remaining vadose zone inventories and threats will thus also be evaluated for these Tank Waste and Farms EUs.

The 200-UP-1 OU and the associated groundwater plumes are located in the Central Plateau (Figure 6-12). Information related to the current plumes from the 200-UP-1 OU from the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) is provided in Table 6-7, where the cleanup level provided in the table is used as the WQS for this demonstration. For example, the cleanup level (3.4 µg/L) for carbon tetrachloride is lower than the corresponding drinking water standard (5 µg/L)[63].

[62] The 200-West DSTs EU (CP-TF-9) is also in the vicinity of the 200-UP-1 OU; however, there is no vadose or saturated zone contamination associated with this EU.
[63] The difference between a threshold value of 3.4 and 5 µg/L is indistinguishable within sampling and chemical analysis uncertainties.

Table 6-7. 200-UP-1 Operable Unit summary (reproduced from DOE/RL-2014-32 Rev. 0).

REDOX Plant Operations: 1952 to 1967 (plutonium separation) U Plant Operations: 1952 to 1957 (uranium recovery)			
2013 Groundwater Monitoring			
Groundwater Contaminant	Cleanup Level[a]	Maximum Concentration	Plume Area[b] (km^2)
Carbon tetrachloride	3.4 µg/L	700 µg/L (299-W14-71)	13.3[c]
Chromium	48[d]/100[e] µg/L	907 µg/L (299-W23-19)	3.86/0.37
Nitrate	45 mg/L	3,210 mg/L (288-W19-43)	5.8
Iodine-129	1 pCi/L	9.14 pCi/L (299-W22-88)	3.1
Technetium-99	900 pCi/L	62,000 pCi/L (299-W23-19)	0.29
Tritium	20,000 pCi/L	310,000 pCi/L (699-36-66B)	5.5
Uranium	30 µg/L	298 µg/L (299-W19-43)	0.34
Remediation			
U Plant pump-and-treat (interim action from 1994 to 2011): • Removed 220.5 kg uranium • Removed 2.17 Ci technetium-99 S-SX Tank Farms Groundwater Extraction System (interim action): • Began operating during July 2012 • Removed 1.03 Ci technetium-99 since startup • Removed 17.9 kg chromium since startup • Removed 9,560 kg nitrate since startup • Removed 121 kg carbon tetrachloride since startup Interim action record of decision approved in September 2012. Remedial Design/Remedial Action Work Plan released September 2013.			

a. From Table 14 in the interim ROD (EPA et al., 2012).
b. Estimated area above the cleanup level unless otherwise noted.
c. Represents the entire extent of the plume (includes the 200-ZP).
d. “Model Toxics Control Act—Cleanup” (WAC 173-340) Method B groundwater cleanup level for hexavalent chromium.
e. Federal drinking water standard for total chromium.

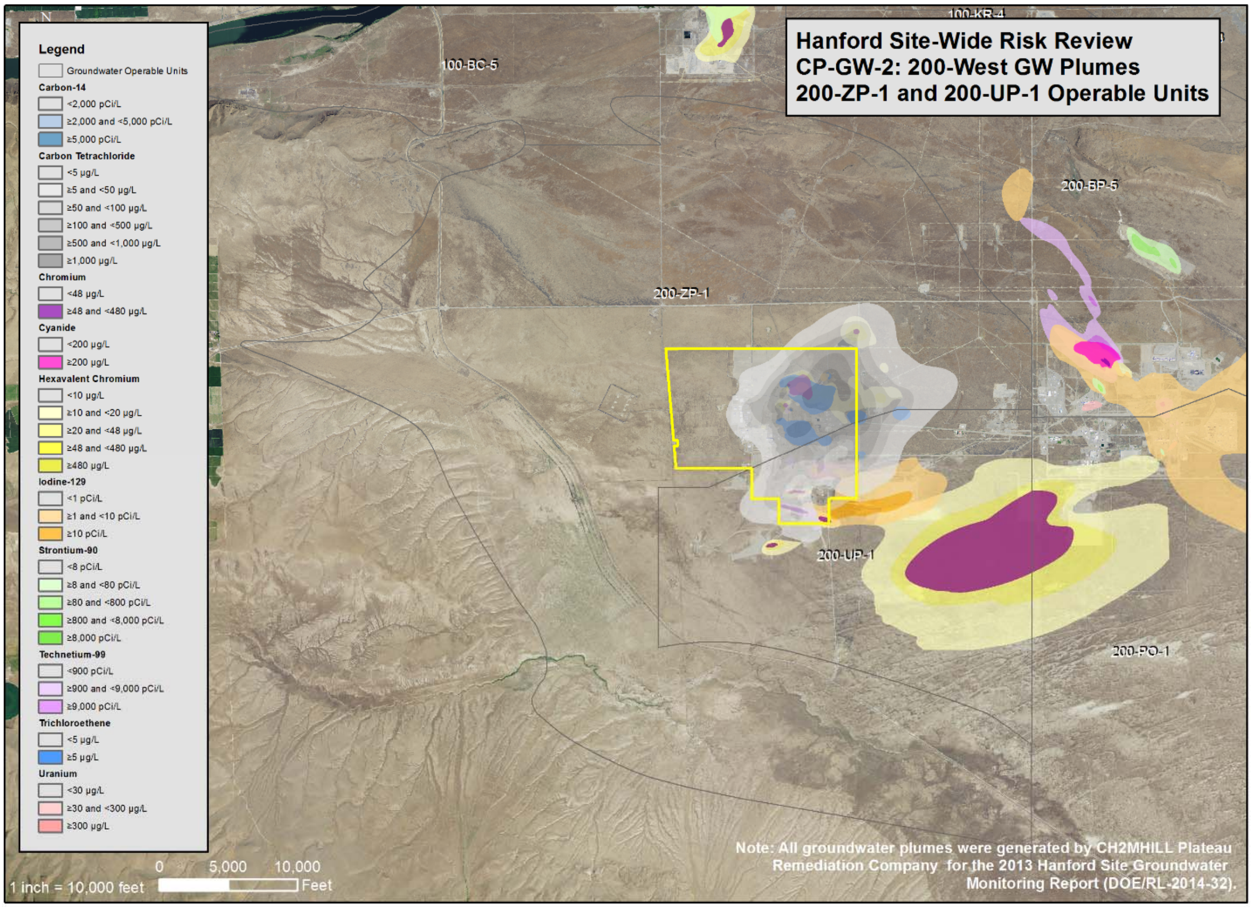

Figure 6-12. 200-ZP-1 and 200-UP-1 OUs and groundwater plumes in the Central Plateau.

PRIMARY CONTAMINANT SELECTION (STEP 4 IN FIGURE 6-8)

For this demonstration, the contaminants monitored in the current groundwater report for the 200-UP-1 OU (Table 6-7) are selected as PCs. The TC&WM EIS groundwater screening analysis (DOE/EIS-0391, Appendix O, p. O-60) at the S and U Barriers (i.e., near the original sources of contamination in the 200-UP-1 OU) suggest that no additional contaminants are likely to exceed thresholds in the future[64]; thus, no additional contaminants are considered. The TC&WM EIS screening analysis was used as an indication of vadose zone and groundwater transport of contaminants for this demonstration (and will be used for many of the Central Plateau EUs); other information should be used where available and appropriate.

[64] The barrier represents the edge of the infiltration barrier to be constructed over disposal areas that are within 100 meters [110 yards] of facility fence lines (DOE/EIS-0391, Appendix O, p. O-17). If no values are reported at the barrier for a given scenario, then predicted peak fluxes were less than 1×10^{-8} Ci/yr for radionuclides or 1×10^{-8} g/yr for chemicals during the 10,000-year assessment period (DOE/EIS-0391, Appendix O, p. O-2). For this example, screening TC&WM EIS results are used as indications of vadose and saturated zone contaminant transport for the purpose of this study. For example, if the contaminant in question does not reach the barrier (in significant fluxes as mentioned above) within the 10,000-yr EIS assessment period, then it is assumed to also not impact groundwater (i.e., be in concentrations exceeding standards) through the 150-yr near-term, post cleanup period. Other results should be used where available or in areas other than the Central Plateau.

THREATS TO GROUNDWATER AS A PROTECTED RESOURCE

As indicated in Figure 6-9, the first step (Step a1) in determining whether a PC poses a threat to groundwater (as a resource) is to determine if there is a current plume (i.e., area exceeding a WQS) from sources linked to the EU associated with the contaminant. Since there are 200-UP-1 plumes that exceed standards (Table 6-7), the threats from the current plumes will be evaluated since these plumes are related directly to the GW EU[65]. From Table 6-1 the tritium (H-3) and nitrate (NO_3) PCs are Group C and both would have a *Medium* rating since their current plume areas exceed 0.1 km^2 (Figure 6-9, Step a6). The other PCs (i.e., uranium, chromium, hexavalent chromium, Tc-99, I-129, and carbon tetrachloride) are in Groups A and B (Table 6-1). The first step in evaluating the threats to groundwater as a resource is to estimate the saturated zone inventories for the A and B PCs (Figure 6-9, Step a3).

Estimating Saturated Zone Inventories, GTMs are Ratings for Threats to Groundwater as a Protected Resource

The method of estimating saturated zone (i.e., groundwater) inventories is outlined in Table 6-2 using Eqs. 6-1 and 6-2, where the 95% UCL on the log-mean of the contaminant data obtained from PHOENIX (http://phoenix.pnnl.gov/) that exceed the WQS for the 200-UP-1 OU as described in the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0). Note that for other areas where plume depths are not given, either the depths shown in Table 6-2 or the unconfined aquifer thickness in the area is used, which likely results in much larger uncertainties than associated with the estimates for the 200-UP-1 OU contaminants in Table 6-2.

For example, the volume associated with the uranium plume is:

$$V_{WQS}^{L}[L] = \theta A_{WQS}^{L}[km^2]\tau_{WQS}^{L}[m] \times 10^6 \left[\frac{m^2}{km^2}\right] 1000 \left[\frac{L}{m^3}\right]$$
$$= (0.23)(0.34\ km^2)(15\ m) \times 10^6 \left[\frac{m^2}{km^2}\right] 1000 \left[\frac{L}{m^3}\right] \quad [6\text{-}7]$$
$$= 1.173 \times 10^9\ L$$
$$= 1.173 \times 10^6\ m^3 \text{ or } 1.2\times 10^6\ m^3\ (2\ significant\ digits)$$

The corresponding inventory in the saturated zone associated with the uranium plume is:

$$M^{L}[kg] = C_{95}^{L}\left[\frac{\mu g\ X}{L\ soln}\right] V_{WQS}^{L}[L\ soln] \times \frac{1}{10^9}\left[\frac{kg\ X}{\mu g\ X}\right]$$
$$= \left(188\frac{\mu g\ X}{L\ soln}\right)(1.173 \times 10^9\ L\ soln) \times \frac{1}{10^9}\left[\frac{kg\ X}{\mu g\ X}\right] \quad [6\text{-}8]$$
$$= 221\ kg\ uranium \text{ or } 220\ kg\ uranium\ (2\ significant\ digits)$$

The GTMs corresponding to the saturated zone inventories are estimated using Eq. 6-3. For example, the GTM associated with the uranium plume is:

$$GTM = V_{WQS}^{L} = \theta V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L}}{C_{WQS}^{L}} = \frac{(0.23)(5.1 \times 10^6 m^3)(188\mu g/L)}{30\ \mu g/L} = 7.4 \times 10^6 m^3 \quad [6\text{-}9]$$

[65] There are current 200-UP-1 OU plumes associated with the S-SX (CP-TF-2) and U (CP-TF-4) Tank Waste and Farms EUs. For CP-TF-2 (WMA S-SX), the nitrate, chromium, and Tc-99 plumes can be associated with EU sources. For CP-TF-4 (WMA U), the nitrate and Tc-99 plumes can be associated with EU sources as described below.

The ratings corresponding to the Group A and B PCs are evaluated using Table 6-3. For example, the GTM of 7.4 × 10^6 m^3 for uranium (i.e., a Group B PC) translates to a rating of *Low*. The results for the evaluation of the potential threats from the 200-UP-1 PCs to groundwater as a protected resource are summarized in Table 6-8. The ratings for the 200-UP-1 OU include *Low* for uranium, chromium, and Tc-99; *Medium* for nitrate, hexavalent chromium, tritium, and I-129; and *Very High* for carbon tetrachloride. Note the primary sources for carbon tetrachloride contamination in the 200-West Areas are past discharges of liquid waste from Plutonium Finishing Plant's (PFP) processes to cribs and tranches above the 200-ZP-1 OU; the contamination has migrated to the 200-UP-1 OU (where it is being treated using the 200-West Groundwater Treatment Facility). The overall rating for the 200-UP-1 OU PCs as threats to groundwater as a protected resource would be *Very High* if carbon tetrachloride is included in the 200-UP-1 evaluation. Note that the 200-UP-1 contaminants are being treated using the 200 West Groundwater Treatment Facility.

Table 6-8. Summary of the evaluation of threats to groundwater as a protected resource from current saturated zone plumes in the 200-UP-1 OU.

Contaminant	Grp	WQS	Porosity(a)	Area (km²)	Thickness (m)	Plume Pore Vol. (x10⁶ m³)	Maximum Concentration	95% UCL(b)	Estimated Inventory	GTM (x10⁶ m³)	Rating(c)
Total uranium	B	30 µg/L	0.23	0.34	15	1.2	298 µg/L	188 µg/L	220 kg	7.4	Low
Nitrate, as NO_3	C	45 pCi/L	0.23	5.80	24	32	3210 mg/L	116 mg/L	3,700,000 kg	---	Medium
Total chromium	B	100 µg/L	0.23	0.37	24	2.0	907 µg/L	294 µg/L	600 kg	6	Low
Hexavalent chromium	A	48 µg/L(d)	0.23	3.85	24	21	907 µg/L	118 µg/L	2500 kg	52	Medium
Tritium (H-3)	C	20,000 pCi/L	0.23	5.50	30	38	310,000 pCi/L	57,600 pCi/L	2200 Ci	---	Medium
Technetium-99	A	900 pCi/L	0.23	0.29	20	1.3	62,000 pCi/L	6340 pCi/L	8.5 Ci	9.4	Low
Iodine-129	A	1 pCi/L	0.23	3.10	30	21	9.14 pCi/L	3.59 pCi/L	0.077 Ci	77	Medium
Carbon tetrachloride	A	3.4 µg/L(e)	0.23	13.3	55	170	2600 µg/L	322 µg/L(f)	54,000 kg	11,000(e)	Very High

a. The porosity is obtained from the analysis provided in Attachment 6-1.
b. 95% UCL on the mean of the natural logarithms of those measurements exceeding the WQS.
c. These contaminants are being treated using the 200 West Groundwater Treatment Facility.
d. "Model Toxics Control Act—Cleanup" (WAC 173-340) Method B groundwater cleanup level for hexavalent chromium.
e. The drinking water standard for carbon tetrachloride is 5 µg/L, which is used to estimate the GTM.
f. The carbon tetrachloride plume covers areas in both the 200-UP-1 and 200-ZP-1 operable units. Measurements from both areas were used to estimate the 95% UCL.

VADOSE ZONE THREATS TO GROUNDWATER AS A PROTECTED RESOURCE

As indicated in Figure 6-10, the first step (Step b1) in determining whether a PC in the vadose zone poses a potential future threat to groundwater (as a protected resource) is to estimate the vadose zone inventory. The groundwater EUs are different than the other legacy EUs in this study because the plumes represent the bounds of the impacted area. However, since legacy areas can impact the future sizes of the plumes, the legacy source sites that are associated with the plumes (i.e., in the vadose zone above the GW OUs) will be evaluated.

Estimating the Source and Remaining Vadose Zone Inventories and GTM

The basis for estimating 2013 source inventories is described in Attachment 6-3. For GW EUs, the legacy source EUs above the GW OU or EU in question are used to represent the possible sources of the contaminant in the vadose zone. For example, the uranium source inventory for the 200-UP-1 OU is 3200 kg (WMA S-SX) and 200 kg (WMA U) for a total of M^{Source} = 3400 kg[66].

The inventory, M^S, adsorbed to the sediment phases corresponding to the 200-UP-1 OU liquid phase inventory, M^L, is estimated using Eq. 6-5 (where uranium is used as an example with the volume estimated in Eq.6-7):

$$\begin{aligned} M^S &= K_d \left[\frac{\mu g\ X / g\ solid}{\mu g\ X / mL\ soln}\right] C_{95}^L \left[\frac{\mu g\ X}{L\ soln}\right] (1-\theta) \left[\frac{L\ solid}{L\ total}\right] V_{WQS}^L [L\ soln] \frac{\rho_{bulk}}{1-\theta} \left[\frac{kg\ solid}{L\ solid}\right] \\ &\qquad \times \frac{1}{10^9}\left[\frac{kg\ X}{\mu g\ X}\right] 1000 \left[\frac{g\ solid}{kg\ solid}\right] \frac{1}{1000}\left[\frac{L\ soln}{mL\ soln}\right] \\ &= \left(0.80\ \frac{mL\ soln}{g\ solid}\right)\left(188\frac{\mu g\ U}{L\ soln}\right)(1-0.23)\left[\frac{L\ solid}{L\ total}\right](1.173\times 10^9\ L\ )\frac{1.84}{1-0.23}\left[\frac{kg\ solid}{L\ solid}\right] \\ &\qquad \times \frac{1}{10^9}\left[\frac{kg\ X}{\mu g\ X}\right] 1000 \left[\frac{g\ solid}{kg\ solid}\right] \frac{1}{1000}\left[\frac{L\ soln}{mL\ soln}\right] \\ &= 1410\ kg\ uranium \text{ or } 1400\ kg\ uranium\ (2\ significant\ digits) \end{aligned} \quad [6\text{-}10]$$

Because of the nature of the K_d's used in this report (i.e., minimum best-estimates to maximize predicted transport), the estimate of adsorbed uranium using Eq. 6-5 or Eq. 6-10 is likely biased low and has a large uncertainty. The total 200-UP-1 OU saturated zone mass for uranium is:

$$M^{SZ} = M^L + M^S = 221 + 1410 = 1631\ kg \text{ or } 1600\ kg\ (2\ significant\ digits) \quad [6\text{-}11]$$

The treatment impact, M^{Treat}, on PCs can be obtained from various information sources[67]. For example, the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) indicates that the U Plant pump-and-treat (interim action from 1994 to 2011) removed 220.5 kg of uranium and the 1985 interim

[66] There is also approximately 2×10^5 kg of uranium in ERDF (CP-OP-6); however, this uranium is in a RCRA landfill and is not likely accessible to the environment during the period of this evaluation. Furthermore, significant sources may be omitted until the complete set of EUs are evaluated.

[67] The only sink typically considered is treatment with the exception of total loss to the atmosphere for carbon tetrachloride as described in Section 6.2. For the GW EUs, the treatment estimates provide in the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) are used. However, if the plume are apportioned to represent specific EUs (e.g., Tank and Waste Farms or Legacy Sources) as described in Attachment 6-4, then the treatment amounts are assumed proportional to the relative plume areas.

action to pump and treat groundwater below the 216-U-1 and 216-U-2 cribs removed 687 kg of uranium, or the remaining vadose zone inventory, M^{Tot}, is:

$$M^{Tot} = M^{Source} - M^{SZ} - M^{Treat} = 3410 - 1631 - (220.5 + 687)$$
$$= 874\ kg\ uranium\ or\ 870\ kg\ uranium\ (2\ significant\ digits) \quad [6\text{-}12]$$

The corresponding GTM for the remaining vadose zone inventory is given by Eq. 6-3. For uranium, the value is given by:

$$GTM = \frac{M^{Tot}}{\left[1 + \frac{\rho_{bulk} K_d}{\theta}\right] C_{WQS}^{L}}$$
$$= \frac{874\ kg}{\left[1 + \frac{\left(1.84 \frac{kg\ solid}{L\ solid}\right)\left(0.8 \frac{mL\ soln}{g\ solid}\right)}{0.23}\right]\left(30 \frac{\mu g\ U}{L\ soln}\right)} = 4.0 \times 10^6 m^3 \quad [6\text{-}13]$$

Table 6-9 summarizes the results for the evaluation of the potential threats from the 200-UP PCs in the vadose zone to groundwater as a protected resource. Some very mobile contaminants (e.g., Tc-99, chromium, tritium, and carbon tetrachloride) that are already impacting groundwater are estimated to have significant remaining vadose zone inventories; this may be due to the manner in which these contaminants were discharged (leaks, cribs, and trenches) to the environment. The ratings for the 200-UP-1 OU are *Low* for uranium and I-129; *Medium* for Tc-99; *High* for chromium (total and hexavalent); and *Very High* for carbon tetrachloride (if included in the evaluation). The overall rating for the 200-UP-1 OU PCs remaining in the vadose zone as threats to groundwater as a protected resource is thus *Very High*, if carbon tetrachloride is included or *High*, if not.

The TC&WM EIS groundwater screening analysis (DOE/EIS-0391 2012, Appendix O) for various Central Plateau sources (single-shell tank farms, ancillary equipment, and selected cribs, trenches, past leaks, and unplanned releases) at the S and U Barriers[68] (i.e., near the original sources of contamination in the 200-UP-1 OU) indicate that the following contaminants would exceed thresholds in the period evaluated in the EIS for the No Action Alternative after CY 2050 (Table O-8, DOE/EIS-0391 2012, p. O-59)[69]:

- Tc-99 with peak concentration of 22,800 pCi/L in CY 3072 at the S Barrier and 9,830 pCi/L in CY 3985 at the U Barrier versus a benchmark (i.e., drinking water standard) of 900 pCi/L

[68] The barrier represents the edge of the infiltration barrier to be constructed over disposal areas that are within 100 meters [110 yards] of facility fence lines (DOE/EIS-0391 2012). Despite including sources other than those for the S-SX and U Tank Waste and Farm EUs, the groundwater screening analysis in the TC&WM EIS (DOE/EIS-0391 2012, Appendix O) was considered reasonable to assess rate of movement of contaminants through the Hanford subsurface. Other information should be used when available.

[69] Peak concentrations for other contaminants (e.g., tritium, uranium, and nitrate) were provided but were less than the corresponding benchmark concentrations during the 10,000-yr EIS evaluation period (Table O-8, DOE/EIS-0391 2012, p. O-59). If no values are reported at the barrier for a given scenario, then predicted peak fluxes were less than 1×10^{-8} Ci/yr for radionuclides or 1×10^{-8} g/yr for chemicals during the 10,000-year assessment period after CY 2050, the approximate time assumed for placement of engineered caps (DOE/EIS-0391, Appendix O, p. O-2 and p. O-58).

- I-129 with peak concentration of 29.1 pCi/L in CY 3136 at the S Barrier and 19.6 pCi/L in CY 4118 at the U Barrier versus a benchmark (i.e., drinking water standard) of 1 pCi/L
- Chromium (total) with peak concentration of 541 µg/L in CY 3242 at the S Barrier and 208 µg/L in CY 3882 at the U Barrier versus a benchmark (i.e., drinking water standard) of 100 µg/L[70]

Thus based on the TC&WM EIS groundwater screening analysis, no additional contaminants in the vadose zone above the 200-UP-1 OU are expected to impact groundwater in the next 150 years (i.e., through the near-term, post-cleanup evaluation period).

The expected outcome of the selected pump-and-treat remedy for the 200-UP-1 OU is that area groundwater will return to levels that allow use as a drinking water source (most beneficial use) within 35 years for all contaminants except for I-129 and carbon tetrachloride (EPA 2012). It is predicted that achieving the cleanup level for carbon tetrachloride contamination will require up to 125 years. Hydraulic containment is expected for I-129 (EPA 2012). Using the above information, a summary of the saturated and vadose zone results is:

- Uranium – There is a current plume in 200-UP-1 associated with 200-UP-1 sources that translates to a *Low* rating (Table 6-8) for Current conditions. The remaining uranium in the vadose zone also translates to a *Low* rating (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that uranium will likely not be very mobile in the subsurface region in the area of the 200-UP-1 OU and thus total uranium is not considered a significant threat to the Hanford groundwater during the Active Cleanup or Near-term, Post Cleanup periods. Because uranium is already in the groundwater and it will not appreciably decay, the ratings of *Low* are maintained for the Active Cleanup and Near-term, Post-Cleanup periods.
- Nitrate – There is a current plume that translates to a *Medium* rating (Table 6-8) for Current conditions (based on plume areal extent since nitrate is in Group C). The remaining vadose zone estimate for nitrate is negative (Table 6-9), which may be either due to uncertainties, missing source sites, or both. The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak nitrate concentrations will be less than the benchmark value (i.e., the drinking water standard) after CY 2050 (i.e., there will be no plume in the area). Thus the Near-term, Post-Cleanup rating is *Not Discernible* (including additional treatment) and the Active Cleanup rating is *Medium* (because of uncertainties).
- Chromium (hexavalent and total) – There are plumes that translate to *High* ratings (Table 6-8) for Current conditions. The remaining vadose zone estimates also translate to *High* ratings for both (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak chromium concentrations are expected to remain above benchmark values (and the thresholds used in this Review as indicated in Table 6-4) after CY 2050. However, since the peak concentrations are less than the maximum measured values in 2013 (Table 6-8), there is no reason to increase the rating (i.e., the rating remains *High* for the Active Cleanup period). Because treatment is anticipated to be effective for chromium in the next 35 years, the rating for the Near-term, Post-Cleanup evaluation period is *Not Discernible*.
- Tritium – There is a current plume that translates to a *Medium* rating (Table 6-8) for Current conditions (based on plume areal extent since tritium is in Group C). The remaining vadose zone

[70] The standards selected in the Risk Review for hexavalent chromium and total chromium are 10 µg/L (surface water standard) and 48 µg/L (MTCA groundwater cleanup standard).

estimate for tritium is higher than that currently estimated to be in the saturated zone (Table 6-9), thus it is assumed that the corresponding plume area from this remaining inventory would be at least the size of the current plume, which translates to a *Low* rating (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak tritium concentrations will be less than the benchmark value (i.e., the drinking water standard) after CY 2050 (i.e., there will be no plume in the area). Thus the Near-term, Post-Cleanup rating is *Not Discernible* and the Active Cleanup rating is *Medium* (because of uncertainties).

- Tc-99 – There is a current plume that translates to a *Low* rating (Table 6-8) for Current conditions. The remaining vadose zone estimate translates to a *Medium* rating (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak Tc-99 concentrations are expected to remain above the benchmark value (i.e., the drinking water standard) after CY 2050. However, since the peak concentration is less than the maximum measured value in 2013 (Table 6-8), there is no reason to increase the rating (i.e., the ratings remain *Low* and *Medium* for the Active Cleanup period). Because treatment is anticipated to be effective for Tc-99 in the next 35 years, the rating for the Near-term, Post-Cleanup evaluation period is *Not Discernible*.
- I-129 – There is a current plume that translates to a *Medium* rating (Table 6-8) for Current conditions. The remaining vadose zone estimate translates to a *Low* rating (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak I-129 concentrations are expected to remain above the benchmark value (i.e., the drinking water standard) after CY 2050. Furthermore, since the peak concentration exceeds the maximum measured value in 2013 (Table 6-8), the plume may increase in size in the future, especially since current treatment will not be effective for I-129. Thus the ratings are maintained for the Active Cleanup period and increased to *High* and *Medium* for the Near-term, Post Cleanup period.
- Carbon tetrachloride – There is a current plume that translates to a *Very High* rating (Table 6-8) for Current conditions. The remaining vadose zone estimate also translates to a *Very High* rating (Table 6-9). The results of the TC&WM EIS groundwater screening analysis (Appendix O, DOE/EIS-0391 2012) provide an indication that peak carbon tetrachloride concentrations are expected to be below the benchmark value (i.e., the drinking water standard) after CY 2050. However, current treatment will likely not be completed for carbon tetrachloride for 125 years (i.e., during the Near-term, Post-Cleanup period). Thus the ratings are *Very High* for the Active Cleanup (since there will likely be a large plume remaining at the beginning of the Active Cleanup period) and *Medium* for the Near-term, Post Cleanup periods (to account for uncertainty in treatment effectiveness).

Table 6-9. Summary of the evaluation of threats to groundwater as a protected resource from vadose zone contamination associated with the 200-UP OU

PC	Grp	WQS	Poro-sity[a]	K_d (mL/g)[a]	P (kg/L)[a]	Source M^{Source}	Liquid M^L	Sediment M^S	SZ Total M^{SZ}	Treated[d] M^{Treat}	Remaining M^{Tot}	GTM (×10^6 m^3)	Rating[f]
U (tot)	B	30 µg/L	0.23	0.8	1.84	3400 kg	220 kg	1400 kg	1600 kg	898.5 kg	870 kg	4	Low
NO_3	C	45 pCi/L	0.23	0	1.84	2,000,000 kg	3,700,000 kg	0 kg	3,700,000 kg	58560 kg	---	---	---
Cr (tot)	B	100 µg/L	0.23	0	1.84	34,000 kg	600 kg	0 kg	600 kg	17.9 kg	33,000 kg	330	High
Cr-VI	A	48 µg/L[b]	0.23	0	1.84	34,000 kg	2500 kg	0 kg	2500 kg	17.9 kg	31,000 kg	650	High
H-3	C	20000 pCi/L	0.23	0	1.84	9000 Ci	2200 Ci	0 Ci	2200 Ci	---	6800 Ci	---	Low
Tc-99	A	900 pCi/L	0.23	0	1.84	48 Ci	8.5 Ci	0 Ci	8.5 Ci	3.2 Ci	36 Ci	40	Medium
I-129	A	1 pCi/L	0.23	0.2	1.84	0.20 Ci	0.077 Ci	0.12 Ci	0.20 Ci	---	0.019 Ci	7.5	Low
CCl_4	A	3.4 µg/L[c]	0.23	0	1.84	910,000 kg	540,000 kg	0 kg	540,000 kg	97760 kg	570,000 kg[e]	110,000	Very High

a. Parameters obtained from the analysis provided in Attachment 6-1.

b. "Model Toxics Control Act—Cleanup" (WAC 173-340) Method B groundwater cleanup level for hexavalent chromium.

c. The drinking water standard for carbon tetrachloride is 5 µg/L. The drinking water standard is used to estimate the GTM.

d. Treatment amounts from the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0).

e. The remaining carbon tetrachloride in the vadose zone accounts for 21% total losses of the original source inventory to the atmosphere (DOE/RL-2007-22 2007, p. 4-3).

f. These contaminants are being treated using the 200 West Groundwater Treatment Facility.

GROUNDWATER-RELATED THREATS TO THE COLUMBIA RIVER

The final assessment related to PCs is to assess threats to the Columbia River and the riparian zone ecology (c-c' in Figure 6-8 and Figure 6-11). The evaluation of benthic, free-flowing, and riparian zone impacts for the 200-UP OU is detailed in the following sections.

Threats to the Columbia River Benthic and Riparian Ecology – Current impacts

As indicated in Figure 6-11, the first step (Step c1) in determining whether a PC poses a threat to the Columbia River is to determine if a plume associated with the EU (on in this case the 200-UP-1 OU) is currently in contact with the Columbia River at concentrations exceeding the WQS. Based on the information in the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) and PHOENIX (http://phoenix.pnnl.gov/), even though 200-UP-1 OU contaminants are in the saturated zone at concentrations exceeding thresholds, no plumes from the 200-UP-1 OU are currently intersecting the Columbia River at concentrations exceeding the WQS[71]. Thus current impacts to the Columbia River from the 200-UP-1 OU would be rated as *Not Discernible*.

Threats to the Columbia River Benthic and Riparian Ecology – Active Cleanup and Near-term, Post Cleanup

The next step (Step c11) in the process (Figure 6-11) is to determine if any PC plumes from the 200-UP-1 OU are expected to reach the Columbia River in the next 150 years. Because 200-UP-1 OU plumes originate from the 200 West Area, it is considered unlikely that a plume might reach the Columbia River since the water travel time is greater than 50 years (and likely significantly more) from the 200 West Area to the 200 East Area and ~10-30 years from the 200 East Area to the Columbia River (Gephart 2003; PNNL-6415 Rev. 18), and significantly more time would likely be required to reach the river in sufficient quantity to exceed the WQS or appropriate aquatic screening values.[72] Any contaminants *predicted* to impact the Columbia River in sufficient amounts from the Central Plateau (e.g., as described in Appendix P in the TC&WM EIS (DOE/EIS-0391 2012)) would thus likely come from 200-East sources[73] and not the 200-ZP-1 OU. Thus the impacts to the Columbia River benthic and riparian ecology for the Active Cleanup and Near-term, Post Cleanup periods are rated as *Not Discernible*.

The No Action Alternative evaluation in the TC&WM EIS (DOE/EIS-0391 2012) suggests that remedial actions (e.g., surface barrier emplacement that would decrease recharge in the areas in the Central Plateau) would appear to not have significant impacts on the long-term peak concentrations in the near-shore area (benthic and riparian receptors) of the Columbia River. This is not due to ineffectiveness of the barrier but instead due to large amounts of contaminants already in the groundwater. Thus ratings would not be changed for the 200-UP-1 OU based on the remedial actions assumed in the TC&WM EIS.

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[71] The only Central Plateau plume currently in contact with the Columbia River is tritium that was primarily discharged to the PUREX cribs and trenches (DOE/RL-2014-32 Rev. 0). There are plumes associated with River Corridor GW OUs that are also in contact with the Columbia River.

[72] Based on current and expected subsurface conditions, the only path from the 200 West Area to the Columbia River currently being considered is from 200 West to 200 East to the Columbia River (Figure 6-13).

[73] Note that TC&WM EIS predictions indicate possible impacts from chromium to the benthic and riparian zones within the next decade; however, actual well measurements for chromium and other contaminants show no likely impacts in the foreseeable future from 200-West or 200-East sources, including the next 150 years. Note there was a path north from 200-West to the Columbia River that is no longer considered reasonable due to changing hydrologic patterns across the Hanford Site.

Threats to the Columbia River Benthic and Riparian Ecology – Long-term

An ecological screening analysis was performed in the TC&WM EIS (Appendix P, DOE/EIS-0391 2012) to evaluate potential long-term impacts of radioactive and chemical contaminants (*from sources including but not limited to those related to the 200-UP-1 OU under a No Action Alternative*[74]) discharged with groundwater on aquatic and riparian receptors at the Columbia River. The screening results indicate that exposure to radioactive contaminants from peak groundwater discharge was below benchmarks (0.1 rad per day for wildlife receptors and 1 rad per day for benthic invertebrates and aquatic biota, including salmonids consistent with DOE Technical Standard DOE-STD-1153-2002[75]) (TC&WM EIS, Appendix P, p. P-52), indicating there should be no expected adverse effects from radionuclides over the 10,000-yr EIS evaluation period.[76]

The corresponding evaluation in the TC&WM EIS for potential impacts of chemical contaminants discharged with groundwater to the near-river ecology (benthic and riparian) indicate that chromium and nitrate would have expected hazard quotients exceeding unity for aquatic and riparian receptors over the evaluation period in the EIS. The results of the screening evaluation at the near-shore region under the No Action Alternative (TC&WM EIS, Appendix O) indicate that the nitrate peak concentration (and discharge) occurred in the past and that future concentrations would appear to not exceed either the drinking water standard or AWQC in the future. Furthermore, the potential impact of increased nitrate levels may depend on other factors (e.g., phosphorus) and the fact that much of the nitrate considered in the TC&WM EIS would be from 200 West sources. Thus, nitrate is considered to have a *Not Discernible* rating for the benthic and riparian ecology.

The TC&WM EIS results of the screening evaluation at the near-shore region under the No Action Alternative (DOE/EIS-0391 2012, Appendix O) indicate that the chromium concentration could exceed the drinking water standard for total chromium (100 µg/L) and the EIS benchmark threshold[77] (and ambient water quality criterion of 10 µg/L) for hexavalent chromium. The predicted concentrations are likely overestimated since all discharge is assumed to occur in a 40-m near-shore region (Figure 6-13)[78]. Furthermore, because of the long travel time of water from 200-West (200-ZP-1 OU) to 200-East (then to the Columbia River) relative to that from 200-East to the Columbia River (Figure 6-13), it is likely that the 200-West sources would provide an insignificant contribution of the chromium predicted to reach the Columbia River exceeding screening values (unless this was assumed to occur via the now defunct northern path from 200-West to the Columbia River), which would likely lead to insignificant long-term

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[74] Despite including sources other than those related to the 200-UP-1 OU, the analysis in the TC&WM EIS was considered a reasonable basis to assess the potential for impact of contaminants on the benthic and riparian zones. However, because the sources are not limited to GW OUs, the evaluation is not restricted to just the GW OU sources but instead those for many Central Plateau sources. Furthermore, the results can thus be divided by the 200-West and 200-East areas based on differences in travel times of water and contaminants to the Columbia River.

[75] The standard also indicates the screening values were used for riparian receptors.

[76] Because these expected impacts are likely to be small, the potential indirect impacts on the ecosystem are assumed to be correspondingly minor (DOE/EIS-0391 2012, Appendix P, p. P-52). Based on the results in the TC&WM EIS (Appendix P), the benchmark values in the DOE Technical Standard would have to be significantly lower in the future to change the evaluation results.

[77] The benchmark value used for chromium (hexavalent) in the TC&WM EIS was the sensitive-species-test-effect concentration that affects 20% of a test population (EC_{20}) despite the fact that the less toxic trivalent form of chromium is more like to be present in oxygenated, aquatic environs (DOE/EIS-0391 2012, Appendix P, pp. P-52 to P-53).

[78] The assumed 40 m near shore region is in contrast to the measured impact area of 4600 m for the tritium plume. Thus, the estimated concentration may be on the order of 100 x too high based on conservation of mass.

impacts to the benthic and riparian ecology from 200-West sources, including those associated with the 200-UP-1 OU.

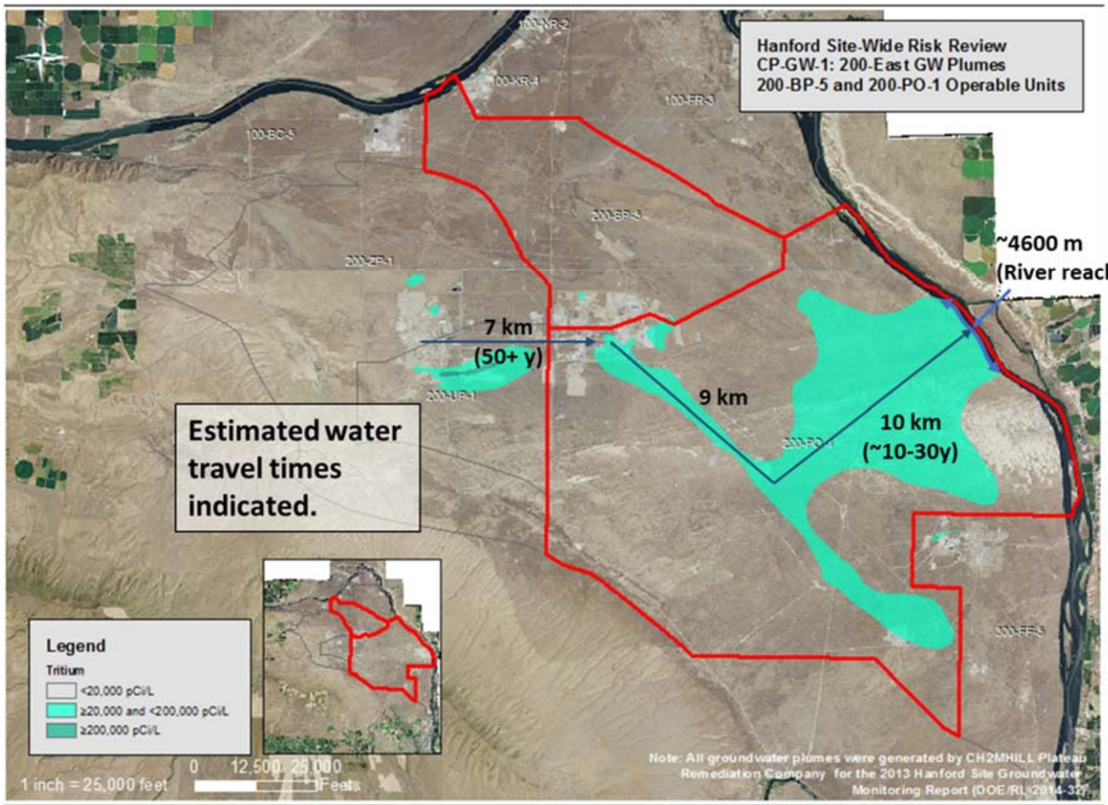

Figure 6-13. Estimating the movement of 200 Area (Central Plateau) plumes using results for tritium. Note that the River Reach intersecting the tritium plume is approximately 4,600 m versus the 40-m reach assumed in the TC&WM EIS for ecological impacts (DOE/EIS-0391, Appendix P, p. P-53).

Threats to the Columbia River Free-flowing Ecology

The threat determination process for the free-flowing Columbia River ecology was evaluated in a manner similar to that described above for benthic receptors (c-c' in Figure 6-8 and Figure 6-11). However, because of the large dilution effect of the Columbia River on the contamination from the seeps and groundwater upwellings,[79] the differences from EU to EU were not found distinguishing and the potential for groundwater contaminant discharges from Hanford through groundwater upwellings and seeps to achieve concentrations above relevant thresholds is very remote[80]. If additional

[79] "Groundwater is a potential pathway for contaminants to enter the Columbia River. Groundwater flows into the river from springs located above the water line and through areas of upwelling in the river bed. Hydrologists estimate that groundwater currently flows from the Hanford unconfined aquifer to the Columbia River at a rate of ~ 0.000012 cubic meters per second (Section 4.1 of PNNL-13674). For comparison, the average flow of the Columbia River is ~3,400 cubic meters per second" (DOE/RL-2014-32 Rev. 0). This represents a dilution effect of more than eight orders of magnitude (a dilution factor of greater than 100 million).

[80] Bioaccumulation and biomagnification of some contaminants in aquatic biota may be possible, however, these effects typically are considered in the development of surface water quality standards, and insufficient information exists at the Hanford site to use potential consideration of these effects in the screening process for the Risk Review Project.

information comes to light (e.g., based on concentration measurements or bioaccumulation in certain areas of the Hanford Reach) that would lead to significant differentiation among EUs based on potential free-flowing river impacts, then the framework will be revised for the Final Hanford Risk Review Report.

SUMMARY TABLES OF RISKS AND POTENTIAL IMPACTS TO RECEPTORS

Based on the information gathered for this demonstration, metrics and ratings were evaluated per the framework as described in Figure 6-8 through Figure 6-11. The Current and Active Cleanup results for potential impacts to groundwater and the Columbia River (as protected resources) from the 200-UP-1 OU are presented in Table 6-10 and those for the Near-term, Post Cleanup period are presented in Table 6-11. However, the demonstration here for the 200-UP-1 OU does not necessarily represent the full analysis of a complete EU.

Table 6-10. 200-UP-1 Operable Unit Impact Rating Summary for Human Health

Population or Resource		Evaluation Time Period[a] Active Cleanup (to 2064) Current Conditions:	During Cleanup Actions:
Environmental	Groundwater	Very High -- CCl4[a] **Overall**: Very High	Very High – CCl4[a] **Overall**: Very High
	Columbia River	Benthic: Not Discernible Riparian: Not Discernible Free-flowing: Not Discernible **Overall**: Not Discernible	Benthic: Not Discernible Riparian: Not Discernible Free-flowing: Not Discernible **Overall**: Not Discernible

a. The large amount of carbon tetrachloride in the groundwater and remaining in the vadose zone above the 200-UP-1 OU translates *Very High* ratings.

Support for Risk and Impact Ratings -- Groundwater, Vadose Zone, and Columbia River

Current Groundwater: As illustrated in Table 6-8, the saturated zone (SZ) GTM values for the 200-UP-1 Group A and B primary contaminants range from *Low* for uranium, total chromium, and Tc-99 to *Medium* for hexavalent chromium and I-129 to *Very High* for carbon tetrachloride. The current nitrate and tritium (Group C) plume areas translate to *Medium* ratings. Thus the overall rating for the 200-UP-1 would be *Very High* if carbon tetrachloride is included in the evaluation[81]. Contamination in the 200-UP-1 OU is being treated using the 200-West P&T System.

Current Columbia River: No plume currently intersects the Columbia River at concentrations exceeding the appropriate water quality standard (WQS). Thus current impacts to the Columbia River benthic and riparian ecology would be rated as *Not Discernable*. The large dilution effect of the Columbia River on the contamination from the seeps and groundwater upwellings results in *Not Discernable* ratings. Thus the overall rating for the Columbia River during the Current period is *Not Discernable*.

[81] The carbon tetrachloride plume covers areas in both the 200-UP-1 and 200-ZP-1 OUs.

Groundwater – Active Cleanup: By the end of the Active Cleanup period, all 200-UP-1 OU contaminants except for carbon tetrachloride and I-129 are assumed to have been treated successfully (i.e., resulting *Not Discernible* ratings). However, because of the large amount of carbon tetrachloride in groundwater and the time predicted for cleanup effectiveness (125 years), the rating will remain *Very High*. Furthermore, because the remedial action for I-129 has not been selected, ratings were increased (to *High* for vadose zone contamination).

Columbia River – Active Cleanup: No 200-UP-1 OU radioactive or chemical contaminants are predicted to be discharged to the Columbia River in concentrations that would pose risk to benthic or riparian zone receptors during the Active Cleanup period. Similarly, because of the large dilution effect in the Columbia River, the free-flowing ratings are *Not Discernable* for all the Tank Farm EUs for all contaminants and evaluation periods. These results are consistent with those from the TC&WM EIS indicating no adverse impacts likely to aquatic and sediment-dwelling biota in the Columbia River (DOE/EIS-0391, Appendix P, p. P-53).

Populations and Resources at Risk or Potentially Impacted After Cleanup Actions (from residual contaminant inventory or long-term activities)

Table 6-11. Summary of Populations and Resources at Risk or Potentially Impacted after Cleanup

Population or Resource		Impact Rating	Comments
Environmental	Groundwater	Not Discernible (all but carbon tetrachloride and I-129 due to treatment) to Medium (carbon tetrachloride) to High (I-129) Overall: High	There are significant impacts to groundwater threats from transport (recharge) and cleanup (200-W P&T) on contaminants. The risk driver (High) is I-129 (treatment not yet selected and monitoring is continuing until a remedial action is defined). Carbon tetrachloride treatment not expected to be completed until during this period although plume size expected to be significantly smaller after Active Cleanup period completed.
	Columbia River	Benthic: Not Discernable Riparian: Not Discernable Free-flowing: Not Discernable **Overall**: Not Discernable	TC&WM EIS screening results indicate that exposure to radioactive and chemical contaminants from peak groundwater discharge below benchmarks for both benthic and riparian receptors. Dilution factor of greater than 100 million between River and upwellings.

LONG-TERM, POST-CLEANUP STATUS – INVENTORIES AND RISKS AND POTENTIAL IMPACT PATHWAYS

The TC&WM ecological screening analysis indicate that that exposure to radioactive contaminants from peak groundwater discharge was below screening levels at the Columbia River near-shore region, indicating there should be no expected adverse effects from radionuclides. Furthermore, results of the corresponding TC&WM screening evaluation for chemicals indicated that predicted chromium and nitrate concentrations could exceed screening values (i.e., Hazard Quotient of unity) in the near-shore region; however, recent well data suggest that contamination is moving toward the Columbia River much more slowly than predicted. Furthermore, the predicted nitrate peak concentration was in the past and would be unlikely to exceed human or aquatic standards in the future. For chromium the long travel time from 200-West to the Columbia River likely indicates that little of the chromium predicted to impact the near-shore region would be from 200-West sources, which would also likely lead to insignificant impacts from the 200-UP-1 OU.

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ATTACHMENT 6-1. SATURATED ZONE PARAMETER ESTIMATES

The saturated zone parameters of porosity (θ), bulk density (ρ_{bulk}), and partition coefficient (K_d) were estimated from existing data. The Hanford Site subsurface is composed of several geologic formations that vary in thickness throughout the site (Figure 6-2 and Figure 6-7). Ten "soil classes" were described by Last et al. (2006) that represent similar soil types (Table 6-12).

Table 6-12. Description of hydraulic-property soil classes (Last et al. 2006).

Formation	Soil Class	Code	Description	Hydro-stratigraphic Unit Code(s)
Holocene deposits	Backfill	Bf	Sand and gravel mixed with finer fraction. Same as the SSG soil category identified by Khaleel and Freeman (1995).	HDb
Hanford formation	Silty Sand	Hss	Sand mixed with finer fraction, containing >50% fine sands, silt, and clay, with >15% silt and clay. Derived from the SS soil category identified by Khaleel and Freeman (1995).	HISSD/HSD(f)
	Fine Sand	Hfs	Sand, containing 35-70% fine sand, silt, and clay, with <15% silt and clay. Derived from the S soil category identified by Khaleel and Freeman (1995).	HSD-Sm
	Coarse Sand	Hcs	Sand, containing >60% coarse sand. Derived from the S soil category identified by Khaleel and Freeman (1995).	HSD-Sh(c)
	Gravelly Sand	Hgs	Gravelly sand. Same as the GS soil category identified by Khaleel and Freeman (1995).	HSD(c)
	Sandy Gravel	Hg	Sandy gravel for which gravel content is approximately <60%. Same as the SG1 soil category identified by Khaleel and Freeman (1995).	HGD
	Gravel	Hrg	Very high gravel content soils (>60% gravel) from the 100 areas (along the river).	HGD(c)
Cold Creek unit (formerly referred to as the Plio-Pliestocene unit)	Silt Dominated	PPlz	Derived from the SS soil category identified by Khaleel and Freeman (1995) but correlated to Cold Creek unit silt. Includes additional samples from borehole B8814.	CCUf(lam-msv)
	Caliche	PPlc	Derived from the SS soil category identified by Khaleel and Freeman (1995) but correlated to the Cold Creek unit carbonate.	CCUf-c(calc)
Ringold Formation	Gravel Dominated	Rg	Sandy gravel for which gravel content is approximately >60%. Same as the SG2 soil category identified by Khaleel and Freeman (1995).	Rwi(e)

Porosity, bulk density, and partition coefficients for both the vadose zone and the saturated zone are documented in Last et al. (2006) for each soil class for each area of interest on the Hanford Site (Table 6-13 and Table 6-14). The best estimate values were selected. Only saturated zone parameters were evaluated for this report.

Table 6-13. Porosity and bulk density for Hanford Site soil classes (extracted from Table 4.5, Last et al. 2006).

Soil Class	θ_s (cm^3/cm^3)	Bulk Density (g/cm^3)
Bf	0.262	1.94
Hss	0.445	1.61
Hfs	0.379	1.60
Hcs	0.349	1.67
Hgs	0.238	1.94
Hg	0.167	1.93
Hrg	0.102	1.97
PPlz	0.419	1.68
PPlc	0.281	1.72
Rg	0.177	1.90

Table 6-14. Saturated zone partition coefficients (extracted from Table 4.11 Last et al. 2006).

Analyte	Groundwater (4G)		
	Kd Estimate (mL/g)		
	Best	Min	Max
Highly Mobile Elements			
H-3	0	0	0
Tc^{99}	0	0	0.1
Cl^{36}	0	0	0
Somewhat Mobile Elements			
I^{129}	0.2	0	2
U^{238}	0.8	0.2	4
Se^{79}	5	3	10
Np^{237}	10	2	30
C^{14}	0	0	100
Moderately Immobile Elements			
Sr^{90}	22	10	50
Cs^{137}	2000	200	10,000
Pu^{239}	600	200	2000
Eu^{152}	200	10	1000

To determine the relevant hydrologic parameters for the saturated zone for the purposes of this methodology, weighted averages of the parameters along the general flow path of the groundwater from the 200 West Area to the 200 East Area to the Columbia River were determined. Using the Cross-Section Tool in the Hanford Site Groundwater Monitoring Report for 2013 (DOE/RL-2014-32 Rev. 0 2013) and PHOENIX (http://phoenix.pnnl.gov/), cross-sections were determined. For the saturated zone from the Central Plateau to the Columbia River, the approximate centerline of the tritium groundwater plume was traced (Figure 6-14). The subsurface cross-section along this centerline pathway was generated (Figure 6-15), including an indication of the water table level.

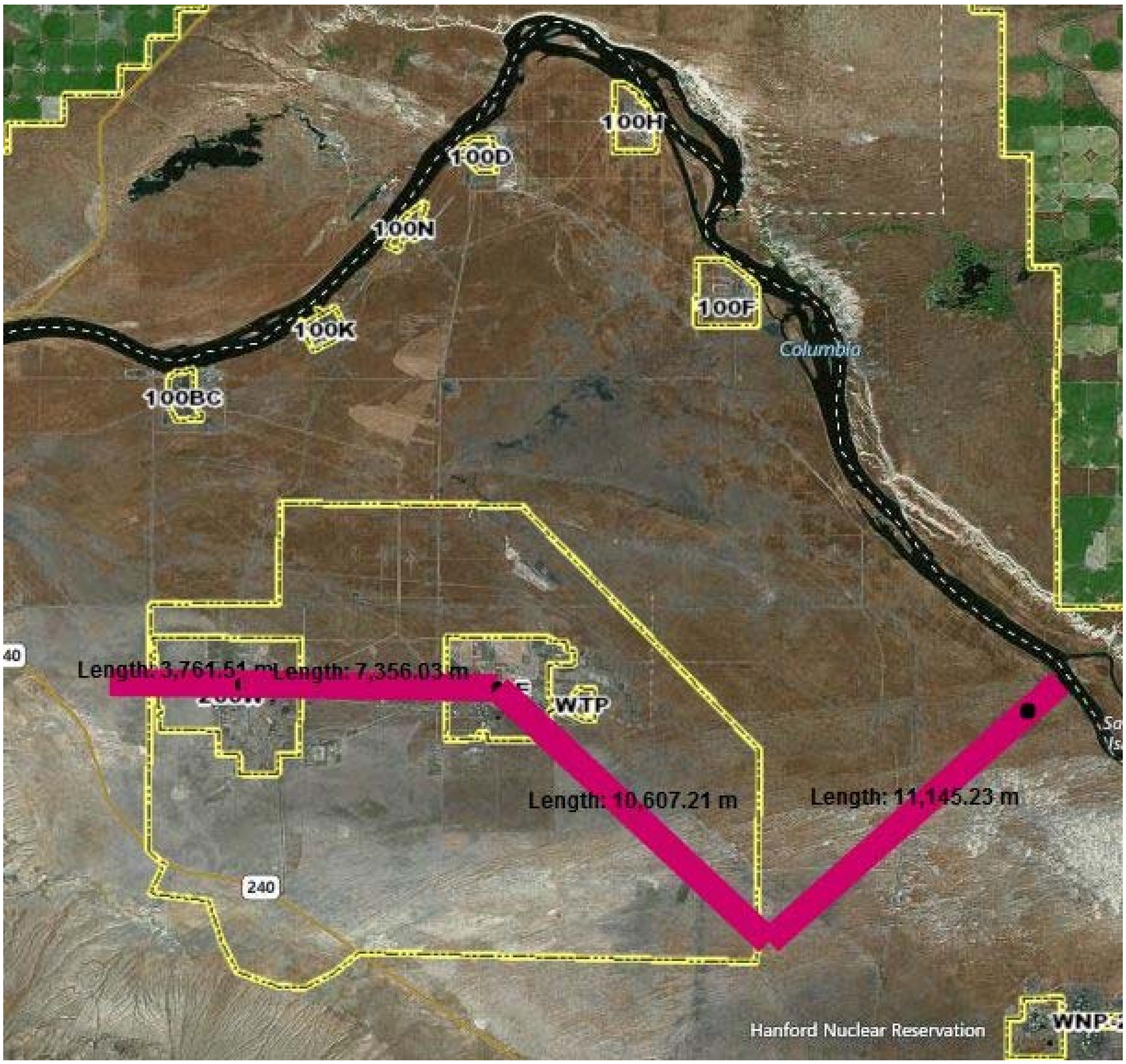


Figure 6-14. Central Plateau to Columbia River cross-section path (indicated in red).

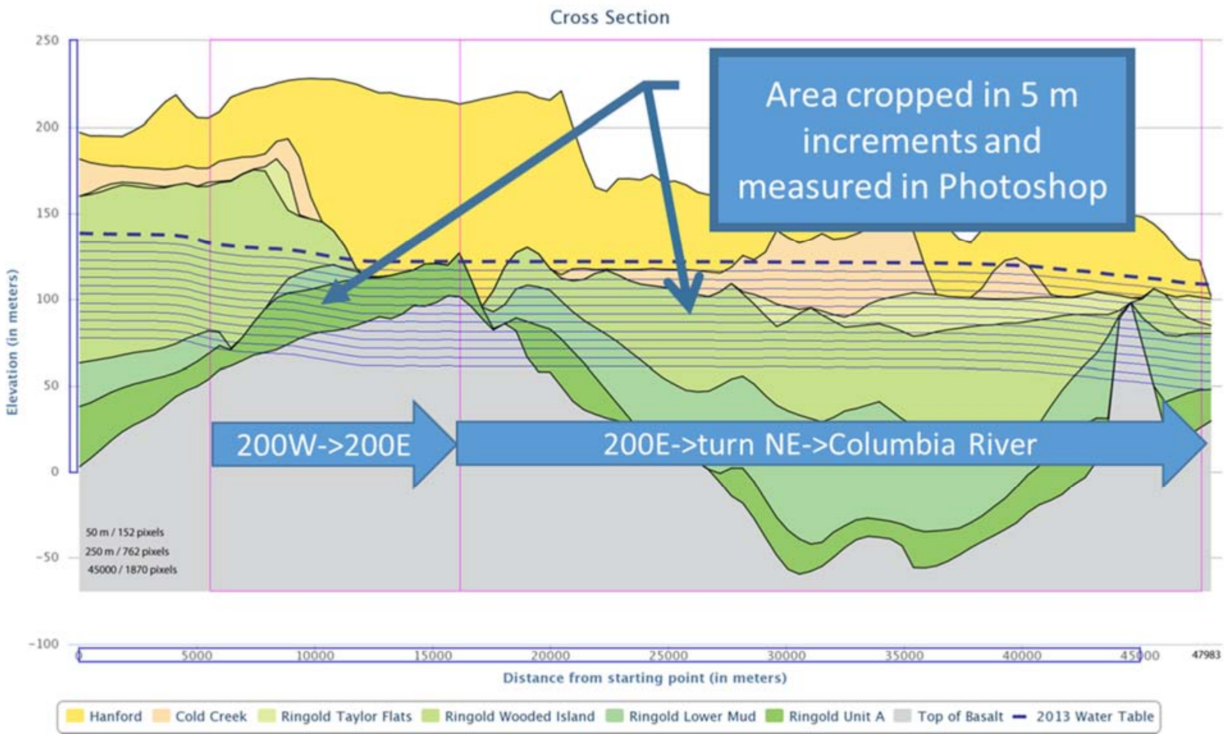


Figure 6-15. Cross-section from the Central Plateau (0 m) to the Columbia River (450,000 m).

The cross-section was evaluated using Adobe Fireworks and Adobe Photoshop. Additional lines that followed the contour of the water table were added to the cross-section image at 5-m increments below the water table. The cross-section was cropped between each 5-m section and the area of the each geologic formation/soil type was measured. The areas of basalt were removed from the area calculations. The area measurements were used to determine the weighting for a weighted average for the porosity and bulk density.

The determined saturated zone hydrologic parameters are shown in Table 6-15.

Table 6-15. Porosity and bulk density.

	Porosity (cm^3/cm^3)	Bulk Density (g/cm^3)
200W to 200E	0.18	1.89
200E to River	0.25	1.82
200W to River	0.23	1.84
River Corridor	0.18	1.84

ATTACHMENT 6-2. DERIVATION OF THE GROUNDWATER THREAT METRIC

The GTM is defined to be the maximum volume of water that could be contaminated by the inventory of a PC from a source (be it groundwater plume, tank, etc.) if it was found in the saturated zone at the appropriate WQS and in equilibrium with the soil. The GTM accounts only for 1) source inventory, 2) partitioning with the surrounding subsurface, and 3) the WQS. It is based on a snapshot in time (assuming only decay of short-lived radionuclides). It does not account for differences in groundwater mobility or bulk groundwater flow.

For each contaminant *i*:

$$GTM \equiv \left[\frac{\begin{matrix} mass\ of\ i\ in\ liquid\ phase \\ equilibrated\ with\ soil\ at\ the\ WQS \end{matrix}}{WQS} \right] = \frac{M_{WQS}^{L}}{C_{WQS}^{L}} = V_{WQS}^{L} = \theta V_{WQS}^{Tot} \qquad [6\text{-}14]$$

Mass balance, partitioning, volumes, and densities:

$$M^{Tot} = M_{95}^{L} + M_{95}^{S} = M_{WQS}^{L} + M_{WQS}^{S}$$

$$C^{S} = C^{L} K_{d}$$

$$V^{L} = \theta V^{Tot} \text{ and } V^{S} = (1-\theta) V^{Tot}$$

$$\rho_{bulk} = (1-\theta)\rho_{particle} + \theta\rho_{void} \qquad [6\text{-}15]$$

$$\rho_{particle} = \frac{\rho_{bulk} - \theta\rho_{void}}{(1-\theta)}$$

$$\rho_{void} = \begin{cases} void = water, & 1.0 \\ void = air, & 0.0 \end{cases}$$

For groundwater plumes where the total plume volume and the plume concentration have been estimated.

Rearranging the mass balance and substituting as needed:

$$M_{WQS}^{L} = M_{95}^{L} + M_{95}^{S} - M_{WQS}^{S}$$

$$M_{95}^{L} = \theta V_{95}^{Tot} C_{95}^{L}$$

$$M_{95}^{S} = (1-\theta) V_{95}^{Tot} \rho_{particle} C_{95}^{S} = V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_{d} \qquad [6\text{-}16]$$

$$M_{WQS}^{S} = (1-\theta) V_{WQS}^{Tot} \rho_{particle} C_{WQS}^{S} = V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_{d}$$

Substitute back into the mass balance as solved for M_{WQS}^{L}:

$$M_{WQS}^{L} = \theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta) C_{95}^{L} K_{d} - V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_{d} \qquad [6\text{-}17]$$

Plug into equation for GTM:

$$GTM = V_{WQS}^{L} = \theta V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_{d} - V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_{d}}{C_{WQS}^{L}} \qquad [6\text{-}18]$$

Rearrange to solve for V_{WQS}^{Tot} and note that $V_{WQS}^{L} = \theta V_{WQS}^{Tot}$:

$$\theta V_{WQS}^{Tot} C_{WQS}^{L} = \theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_d - V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d$$

$$\theta V_{WQS}^{Tot} C_{WQS}^{L} + V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d = \theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_d$$

$$V_{WQS}^{Tot}\left[\theta C_{WQS}^{L} + (\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d\right] = \theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_d$$

$$V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L} + V_{95}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{95}^{L} K_d}{\theta C_{WQS}^{L} + (\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d} \quad [6\text{-}20]$$

$$V_{WQS}^{Tot} = \frac{V_{95}^{Tot} C_{95}^{L}[\theta + (\rho_{bulk} - \theta\rho_{void}) K_d]}{C_{WQS}^{L}[\theta + (\rho_{bulk} - \theta\rho_{void}) K_d]}$$

$$V_{WQS}^{Tot} = \frac{V_{95}^{Tot} C_{95}^{L}}{C_{WQS}^{L}}$$

Finally, multiply by the porosity:

$$GTM = V_{WQS}^{L} = \theta V_{WQS}^{Tot} = \frac{\theta V_{95}^{Tot} C_{95}^{L}}{C_{WQS}^{L}} \quad [6\text{-}21]$$

For sources that start with a total inventory (mass or curies), solve the mass balance for the liquid phase inventory:

$$M_{WQS}^{L} = M^{Tot} - M_{WQS}^{S} \quad [6\text{-}22]$$

Substitute for the solid inventory:

$$M_{WQS}^{L} = M^{Tot} - V_{WQS}^{Tot}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d \quad [6\text{-}23]$$

Substitute for the total volume:

$$M_{WQS}^{L} = M^{Tot} - \frac{V_{WQS}^{L}(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d}{\theta} \quad [6\text{-}24]$$

Divide through by the WQS concentration to get the GTM. Note that the GTM = V_{WQS}^{L} by the definition of the GTM:

$$GTM = \frac{M_{WQS}^{L}}{C_{WQS}^{L}} = \frac{\theta M^{Tot} - GTM(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d}{\theta C_{WQS}^{L}} \quad [6\text{-}25]$$

Solve for the GWTM:

$$\theta C_{WQS}^{L} GTM = \theta M^{Tot} - GTM(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d$$

$$\theta C_{WQS}^{L} GTM + GTM(\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d = \theta M^{Tot}$$

$$GTM\left[\theta C_{WQS}^{L} + (\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d\right] = \theta M^{Tot}$$

$$GTM = \frac{\theta M^{Tot}}{\left[\theta C_{WQS}^{L} + (\rho_{bulk} - \theta\rho_{void}) C_{WQS}^{L} K_d\right]} \qquad [6\text{-}26]$$

$$GTM = \frac{M^{Tot}}{\left[1 + \frac{(\rho_{bulk} - \theta\rho_{void}) K_d}{\theta}\right] C_{WQS}^{L}}$$

$\rho_{void} = 0.0$ for dry bulk density data:

$$GTM = \frac{M^{Tot}}{\left[1 + \frac{\rho_{bulk} K_d}{\theta}\right] C_{WQS}^{L}} \qquad [6\text{-}27]$$

where

- GTM is the groundwater threat metric
- C is concentration
- i is the contaminant
- K_d is solid liquid partition coefficient
- M is inventory (mass or curies)
- V is volume
- θ is porosity
- ρ_{bulk} is bulk density
- $\rho_{particle}$ is solid particle density
- ρ_{water} is water density
- Superscript (*L*, *S*, or *Tot*) indicates phase or total
- Subscript *95* indicates the 95 percentile on the mean value
- Subscript *WQS* indicates the Water Quality Standard

ATTACHMENT 6-3. SOURCE INVENTORY ESTIMATES

Source inventories for the tank farm EUs were determined after a review of the available data sources. The sources were grouped into the following eight types:

- Tanks (single-shell [SST] and double-shell [DST])
- Ancillary equipment (Anc Eq)
- Unplanned releases (UPRs)
- Ponds
- Cribs
- Trenches
- Leaks
- Miscellaneous underground storage tanks (MUSTs)

Every effort was made to identify all sources, as determined by Waste Information Data System (WIDS) code, in each EU. In some cases, multiple data sources were found. The most appropriate data source for each inventory source type was determined. Table 6-16 summarizes the source of the inventory estimates. For trenches and MUSTs, data for sources (as determined by unique WIDS codes) were found in Appendix S of the TC&WM EIS that were not in the SIM. These sources of inventory were included in addition to the inventories in the SIM.

In all cases, the data was consolidated in Excel spreadsheets and a central database. The units of all data were converted to curies for radiological contaminants and kilograms for chemical contaminants.

Table 6-16. Summary of the inventory estimates sources.

Inventory Source Type	Source of Data
Tanks (SST and DST)	BBI March 2014[82]
Ancillary Equipment (Anc Eq)	TC&WM EIS (DOE/EIS-0391 2012) Appendix D
Unplanned Releases (UPRs)	SIM Rev. 1 (RPP-26744, Rev. 0)
Ponds	SIM Rev. 1 (RPP-26744, Rev. 0)
Cribs	SIM Rev. 1 (RPP-26744, Rev. 0)
Trenches	SIM Rev. 1 (RPP-26744, Rev. 0) and TC&WM EIS (DOE/EIS-0391 2012) Appendix S
Leaks[83]	TC&WM EIS (DOE/EIS-0391 2012) Appendix D
MUSTs	SIM Rev. 1 (RPP-26744, Rev. 0) and TC&WM EIS (DOE/EIS-0391 2012) Appendix S

[82] The current version of the BBI is stored online and can be accessed using the Tank Waste Information Network System (TWINS) at: https://twinsweb.labworks.org/ (July 2015).
[83] The single-shell tank leak information in Appendix D of the TC&WM EIS (DOE/EIS-0391 2012) was used for this Review because it was reconciled with the other inventory information used. Updated estimates of the SST leak volumes are available for various SST Farms (e.g., A-AX, BX-BY, C, SX, and TY) that include both increases and decreases n leak volume estimates. Because the corresponding radionuclide and chemical inventories are needed for our evaluation and these are not provided in the updated Leak Assessments Reports, the leak inventory estimates from the TC&WM EIS (DOE/EIS-0391 2012) are used.

ATTACHMENT 6-4. ESTIMATING RELATIVE PLUME AREAS AND VOLUMES USING PHOTOSHOP

For many primary contaminants, there are multiple distinct plumes in a groundwater Operable Unit (OU). An example is Tc-99 in the 200-UP-1 and 200-ZP-01 OUs as shown in Figure 6-16. However, the 2013 Hanford Annual Groundwater Report (DOE/RL-2014-32 Rev. 0) provides estimates of the total plume area for a given contaminant in a groundwater OU. When focusing on individual EUs, it is useful to be able to apportion the overall plume areas given in the Annual Monitoring Report to individual plumes.

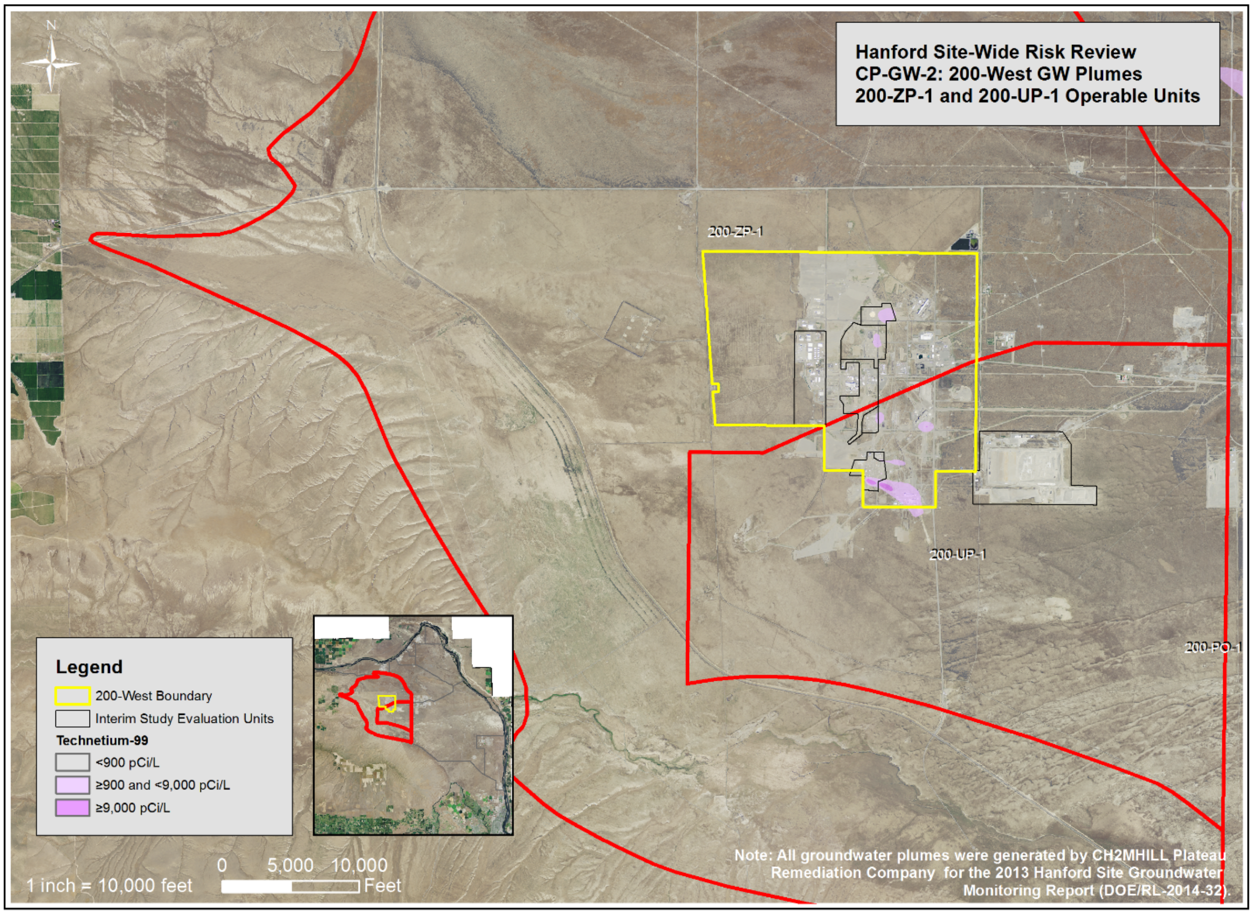


Figure 6-16. Tc-99 plumes in the 200-UP-1 and 200-ZP-1 Operable Units.

To apportion plume areas, the image file is loaded into Photoshop and the desired plumes are selected using the Magic Wand tool as indicated in Figure 6-17. The Record Measurements button is then selected in the Measurements Log and the areas are provided (in square pixels by default), which can be saved. The map scale can be entered into Photoshop to provide the relative plume areas in the desired units (e.g., km^2).

It is assumed that plume volumes and treatment amounts are highly positively correlated to the relative plume areas; the relative plume areas are assumed to also represent these other values.

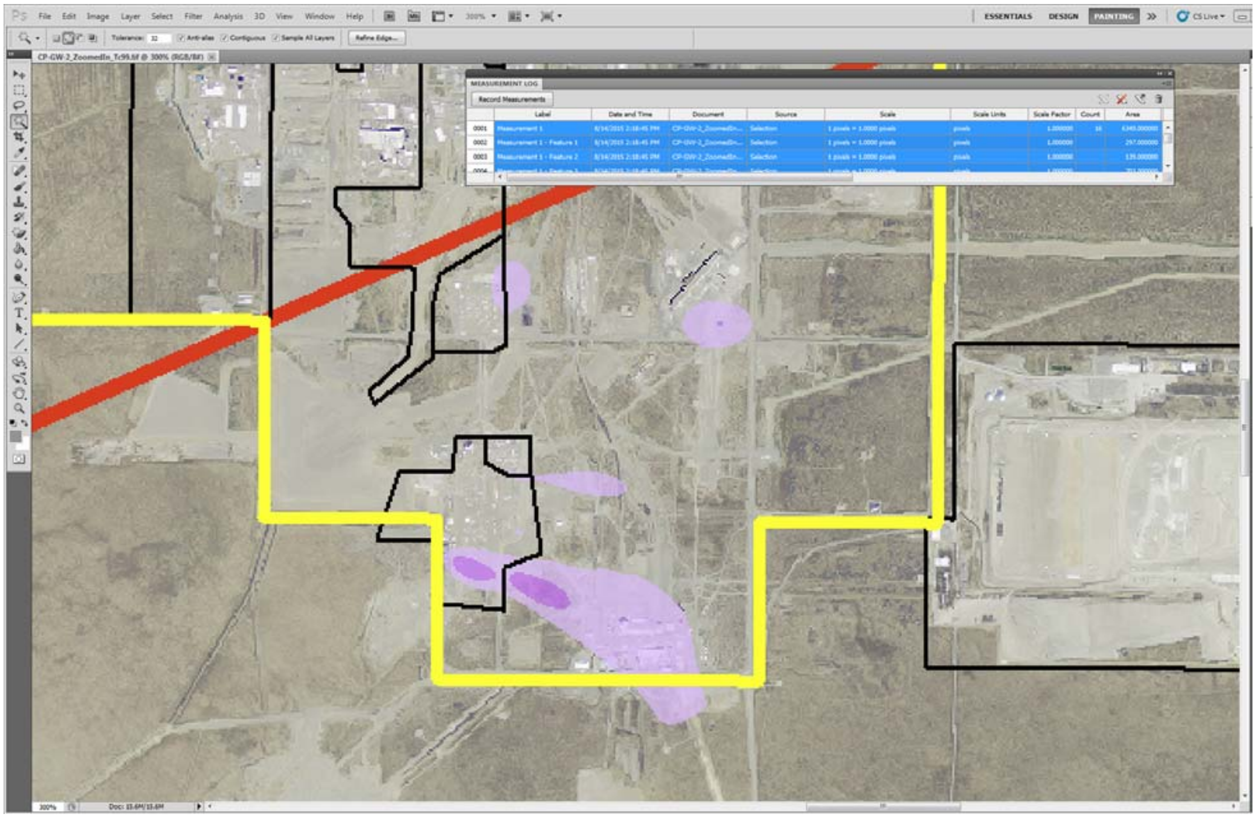


Figure 6-17. Using the Photoshop magic Wand tool and Record Measurements Log to estimate relative Tc-99 plume areas in the 200-UP-1 Operable Unit.

CHAPTER 7. EVALUATING RISKS TO ECOLOGICAL RESOURCES

ABSTRACT

The Risk Review Project evaluation of ecological resources on the Hanford Site is an independent evaluation that encompasses evaluations of site resources in comparison to the Columbia Basin Ecoregion; evaluations made by DOE, the state of Washington, the state of Oregon, Nature Conservancy, and Tribes (where available); and on-site field evaluations. It uses the Level of Resource Values designed by DOE (DOE/RL-96-32 Rev. 1 2013) in conjunction with information from the State of Washington, Tribes, and others, modified by field work evaluations (landscape features [patch size, patch shape, connectivity], and exotic/alien species) and considerations of contamination (potential exposure during active cleanup or in the 100 years thereafter). A major contribution of the ecological risk evaluation is the acquisition of new field data on resource level values (1-5, 5 is the highest) for the EUs and surrounding buffer areas.

The risk that ecological resources experience is a function of contaminants present and ecological accessibility, remediation types, functional remediation parameters (e.g., number of cars, trucks, heavy equipment, capping, excavation), and scales (temporal, spatial). Ecological resources are at risk not only from contaminants and on-site activities but from the activities on adjacent habitat. That is, people, cars and trucks moving through a non-target site to reach the target remediation site can affect adjacent, not-target sites. These effects can be direct (e.g., traffic and habitat disruption, exposure to contaminants) and indirect (e.g., disturbance to animals, dispersal of seeds). Laydown areas can have an important effect, and must be selected carefully to minimize disruption.

7.1. INTRODUCTION

Environmental assessment and management involve preserving, protecting, and enhancing ecological, human, and cultural health and well-being. Ensuring well-being for ecological resources requires understanding the diversity and condition of natural resources, which range from populations of individuals of a single species to whole ecosystems (as well as landscapes). Some species are protected by law to prevent further declines and to increase current population levels. The U.S. Endangered Species Act (ESA 1973) provides legal protection and recovery efforts for plant and animal species listed as threatened or endangered. States also have lists of threatened and endangered species. Both entities list candidate species (those being considered for listing) and species of special concern (those that could become listed in the future due to their small population numbers or vulnerability). Thus, at a basic level, understanding potential impacts to endangered and threatened species and species of special concern is paramount when determining ecological risks.

At the other end of biological organization is an identifiable, vulnerable, or unique habitat or ecosystem (i.e., shrub-steppe, vernal pond, talus slope) critical to species health and well-being. While being on the Endangered Species List results in legal protection of the species, the Act also affords some protection for the habitat of listed species. In addition, there is considerable concern for sensitive or unique ecosystems (Downs et al. 1993). These are habitats most at risk, limited in quantity or extent, and which often contain one or more endangered species, endemic species (species that occur only in those areas), or threatened species assemblages (e.g., migrant songbirds, breeding frogs, hibernating snakes). Unique habitats are those that are rare locally (e.g., Hanford Site) and regionally (e.g., Washington State, the

Pacific Northwest). Such habitats are limited and often fragmented, and any decreases in quantity or declines in quality[84] have severe consequences.

This chapter describes key ecological resources for the Hanford Site and the Risk Review Project, including 1) major habitat types for the Hanford Site and the Columbia Basin Ecoregion; 2) endangered and threatened species and species of special concern, including species that are unique to Washington State or new to science; 3) DOE's evaluation of rare, unique, and irreplaceable resources (DOE/RL-96-32 Rev.1 2013); 4) how remediation types (and initiating events) affect ecological resources; and 5) the Risk Review Project's approach to evaluating potential impacts and risks to ecological resources in EUs. The first three provide an overview of what ecological receptors are at risk in different EUs at Hanford, and the latter two describe the Risk Review Project's approach to evaluating these units. Habitats are described first because they are more straightforward in that their occurrence is site-specific and can be mapped for the Hanford Site. Examination of habitat maps can identify general habitats and habitats of special or unique concern, but this must be followed by field examinations. In addition, the section below describes critical issues to consider in evaluating relative risk to ecological resources, including current contamination. It is important to distinguish between environmental and ecological resources. This evaluation is not an EIS or a natural resource damage assessment, nor does it cover the entire Hanford Site. Rather, it provides an overview of ecological resources on site, and in-depth information about the level of resources that are at risk in specific EUs[85] and in buffer areas around the EUs. Ecological resources refer to the living component of the ecosystem. Environmental is a broader category that includes living resources, geology (soils, physiognomy), and, importantly, chemical plumes and levels. A facilities and land use area map is shown in Figure 7-1.

[84] Declines in quality are referred to as degradation.
[85] Evaluation units are the groupings of contaminant sources that serve as the basis for evaluation as part of this Risk Review (see Methodology for Grouping Contaminant Sources for Evaluation).

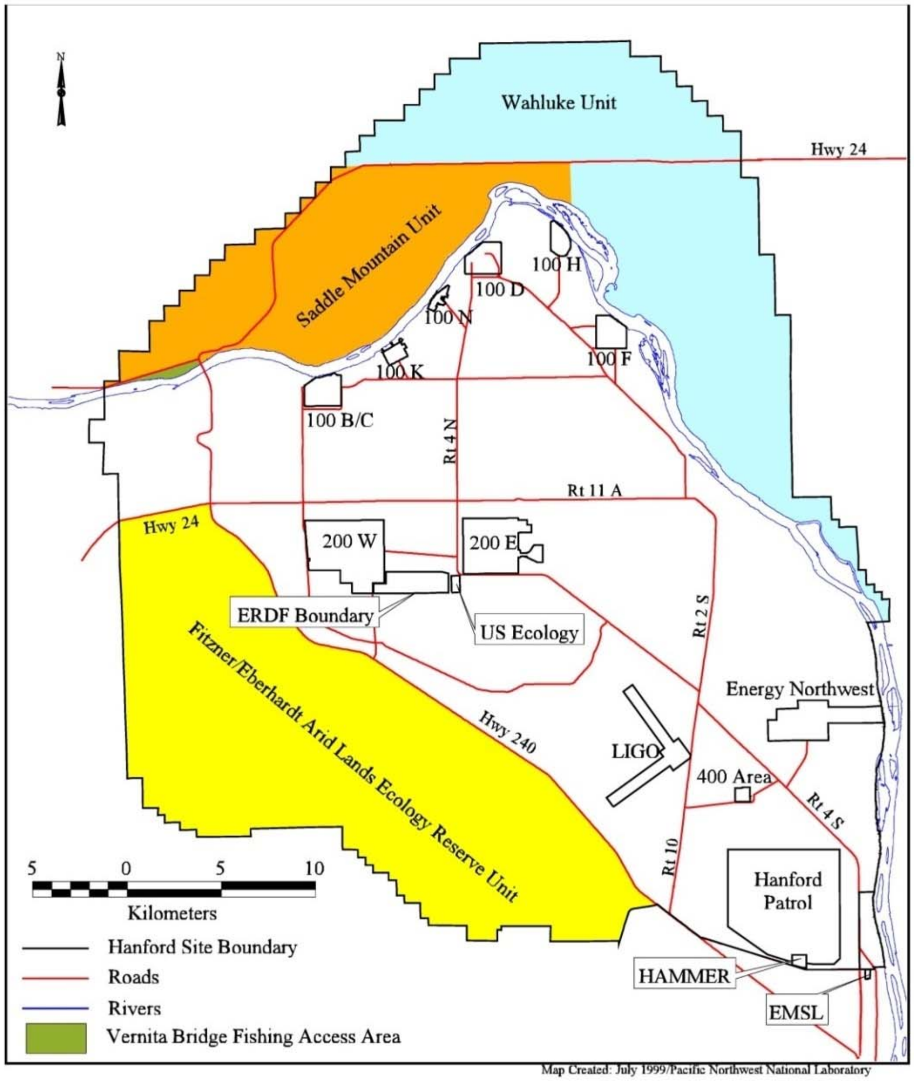


Figure D.2 Hanford Site Facilities and Land Use Areas (ERDF = Environmental Restoration Disposal Facility, LIGO = Laser Interferometer Gravitational-Wave Observatory, HAMMER = Hazardous Materials Management and Emergency Response Training Center, EMSL = Environmental Molecular Sciences Laboratory; *Energy Northwest formerly was the Washington Public Power Supply System)

Figure 7-1. Hanford Site facilities map (from DOE/RL 96-32 2001b, Appendix D).

The main factors affecting habitats on the Hanford Site (in addition to climate and geology) are fire, exotic/alien species, human development and disturbance, and succession. Succession is the natural progression of change of vegetation types from early stages (e.g., after a fire or other perturbation) to climax vegetation (the community that occurs under the prevailing geologic and climatic conditions). Fire is one of the primary factors that set back habitats to early successional stages. Fires on Hanford Site have burned as many as 800 km^2 (1984), and during 2000, a fire burned most of the shrub-steppe habitat on the Fitzner-Eberhardt Arid Lands Ecology Reserve (Duncan 2007). Fire has the potential to drastically alter the amount of critical or unique habitats on the Hanford Site. Post-fire revegetation on Hanford is an important process aimed at reducing sand movement and decreasing invasion of noxious weeds (Roos et al. 2009).

7.2. RELATIVE RISK ISSUES AND UNCERTAINTIES WITH ECOLOGICAL RESOURCES

Species and ecosystems are not static, which can result in difficulties in rating vulnerabilities. The following are some of the issues to consider when evaluating risk or impacts to ecological resources.

1. Ascribing ecological resources to a finite, discrete location (or waste unit) is difficult because of mobility and seasonality of species (e.g., monitoring immediately before remediation is critical).
2. Some species move within habitats depending on season (e.g., snakes and bats move to hibernation sites in the winter).
3. Species can have different life stages, requiring different habitats or locations (e.g., salmon).
4. Habitats change with ecological succession, as well as with fire, human disturbance, and human activities (e.g., early successional stages may involve grassland, while later stages may have shrubs).
5. Habitats become degraded by alien/exotic species, which can replace native ones, or change the relative abundance of different plant species.
6. Edge effects can be important. The value of equal acreages varies by configurations (e.g., round habitats [smaller edge-to-area ratio] have higher value than long, thin ones or fragmented ones). Some species require interior habitats, while others prefer edge areas.
7. The value of equal acreages varies by the number of barriers (e.g., roads, ditches, dikes, or extensive fire barriers through an area) that disrupt animal movements and ecological functions.
8. Ecological risk is dependent on the stressors (e.g., natural, man-made), especially the extent and type of physical disturbances and remediation, as well as the type, extent, and magnitude of current contamination.
9. Ecological resources can be exposed to contaminants prior to or during remediation, or from those left in place. A pathway must exist for contaminant uptake by flora or fauna, and at sufficient contaminant concentrations for ecological resources to be at risk.
10. Ecological risk is dependent on timing and varies before, during, and after remediation, as well as during different periods in the “after remediation” phase.
11. Ecological risk can be affected by the release of contaminants during remediation, or additional exposure that may occur following active cleanup.
12. Ecological risk can be affected by dispersal of contaminants by plants/animals (e.g., birds and mammals can carry contaminants over land, fish move contaminants in aquatic habitats, tumbleweeds can carry contaminants).
13. Ecological resources are vulnerable to off-site effects from nearby remediation (e.g., building roads to a remediation site can introduce exotic/alien species, widening a road or increasing traffic can serve as a barrier to wildlife movement) and dust suppression/herbicides.
14. Impacts to resources can be evaluated, but risk depends on the stressors and the frequency and duration of those stressors (e.g., frequent fires have a greater effect than infrequent ones, increased road traffic disrupts population movement, physical disruption in sensitive habitats like riparian zones can have a greater effect than in habitats already impacted, contamination closer to the surface has a greater effect on plants and animals than deeper contamination).
15. Monitoring data on species occurrences, species abundances, and spatial patterns of habitat are not available for most species or habitats on the Hanford Site.
16. Monitoring data on alien/exotic species site-wide are not available (e.g., exotic/alien species, such as cheatgrass (*Bromus tectorum*) and thistle.

17. Mitigation of ecological risks is part of required planning and execution of cleanup activities, but the actual success of mitigation and restoration plans often is unclear for periods beyond 2164. Extensive plans are underway to monitor river corridor revegetation and mitigation (Shaw et al. 2013). Revegetation must include forbs in addition to grasses and shrubs as they are a critical component, particularly for pollinators.

Thus, there are issues that relate to the nature of species and habitats (e.g., seasonal movements, population variations), those that relate to lack of data on species and habitats (e.g., lack of consistent monitoring, variations in species examined or methods of monitoring), those that relate to impacts (e.g., nature, extent, quality, and quantity of stressors; type of stressor), and levels and locations of contamination. These factors need to be considered in any risk evaluation of any specific site. Interactions need to be considered as well. For example, effects of subsurface contamination can be reduced by removing particularly deep-rooted plants to prevent roots from penetrating too deeply (Arana 2003).

Plants and animals can disburse contaminants/radionuclides by means ranging from food chain uptake to transference between environmental media. For example, contaminants can move from soil to plants, and to atmospheric dispersion by fire or wind. At Hanford, radionuclides have been dispersed by blowing Russian thistle (*Salsola tragus*). Environmental surveys, currently part of an integrated control plan, are conducted to prevent tumbleweeds and other deep-rooted plants from growing in contaminated areas (Arana 2003). Herbicides and cleanup crews are used by contractors to minimize the growth of deep-rooted vegetation—thus, tumbleweeds outside of contaminated areas are considered free of radionuclide contamination (as determined by screen levels, Arana 2003). The technical basis for screening levels of radionuclides can be found in ANL (1993).

Birds and animals can transport contaminants in seeds that have attached to their fur/feathers or are deposited in their droppings. Burrowing animals can move contaminants through the soil, both horizontally and vertically, and introduce them to ground or surface water. In addition, contaminants can obviously adversely affect plants and animals directly, as individuals and as populations.

The following sections describe why landscape features are critical in evaluating ecological resources in any given site. The value of the "whole" is greater than the individual parts. And conversely, while losing one small habitat patch may not cause severe degradation, losing several may. The critical landscape features that need to be considered include patch size, patch shape, patch isolation, and connectivity among patches (Fahrig 2002; Fischer & Lindenmayer 2007). These can be defined as follows.

Patch size: How big is the habitat? Some species require interior space far from edges to survive and reproduce (e.g., predatory mammals and secretive birds) and other species may require large patches.

Patch shape: Is the patch circular, rectangular, or long and thin? A long, thin patch has a significant amount of edge for the amount of interior habitats. Some species require interior habitat, and others prefer edge areas.

Patch isolation: How far is the habitat type from similar habitats and what is it surrounded by? Similarly sized patches have different values, depending on whether they are surrounded by urban development or another natural habitat.

Connectivity: Are patches connected and how are they connected? Isolated patches are less valuable than similar-sized patches that are connected. Two patches of the same size that are NOT connected are less valuable that two patches of the same size that are connected. The latter allows animals to move between the patches. The size of the connecting corridor is important.

In addition, exotic/alien species (non-native species) have the potential to degrade habitats, and the degree of degradation should enter into any evaluation of the value of a given habitat type. This is discussed further below.

7.3. HABITAT/ECOSYSTEMS ON THE HANFORD SITE IN A REGIONAL CONTEXT

Hanford's biological resources can be examined as part of the Columbia Basin Ecoregion. Ecoregions are regions of the United States that are defined based on geology, soils, physiography, climate, vegetation, wildlife, and land use (Omernik 1987, 2004). The Columbia Basin Ecoregion occupies the area south of the Columbia River between the Cascade mountain range and the Blue Mountains in Oregon and includes about two-thirds of the area east of the Cascades in Washington State (DOE/RL 96-32 2001a). Thus, ecotypes on Hanford Site are compared to those in the state of Washington (DOE/RL-96-32 2013) and to the state's priority habitats and species in Figure 7-2 (Azerrad et al. 2011; Rodrick & Milner 1991). Ecological resources at DOE sites around the country were examined in detail in by McAllister et al. (1996). They also described both sensitive habitats and wildlife and plants species of concern (including endangered and threatened species). Yearly ecological monitoring reports for the Hanford Site continue to describe critical resources and important/emerging issues (DOE 2013, and previous environmental monitoring reports).

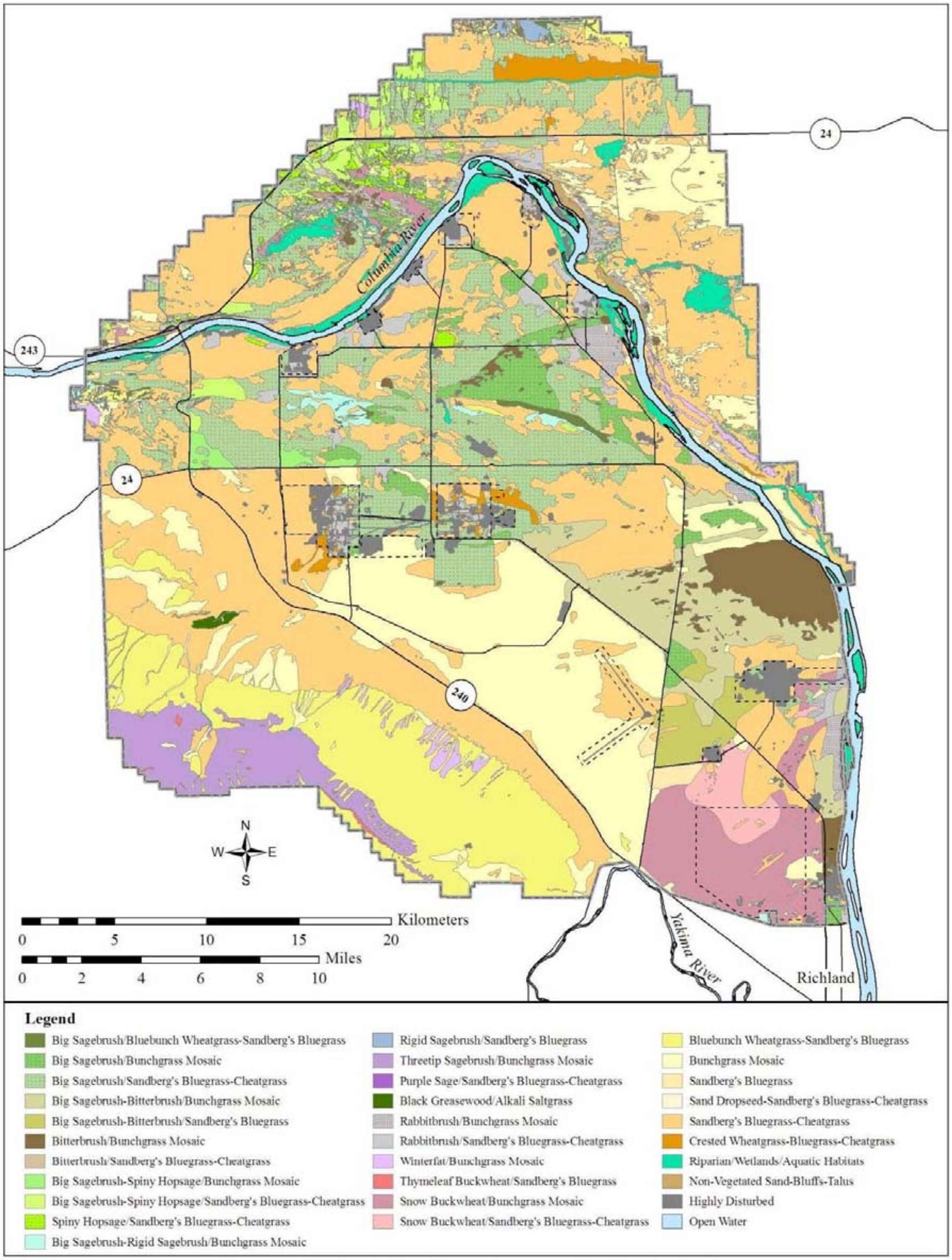


Figure 7-2. Vegetation cover types on the Hanford Site (from DOE/RL-96-32 Rev. 1 2013, Figure 4.6, page 4.10).

The Hanford Site is in the middle of the Columbia Basin Ecoregion (DOE/RL-96-32 Rev. 1 2013), allowing the habitats of the Hanford Site to be compared with the surrounding ecoregion. Examining the relationship of current to historical habitats provides insights into what has been lost on the site, and comparisons with the ecoregion provide information on both the relative importance of current habitats on Hanford and of those most at risk in the ecoregion generally (Table 7-1). Habitats indicated in red are those for which the Hanford Site has a significant proportion of regional resources, and/or those that have decreased less proportionately on the Hanford Site compared to the Columbia Basin Ecoregion.

Table 7-1. Changes in habitat types from historical records to 2001 for the Hanford Site and the Columbia Basin Ecoregion.

Given are habitat or cover types in the region and at Hanford, and the percentage change in each over this period. Data are adapted from Appendix C of Hanford Environmental Report (DOE/RL 96-32 2001a, Tables C.3 and C.4). Some of the habitat types (e.g., threetip sagebrush) were not examined (recorded) in 2001, and a direct comparison cannot be made. Rows in red indicate habitat that is particularly significant on the Hanford Site, especially in relationship to the ecoregion. Historical data are based on potential vegetation predicted to be at the end of plant succession (in the absence of human-induced change for that climate and geology).

Cover Type	Historic Ecoregion Area (ha)	Current Ecoregion Area (ha)	Historic Hanford Site Area (ha)	Current Hanford Area (ha)	% Change in Ecoregion	% Change in Hanford Site
Bluebunch wheatgrass steppe	1,028,900	431,400	612	1602	-58.1%	161.8%
Idaho fescue steppe	436,700	122,200	0	0	-72.0%	No change
Bitterbrush steppe	118,600	78,100	915	904	-34.1%	-1.2%
Big sagebrush steppe	4,096,900	1,662,400	148,902	137,834	-59.4%	-7.4%
Juniper/sagebrush	110,300	109,100	508	508	-1.1%	No change
Threetip sagebrush[a]	746,000	0	16	0[(a)]	-100%	-100%
Black greasewood	134,900	0	503	0[(a)]	-100%	-100%
Conifers/Idaho fescue	225,000	0	0	0	-100%	-100%
Ponderosa pine	302,900	335,100	102	102	10.6%	10.6%
Water	71,100	71,100	25	25	No change	No change
Other	205,500	4,667,400	0	10,612	2,171%	
Total	7,476,800	7,476,800	151,583	151,587		

a. This disappearance is likely due to not being documented in later years. A 100% decrease means it went from some amount to none (or it was not measured). The change in bitterbrush steppe is likely non-significant because fire does not affect its presence and it currently occurs mainly on the Hanford Reach National Monument.

The table indicates the relative change on the Hanford Site compared to the region. It is also possible to look at differences that have occurred on the Hanford Site itself, which partly indicates the declining habitats on-site. It is not the whole ecological picture, as percent occurrence does not indicate critical ecological features such as patch size, patch shape, interspersion of patches (including isolation and fragmentation), connectivity, and habitat corridors. For example, the same size patch (in hectares) provides more protection for sensitive species if it is round rather than long and thin because the latter has more edge where predators, alien/exotic species, and people/vehicles can enter and has less interior than the former. While PNNL regularly conducts surveys of alien/exotic species on their building site (Becker & Chamness 2012), these are not conducted site-wide.

In general, the habitats most at risk are those that are in short supply (both at Hanford Site and in the region) and those that have been declining most rapidly on-site or in the ecoregion (Table 7-1). Bluebunch wheatgrass is a unique habitat that increased on Hanford but decreased markedly in the ecoregion. Big sagebrush steppe is also of concern because Hanford has a significant component of this habitat in the ecoregion, and it has decreased both at Hanford and in the ecoregion (although it is still the dominant and largest habitat on the Hanford Site). Big sagebrush habitats are considered at risk even though they form a common habitat on the Hanford Site. Further, large areas of sagebrush can be destroyed by fire, reducing its availability for decades. Sagebrush is a priority habitat in Washington State. The importance of habitats are evaluated using the Levels of resources (0-5, where 5 is most valuable resources, DOE/RL-96-32 Rev. 1 2013, See Section 7.5), incorporating quality component (e.g., modifiers, such as contamination and degradation by exotic/alien species, as well as vegetation complexity (presence of grasses, forbs and shrubs).

The categories listed in Table 7-1, however, are actually a mixture of different habitats—it is the major vegetation type that has defined them. Thus, much finer gradations are possible, and it is these more detailed vegetation cover types that reveal the sensitive habitats on the Hanford Site. For example, Bluebunch wheatgrass is a native grass habitat that can be infiltrated with cheatgrass (an exotic species), which reduces the quality of the wheatgrass. Cheatgrass often invades from roadways, as construction allows this species to move in by disrupting the natural vegetation, soil ecosystem, and drainage (see the Hanford Site evaluation below). Shrub-steppe communities at the lowest elevation on the Hanford Site and on the Hanford Reach National Monument are at the greatest risk of invasion of non-native plants. The bluebunch wheatgrass steppe communities above 800 ft are more resilient to invasion than are big sagebrush/needlegrass communities. Fire, however, can affect habitat in many different places.

Aquatic habitats embedded within the terrestrial environment at the Hanford Site are critical because they are so limited in space (see Table 7-1) and act as habitat islands for many species. That is, some species are limited to these regions, and the dry steppe habitat that surrounds them serves as a barrier to movement. In addition, many species are sedentary or have few movement options. For example, tiger salamander (*Ambystoma tigrinum*) will not move over very dry areas to reach another water source if its habitat is destroyed.

In addition, sections of Hanford Site can be considered alone, especially those managed separately, such as the Hanford Reach National Monument (U.S. Fish and Wildlife Service 2008a). Comprehensive conservation plans have been developed for the monument, describing rare habitats and species (U.S. Fish and Wildlife Service 2008a).

7.4. SPECIES AND SPECIES GROUPS ON THE HANFORD SITE

Species on federal and state endangered species lists and other listed species (species of special concern, candidate species) must be considered in any ecological evaluation of Hanford Site resources. Of the 25 DOE sites slated for remediation/restoration as of 2007, Burger et al. (2007) reported that the Hanford Site had 8 federally endangered/threatened species compared to 7 or less for the other sites, and Hanford had 18 state-listed species (Fermi Lab had 22, all others had fewer than Hanford).

Comparing Burger et al data to the table below indicates the rapid shift and designation. This indicates the importance of the resources on the Hanford Site compared to other DOE sites. Although the number of habitats and endangered species were significantly correlated with total acreage of these DOE sites, the correlations were only 0.57 and 0.48 respectively (Burger et al. 2004). Thus, habitat and total acreage is not the whole answer to the importance of ecological resources on Hanford or any other DOE site.

The number of species on both the federal and state endangered species lists, however, shifts over time. Some species are removed and others are added (Table 7-2). This makes characterization of ecological resources more complex.

Table 7-2. Summary of number of species with federal and state of Washington listing status from 1996 to 2013. Given are endangered, threatened, and candidate species, and species of concern (called "monitored" for Washington State). References are given in Table 7-12 at the end of this chapter, which is a full listing of species.

Species Group	Total #	1996 Federal	2001 Federal	2005 Federal	2013 Federal	1996 Wash.	2001 Wash.	2005 Wash.	2013 Wash
Plants	60	4	4	6	6	12	48	53	52
Invertebrates	20	2	4	2	2	0	15	19	17
Fish	10	2	4	5	5	0	6	9	10
Amphibians and reptiles	9	1	1	1	2	0	5	6	8
Birds	47	11	14	8	8	12	42	41	40
Mammals	19	7	6	1	4	1	11	11	11
TOTAL	165	27	33	23	27	25	127	139	138

Table 7-2 clearly indicates that both federal and state agencies are continually monitoring the status of species and that the list is dynamic. In some years, several species were being monitored, considered species of concern, or identified as federal candidate species. In the following years, species status may be clarified, and the numbers of species on the protected list declines. The full list of species with their changing status over the years is given in Table 7-12. A fuller description of federally listed plants can be found in Sackschewsky & Downs (2001). However, the number of species that are federally listed at present or are listed by Washington State as threatened or endangered is relatively small (Table 7-3).

The federally endangered fish are spring Chinook salmon (spring run), and threatened fish are steelhead and bull trout. Although bull trout have been reported on the Hanford Reach, their natural habitat is mountain streams (U.S. Fish and Wildlife Service 2014a). Bull trout are also listed as threatened by the state of Oregon (McAllister et al. 1996). The peregrine falcon, which is occasionally seen on the Hanford Site during migration, is no longer listed as a state or federal endangered species, and the bald eagle once was considered a federally threatened species in Oregon but has "recovered" and has been removed from the Endangered Species List (U.S. Fish and Wildlife Service 2014a). The Oregon Biodiversity Information Center (2013) developed a list of rare, threatened, and endangered species of Oregon. Table 7-3, in conjunction with the Table 7-2, indicates that although many species are being monitored or are of special concern, few are actually listed as endangered or threatened by the U.S. Fish and Wildlife Service or Washington State at any one time.

Table 7-3. Current (2013) data on the number of threatened and endangered species on the Hanford Site (for a full listing, see Table 7-12 at the end of this chapter).

Group	Federally Listed as Endangered or Threatened	Listed as Endangered or Threatened by State of Washington	Threatened and Endangered Species in 2013
Invertebrates	0	0	
Fish	3	0	Spring Chinook salmon, steelhead, bull trout
Amphibians and reptiles	0	0	
Birds	0	4	Ferruginous hawk, sage grouse, sandhill crane, American white pelican
Mammals	0	0	
Plants	0	12	Great Basin gilia, grand redstem, Geyer's milkvetch, rosy pussypaws, desert dodder, white eatonella, awned halfchaff sedge, loeflingia, White Bluffs bladderpod, Columbia yellowcress, lowland toothcup

Exotic/alien species are considered the second largest threat to vegetation integrity at Hanford, second only to wildfires (DOE/EA-1728-F 2012), and presumably they are important threats in the ecoregion overall (after development). Exotic species gain a foothold when native vegetation (and soil) is disturbed, especially by vehicular traffic or other disruptive activities. Noxious weed seeds can lay dormant in soil for decades, and are often transported by wind, animals, vehicles, and clothing. Introduction and off-project transport of exotic plants can be minimized by inspecting vehicles and clothing, and covering trucks carrying soil. The impacts of vehicular traffic or other disruptive activities that can introduce exotic species adjacent to remediation sites indicate the importance of considering the total footprint of remediation activities (not just the specific remediation site). Even remediation on industrial areas (e.g., tank farms) can have secondary effects both within the site itself and on adjacent lands (including from the development of roads to provide access), due to disruption of vegetation and soils, with increases in exotics and other noxious weed species (e.g., DOE/EIS-0391 2012).

In addition to development, fire, and exotic species, habitat fragmentation often isolates habitat patches (an important barrier to biodiversity). Connectivity of terrestrial habitats promotes biological diversity and integrity (DOE/EA-1728-F 2012), and isolation of habitat patches should always be considered when rating risks. Physical disruptions not only affect connectivity, but also reproductive success of ground-nesting species or burrowing species (e.g., burrowing owls).

7.5. CURRENT HANFORD SITE ECOLOGICAL EVALUATION

RANKING OF ECOLOGICAL RESOURCES BY DOE

The Hanford Site has been concerned about ecological resources for some time, including describing and evaluating sensitive ecosystems, as well as monitoring species of concern (Downs et al. 1993; Duncan et al. 2007). Ecological resources at selected DOE sites were examined in detail by McAllister et al. (1996). They described sensitive habitats, wildlife, and plants (including endangered and threatened species).

Yearly ecological monitoring reports for Hanford continue to describe critical resources and important/emerging issues (e.g., DOE 2013). "Species of concern" include threatened and endangered species, as well as those that are vulnerable. DOE's evaluation included detailed information from the state of Washington's significant habitat delineations (DOE/RL-96-32 Rev. 1 2013, see section below). A detailed evaluation of species and habitats was conducted by DOE (DOE/RL-96-32 Rev. 1 2013). Significant or rare habitats on-site included desert streams, non-riverine wetlands, vernal ponds, sloughs, river islands, and open water, as well as physical features such as dunes, cliffs (White Bluffs), basalt, and outcrops (Figure 7-8). Many aquatic habitats are significant because they are rare, and some species are limited to these areas or to the habitat immediately fringing these habitats.

DOE developed habitat criteria, with associated levels of concern (DOE/RL 96-32 2013, pp. 5.6-5.9). While these habitat map categories are useful for planning, field research is essential to confirm or determine distribution and abundance prior to any cleanup-related activities. And, as this review and discussion points out, landscape features and exotic/alien species aspects need to be added as an overlay. The categories can be summarized as follows:

Levels of Ecological Resources (DOE/RL-96-32 Rev. 1 2013)

Level 5 = Irreplaceable habitat or federal threatened and endangered species (including proposed species, and species that are new to science or unique to Washington State).

Level 4 = Essential habitat for important species.

Level 3 = Important habitat.

Level 2 = Habitat with high potential for restoration.[86]

Level 1 = Industrial or developed.

Level 0 = Non-native plants and animals.

The implication of this characterization is that Levels 0 and 1 are of little concern, although it is imperative to account for two factors: 1) off-site effects can occur from remediation or actions within an industrial site (e.g., through roads or exposure to exotic/alien species or fire), and 2) use of buildings by native animal species can occur (e.g., bats can occupy buildings, posing a potential risk from demolition). Further, animals can carry contamination away from buildings, other structures, or soil or vegetation. Buildings, including underground facilities, can serve as roosting places for bats, including maternity colonies of *Myotis* (Lucas 2011). The presence of a maternity colony of Yuma Myotis in the 183 clearwell halted the demolition of building 183-F (Lucas 2011). Snakes can form dens or hibernate in buildings, and can be exposed to contamination as well. A more complete description of the levels of ecological resources is given below.

Level 1 resources are in habitats where DOE is not required to complete habitat replacement, but habitat could be restored there. There may be common native plants and animals, as well as stands of non-native plants or abandoned agricultural fields. There may be small patches of shrub-steppe surrounded by industrial areas (DOE/RL-96-32 Rev.1 2013).

Level 2 resources include migratory birds and state-monitored plants and animals, as well as upland stands of shrub overstory, non-native plants, and some steppe stands that co-occur with non-native plants (DOE/RL-96-32 Rev.1 2013). Maps of Level 1 and Level 2 follow (Figure 7-3 and Figure 7-4). Note

[86] Restoration is used here in the biological sense and does not relate to the CERCLA process.

that in all cases, the original DOE figure number is given at the bottom to facilitate location in the original document.

Level 3 (Figure 7-5) resources are state sensitive or candidate plants and animals that may have cultural importance. There is shrub-steppe with native climax shrub overstory with native grasses below. It also includes some wetlands and riparian habitat and conservation corridors.

Level 4 (Figure 7-6) resources include state threatened or endangered species, federal candidates, upland stands with native climax shrub overstory and native grass understory, and wetlands and riparian habitats. These resources are designated for preservation, with avoidance/minimization of disturbance. They require habitat replacement (DOE/RL-96-32 Rev. 1 2013). The other levels of concern are designated as either conservation (Levels 3, 2) or mission support (Levels 1, 0). Conservation areas can have habitat replacement at a less stringent level and may be areas to perform mitigation actions.

Level 5 (Figure 7-7) resources include not only federally listed species, but sensitive habitats. Irreplaceable habitats included cliffs, lithosols, dune fields, ephemeral streams and vernal ponds, as well as fall Chinook salmon and steelhead spawning areas (DOE/RL-96-32 Rev.1 2013). Rare habitats on the Hanford Site are shown in Figure 7-8. Although the Hanford Site evaluation includes only these as Level 5 resources, largely because they are exceedingly rare on the site, bluebunch wheatgrass habitats are also considered critical and unique because they are rare on Hanford, are decreasing at a more rapid rate in the ecoregion, and are very vulnerable to cheatgrass invasion. Shrub-steppe communities at the lowest elevation on the Hanford Site and the Hanford Reach National Monument are at greater risk from the invasion of exotic species than are those at higher elevations. Bluebunch wheatgrass steppe communities above 800 ft elevation are less at risk because they are more resistant to invasion by exotic species. The management goal is preservation, *with an avoidance of management actions.* Monitoring effort is high. Level 5 resources are shown in Figure 7-7. The corridor along Highway 240 is not considered a Level 5 (or 4) because, although the habitat climax is similar to adjacent habitat, it has cheatgrass.

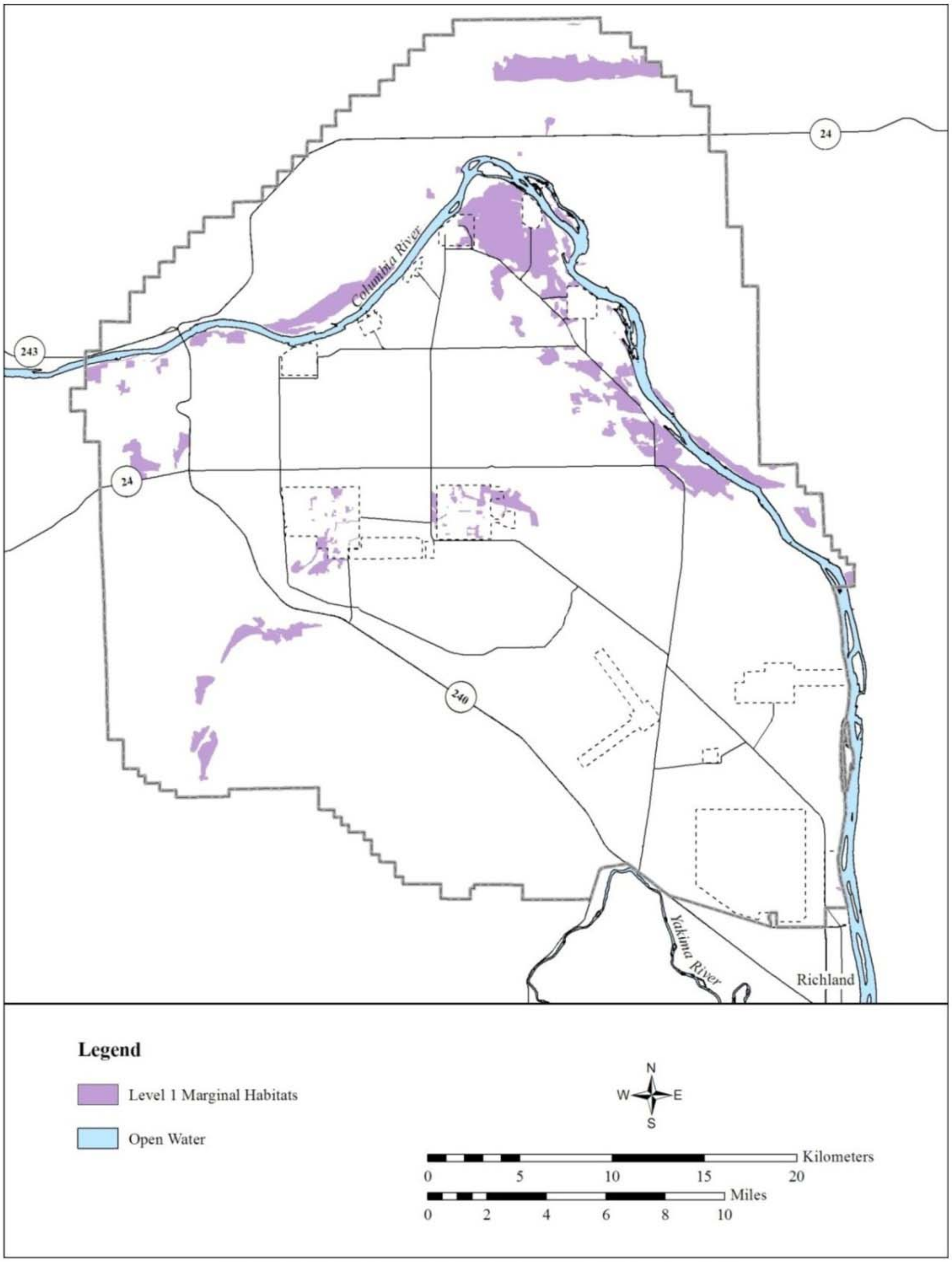


Figure 7-3. Map of Level 1 habitat types on the Hanford Site (from DOE/RL-96-32 2013, Figure 5.6, p. 5.17).

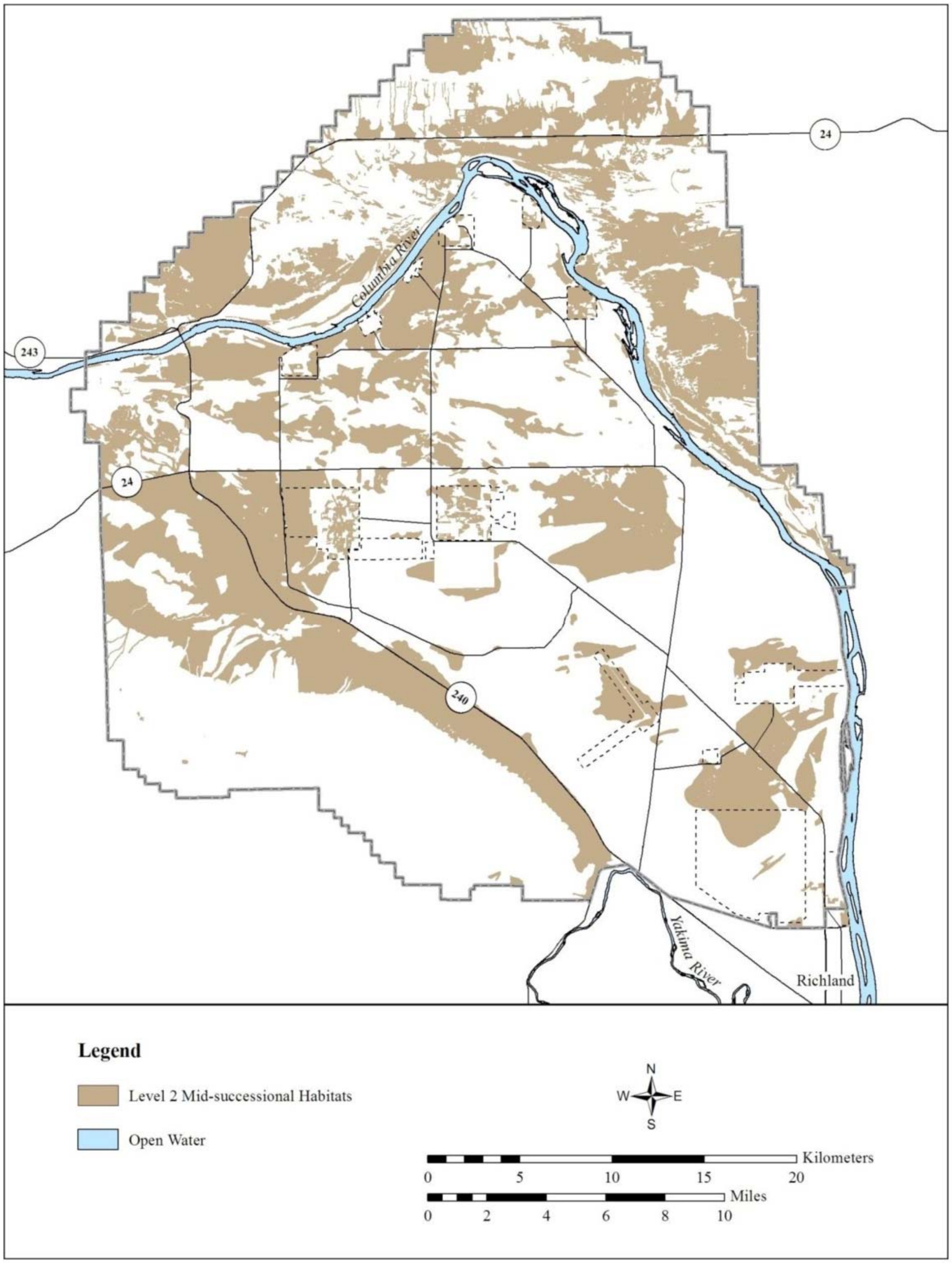


Figure 7-4. Map of mid-successional habitats classified as Level 2 (from DOE/RL-96-32 Rev.1 2013, Figure 5.5, p. 5.16).

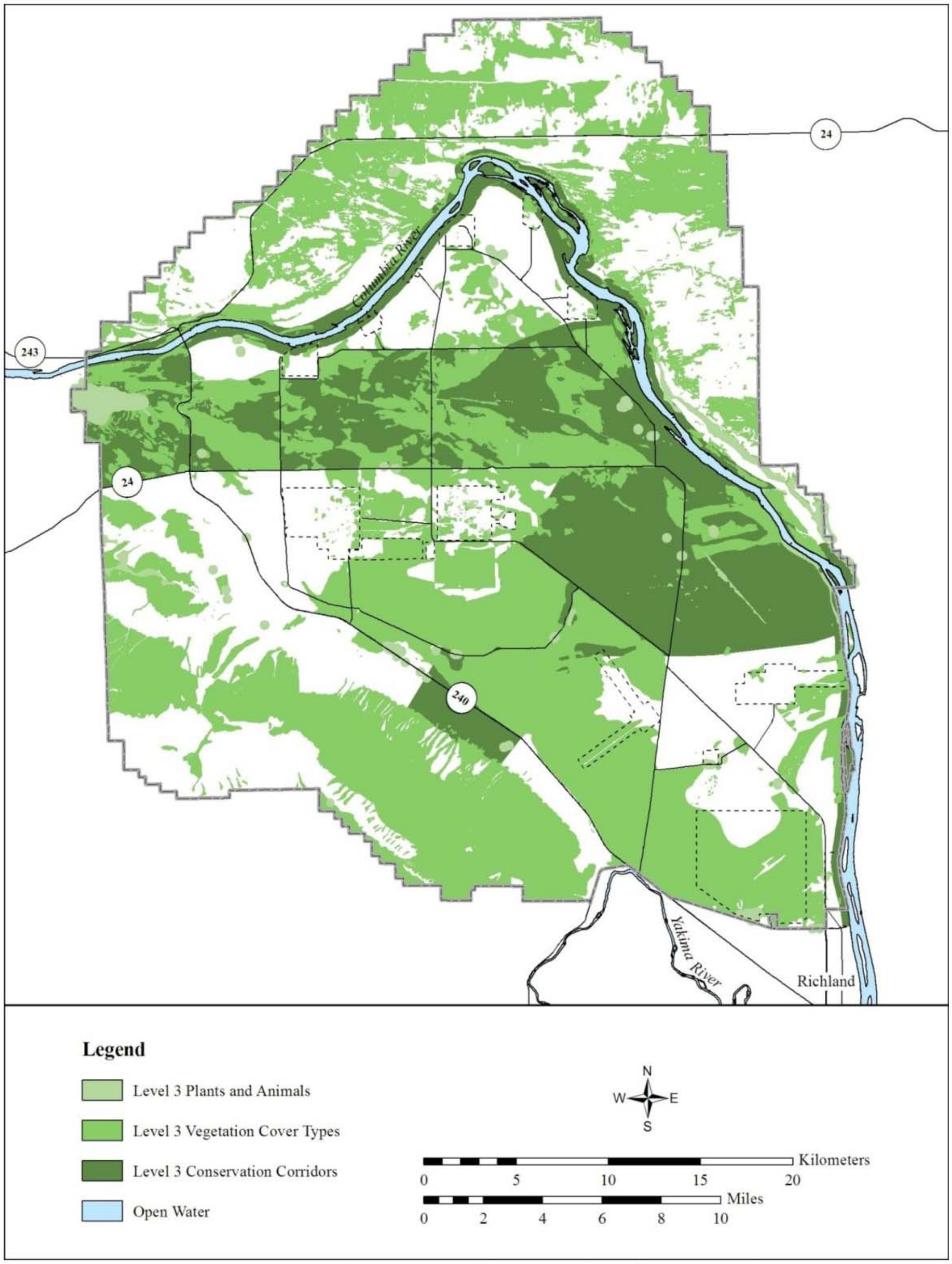


Figure 7-5. Map of important biological resources classified as Level 3 (from DOE/RL-96-32 Rev.1 2013, Figure 5.4, p. 5.15).

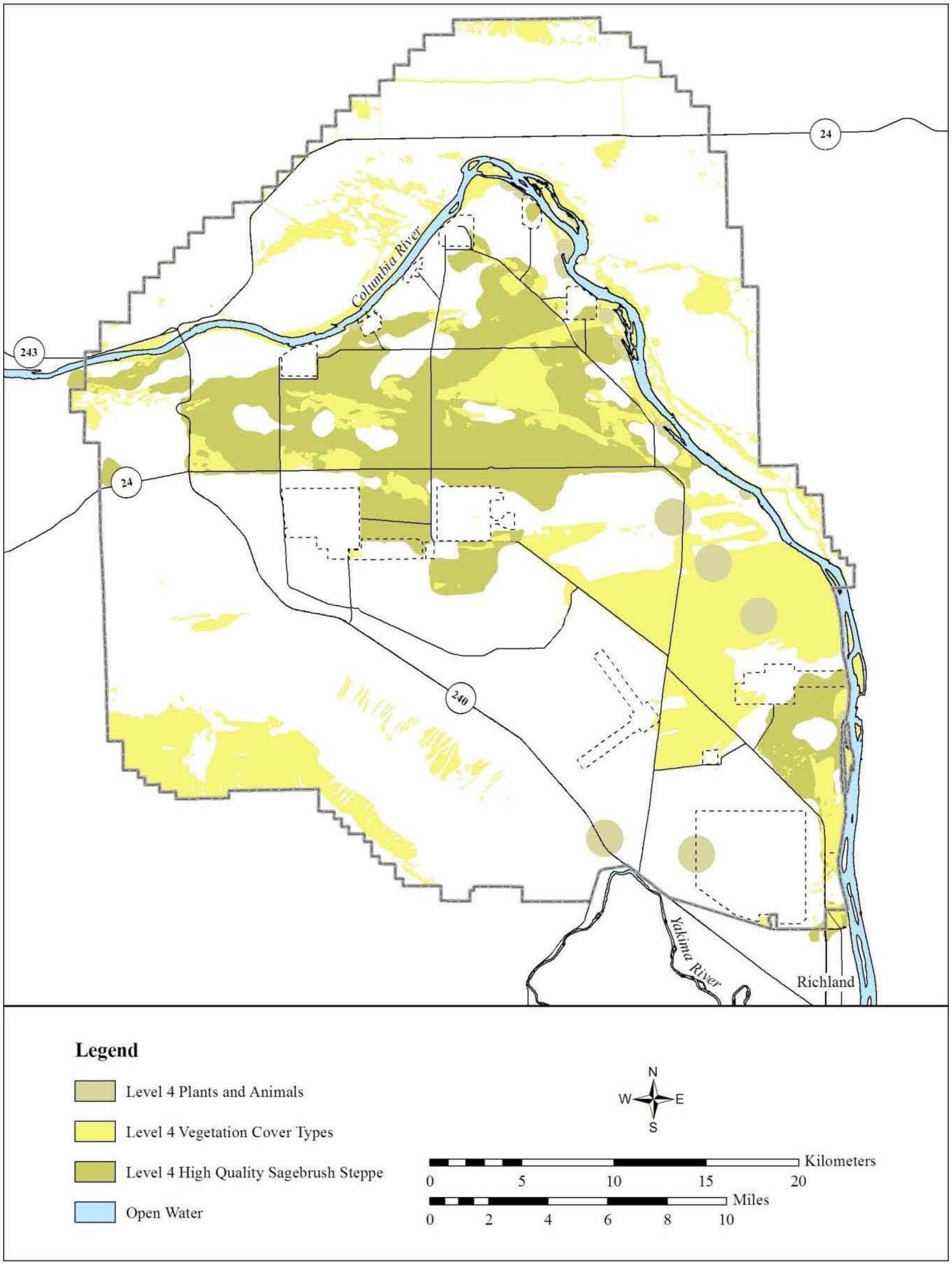


Figure 7-6. Map of DOE's (2013) evaluation of Level 4 species and unique or rare habitats (from DOE/RL-96-32 Rev.1 2013, Figure 5.3, p. 5.14).

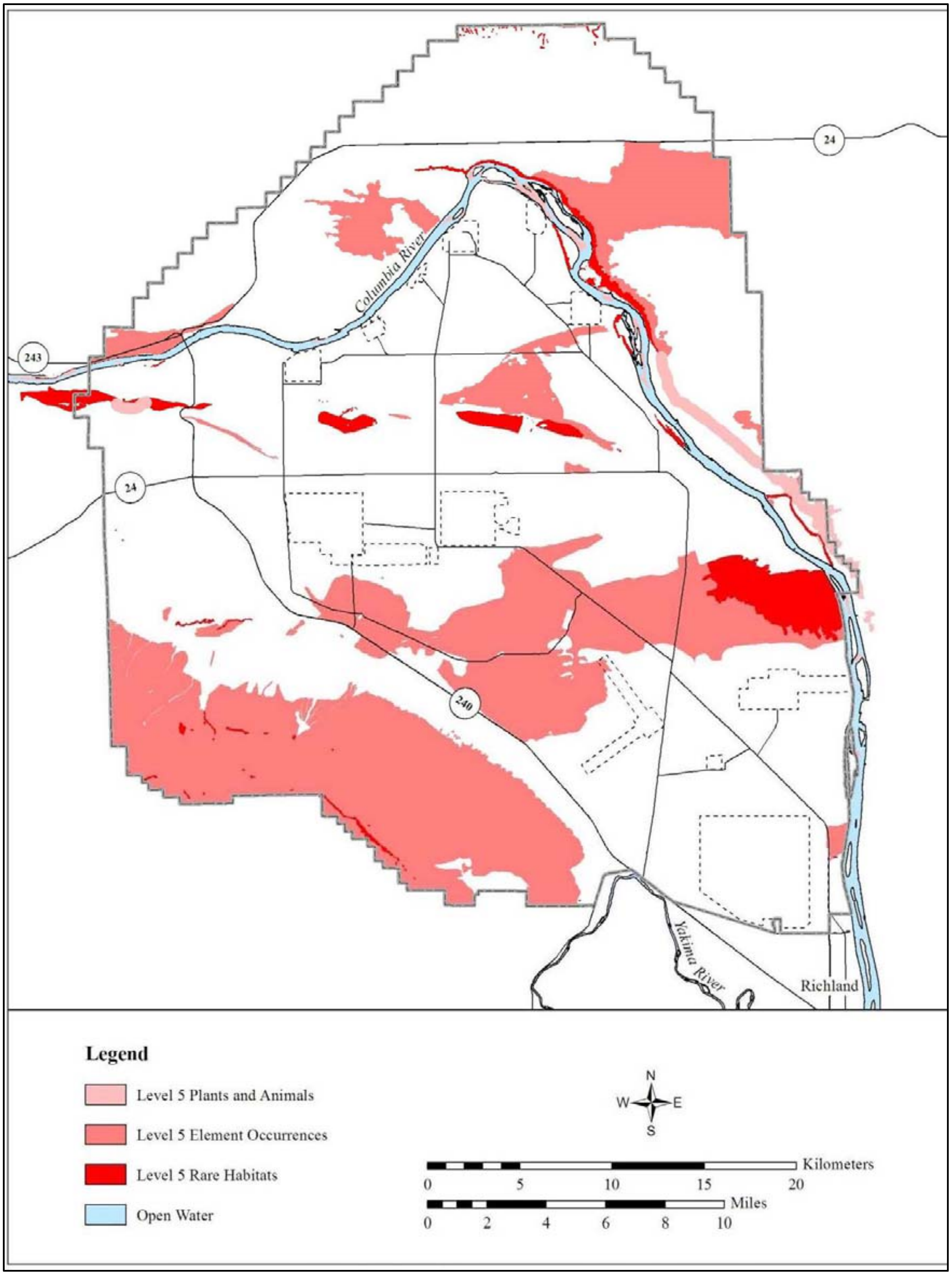


Figure 7-7. Map of resources classified as Level 5 (from DOE/RL-96-32 Rev.1 2013, Figure 5.2, p. 5.13).

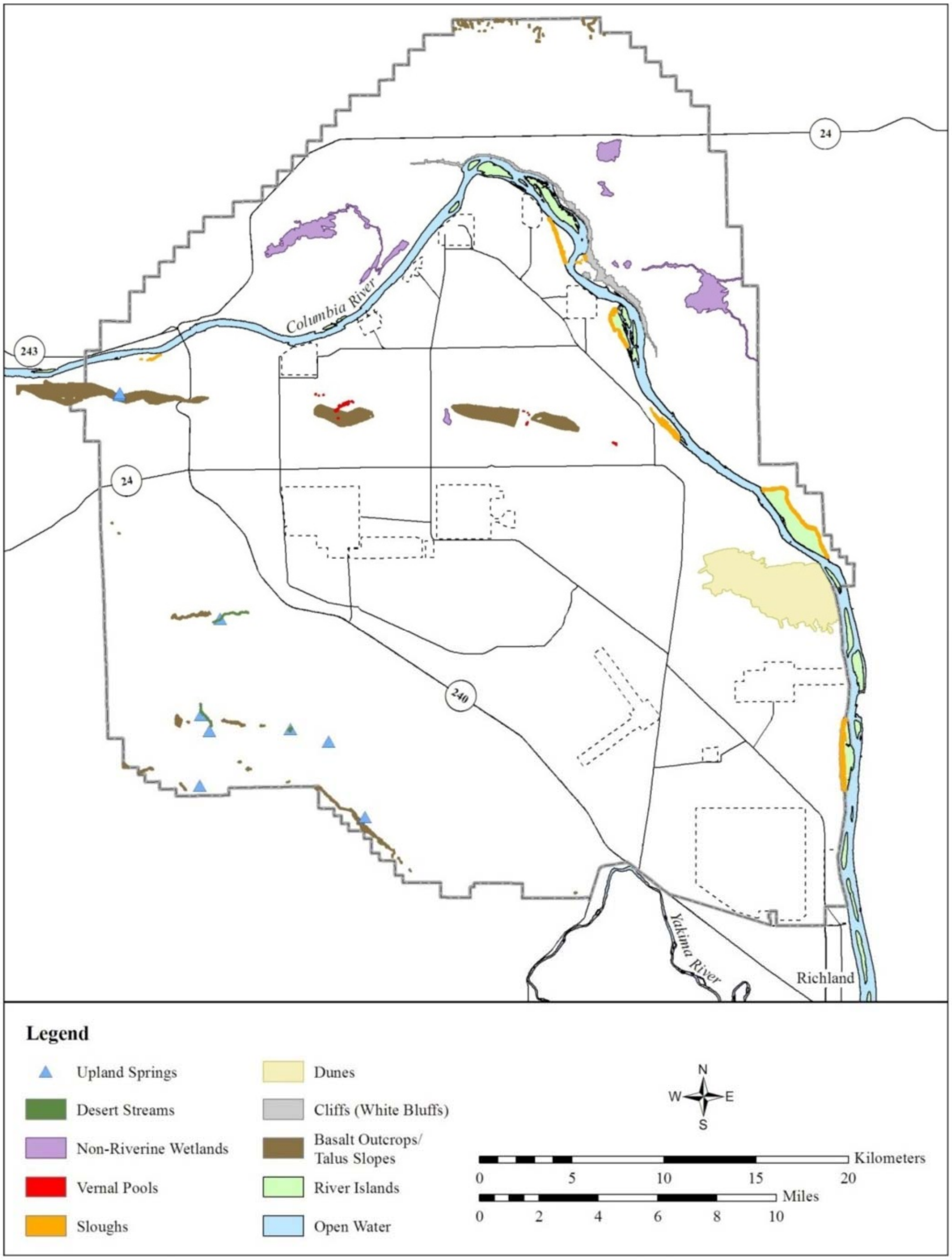


Figure 7-8. Significant or rare habitats on the Hanford Site (from DOE/RL-96-32 Rev.1 2013, Figure 4.8, p. 4.14).

Key resources are those that were evaluated as Level 3 (shrub-steppe with native climax shrub overstory with native grasses below, Figure 7-5), as Level 4 (essential, Figure 7-6), and as Level 5 (irreplaceable, Figure 7-7). These figures provide information on resources as risk and account for the quality of the resources, not just the presence. In the case of vegetation, one of the primary degradation features is the presence (and extensive presence) of exotic species (e.g., cheatgrass).

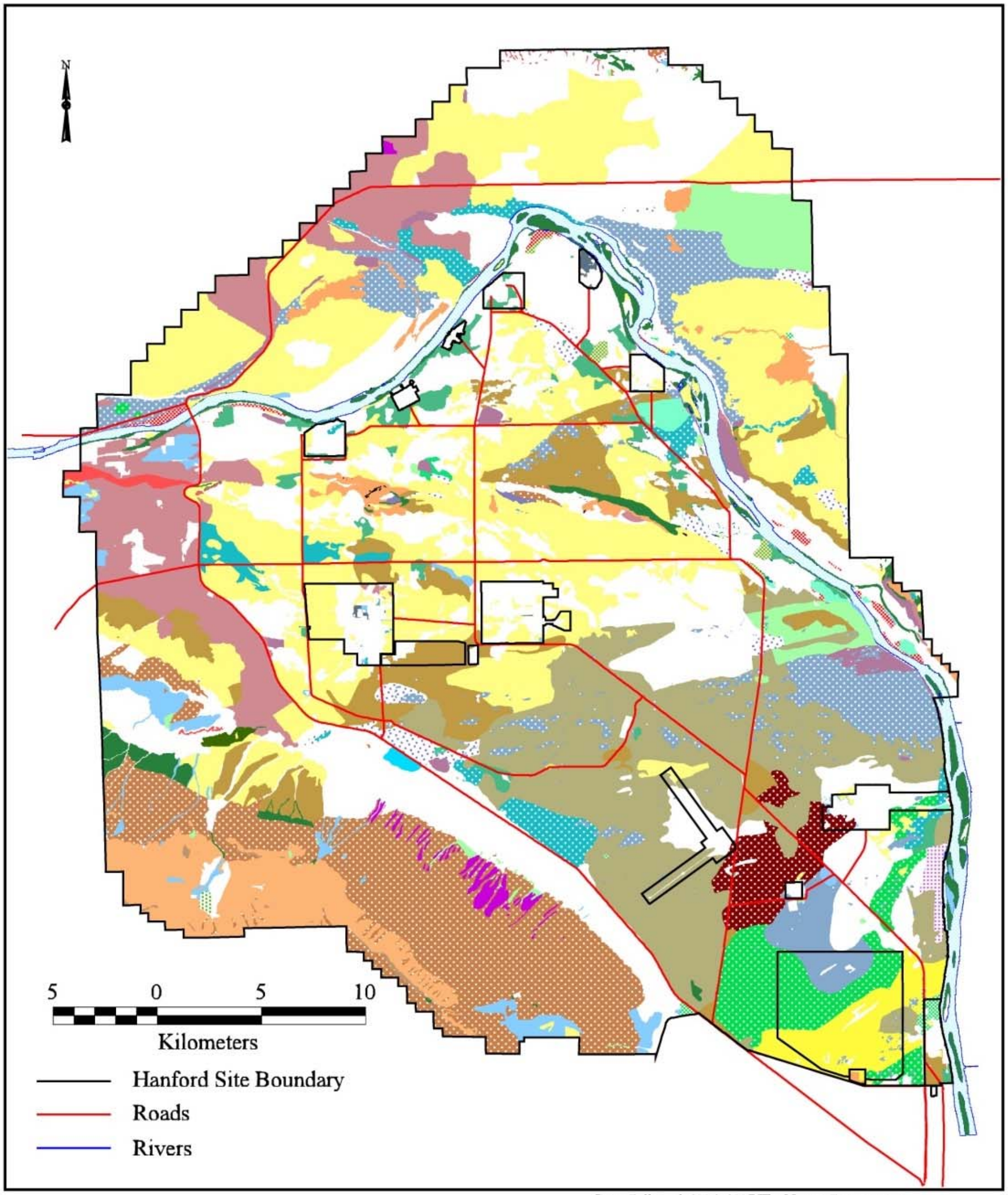
For the Risk Review Project evaluation, Level 3-5 resources are of greatest concern because they reflect both species of high concern/value and ecosystems of high concern/value. Level 3 resources are important for preservation because they contain important shrub/steppe habitat. During the rating for all levels, additional landscape features need to be considered, including patch size and shape, and connectivity, as well as exotic/alien species and contamination.

EVALUATIONS BY OTHER ENTITIES OF ECOLOGICAL RESOURCES ON THE HANFORD SITE

The state of Washington also has established priority habitats and species (WDFW 2008; DOE/RL 96-32 2001b). These are defined as those “habitat types or elements with unique or significant value to a diverse assemblage of species” (DOE/RL 96-32 2001b, p. D.17). The state ecosystem evaluations are slightly different from DOE’s, but they are basically similar. To be classified as high priority, habitats must have one or more of the following:

- Comparatively high fish and wildlife density
- Comparatively high fish and wildlife species diversity
- Important fish and wildlife breeding habitat
- Important fish and wildlife seasonal ranges
- Important fish and wildlife movement corridors
- Limited availability
- High vulnerability to habitat alteration
- Unique or dependent species

DOE used these categories to create a Hanford Site map of habitats of concern (Figure 7-9 and Figure 7-10), which is similar, although more inclusive, than Hanford’s Level 4 and 5 maps. Further, the state maps were taken into account when determining DOE’s Levels of Concern (DOE/RL-96-32 Rev.1 2013, pages 5.6-5.9). Areas of Concern as designated by Washington State, and DOE’s areas with Level 3-5 resources can be used in conjunction with a site facilities map to determine which resources are at risk (Figure 7-1).



Data Collected: 1994, 1997/The Nature Conservancy
1991, 1999 Pacific Northwest National Laboratory
Map Created: September 1999/Pacific Northwest National Laboratory

Figure 7-9. Habitats of concern for the Hanford Site, based on the state of Washington's evaluation (DOE/RL 96-32 2001b, p. D.18).

Figure D.12 Habitats of Concern for the Hanford Site (Legend)

Figure 7-10. Legend for Figure 7-9 (DOE/RL 96-32 2001b, p. D.19).

Other evaluations of ecological resources should be considered, including those of the Nature Conservancy, the four Native American Tribes, and recreational or commercial users of resources. The Nature Conservancy has conducted a number of evaluations at Hanford Site, mainly concentrating on biodiversity (Soll et al. 1999; Evans et al. 2003), but they also described rare communities, as well as plants and wildlife at risk. The Nature Conservancy and DOE are in the process of creating a new vegetation map for Hanford that may require new ratings for Level 1-5 resources.

The four main Tribes having historical and cultural ties to the Hanford Site have both species of concern and habitats/locations of interest, even though these may not be formally cataloged or published. Ecological resources of high value (e.g., Level 3-5 resources) have additional cultural value to Native Americans since ecological resources are often important components of Native traditional/cultural places (Burger et al. 2008). While many of these do not explicitly involve ecological resources, several require them either for goods and services (food, herbs, medicines, or fiber) or for aesthetic/religious purposes (e.g., view sheds, specific geological features). Although not the main subject of this chapter, it should be noted that ecological resources intersect cultural resources evaluations (U.S. Fish and Wildlife Service 2008b), especially for Tribal members. Ecological and cultural resources of Tribes have both spatial and temporal patterns, and tribal members recognize use of specific ecological resources in all 12 months (Bohnee et al. 2011). Although a brief list is shown in Bohnee et al. (2011), a complete list of plant or animals of special concern to Tribes is not available for cultural sensitivity reasons, but any list provided by Tribes will be included. Further, it is often a combination of habitats over large spatial areas that provides important view sheds, cultural places, or religious places.

Finally, there are species that are of special interest recreationally and commercially. A list is shown in Table 7-4. Recreational uses include hunting (game birds, wild game) and fishing. Salmon are an iconic and important species in the Columbia River tribally, commercially, and recreationally. Chinook and steelhead salmon are an integral part of Tribal culture. The economic value of these ecological resources is not examined here. This list, as well as those species of interest to the Tribes, qualifies as cultural resources that depend on ecological resources, and are described more fully in Chapter 8.

Table 7-4. Species of recreational and commercial interest found on or near the Hanford Site (DOE/RL 96-32 2001b, p. D.86).

Species	Habitat
Chukar	Upper elevations
Ring-necked pheasant	Riparian
White-tailed jackrabbit	Upper elevations of Arid Land Ecology Reserve
Mink	Riparian and Columbia River
Rocky Mountain elk	Arid Land Ecology Reserve
Rocky Mountain mule deer	Entire site
White sturgeon	Deep pools and main channel, Columbia River
Channel catfish	Slack areas near McNary Pool
Fall Chinook salmon	Life-stage dependent, Columbia River
Coho salmon	Main channel of Columbia River
Rainbow trout/steelhead	Main channel of Columbia River
Sockeye salmon	Main channel of Columbia River
Largemouth bass	Sloughs of Hanford Reach
Smallmouth bass	Sloughs of the Hanford Reach
Walleye	Main channel of Columbia River

7.6. METHODOLOGY FOR EVALUATING ECOLOGICAL RESOURCES

Developing the methodology for the Risk Review Project involves considering potential effects of contaminants and remediation, conducting additional field work to assess current ecological resource levels, formulating an overall paradigm that uses DOE's resource-level designations (DOE/RL-96-32 Rev. 1 2013), and conducting field assessments.

CURRENT ON-SITE ECOLOGICAL RESOURCES

Current on-site resources can be determined by examining maps developed previously by DOE (DOE/RL-96-32 Rev. 1 2013), and updating these with field work to determine the current level of resources on-site. In other words, what percent of each EU has Level 0-5 resources? Further, in evaluating resource level, the degree of physical disruption is important. For example, physical disruption and runoff from past activities can adversely affect sensitive habitats with Level 5 resources (e.g. riparian zone). The impact of current contamination needs to be considered. The only contaminants available to ecological resources would be those near the surface (without engineered controls), at facilities not enclosed (e.g., access by birds, insects, or snakes), in the riparian zone, or from seep in river sediment. Contamination near the surface would be available to plants with deep roots, and to burrowing animals, although there is an integrated control plan for tumbleweed removal (Arana 2003).

POTENTIAL EFFECTS ON ECOLOGICAL RESOURCES FROM CONTAMINANTS

Previous sections describe the ecological resources on the Hanford Site, both regionally and internally. This section examines the potential effects of remediation, and functional aspects of remediation on ecological resources. Contaminants (radionuclides or other contaminants of concern) can affect aquatic and terrestrial ecosystems. Both flora and fauna may be impacted by near-surface contamination (within 4 m of the ground surface), either through root uptake from soils or animal burrowing. Exposure to radiologic or chemical contaminants may occur through root uptake from water or surface deposition prior to, during, or after remediation, and may adversely affect some plant and animal individuals, populations, and associated ecosystems. Uptake by plants can lead to exposure in animals through the food chain, and can lead to transport of contaminants off an area.

Exposure can also occur in riparian and Columbia River habitats through upwellings and seeps (see Chapter 6). Given the relatively low levels of surface contamination over most of the Hanford Site, the long period of recovery from potentially high exposures during the Manhattan Project Era, and the natural recovery (resiliency) of biota, plant and animal communities at Hanford appear to show relatively little documentable effects from contaminants (particularly on most of the non-industrial sites). Contamination in riparian and benthic aquatic environments resulting from groundwater contaminants discharging through seeps and upwellings has a greater potential to result in exposure to biota. Plants, predominantly those in the riparian zone, also may directly uptake contaminants from relatively shallow groundwater. Remediation, however, may increase exposure to contaminants due to disruption of soil or water. Periodic ecological risk assessments are essential to ensure that biota are not exposed, particularly in areas where contaminants are near the surface. Further, the risk to people who consume plants or animals from the site needs to be considered, and should be evaluated periodically through appropriately designed biomonitoring and exposure assessments.

Given the above considerations, existing environmental contamination has the potential to impact ecological resources as follows:

Legacy source sites – when the contaminated areas have not been sufficiently covered with soil or other materials (e.g., gravel or pavement) to prevent root or animal ingress to contaminated materials. Many of the legacy source sites have been covered and are actively managed to prevent such ingress (i.e., weed control on gravel covered areas).

Groundwater plumes – when contaminated groundwater underlies or is discharged at the riparian zone or through upwellings in the bottom of the Columbia River.

D&D of inactive facilities – when the building envelope or structure is no longer intact and allows ingress of fauna (birds, snakes, rodents, etc.) that also permits uptake of contaminants by fauna (e.g., when the ingress is to areas with transferable contamination).

Tank waste and farms – minimal potential for impact to ecological resources under current management conditions (e.g., covered and actively maintained surface conditions).

Operating facilities – minimal potential for impact to ecological resources under current management conditions (e.g., intact and actively maintained buildings, engineered containment systems, ground cover).

Potential Effects on Ecological Resources from Remediation

Remediation includes types of practices occurring on Hanford Site, such as natural attenuation, pump-and-treat, capping, drilling, and excavation. Although there are recognized remediation types, functional remediation activities can be described. These include the actual agents that can damage ecological resources, such as people, trucks, drill rigs, heavy equipment, and large hoses. These remediation activities can be combined at any one remediation site, both in quantity and spatial activity. Further, while not a functional remediation type, the potential for increased exposure to radionuclides or other contaminants during remediation needs to be considered (Table 7-6 and Table 7-7).

Functional aspects of remediation are defined here as the salient features that affect ecological resources (e.g., people, cars, trucks, heavy equipment). These entities can be common to many different types of remediation, and can be combined differently as a function of remediation type. Also discussed are temporal aspects (during and after remediation), and the relationship to future land use. Remediation activities are a specific class of human activities that can affect the health and well-being of ecological resources. It should be noted that normally when an area is slated for remediation, both ecologists and cultural personnel are involved in the planning and execution.

As previously discussed, resources can be categorized as a function of importance and rarity on a scale from 1 - 5, where Level 5 resources are unique habitats and federal endangered/threatened species (after DOE/RL-96-32 Rev. 1 2013). These levels of resources, with maps for their distribution on the Hanford Site, are described in the previous section. The main method of rating potential impacts to ecological resources for the purpose of this Risk Review Project includes a combination of resource value (percent of different level resources), remediation options for each EU, and modifications that are described below.

Detailed information on the percent of different resource levels on-site, however, does not by itself provide a sufficient basis for rating risk or impact from remediation activities. Therefore, risk evaluations or ratings were defined (Table 7-5). The risks ratings for EUs are based on the degree of physical disruption (and potential additional exposure to contaminants) as a result of remediation options. Increases in personnel, vehicles, heavy equipment, and hoses can cause injury or death to resident plants and animals. In addition, creation of lay-down areas for equipment, storage, and transfer can have major effects. Some of these areas, newly created for remediation, can be quite large and usually are located on adjacent places not slated for remediation. Where Level 3 - 5 resources are concerned, these disruptions can cause long-term or permanent effects. The ecological evaluation for each EU includes resource levels, quality and quantity of resources (percent of each resource level), alien/exotic species, contamination, and the matrix of remediation options adopted or being considered. This can result in a range of ratings from ND to Very High (Table 7-5).

Table 7-5. Ecological risk evaluations during cleanup and remediation. Levels refer to an evaluation of ecological resources, including unique/sensitive habitats and endangered/threatened species at Level 5, and few resources at Level 1.

ND = not discernible from the surrounding conditions; no additional risk.
Low = Little risk to disrupt or impact Level 3 - 5 ecological resources.
Medium = Potential to disrupt or impair Level 3 - 5 ecological resources, but the remedial action is not expected to disrupt communities permanently.
High = Likely to disrupt and impair Level 3 - 5 ecological resources of high value or resources that have restoration potential, and can cause permanent disruption.
Very High = Very high probability of impairing (or destroying) ecological resources of high value (Level 3 - 5) that have typical (and healthy) shrub-steppe species, have a low percent of exotic species, and may have federally listed species. The remediation likely results in permanent destruction or degradation of habitat.

The quality of a specific patch of habitat should be assessed based on three additional factors: 1) presence or amount of exotic/alien species, 2) landscape features (patch size, patch shape, connectivity), and 3) contamination. Thus, a low-quality Level 5 resource may be equivalent to a high-quality Level 4 resource. This might happen if a patch of Level 5 resource has a high amount of exotic/alien species and is small, while a patch of Level 4 resource is large, with no exotic/alien species, and is connected to other Level 4 or 5 resource habitats. Or it could occur if there is potential for exposure to radionuclides or contaminants.

Each type of remediation varies by both the intensity and extent of potentially disruptive activity. Any type can involve either few or many people and vehicles on site, for a long or short period. The occurrence of continued monitoring is also important, since this involves on-site people and vehicles. Further, these activities need to be evaluated both on the remediation site and on adjacent lands, as the latter may be more pristine and thus more at risk in terms of ecological resource value. Table 7-6 examines and describes the ecological effects of functional remediation activities. Ecological damages are a function of both direct (i.e., destruction or degradation of plants or animals) or indirect (i.e., inadvertent introduction of seeds) effects. Further, they involve cascading effects (where an effect on one species has further effects on species that depend on it). For example, if the population of particular predator (A) decreases rapidly, another predator (B) may increase because the overall prey population is higher (due to a decline in predator A). Prey populations released from the predator pressure from A may increase relative to other prey populations, and so on. Resources can be rated initially based on the resource level maps, followed by field examination to determine if the resources should be upgraded or downgraded depending upon current conditions, the landscape features, and percent exotic/alien species. Additionally, remediation may increase exposure of biota to contaminants on site (released during remediation).

The following tables are to be used for populations and resources at risk or potentially impacted during active cleanup activities (Table 7-6) and in the post-cleanup period of 100 years when institutional controls are in place (Table 7-7). In each case, care must be taken to include all the effects, while eliminating overlap if multiple functional remediation activities occur.

Table 7-6. Potential effects of functional remediation/cleanup activities and risk to ecological resources (during active cleanup, until 2064). This list is arranged from lowest to highest risks, except for dust suppression, vegetation control, and irrigation, which are components of the other categories. Note that movement of seeds includes both native and non-native exotic/alien species. To some extent the effects increase down the list.

Type of Disturbance from Remediation	Ecological Effects
Personnel traffic through non-target area	Carry seeds or propagules (pieces of vegetation or other biological parts that can grow and/or reproduce) on person (boots, clothes, equipment); injure vegetation or small invertebrates or small animals (e.g., insects, snakes); make paths or compact soil.
Personnel traffic through target (remediation) area	Carry seeds or propagules (pieces of vegetation or other biological parts that can grow and/or reproduce) on person (boots, clothes, equipment); injure vegetation or small invertebrates or small animals; make paths or compact soil. These effects will be higher in the EU itself.
Car and pickup truck traffic adjacent to the site	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, scare or displace animals.

Type of Disturbance from Remediation	Ecological Effects
Car and pickup truck traffic through remediation site	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, scare or displace animals. Can create permanent or long-term trails and compaction; can impact animal behavior or reproductive success. Due to potential for revegetation following physical remediation, the potential for exotic species invasion is high.
Truck traffic on roads through non-target area	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, scare or displace animals. Also carry seeds or propagules from soil from truck or blowing from filled dump trunks. Affect animal dispersion and habitat use (e.g., some birds avoid nesting near roads because of song masking). Traffic is usually on established roads.
Truck traffic on roads through remediation site	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, scare or displace animals. Also carry seeds and propagules from soil from truck or blowing from filled dump trunks. Disruption and displacement of animals from near roads due to increased noise or other disturbances. Often permanent or long-term compaction of roads or trails, disruption and destruction of areas where trucks turn or engage in other activities; some destruction of soil invertebrates. Compaction can decrease plant growth in those areas, decrease abundance and diversity of soil invertebrates, and prevent fossorial snakes or mammals from using the area.
Heavy equipment	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, displace animals and disrupt behavior/reproductive success. Also carry seeds or propagules dispersed from soil from truck or blowing from heavy equipment. Often permanent or long-term compaction, destruction of soil invertebrates. Compaction can decrease plant growth in those areas, decrease abundance and diversity of soil invertebrates, and prevent fossorial snakes or mammals from using the area. May permanently destroy areas of the site with intense activity.
Heavy, wide hoses	Carry seeds, disrupt soil, remove or crush vegetation, kill vegetation. May have semi-permanent effects from compaction or vegetation removal. Effects continue if hoses remain or are moved over time.
Drill rigs	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, displace animals and disrupt behavior/reproductive success. Also carry seeds or propagules dispersed from soil from truck or blowing from heavy equipment. Often permanent or long-term compaction, which can delay plant revegetation and prevent fossorial animals from using these areas. Destruction of soil invertebrates at greater depths. Potential bringing up of dormant seeds from deeper soil layers. Disruption of ground-living small mammals and hibernation sites of snakes and other animals. Effects additive with other traffic types.

Type of Disturbance from Remediation	Ecological Effects
Construction buildings	Carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, displace animals and disrupt behavior/reproductive success. Also carry seeds or propagules dispersed from soil from truck or blowing from heavy equipment. Often permanent or long-term compaction. Destruction of soil invertebrates at greater depths. Potential bringing up of dormant seeds from deeper soil layers. Disruption of ground-living small mammals and hibernation sites of snakes and other animals. Effects additive with other traffic types. Permanent destruction of plants and animals, and of the on-site ecosystem larger than the footprint of the building. Effects will radiate from the building, and post-remediation effects depend on the degree of use (e.g., personnel and truck traffic, type of truck traffic and heavy equipment activity).
Caps, other containment	During construction, carry seeds or propagules on tires, injure or kill vegetation or animals, make paths, increase compaction of soil, displace animals and disrupt behavior/reproductive success. Also carry seeds or propagules dispersed from soil or tailings from truck or blowing from heavy equipment. Often permanent or long-term compaction of soil from cars, trucks, and heavy equipment on roads or paths. Compaction can decrease plant growth in those areas, decrease abundance and diversity of soil invertebrates, and prevent fossorial snakes or mammals from using the area. Destruction of soil invertebrates at depths of pits. Potential bringing up of dormant seeds from soil layers. Disruption of ground-living small mammals and hibernation sites of snakes and other animals on-site of containment. Often disrupts local aquatic environment and drainage; often non-native plants used on caps (which can become exotic/alien adjacent to the containment site).
Soil removal	Complete destruction of existing ecosystem, all of the above effects on adjacent sites, but these effects are potentially more severe because of blowing soil (and seeds); potential for exposure of dormant seeds. In the revegetation stage, there is the potential for invasion of exotic species, changing the species diversity of native communities.
Contamination	During remediation, radionuclides or other contaminants could be released or spilled on the surface, and depending upon the type and quantity, could have adverse effects on the plants and animals on-site.
Dust suppression	Additional water could lead to more diverse and abundant vegetation in areas that receive water, which could encourage invasion of exotic species. The latter could displace native plant communities. Excessive dust suppression activities could lead to compaction, which can decrease plant growth in those areas, decrease abundance and diversity of soil invertebrates, and prevent fossorial snakes or mammals from using the area.
Vegetation control	Use of non-specific herbicides results in some mortality of native vegetation (especially native forbes), and allows exotic species to move in. It may change species composition of native communities, but it also could make it easier for native species to move in. Improved methods could yield positive results.

Type of Disturbance from Remediation	Ecological Effects
Irrigation (revegetation)	This requires a system of pumps and water, resulting in physical disturbance. This is used to reestablish native plant species. Repeated irrigation from the same locations could result in some soil compaction, which can decrease plant growth in those areas, decrease abundance and diversity of soil invertebrates, and prevent fossorial snakes or mammals from using the area.

The above table provides examples of effects that occur during remediation. However, these effects can remain for many years before ecosystems recover. There is natural recovery of ecosystems, provided the stressor (remediation activity) does not continue and remnants of the system (e.g., seeds, plants, nearby animals) remain. Table 7-7 examines potential effects during the near-term post-cleanup period (over the 100 years after remediation).

Table 7-7. Potential ecological effects from remediation in the 100 years post remediation (2164).

Type of Disturbance from Remediation	Ecological Effects
Personnel traffic through non-target area	Likely no longer present.
Personnel traffic through target (remediation) area	Likely no longer present, except for invasive species if they became established.
Car and pickup truck traffic on adjacent site	Likely no longer present, unless heavy traffic caused ruts.
Car and pickup truck traffic on remediation site	Likely no longer present, unless heavy traffic caused ruts, except for alien/exotic species if they became established.
Truck traffic on roads through non-target area	Likely effects only adjacent to roadway (may involve exotic/alien species, but less likely to affect animal populations).
Truck traffic on roads through remediation site	Likely effects only adjacent to roadway (may involve alien/exotic species, but less likely to affect animal populations).
Heavy equipment	Permanent effects likely in areas of heavy equipment use; effects likely to include exotic/alien species, differences in native species structure, soil invertebrate changes in areas of high activity (compaction).
Drill rigs	Permanent effects in the area of drill rig construction. Possible permanent effects in area surrounding rigs, depending on traffic and current activities.
Construction buildings	Permanent effects in the area of building site. Permanent effects in area surrounding building, depending on traffic and current activities.

Type of Disturbance from Remediation	Ecological Effects
Caps, Other containment	Permanent effects in the area of cap site. Permanent effects in area surrounding cap or containment, depending on traffic and current activities. Periodic monitoring will involve effects due to personnel, car, and truck traffic (see previous table).
Soil removal	Permanent effects in the area of soil removal. Degree of effect depends on restoration activities, and whether restoration included vegetation and animal restoration (e.g., native vegetation, insects, pollinators, and other essential ecosystem components). Permanent effects in area surrounding soil removal, depending upon traffic and current activities. Periodic monitoring will involve effects due to personnel, car, and truck traffic, as well as level of activities.
Contamination	During remediation, radionuclides or other contaminants released or spilled on the surface could have long-term effects if the contamination remained, and plants did not recolonize or thrive. Such disruptions could affect the associated animal community.

For an ecologist, it is impossible to evaluate the resources at risk 1000 years hence or any period greater than 100 years after cleanup has been completed. Ecosystems change, both naturally and in response to anthropogenic factors (physical and radiological/chemical). Climate change may have dramatic effects over the next 100 years, and any changes in mean temperature or snowfall/rainfall could have major effects on the ecosystems at Hanford. Increased temperatures and decreased snowmelt/rainfall would change the climax vegetation on the site, with concurrent changes in the animals on site. Similar climate changes could affect the depth, flow, and seasonal patterns of water in the Columbia River, which would in turn affect the fish and other animals living in the river. While not the subject of this section, climate change should be borne in mind when considering any future resources at risk on the Hanford Site.

Ecosystems on the Hanford Site, as on other sites, are subject to initiating events that could affect their health and well-being. Some of these include failure of institutional and engineered controls, and others involve natural catastrophes, such as fires, earthquakes, or volcanic eruptions (leading to ash fall). A more complete list can be found in Chapter 4. Many of the initiating events considered as part of the Risk Review Project can affect ecological resources, even natural, undisturbed ones. Initiating events can change the existing ecosystem, but can also change exposure to contaminants. It also should be noted that areas that at first appear undisturbed may have been disturbed by human land use 100–200 years ago, or even more. However, valuable ecological resources on remediated/restored lands can be affected by the interaction of initiating events with remediation itself. Some of these are described below (Table 7-8).

Table 7-8. Initiating events that could impact the integrity and health of ecological resources. Some of the effects are similar to those of functional remediation. Loss of institutional controls refers to loss of active controls.

Event	Immediate Effects	Longer-Term Effects
Loss of institutional controls	Increased human activities, same effects as personnel on-site.	No interaction
Loss of engineered controls	Immediate exposure to contaminants the engineered controls managed.	Increased human activities; same effects as those listed in previous table, depending on level of functional impacts of remediation. Could also result in increased exposure to contaminants.
Structural decay	Immediate exposure to contaminants the structure contained; immediate exposure to building materials.	Increased human activities; same effects as those listed in previous table, depending on level of functional impacts of remediation or constructed needed to either repair or remediation the building. Could also increase exposure to contaminants.
Fire	Habitat destruction, and possible resetting of succession to early successional phase.	Increased human activity related to firefighting, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity.
Earthquake	Little effect	Increased human activity related to addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity and level of contamination.
Dam failure (flooding)	Can wash away or kill plants and associated animals (from soil invertebrates to birds or mammals unable to escape quickly).	Long-term effects resulting in resetting succession, erosion of habitats, and potential loss of species diversity. Potential increases of human activity related to addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity and level of contamination.
Ash fall (volcanic)	Depending on depth of ash, can degrade or destroy ecosystems, and associated plants and animals.	Long-term effects resulting in resetting succession, erosion of habitats, and potential loss of species diversity. Deep ash will prevent photosynthesis of covered plants, potentially eliminating some species. Potential increases of human activity related to dealing with any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on site. Effects vary depending on degree of human activity.

Event	Immediate Effects	Longer-Term Effects
Drought	Shift in species diversity, selecting for drought-tolerant species.	Few expected effects on native species adapted to the climate. However, severe drought may affect performance of caps, covers, or other engineered controls.
Plane crash	Limited destruction to site of crash.	Long-term effects resulting in resetting succession, erosion of habitats, and potential loss of species diversity in immediate vicinity of crash. Potential increases of human activity resulting from immediate rescue and human safety activities, as well as those addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on site. Effects vary depending on degree of human activity, both immediate and longer-term.
Climate change	Potential shifts in biodiversity and abundance of specific plants or animals. Could result in on-site movement of animals to other habitats.	Long-term shifts in biodiversity and major habitat types.
Water table changes	Changes in plant composition, abundance and diversity.	Increased human activity as a result of increased need for engineered controls or remediation of existing facilities. Could also result in increased exposure to contaminants.

Future land use designations can also affect the health and well-being of ecological resources at Hanford. Land use designations considered are those in the CLUP (DOE/EIS-0222-F 1999, as well as the designation called “unrestricted.” To consider risk of ecological resources as a function of future land use (what would occur following the designated remediation), two evaluations of risk can be made:

1) Are there resources that are at risk? If not, the ecological risk is low.

2) Are the resources that are there (no matter how few or limited) at risk?

Table 7-9 addresses the near-term post-cleanup evaluation period (2064 to 2164).

Table 7-9. Ecological risk as a function of land use designations. Given are scenarios involving Level 4 and 5 resources (most critical, sensitive, unique habitats, with federal endangered/threatened species). Land use designations are from the CLUP (DOE/EIS-0222-F 1999). The right two columns summarize the likelihood of Level 4 and 5 resources being present, and whether these resources would be at risk from the current land use designations. This table addresses the period after 2064 (when cleanup is complete).

Land Use	Levels 4 and 5 Ecological Resources: Presence and Potential Management Actions	Likelihood of Presence	Risk to Resources
Industrial-exclusive (hazardous wastes)	Few Level 4 or 5 resources co-located with the industrial-exclusive land use designation.	Few	Low
Industrial	Few present.	Few	Low
Research and development	May occur in patches, or in larger sections that could be protected and connected.	Medium	Medium
High-intensity recreation	May occur in patches, or in larger sections that could be protected and connected. Need to limit high intensity recreation in patches that have high biological integrity (few exotic/alien species, few trails).	Medium	High
Low-intensity recreation	Likely present in larger sections that could be protected and connected to provide high quality habitat.	Likely Present	High
Conservation (mining)	Likely present in large sections that could be protected and connected to provide high quality habitat.	Likely Present	Low
Preservation	Present in patches and large sections that should be protected from human activities (especially Level 4 and 5 resource areas of high quality).	Present	Low
Unrestricted	Resources present before this use, impact depending on presence and level of resource.	Present	High

The likelihood of presence reflects whether unique habitats and threatened/endangered/species of concern may be in areas with these land use designations. That is, are there any ecological resources, and what level are they? The risk to those resources is a result of the degree of human activity that resources would be exposed to, as well as residual contamination. Thus, industrial areas have low risk because there are few resources, and conservation areas have low risk because, although there are Level 4 and 5 resources on-site, the human disturbance is expected to be very low and future land management agencies may restrict or prohibit human activity to help ensure a low level of disturbance. Thus, absent further remediation activities, or other human activities, the resources are not at risk.

Finally, it should be noted that contamination left in place has the potential to adversely affect eco-receptors, and therefore populations, communities, and ecosystems. Evaluation of contamination left in place requires detailed, site-specific risk assessments of indicator species, on a regular and periodic basis. This chapter does not provide such risk assessments.

FIELD ASSESSMENT AND RESOURCE LEVEL UPDATE

The overall objective of the field assessment is to evaluate ecological resources on and around the EUs to provide additional possible "impact" information to managers that can inform sequencing and provide information to reduce impacts to ecological resources. The first step must be to evaluate the level of resources on each EU. This information should also include the possible lay-down areas adjacent to the site (which may be 1‑3 times the size of the EU), as well as other project operations (e.g., spoil piles). The field assessment includes the following:

1. Assessment of EU and adjacent habitat (buffer zone) from the resource level figures in DOE/RL-96-32 Rev. 1 2013
2. Field assessment of current habitat resource level (using DOE/RL-96-32 Rev. 1 2013)
3. Field assessment of exotic/alien species
4. Field assessment of presence of federal and state endangered and threatened species, or unique species or assemblages
5. Field assessment of landscape features (patch size and shape, connectivity) where applicable

The field methodology was developed under the leadership of J Burger, Rutgers/CRESP in collaboration with A Bunn, JL Downs, MR Sackchewsky, MA Chamness, and KB Larson of PNNL. Field maps showing the EU itself and expected impact area, along with a buffer area 1 times the EU length (or width, whichever is greater) were developed by PNNL, and were used by the field crews. An ecological evaluation of species, populations, and habitats is an important part of the Risk Review Project evaluation. The evaluation includes using the DOE evaluation of ecological resources (DOE/RL-96-32 Rev. 1 2013). These levels include (a more complete definition is given above) the following:

Level 5 = Irreplaceable habitat or federal threatened and endangered species (including proposed species

Level 4 = Essential habitat for important species

Level 3 = Important habitat

Level 2 = Habitat with high potential for restoration

Level 1 = Industrial or developed

Level 0 = Non-native plants and animals

Survey and Analysis Methods

The evaluation process uses existing biological resource level maps (DOE/RL-96-32 Rev. 1 2013), field surveys and measurement of current vegetation and habitat conditions, Geographic Information System (GIS) information, and wildlife observations to evaluate potential ecological impacts associated with cleanup activities at the EU. Additional information used in the ecological evaluation includes the current endangered and threatened species (federal and state) distribution data (U.S. Fish and Wildlife Service 2014b,c; WDFW 2008, 2014; WSDNR 2014); priority habitats as defined by Washington State Department of Fish and Wildlife (WDFW 2008); current aerial imagery, locations of Hanford Site waste units, and infrastructure spatial data; and available information about species of concern distribution and habitat use near the EUs, including data previously collected by PNNL for DOE-RL, as well as noxious weeds (WNWCB 2014).

The following steps are taken in the field to assess each EU:

1. The EU boundary (polygon) is assumed to represent the estimated boundary or extent of potential habitat removal and direct disturbance due to remediation.
2. A second boundary (polygon) outside the EU is established to evaluate indirect effects and assess the remediation in relation to adjacent landscape features. This polygon is centered on the EU and encompasses a circular area with a radius 1 times the maximum width of the EU, and is referred to as the adjacent landscape buffer.
3. A visual survey is conducted within the EU boundary by experienced shrub-steppe ecologists. PNNL biologists also review the observations and biological survey data available in the Ecological Compliance and Assessment Project (ECAP) database from the past 5 years for the EU to determine the status and resource level of the habitats within the EU and supplement the evaluation with previous observations of wildlife or plant species. PNNL performed ecological reviews for individual projects, and annually surveyed selected areas or buildings on the Hanford Site under the DOE-RL Public Safety and Resource Protection Program (until 2011). This PNNL database is consulted to supplement ecological evaluations.
4. A reconnaissance survey of the boundary of the EU is conducted to confirm the validity of past mapping of biological resources. Aerial imagery from 2012 is reviewed to identify any significant changes in habitat and resource levels (such as new well pads, roads, or other ground disturbances not captured by the available biological resources mapping) within the EU and adjacent landscape buffer. Where significant change is evident from ground survey or imagery, the biological resource map will be updated to reflect the change in resource level.
5. The spatial extent of habitat classified at each of the 6 resource levels (0–5) (DOE/RL-96-32 Rev. 1 2013) within the adjacent landscape buffer area and the EU is assessed and compared using a GIS device to examine potential indirect effects on habitat condition within the adjacent landscape. For purposes of assessing indirect effects on the adjacent landscape, this evaluation assumes the maximum potential change in biological resources—that is, all habitat within the EU is assumed to be lost to remediation and cleanup activities and resources in the EU are considered Level 0.
6. PNNL biologists assemble the information from field survey, reconnaissance, and spatial analyses of resource availability to provide a subjective evaluation of potential effects on habitat connectivity near the EU.
7. Field data is then reviewed by CRESP and PNNL ecologists for quality assurance and quality control considerations, consistency, and overall appropriateness.
8. The field data, in conjunction with 1) ecoregion considerations, 2) Hanford Site vegetation, and 3) accepted or considered remediation options is then used by CRESP and PNNL (Burger and Bunn) to rate the relative risk (or potential impact) to ecological resources on the EU and buffer areas.

To ensure consistency within and among EUs, field data sheets are used, and initially filled out by PNNL plant ecologists, in conjunction with site visits by Burger and PNNL plant ecologists and other knowledgeable PNNL staff. Each field visit of an EU takes 2‑8 hours (depending on size and complexity). The field visit requires walking transects through the relevant habitat on or adjacent to the EU to collect the appropriate data.

The field methodology and tables are ideal for areas with high-level resources (3–5). Modifications are to be made in the field depending on conditions (e.g., inability for security reasons to have access, condition of the vegetation). Definitions of key ecological concepts follow:

1. Percent estimates – field estimates of each characteristic (e.g., pavement, gravel, vegetation, native grasses, etc.). For many sites it will be necessary to either use transects or quadrants to estimate these, obtaining a mean value for each.
2. Exotic/alien species – a list of exotic/alien species found, with approximate percent occurrence (by quadrant) or percent cover.
3. Resource level – a field assessment of the current resource level (0-5), which may have changed since the previous evaluation, or may not have actually been done during the previous evaluation.
4. Size of the EU and habitat patch – either acres or dimensions (with map).
5. Shape of EU and patch – round, square, oblong (with approximate dimensions)(ratio of length to width).
6. Connectivity – is the habitat patch continuous with, or connected to similar (or higher/lower quality habitat)? If connected, how wide is the corridor?
7. Number of type of roads – roads through the area (number of lanes, traffic indication [heavy trucks, cars, etc.]).
8. Lay-down – is the lay-down in areas with high resource value? Or what areas should be avoided because of high resource value?

Information to be gathered during the field visits is shown below. Transects are used to provide quantitative data for the whole EU. Examples of ecological evaluations are shown in Attachment 7.1.

Table 7-10. Percent canopy cover and surface cover measured at each EU. This table for illustrative purposes, and the number of transects required will depend on the size of the EU.

Vegetation/surface cover	Transect 1	Transect 2	Transect 3	Transect 4
Bare ground				
Crust				
Litter				
Introduced forb				
Introduced grass				
Native forb				
Native grass				
Climax shrubs				
Successional shrubs				

Table 7-11. Area and proportion of each biological resource level within the EU in relation to adjacent landscape and potential maximum change in resources. Area and proportion of each biological resource level within the EU in relation to adjacent landscape and potential maximum change in resources. Given are resource levels.

	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Total
EU area (acres)							
Adjacent landscape buffer (acres)							
Combined total area							
% resource level in combined total area							
% resource level in combined total area after cleanup							
% difference at landscape scale after cleanup							

Note: The percentage difference at the landscape scale = potential maximum change in area of a given resource level within the combined total area that would occur assuming that all habitat within the EU would be destroyed by remediation activities.

7.7. SUMMARY OF OVERALL METHODOLOGY FOR EVALUATING ECOLOGICAL RESOURCES

The proposed Risk Review Project approach for evaluating the ecological resources with respect to specific cleanup EUs includes the following steps:

1. Describe and analyze ecological resources at three levels.
    a. Regional context (comparison with Columbia Basin Ecoregion)
    b. Hanford Site context
    c. Site-specific resources
2. Evaluate importance using level of resources (0-5, where 5 is most valuable resources, DOE/RL-96-32 Rev. 1 2013), incorporating quality component (e.g., modifiers, such as contamination and degradation by exotic/alien species).
3. Collect on-site ecological information (field data) from EU and buffer area, including:
    a. Past resource level from maps (DOE/RL-96-32-Rev. 1 2013)
    b. Field data collected in 2014-2015
    c. Landscape scale issues
    d. Exotic, alien or endangered/threatened species
4. Evaluate potential for hazards and existing environmental contamination to impact ecological resources.

5. Describe physical disruptions from past activities that affect current ecological resource conditions (e.g., disruption to riparian zone).
6. Describe potential damage to ecological resources, using remediation matrices developed above, along with a table of remediation actions (or range of remediation options being considered).
7. Bin potential risks to ecological receptors currently, during active remediation, and in the near-term post-remediation period (2064-2164).
8. Provide rationale for risk ratings.

This methodology is designed to use available, GIS-based information on ecological resources on the Hanford Site, in addition to field data gathered in 2014 and 2015. The information relates to individual species (which are at risk), species groups (e.g., native grasses), and key unique habitats or ecosystems that could be at risk. The methodology was developed so that it could be applied to different EUs and by personnel with basic ecological knowledge. While landscape features can be determined from maps, they must be checked in the field, and other necessary field work includes the determination of the percent of alien/exotic species present on the site, as well as the occurrence of endangered/threated/species of special concern. The proposed Risk Review Project methodology is diagramed in Figure 7-11.

This Risk Review Project approach uses the resource levels developed by DOE (2013), as modified by field investigations. The resource levels developed by DOE were refined over many years (as indicated by DOE yearly environmental reports), and include the state of Washington's resource evaluations, as well as those of others. It includes federally listed species as its highest level (in addition to unique habitats), which is based on the U.S. Endangered Species Act. Inclusion on this list involves a long, involved process that considers many different ecological factors, and has legal standing.

Since Level 4 resources include state of Washington listed species, as well as critical habitat, the two levels are firmly based in law and involve both a national and regional perspective. Level 3-5 resources are of the highest value, although their relative value can be compromised by the degree of exotic/alien species (an indication of degradation), landscape features (patch size and shape, connectivity), and contamination.

The level of resources present will be ascertained from the resource maps provided (Figure 7-3 to Figure 7-7); the degree to which the site is compromised by landscape features can be ascertained from these maps as well, and the level of contamination is described in the individual EUs, but the current resource level will be determined from field work, landscape features, amount and significance of exotic/alien species, and contaminants that could result in exposure. This indicates the importance of an initial exotic/alien species evaluation (particularly plants), an ongoing program to track exotic/alien species, and regular updating of exotic/exotic/alien species maps. Exotic/alien plants will be most important because plants are at the base of the food chain, many have toxic chemicals that prevent native plant species from continued growth and colonization, and affect the animal communities inhabiting them.

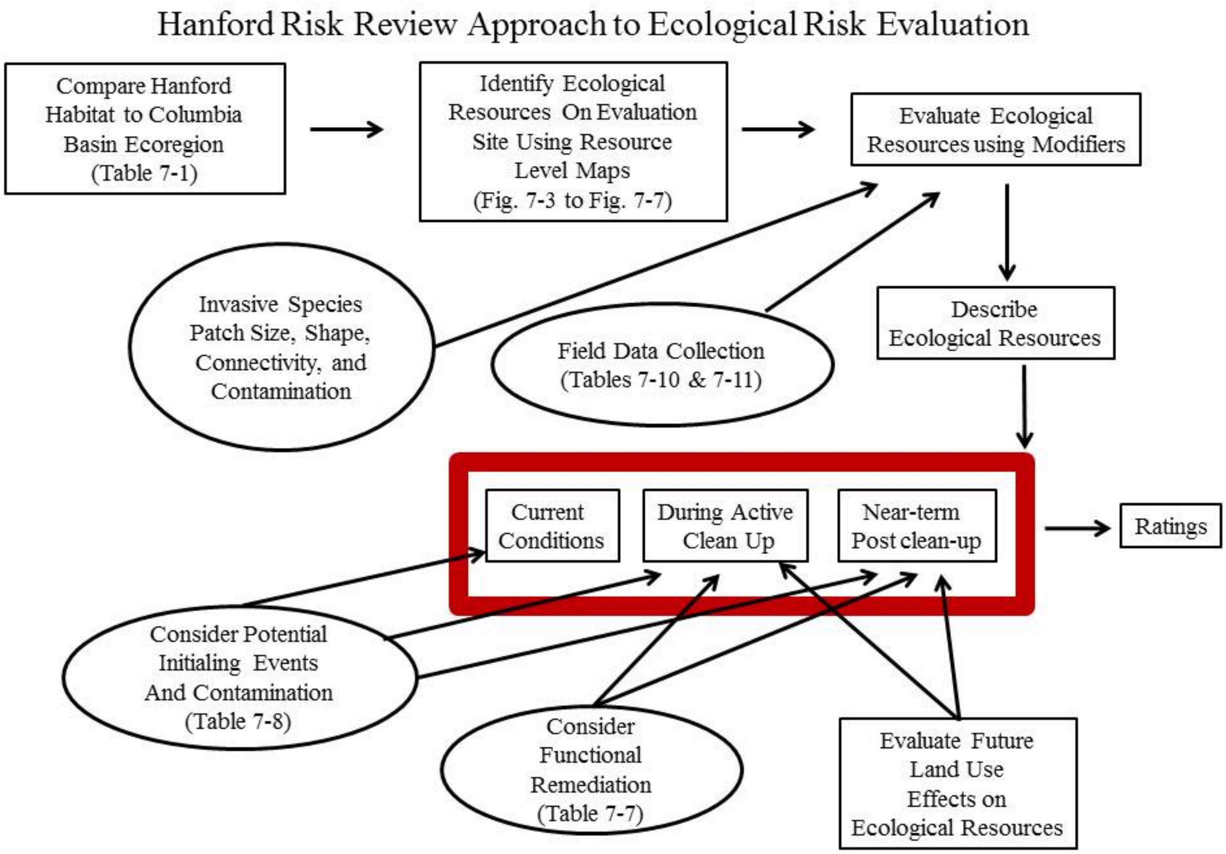


Figure 7-11. Schematic of the risk review approach to evaluating ecological resources on the Hanford Site, using the DOE's levels of resources (DOE/RL-96-32 Rev. 1 2013).

In summary, the methodology for evaluation of risk to ecological resources includes the following steps:

1. Examine importance of resources to Columbia River Basin (Table 7-1). This is descriptive, not evaluative.
2. Use resource maps to arrive at resource level (Figure 7-3 to Figure 7-7) for EUs and buffer areas.
3. Conduct field evaluations (see appropriate section above) in 2013 and 2014.
4. Consider physical disruption and contamination on current ecological resources.
5. Consider effects of functional remediation (and functional remediation during active cleanup, and in the near-term post-cleanup period, Table 7-6 and Table 7-7), including exposure to contaminants.
6. Complete ecological risk rating for each evaluation period (see Table 7-11) considering the table of remediation options selected (or being considered) with the functional remediation effects (Table 7-6 and Table 7-7).
7. Fill out Final Risk Evaluation Table in the EU template.

In summary, the ecological evaluation for each EU includes resource levels, quality and quantity of resources (percent of each resource level present in the EU and buffer), alien/exotic species, contamination, and the matrix of remediation options adopted or being considered. This can result in a range of ratings from ND to Very High. The ratings for each EU, along with summary comments, are prepared for current conditions, during active cleanup, and in the near-term post cleanup period (2064–2164).

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Table 7-12. Federal and state-listed species on the Hanford Site. Data from McAllister et al. 1996; DOE/RL-96-32 2001b; DOE/RL-96-13 Rev. 1 2013; Goldstein 2005.

- Abbreviations are as follows: SoC = Species of concern; Can = Candidate; End = Endangered; Sens = Sensitive; F. Can = Former Candidate; Watch = Watch; Mon = Monitor; R1 = Review Group 1 (insufficient data to support listing); R2 = Review Group 2 (unresolved taxonomic questions); P. Thre = Proposed Threatened; P. Can = Proposed Candidate

Plants **Scientific Name**	**Common Name**	**1996 FED**	**2001 FED**	**2005 FED**	**2013 FED**	**1996 STA**	**2001 STA**	**2005 STA**	**2013 STA**
Aliciella (= Gilia) leptomeria	Great Basin gilia						R1	Thre	Thre
Allium robinsonii	Robinson's onion						Watch	Watch	Watch
Allium scillioides	Squill onion						Watch	Watch	Watch
Ammannia robusts	Grand redstem						R1	Thre	Thre
Anagallis (= Centunculus) minima, (Centunculus minimus)	Chaffweed						R1	R1	Sens
Arenaria franklinii var. thompsonii	Thompson's sandwort						R2	R2	
Artemisia campestris borealis var. wormskioldii	Northern wormwood	Can	F. Can			End	End, (1)		
Artemisia lindleyana	Columbia River mugwort						Watch	Watch	Watch
Astragalus arrectus	Palouse milkvetch						Sens, (3)		
Astragalus columbianus	Columbia milkvetch	Can	F. Can	SoC	SoC	Thre	Thre, (2)	Sens	Sens
Astragalus conjunctus var rickardii	Basalt milkvetch						R1	Watch	Watch
Astragalus geyeri	Geyer's milkvetch						Sens, (3)	Thre	Thre
Astragalus sclerocarpus	Stalked-pod milkvetch						Watch	Watch	Watch
Astragalus speirocarpus	Medick milkvetch						Watch	Watch	Watch
Astragalus succumbens	Crouching milkvetch						Watch	Watch	Watch
Balsamorhiza rosea	Rosy balsamroot						Watch	Watch	Watch
Camissonia (= Oenothera) minor	Smallflower evening-primrose						R1	Sens	Sens

Plants Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Camissonia (=Oenothera) pygmaea	Dwarf evening-primrose						Thre, (2)	Sens	Sens
Carex densa	Dense sedge					Sens	Sens, (3)		
Carex hystericina	Porcupine sedge							Watch	Watch
Castilleja exilis	Smallflower annual paintbrush						R1	Watch	Watch
Cirsium brevifolium	Palouse thistle						R1		
Cistanthe (= Calyptridium) rosea	Rosy pussypaws						Sens	Thre	Thre
Collinsia sparsiflora var. bruceae	Few-flowered collinsia						Sens, (3)		
Crassula aquatica	Pigmy-weed							Watch	Watch
Cryptantha leucophaea	Gray cryptantha			SoC	SoC	Sens	Sens, (3)	Sens	Sens
Cryptantha scoparia	Miner's candle						R1	Sens	Sens
Cryptantha spiculifera (= C. interrupta)	Snake River cryptantha					Sens	Sens	Sens	Sens
Cuscuta denticulata	Desert dodder						Sens	Thre	Thre
Cyperus bipartitus (=C. rivularis)	Shining flatsedge					Sens	Sens, (3)	Watch	Watch
Delphinium multiplex	Kittitas larkspur							Watch	Watch
Eatonella nivea	White eatonella						Thre, (2)	Thre	Thre
Eleocharis rostellata	Beaked spike-rush							Sens	Sens
Epilobium pymaeum	Smooth willowherb								R1
Epipactis gigantea	Giant helleborine							Watch	Watch
Erigeron piperianus	Piper's daisy					Sens	Sens, (3)	Sens	Sens
Eriogonum codium	Umtanum desert buckwheat			Can	P. Thre		End	End	End
Gilia inconspicua	Shy gily-flower								R1
Hierchloe odorata (= Anthoxanthum hirtum)	Vanilla grass							R1	R1
Hypericum majus	Canadian St. John's-wort						Sens	Sens	Sens

Plants Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Lesquerella tuplashensis	White Bluffs bladderpod			Can			End	Thre	
Limosella acaulis	Southern mudwort					Sens	Sens, (3)	Watch	Watch
Lindernia dubia var. anagallidea	False pimpernel					Sens	R2	Watch	Watch
Lipocarpha (= Hemicarpha) aristulata	Awned halfchaff sedge						R1	Thre	Thre
Loeflingia squarrosa var squarrosa	Loeflingia						Thre	Thre	Thre
Lomatium tuberosum	Hoover's desert parsley	Can	F. Can	SoC	SoC	Thre	Thre, (2)	Sens	Sens
Mimulus suksdorfii	Suksdorf's monkey-flower						Sens, (3)	Sens	Sens
Minuartia pusilla var. pusilla	Annual sandwort							R1	R1
Myosurus clavicaulis	Mousetail							Sens	
Nama densum var. parviflorum	Small-flowered nama						R1	Watch	Watch
Nicotiana attenuata	Coyote tobacco						Sens, (3)	Sens	Sens
Oenothera caespitosa	Desert evening-primrose					Sens	Sens, (3)	Sens	Sens
Opuntia fragilis	Brittle prickly pear							R1	
Pectocarya linearis var. penicillata	Winged combseed						R1	Watch	Watch
Pectocarya setosa	Bristly combseed						Sens, (3)	Watch	Watch
Pediocactus nigrispinus (=P. simpsonii var. robustior)	Hedgehog cactus							R1	Sens
Pellaea glabella var. slimpex	Smooth cliffbrake						Watch	Watch	Watch
Penstemon eriantherus var. whitedii	Fuzzytongue penstemon						Mon. 3	Sens	Sens
Physaria (= Lesquerella) tuplashensis	White Bluffs bladderpod				P. Thre				Thre
Rorippa columbiae	Columbia yellowcress	Can	F. Can	SoC	SoC	End	End, (1)	End	End
Rotala ramosior	Lowland toothcup						R1	Thre	Thre

Animal Type	Invertebrates Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Insects	*Boloria selene atrocostalis*	Silver-bordered fritillary						Can	Can	Can
Insects	*Callophrys sheridanii neoperplexa*	Canyon green hairstreak						Mon	Mon	
Insects	*Chlosyne palla palla*	Northern checkerspot							Mon	
Insects	*Cicindela columbica*	Columbia River tiger beetle						Can	Can	Can
Insects	*Erynnis persius*	Persius' duskywing							Mon	*Mon*
Insects	*Harkenclenus titus immaculosus*	Coral hairstreak						Mon	Mon	
Insects	*Hesperia juba*	Juba skipper						Mon	Mon	Mon
Insects	*Hesperia nevada*	Nevada skipper						Mon	Mon	Mon
Insects	*Limenitis archippus lahontani*	Nevada viceroy		F. Can				Mon	Mon	Mon
Insects	*Lycaena helloides*	Purplish copper						Mon	Mon	Mon
Insects	*Lycaena rubida perkinsorum*	Ruddy copper						Mon	Mon	Mon
Insects	*Mitoura siva*	Juniper hairstreak						Can		
Insects	*Ochlodes sylvanoides bonnevilla*	Bonneville skipper						Mon	Mon	Mon
Insects	*Phyciodes tharos pascoensis*	Pasco pearl						Mon	Mon	Mon
Mollusks	*Anodonta californiensis*	California floater	Can	F. Can	SoC	SoC		Can	Can	Can
Mollusks	*Anodonta kennerlyi*	Western floater							Mon	Mon
Mollusks	*Anodonta oregonensis*	Oregon floater							Mon	Mon
Mollusks	*Fisherola nuttalli*	Shortface lanx		F. Can				Can	Can	Can

Animal Type	Invertebrates Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Mollusks	*Fluminicola columbiana*	Great Columbia River spire snail	Can	F. Can	SoC	SoC		Can	Can	Can
Mollusks	*Margaritifera falcata*	Western pearlshell							Mon	Mon

Fish Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Catostomus platyrhynchus	Mountain sucker						Mon	Can	Can
Cottus beldingi	Piute sculpin						Mon	Mon	Mon
Cottus perplexus	Reticulate sculpin						Mon	Mon	Mon
Lampetra ayresi	River lamprey	Can	F. Can	SoC	SoC			Can	Can
Lampetra tridentata	Pacific lamprey			SoC	Con				Mon
Oncorhynchus mykiss	Steelhead		End	End	Thre		Can	Can	Can
Oncorhynchus tshawytscha	Chinook salmon		End	End	End		Can	Can	Can
Percopsis transmontana	Sand roller						Mon	Mon	Mon
Rhinichthys falcatus	Leopard dace							Can	Can
Salvelinus confluentus	Bull trout	Can	Can	Thre	Thre			Can	Can

Reptiles and Amphibians Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Ambystoma tigrinum	Tiger salamander							Mon	Mon
Anaxyrus boreas	Western toad				SoC			Can	Can
Anaxyrus woodhousii	Woodhouse’s toad						Mon	Mon	Mon
Coluber constrictor	Racer								Mon
Hypsiglena torquata	Night snake						Mon	Mon	Mon
Masticophis taeniatus	Striped whipsnake						Can	Can	Can
Phrynosoma douglasii	Short-horned lizard								Mon
Pituophis melanoleucus	Pacific gopher snake						Mon		

Reptiles and Amphibians **Scientific Name**	**Common Name**	**1996 FED**	**2001 FED**	**2005 FED**	**2013 FED**	**1996 STA**	**2001 STA**	**2005 STA**	**2013 STA**
Sceloporus graciosus	Sagebrush lizard	Can	F. Can	SoC	SoC		Mon	Can	Can

Birds ***Scientific Name***	**Common Name**	**1996 FED**	**2001 FED**	**2005 FED**	**2013 FED**	**1996 STA**	**2001 STA**	**2005 STA**	**2013 STA**
Accipter gentilis	Northern goshawk	Can	F. Can	SoC	SoC		Can	Can	Can
Aechmophorus clarkii	Clark's grebe						Mon	Mon	Can
Aechmophorus occidentalis	Western grebe						Mon	Can	Can
Ammodramus savannarum	Grasshopper sparrow						Mon	Mon	Mon
Amphispiza belli	Sage sparrow					Can	Can	Can	Can
Aquila chrysaetos	Golden eagle					Can	Can	Can	Can
Ardea alba	Great egret						Mon	Mon	Mon
Ardea herodias	Great blue heron						Mon	Mon	Mon
Athene cunicularia	Burrowing owl	Can	F. Can	SoC	SoC		Can	Can	Can
Branta hutchinsii leucopareia	Aleutian Canada goose	Thre	Thre			End	End		
Buteo regalis	Ferruginous hawk	Can	F. Can	SoC	SoC	Thre	Thre	Thre	Thre
Buteo swainsoni	Swainson's hawk		F. Can			Can	Mon	Mon	Mon
Cathartes aura	Turkey vulture						Mon	Mon	Mon
Centrocercus urophasianus	Sage grouse	Can	F. Can	Can	Can		Can	Thre	Thre
Chlidonias niger	Black tern	Can	F. Can				Mon	Mon	Mon
Contopus cooperi	Olive-sided flycatcher		F. Can	SoC	SoC				
Dolichonyx oryzivorus	Bobolink							Mon	Mon
Empidonax traillii	Willow flycatcher		F. Can						
Empidonax wrightii	Gray flycatcher							Mon	Mon
Falco columbarius	Merlin						Can	Can	
Falco mexicanus	Prairie falcon						Mon	Mon	Mon
Falco peregrinus	Peregrine falcon	End	End	SoC	SoC	End	End	Sens	Sens

Birds ***Scientific Name***	**Common Name**	**1996 FED**	**2001 FED**	**2005 FED**	**2013 FED**	**1996 STA**	**2001 STA**	**2005 STA**	**2013 STA**
Falco rusticolus	Gyrfalcon						Mon	Mon	Mon
Gavia immer	Common loon					Can	Can	Sens	Sens
Grus canadensis	Sandhill crane	End					End	End	End
Haliaeetus leucocephalus	Bald eagle	Thre	Thre	Thre	SoC	Thre	Thre	Thre	Sens
Himantopus mexicanus	Black-necked stilt						Mon	Mon	Mon
Lanius ludovicianus	Loggerhead shrike	P. Can	F. Can	SoC	SoC		Can	Can	Can
Melanerpes lewisii	Lewis' woodpecker					Can	Can	Can	Can
Myiarchus cinerascens	Ash-throated flycatcher						Mon	Mon	Mon
Numenius americanus	Long-billed curlew	Can	F. Can				Mon	Mon	Mon
Nyctea scandiaca	Snowy owl						Mon	Mon	Mon
Nycticorax nycticorax	Black-crowned night heron						Mon	Mon	Mon
Oreoscoptes montanus	Sage thrasher					Can	Can	Can	Can
Otus flammeolus	Flammulated owl					Can	Can	Can	Can
Pandion haliaetus	Osprey						Mon	Mon	Mon
Pelecanus erythrorhynchos	American white pelican					End	End	End	End
Podiceps auritus	Horned grebe						Mon	Mon	Mon
Podiceps grisegena	Red-necked grebe						Mon	Mon	Mon
Pooecetes gramineus affinins	Oregon vesper sparrow						Mon		
Sialia mexicana	Western bluebird						Mon	Mon	Mon
Spinus psaltria	Lesser goldfinch							Mon	Mon
Sterna caspia	Caspian tern						Mon	Mon	Mon
Sterna forsteri	Forster's tern						Mon	Mon	Mon
Sterna paradisaea	Arctic tern						Mon	Mon	Mon
Strix varia	Barred owl						Mon		
Tympanuchus phasianellus	Sharp-tailed grouse		F. Can				Mon		

Mammals Scientific Name	Common Name	1996 FED	2001 FED	2005 FED	2013 FED	1996 STA	2001 STA	2005 STA	2013 STA
Antrozous pallidus	Pallid bat						Mon	Mon	Mon
Brachylagus idahoensis	Pygmy rabbit	Can	F. Can			End	End		
Corynorhinus townsendii	Pale Townsend's big-eared bat	Can							
Dipodomys ordii	Ord's kangaroo rat						Mon		
Lemmiscus curtatus	Sagebrush vole						Mon	Mon	Mon
Lepus californicus	Black-tailed jackrabbit							Can	Can
Lepus townsendii	White-tailed jackrabbit							Can	Can
Myotis ciliolabrum	Small-footed myotis	Can	F. Can		Con		Mon	Mon	Mon
Myotis evotis	Long-eared myotis						Mon		
Myotis thysanodes	Fringed myotis	Can	F. Can				Mon		
Myotis volans	Long-legged myotis	Can	F. Can		Con		Mon	Mon	Mon
Myotis yumanensis	Yuma myotis	Can	F. Can						
Onychomys leucogaster	Northern grasshopper mouse						Mon	Mon	Mon
Parastrellus hesperus	Western pipistrelle							Mon	Mon
Plecotus townsendii pallescens	Pale Townsend's big-eared bat		F. Can						
Sorex merriami	Merriam's shrew						Can	Can	Can
Spermophilus townsendii	Townsend's ground squirrel				SoC			Can	Can
Spermophilus washingtoni	Washington ground squirrel	Can		Can	Can		Mon	Can	
Taxidea taxus	Badger								Mon

Attachment 7.1. Ecological Evaluation of Three Pilot Sites on the U.S. Department of Energy Hanford Site

KB Larson, JL Downs, MR Sackschewsky, MA Chamness

Introduction

As part of waste site remediation and evaluation, the assessment of species, populations and habitats is important in determining potential ecological impacts. As part of this evaluation process, field assessments must be performed to document current vegetation, percent and type of invasive species, landscape features, and presence of listed species. Procedures for performing field assessments were developed by CRESP members and implemented by PNNL ecologists at three pilot sites in July 2014. The following describes the preliminary results of these field assessments.

Methods

The Risk Review Project approach evaluates potential ecological impacts of waste site remediation at two scales. The evaluation process makes use of existing resource level maps (DOE/RL-96-32 2013) and field surveys of current vegetation conditions to evaluate potential ecological impacts associated with cleanup activities at the waste sites. The footprint for cleanup and remediation for each site or designated area is also evaluated in the context of habitat conditions in the immediate surrounding landscape. Additional information used in the Risk Review Project approach includes the current Endangered and Threatened Species (federal and state) distribution data; available imagery and Hanford Site waste site and infrastructure spatial data; and available information about species of concern distribution and habitat use in the vicinity of the evaluation sites.

This report discusses three pilot waste site areas that were surveyed and evaluated with respect to potential ecological impacts of remediation. For each target waste site, a polygon was defined to represent the estimated boundary or extent of habitat removal and direct disturbance due to remediation before surveys were attempted. This estimated polygon is referred to as the evaluation site. A second outer polygon buffering the remediation area was defined based on the assumed size of the remediation disturbance to evaluate indirect effects and assess the remediation in relation to adjacent landscape features (Table 7-12).

Field Surveys

As part of the evaluation, field measurements of current vegetation conditions were made to characterize the habitat and species existing within the area to be remediated, as feasible. PNNL ecologists surveyed the three sites described in this report on 16 July, 2014 to characterize habitats surrounding the pilot waste sites and quantify vegetation cover by species. Collection of field data to describe the current habitat conditions was limited by the timing of the pilot evaluation with respect to both the season and time constraints to provide data and evaluations within a very short timeframe. Much of the vegetation in shrub-steppe habitats is senescent or dormant during the summer. In addition, the timing of the current assessments was not favorable for observing wildlife.

To address this limitation, previously collected information from the PNNL/DOE-RL ECAP was used to supplement site wildlife and vegetation evaluations where possible. The ECAP field surveys included information describing observed plant and animal presence in defined polygons adjacent to the target waste sites. ECAP building survey data were also reviewed for past presence of nesting birds that may be protected under the Migratory Bird Treaty Act (MBTA). Observations of fauna were made during the field surveys, however, more extensive surveys should be conducted to adequately describe fauna diversity and habitats at the sites. These surveys should consider types of species potentially present and time of year and day these species are most likely to be detected.

For the July 2014 effort, field measurement of vegetation composition and habitat structural characteristics was limited to selected habitat patches that contained climax shrubs within the boundary of the evaluation site. Because time for field investigation was limited, pedestrian surveys were made of adjacent habitat types, without climax shrubs, to visually assess habitat structure and composition. Additional observational data gathered during previous ECAP surveys were used to further characterize particular areas within the evaluation site boundary.

Vegetation metrics measured by PNNL in the field included estimates of percent canopy cover by species and surface cover of bare soils, microbiotic crust, native and invasive grasses, and native shrubs. Ocular estimates of surface cover of non-vegetation characteristics (e.g., pavement, gravel) were also recorded. In selected habitat patches, percent canopy cover of herbaceous species and percent surface cover (e.g., bare, litter, crust, and gravel) were measured using four to six 0.5-m^2 quadrants placed randomly within the patch. Line-intercept methods were used to measure shrub cover in habitat patches > 1 acre in size containing climax shrubs.

PNNL used field data collection sheets to organize information for inclusion in the evaluation (Figure 7-17). Summary field data sheets were provided by CRESP to PNNL ecologists to guide data collection and ensure consistency among sites. These summary data sheets can be used to synthesize the species level cover information into functional groups.

Landscape Context Evaluation

Sites were evaluated in relation to landscape features using available imagery of the Hanford Site (1-ft resolution imagery taken in 2012), Hanford Site resource-level spatial data, historical ECAP field data, and field reconnaissance data. The primary landscape features evaluated include the amount of higher quality shrub-steppe habitat (resource Level 3 or higher) present within the site and within a circular area radiating from the geometric center of the site with a radius equal to the maximum width of the evaluation site. The removal of habitat that would occur during cleanup activities at the evaluation site was put into context of surrounding habitat conditions by quantifying changes in the amount of higher-quality habitat within the circular area. For this analysis it was assumed that the habitat conditions of the evaluation site after cleanup would be consistent with Level 0 biological resources. This method for examining landscape context was chosen because it is repeatable, relatively easy to understand, and provides context at a scale that is relevant to the size of the evaluation site (i.e., larger context area is needed as site area increases). Landscape context analyses were performed in a GIS.

Resource Classification

To the extent possible, efforts were made to evaluate current habitat conditions and determine the need for reclassifying biological resource levels within the evaluation site. Resource reclassification was done based on field observations, vegetation measurements, and analysis of aerial imagery. With the exception of industrial or heavily disturbed areas that were clearly visible in aerial imagery, habitats outside of the evaluation site boundaries were not reclassified due to the limited time available and level of effort needed to adequately characterize these larger areas. In addition, DOE intends to reevaluate resource levels for the entire Hanford Site in the near future. Therefore, although the evaluation of landscape features around the waste area and evaluation site can provide some context for ranking habitat loss within the evaluation site proper, the results presented herein should be interpreted cautiously with the understanding that future habitat mapping may alter the resource classifications for habitats adjacent to the evaluation site that are used in landscape analyses.

SITE EVALUATION

Results

Six Hanford Site waste sites were initially selected for piloting the Risk Review Project methodology (Figure 7-12). Of these six sites, the 324 Building (300 Area), 618-11 burial grounds (Energy Northwest), and BC Cribs and Trenches (600 Area) were selected for this assessment. Results of site evaluations for each of these sites are described in the following sections.

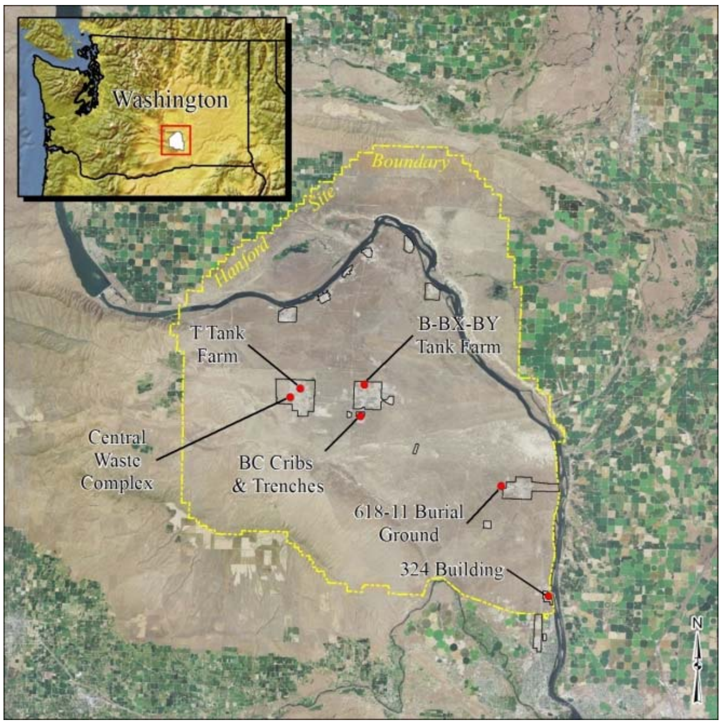

Figure 7-12. Location of Risk Review Project pilot sites on the DOE Hanford Site in Washington State.

324 Building

Reconnaissance of the 324 Building evaluation site indicated the site consists entirely of non-vegetated areas, industrial sites, paved and compacted gravel areas (i.e., Level 0 resources; Figure 7-13). Therefore, no field measurements of vegetation were taken during the July 2014 survey. The amount of each category of biological resources within the 324 Building evaluation site and within a circular area radiating 231 m from the geometric center of the site (equivalent to 41.5 acres) was also evaluated to provide additional landscape context. The evaluation site and buffer area north, south, and east of the site was previously classified as Level 3 because it is within 0.25 miles of the Columbia River. These areas were reclassified for this assessment to Level 0 to reflect current vegetation conditions. Because the site consists entirely of Level 0 resources, there would be no net change in the amount of Level 3 or higher resources within a 231 m radius of the site

Historical ECAP building survey data were reviewed to determine past presence of nesting birds on the 324 Building and associated structures. European starling (*Sturnus vulgaris*), which is not protected by the MBTA, has been observed nesting on the building as recently as 2009.

Table 7-13. Summary of biological resource classification areas at the 324 Building.

	Resource Level						Total
	0	1	2	3	4	5	
Evaluation Site	6.2	0	0	0	0	0	6.2
Buffer Area Excluding Evaluation Site	35.3	0	0	0	0	0	35.3
Total Area	41.5	0	0	0	0	0	41.5
% Total Area Pre-Cleanup	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
% Total Area Post-Cleanup	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
% Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	

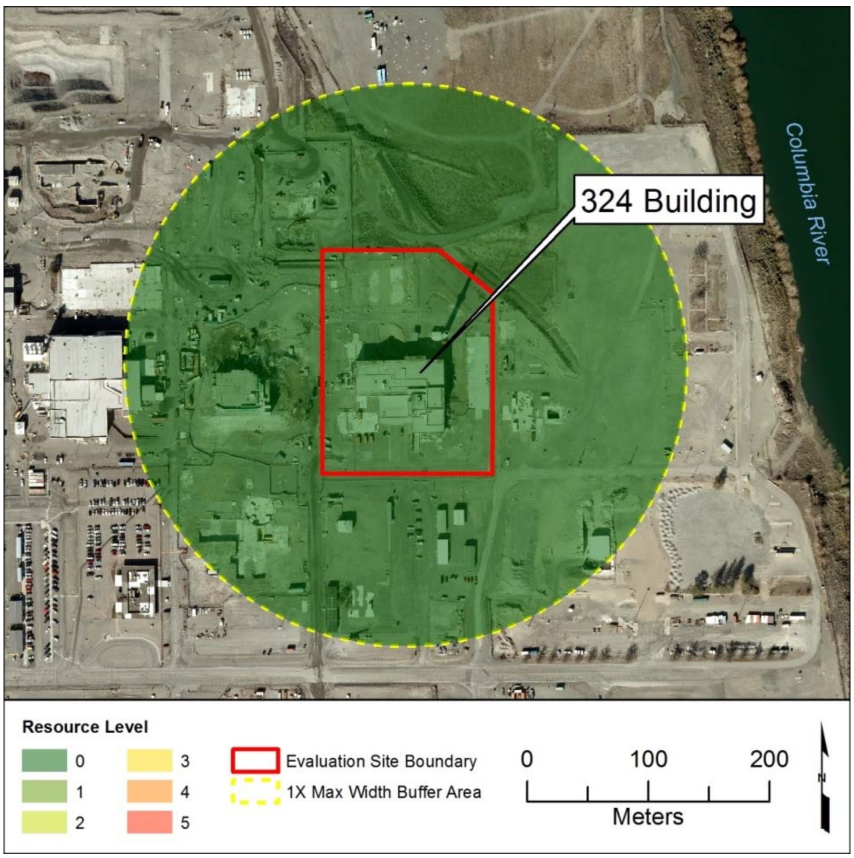

Figure 7-13. Map of biological resource level classifications for the 324 Building evaluation site (red) and landscape metrics buffer area (yellow).

618-11 Burial Grounds

Vegetation on the 618-11 Burial Ground site was visually estimated to be composed of approximately 30% to 40% crested wheatgrass (*Agropyron cristatum*), an introduced perennial bunchgrass planted for erosion control. Russian thistle was also prevalent on the burial ground—approximately 10% to 20%. Vegetation was measured in habitat patches to the north, west, and south of the burial ground. A summary of these data are provided in Table 7-14.

Table 7-14. Percentage canopy cover and surface cover measured for the 618-11 Burial Ground.

Vegetation/Surface Cover	618-11 South	618-11 West	618-11 North	Borrow/ Laydown Area
BARE	3	30.5	19.3	22.8
CRUST	2.5	4.5	17.6	5.5
Introduced Forb	20	14.8	3.7	6.3
Introduced Grass	17.8	15	16.1	27.5
LITTER	40	29.3	32.4	28.5
Native Forb	2.8	3.8	1.1	
Native Grass	14	2.3	9.7	11.5
Climax Shrubs			9.6	
Successional Shrubs	<1	< 1	.3	

To the authors' knowledge, the 618-11 Burial Ground evaluation site has not been surveyed for nesting birds. Species (or their sign) observed during the 16 July 2014 survey include horned lark (*Eremophila alpestris*), loggerhead shrike (*Lanius ludovicianus*), western meadowlark (*Sturnella neglecta*), common raven (*Corvus corax*), unknown hawk (*Buteo* spp.), northern pocket gopher (*Thomomys talpoides*), coyote (*Canis latrans*), and American badger (*Taxidea taxus*).

The amount of each category of biological resources was evaluated within the 618-11 burial grounds evaluation site and within a circular area radiating 1164 m from the geometric center of the site (equivalent to 1052 acres; Figure 7-14). The evaluation site was previously characterized as having Levels 0, 2, and 4 biological resources in the existing resource level map (DOE/RL-96-32 2013). However, portions of the evaluation site that were classified as Level 4 were reclassified in this assessment as Levels 0 and 2 based on observations and field data collected during the field visit. Resource levels outside the evaluation site and within the circular buffer area were not reclassified for this assessment, although preliminary field observations suggest resource levels in this area may need to be reevaluated.

Approximately 56% of the 618-11 total landscape area (evaluation site and associated buffer area) is classified as Level 3 or higher biological resource in the existing resource map. None of the evaluation site is classified above Level 2 (Table 7-15). Thus, the removal of vegetation within the proposed spatial footprint of 618-11 cleanup activities would result in no net change in the amount of Level 3 or higher resources within a 1.1 km radius.

Table 7-15. Summary of biological resource classification areas for the 618-11 Burial Ground.

	Resource Level						Total
	0	1	2	3	4	5	
Evaluation Site	62	0	74.8	0	0	0	136.8
Buffer Area Excluding Evaluation Site	197.9	0	130.6	33.3	553.6	0	915.4
Total Area	259.9	0	205.4	33.3	553.6	0	1052.2
% Total Area Pre-Cleanup	24.7%	0.0%	19.5%	3.2%	52.6%	0.0%	100.0%
% Total Area Post-Cleanup	31.8%	0.0%	12.4%	3.2%	52.6%	0.0%	100.0%
% Change	7.1%	0.0%	-7.1%	0.0%	0.0%	0.0%	

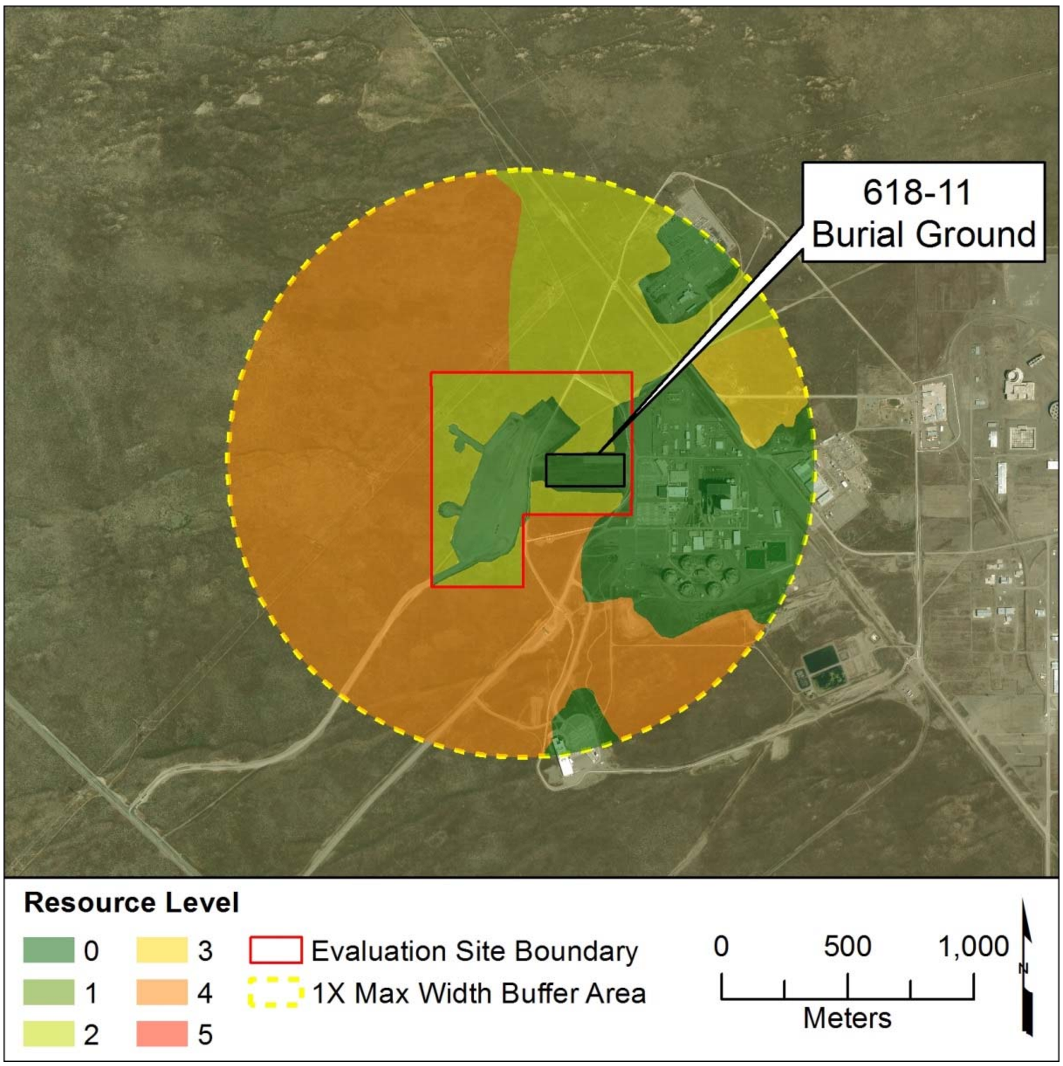

Figure 7-14. Map of biological resource level classifications for the 618-11 Burial Ground evaluation site (red) and landscape metrics buffer area (yellow).

BC Cribs and Trenches

Reconnaissance of the BC Cribs and Trenches evaluation site indicated that most of site currently consists of non-vegetated areas, heavily disturbed or revegetated areas, and compacted gravel areas (i.e., Level 0 resources; Table 7-16). A portion of this area that was previously classified as Level 3 and 4 (approximately 153 acres) was reclassified as Level 0 for this assessment to reflect current vegetation conditions (Figure 7-15). Areas of Level 3 and 4 resources still exist around the perimeter of the evaluation site and surrounding landscape, but these areas could not be accessed for field measurements due to radiological contamination restrictions. (Because this waste site and evaluation area lie within a radiological control area, no pedestrial surveys, or field survey of quadrants, or transects were attempted.)

Figure 7-15. Photograph of disturbed/revegetated area within the BC Cribs and Trenches evaluation area.

The amount of each category of biological resources at the BC Cribs and Trenches site was examined within a circular area radiating 1830 m from the geometric center of the site (equivalent to 2598 acres) to provide additional landscape context (Figure 7-16). Approximately 71% of the total site area (evaluation site and associated buffer area) is classified as Level 3 or higher biological resources in the existing resource level map. However, most of this area lies to outside of the evaluation site boundary (Figure 7-16). The removal of vegetation within the proposed spatial footprint of BC Cribs and Trenches cleanup activities would result in a 4.3% reduction in the amount of Level 3 or higher resources within a 1.8 km radius of the site.

Table 7-16. Summary of biological resource classification areas for the BC Cribs and Trenches.

	Resource Level						Total
	0	1	2	3	4	5	
Evaluation Site	255.9	0	0	41.5	69.6	0	367
Buffer Area Excluding Evaluation Site	294.7	52.1	163.2	429	1292.5	0	2231.5
Total Area	550.6	52.1	163.2	470.5	1362.1	0	2598.5
% Total Area Pre-Cleanup	21.2%	2.0%	6.3%	18.1%	52.4%	0.0%	100.0%
% Total Area Post-Cleanup	25.5%	2.0%	6.3%	16.5%	49.7%	0.0%	100.0%
% Change	4.3%	0.0%	0.0%	-1.6%	-2.7%	0.0%	

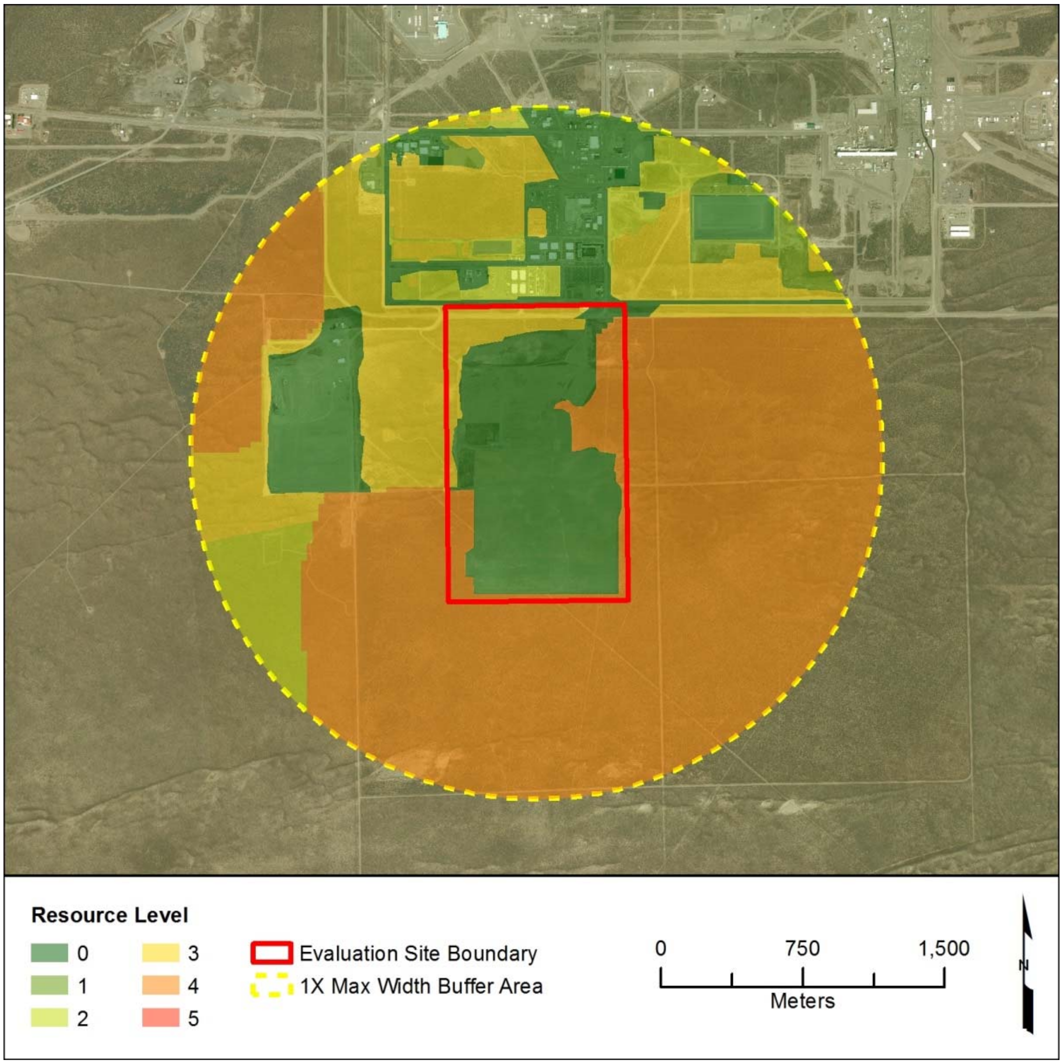

Figure 7-16. Map of biological resource level classifications at the BC Cribs and Trenches evaluation site (red) and landscape metrics buffer area (yellow).

Site												
Species	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**

Notes

Figure 7-17. Field Data Sheets. Methodology for completing the cultural resources literature review (PNNL 2014). Field data sheet utilized by PNNL staff to record vegetation composition and cover.

CHAPTER 8. EVALUATING CULTURAL RESOURCES

ABSTRACT

This chapter describes the cultural resources at risk during two of the periods being evaluated under the Risk Review Project: active cleanup (50 years or until 2064) and near-term-post-cleanup (100 years after cleanup or until 2164). The definition of the term "cultural resources," which is used throughout this chapter as well as the entire methodology document, is identical to the definition used in the Hanford Cultural and Historic Resources Management Plan. The Plan states:

> "…cultural resources is a collective term applicable to: 1) prehistoric-and historic-archaeological sites and artifacts designating past Native American utilization of the Hanford Site; 2) historic-archaeological sites and artifacts indicating post Euro-American activities relating to the pre-Hanford period; 3) Hanford Site Manhattan Project and Cold War era buildings, structures, and artifacts; 4) landscapes, sites, and plants and animals of cultural value to the Native American community; and 5) landscapes, sites, and materials of traditional cultural value to non-Native Americans" (DOE/EIS/RL-98-10 Rev. 0 Appendix A2003A 2003).

The methodology described in this chapter does not include an overall risk or impact rating or binning for two reasons. First, cultural resources risks cannot be estimated mathematically in the same way that risks, for example, to groundwater, can be characterized. Second, federal law requires that a cultural resources review be completed before any project activity may begin, including those associated with remediation, regardless of any rating that may be provided (16 U.S.C. 470 et seq.; 36 CFR Part 800 [2004]). A similar mandate is not imposed for other receptors being evaluated. At Hanford Site, this required cultural resources review is carried out for each project activity consistent with federal statutory and regulatory requirements. Requirements include identification, evaluation, and assessment of potential effects of remediation on cultural resources. If adverse impacts to cultural resources are anticipated from the activity, the regulatory process calls for an agreement to be negotiated that outlines mitigation measures intended to minimize and/or avoid any adverse impacts, including those resources located subsurface. The process also mandates procedures for consultation with Washington State Department of Archaeology and Historic Preservation, State Historic Preservation Officer (SHPO), Native American Tribes, and interested parties or stakeholders.

While the analysis does not include an overall impact rating of Not Discernible, Low, Medium, or High, the impacts during current operations and the active cleanup and near-term post-cleanup evaluation periods are made and expressed as Known, Unknown, or None to cultural resources. These assignations are based on existing cultural resources documentation from DOE and Washington State records for the unit being evaluated (and immediate surrounding area) or other information made available by Tribes and/or historical societies, which establishes whether cultural resources are or have been present within that EU.

The purpose of the cultural resources documentation review is to provide guidance to DOE and regulatory agencies as remediation options for the EU are considered. And, if the remediation option has already been determined, the purpose is to provide additional insights to DOE, regulatory agencies, Washington's SHPO, Tribes, and other interested parties or stakeholders on the extent to which remediation activities may have an adverse impact or effect cultural resources. Finally, the analysis of cultural resource related documentation is intended to provide insights into the residual effects that may remain after completion of cleanup.

The third period—long-term post-cleanup (until 3064) —is not being evaluated for risks to cultural resources. This is because it is difficult to predict the presence of cultural resources for a period so remote or whether resources considered significant today and in the near future will have the same level of significance hundreds of years from now.

Information is provided on the potential effects to cultural resources from remediation activities after the occurrence of an initiating event, such as fire, which may occur during any of the three periods for evaluation. Probabilities for the occurrence of an initiating event are discussed in Chapter 4.

8.1. OVERVIEW OF CULTURAL RESOURCES

BACKGROUND

The Hanford Site contains an extensive record of human occupation, stretching over a period of more than 10,000 years. Archaeological remains and written accounts, together with the oral histories associated with the practices and beliefs of Tribes, document how people lived and used the Hanford Site. As part of its responsibility for managing the site's archeological, cultural, and historic properties and resources under federal law, DOE has identified the site's cultural setting following overlapping cultural landscapes (DOE/RL-98-10 Rev. 0 2003), as follows:

- **Native American (Pre-Contact): Approximately 10,000 Years before the Present to the Present -** encompasses hundreds of archaeological sites, prehistoric artifacts, features and places of traditional significance to living communities of Native Americans, such as prominent landforms that are considered sacred and where traditional cultural practices have taken place over thousands of years. Native Americans continue to hold religious and cultural affinities for the entire Hanford Site. Maintaining the integrity of traditional cultural places (TCPs),[87] including a view shed, is considered important to Native Americans.
- **Historic Pre-Hanford: 1805 to 1943 -** encompasses evidence of settlement in the Columbia River Plateau by people mainly of European descent before the commencement of the Manhattan Project and includes explorers (e.g., David Thompson in 1811), traders, travelers, and settlers. Most structures in this landscape were razed to make way for the Manhattan Project, but evidence of some past land use still exists in the form of farmsteads, homesteads, ranches, roads, orchards, town sites, irrigation features, and buildings (e.g., Hanford High School). TCPs could be present in this landscape.
- **Manhattan Project and Cold War Era: 1943 to 1990 - e**ncompasses evidence of the era including construction, operations, buildings, structures, and artifacts associated with plutonium production, research and development, waste management, and environmental monitoring as well as military activities to defend the nuclear weapons development program. The primary purpose of the Manhattan Project was to build a bomb from plutonium for use during World War II. The Manhattan Project ended December 31, 1946. After the war, plutonium production

[87] In the glossary for DOE's Cultural and Historic Resources Management Plan, DOE defines the phrase "traditional cultural places" rather than "traditional cultural property," which is the term used under the National Historic Preservation Act. Hanford Site's term is a reflection of DOE-RL efforts to cooperatively manage the Hanford Site with the Tribes as those cultural landscapes, places, and objects having special significance to Native Americans and other ethnic groups are identified and protected. In the glossary, a TCP is defined as a place that is associated with cultural practices or beliefs of a living community that 1) are rooted in that community's history, and 2) are important in maintaining the continuing cultural identity of that community (NHPA Section 110 1998). (DOE/RL-98-10 Rev. 1 1998; see also ed. Neitzel DA 2004) It should be noted that under the Act, a TCP could be present in any community.

for use as a military deterrent continued to be Hanford's primary mission until the Cold War Era ended in 1990.[88]

According to the most recent publicly available source, as of 2004, about 25% of the site has been surveyed for cultural resources (ed. Neitzel DA 2004). Those surveys, conducted between 1926 and 2004, documented 1447 cultural resource sites and isolated finds and 531 buildings. See Figure 8-1. Areas surveyed for cultural resources on the Hanford Site.(ed. Neitzel DA 2004).

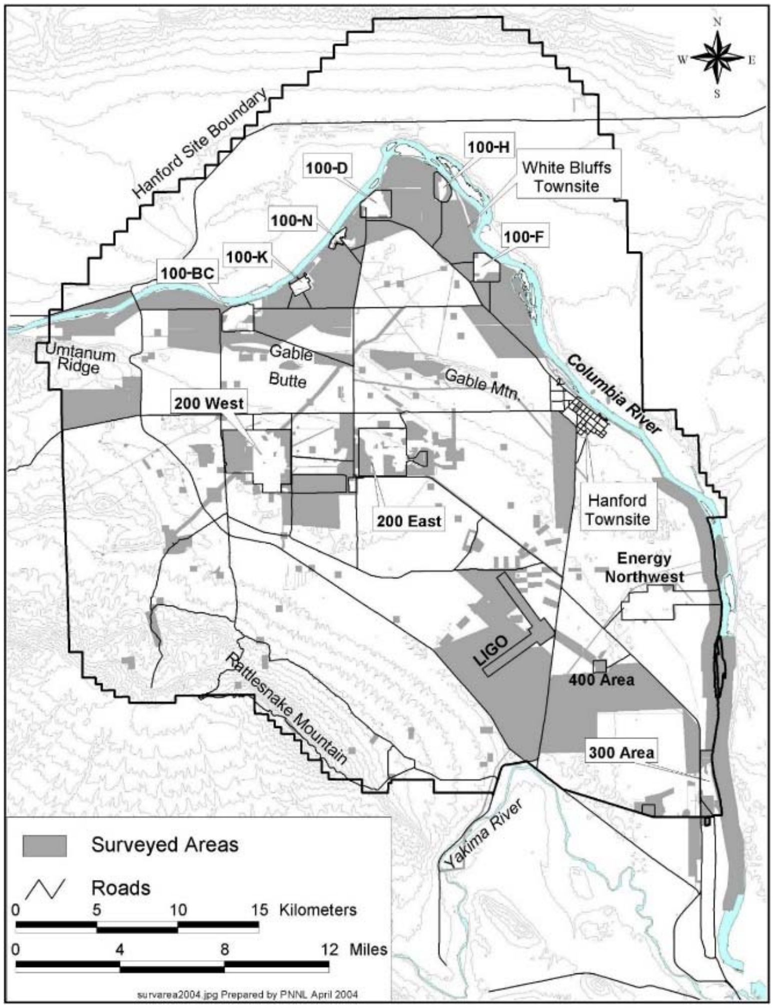

Figure 8-1. Areas surveyed for cultural resources on the Hanford Site.

Of the 127 sites evaluated for listing in the National Register of Historic Places, 49 were listed as of 2004 (ed. Neitzel DA 2004). More properties have been identified for listing in the register since that date, but the information is not publicly available. The register contains the nation's official listing of historic properties.[89] The B Reactor is the only property listed in the National Register of Historic Places from the

[88] Structures and other items erected or installed and used after 1990 to support the cleanup effort are not included as part of the evaluation.

[89] Under federal law, the term "historic property" means any prehistoric or historic district, site, building, structure, or objects significant in American history, architecture, archaeology, engineering, and culture on, or eligible for inclusion on the National Register, including artifacts, records, and material remains related to such a property or

Manhattan Project and Cold War Era landscape.[90] All other listed properties relate to the landscape associated with Native Americans. Historic properties eligible for listing in the National Register, but not formally listed, are dispersed throughout Hanford Site and represent all three landscapes, including such properties as White Bluffs Bank and anti-aircraft artillery sites. DOE does not distinguish between properties that have been nominated and are actually listed in the register from those that are eligible for listing as the criteria or standards for identifying and evaluating properties are identical (16 U.S.C. 470h-2(a)).

In 2000, President Clinton issued a Presidential Proclamation establishing the Hanford Reach National Monument to protect wildlife, rare plants, and cultural resources (Presidential Proclamation 73019 2000). The monument consists of 195,000 acres of contiguous, federally owned land and includes about 51 miles of the Columbia River. The Proclamation states in part: "As the Department of Energy and the U.S. Fish and Wildlife Service determine that lands within the Monument managed by the Department of Energy become suitable for management by the U.S. Fish and Wildlife Service, the U.S. Fish and Wildlife Service will assume management by agreement with the Department of Energy." (Presidential Proclamation 73019 2000). Currently, approximately 65,000 acres of the monument managed by the U.S. Fish and Wildlife Service are accessible to the public.

In December 2014, the United States Congress passed and President Obama signed legislation directing the establishment of the Manhattan Project National Historical Park within 1 year of enactment at Hanford, Oak Ridge, and Los Alamos as a unit of the National Park system (HR 3979, section 3039, 2014). The legislation, titled the Manhattan Project Historical Park Act specifically requires that the B Reactor National Historic Landmark be included as part of the park. The Act also requires the Secretary of the Interior in consultation with the Secretary of Energy to determine other "facilities and areas" from the facilities, land or interest in land at the Hanford Site that are listed in the Act as eligible for inclusion (Section 5(b)(3)). The other eligible areas listed in the Act are Hanford High School in the town of Hanford and Hanford Construction Camp Historic District; the White Bluffs Bank building in the White Bluffs Historic District; the warehouse at the Bruggemann's Agricultural Complex; the Hanford Irrigation District Pump House; and the T Plant (221-T Process Building) (Section 5(b)(3). The T-Plant was used to separate plutonium from irradiated fuel rods and is located in the 200 West Area of the Hanford Site.

To carry out the provisions of the Act, the Secretaries of the Interior and Energy are required to enter into an agreement "governing the respective roles of the Secretary (Interior) and the Secretary of Energy in administering the facilities, land, or interests in land under the administrative jurisdiction of the Department of Energy that is to be included in the Historical Park" (Section 6(a)). Responsibilities of the Secretary of Energy include ensuring that the agreement "protects public safety, national security, and other aspects of the ongoing mission" of the DOE and that the DOE would "retain responsibility, in accordance, with applicable law, for any environmental remediation that may be necessary in or around the facilities, land or interest in land governed by the agreement" (Section 6(c)(1),(3)). DOE also would be responsible for ensuring "safe access" (Section 6(c)(4)). Publication of the official boundary map of the Historical Park is another requirement under the Act (Section 7(b)).

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resource. The National Register of Historic Places is the official listing of these properties and is maintained by the Secretary of the Interior. National Historic Preservation Act, 16 U.S.C. 470a (a)(1)(A); 36 CFR Part 800 (2004).

[90] In 2008, the Department of the Interior designated the B Reactor a National Historic Landmark.

CULTURAL RESOURCES PROGRAM OVERVIEW

In 1987, DOE established the Hanford Cultural and Historic Resources program to manage Hanford Site cultural resources (DOE/RL-98-10 Rev. 1 1998)(DOE/RL-97-56, Rev.1 1998)). The primary objectives of the program are to achieve regulatory compliance under federal law, meet DOE stewardship responsibilities, promote outreach with Native Americans and former residents at the site, and protect the site's resources consistent with the 1999 Department of the Interior's National Strategy for Federal Archaeology (DOE/RL-98-10 Rev. 1 1998).

During the program's first decade, a management plan was developed and procedures were implemented to ensure that all DOE undertakings (i.e., projects, activities) receive a cultural resources clearance in accord with the National Historic Preservation Act and its regulations before the activity or project is authorized to proceed (16 U.S.C.470 et seq.; 36 CFR Part 800). These cultural resources reviews are conducted project-by-project as described below.

The program's first decade also saw significant efforts to better understand the extent of the historic properties and cultural resources located at the Hanford Site and their historic, cultural, archaeological, and architectural importance or value (DOE/RL-98-10 Rev. 1 1998). As an example, a comprehensive inventory of the buildings and structures from the Manhattan Project and Cold War period was completed. About 2200 were identified (DOE/RL-97-56 Rev. 1 1998).

Additionally, a programmatic agreement was negotiated with the SHPO[91] to provide "a streamlined framework that will direct the management of all Manhattan Project and Cold War Era properties on Hanford and will guarantee that preservation efforts are expedited while ensuring that cleanup activities are not delayed" (DOE/RL-96-77 Rev. 0 1996). The strategy developed included organizing all the buildings and structures (not considered exempt, such as mobile trailers and fuel storage tanks) as part of a single district and then classifying the included buildings and structures by type and evaluating each for its significance as either a contributing or non-contributing property to the Manhattan Project and/or Cold War eras. Approximately 1100 buildings were considered exempt. Standards for evaluating the built environment not considered exempt were identified and agreed upon as were appropriate mitigation measures (DOE/RL-97-56, Rev. 1 1998, p. 28). Mitigation measures that were developed include such actions as documentation through drawings, photographs, and historical research; preservation in place; salvage of information; restoration; and collection of artifacts. As required under Stipulation IV of the programmatic agreement with the state of Washington, a Historic Buildings Site-wide Treatment Plan was developed and implemented. As such, the plan "identifies which properties will be individually documented and what specific measure will be required" (DOE/RL-97-56, Rev. 1 1998, p. 28). This plan satisfies the regulatory requirements imposed under the National Historic Preservation Act "for identification, evaluation, and treatment necessary for all undertakings, up to and including demolition" (DOE/RL-96-77 Rev 0 1996, p.3).

Cultural resources reviews are conducted in advance of all undertakings (federal project or activities) as required under the National Historic Preservation Act (16 U.S.C. 470 et seq.; 36 CFR 800 2004). Complying with the Act and its regulations at the Hanford Site has meant that complex sets of planned activities for one geographic area ultimately could be subject to several cultural resources reviews. As described above, the programmatic agreement entered into with the SHPO only covers the built environment constructed during the Manhattan Project and the Cold War eras. This agreement with its streamlined review process satisfies the review requirements under the National Historic Preservation Act. However, a similar programmatic agreement or agreements that would include a site-wide

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[91] The SHPO is the state official designated to administer the state historic preservation program under the National Historic Preservation Act, 16 U.S.C. 470a (b)(3).

treatment plan covering the identification, evaluation, and treatment of cultural resources considered to be within the Native American and/or Pre-Hanford Era landscapes have not been negotiated with the SHPO, and so, for these two landscapes, the regulatory review process must be followed for each undertaking, or in other words, project-by-project (36 CFR 800 2004).

The DOE cultural resources review process comprises several steps and provides opportunities for Washington's SHPO, Native American Tribes, and other interested parties to participate. Once the proposed action has been identified and a request submitted for a review, existing cultural resources information is researched. If additional actions are required, DOE sends an Area of Potential Effect notice to the SHPO, Tribes, and any interested parties. Recipients of the notification have 10 days to submit comments and voice concerns about issues such as the proposed action or project and potential impacts.

The level of effort for any required fieldwork also is determined from the undertaking proposed. The primary focus is the identification of cultural resources and, if cultural resources are found, the evaluation of those resources for eligibility for listing in the National Register for Historic Property.[92] Required fieldwork may include such activities as surveys and subsurface testing. Then, a cultural resources report with a summary of any fieldwork performed together with findings and recommendations (e.g., no historic property affected, no adverse effect[93] to historic property, or adverse effect to historic property) is prepared and sent to the SHPO, Tribes, and any interested parties for review and comment within 30 days of receipt of the request for review. The process also directs that DOE consult with the SHPO, Tribes, and/or interested parties to resolve their comments/concerns. The SHPO's written concurrence on the final cultural resources review (along with resolution of comments/concerns made by consulting parties) is required to complete the review process and allow the proposed activity or project to proceed.

If the proposed undertaking is found to have an adverse effect on historic property either eligible for listing or listed in the National Register, and the historic property is not a Manhattan Project/Cold War Era building or structure (for which adverse effects have been previously mitigated under the Programmatic Agreement and Treatment Plan), further consultation is required. Additionally, a memorandum of agreement that provides agreed upon conditions must be negotiated with the Advisory Council on Historic Preservation (should that federal agency decide to participate), the SHPO, Tribes, and other interested parties before the project activity may proceed. Conditions may include a variety of mitigation measures designed to "avoid, minimize, or mitigate adverse effects" from the planned activity to the historic property. On execution of the agreement, the project or activity may begin, but only in accord with the conditions outlined in the agreement. Both DOE and the SHPO maintain written records on the memoranda of agreement entered into, including the conditions imposed.

In addition to implementing a cultural resources review process consistent with the National Historic Preservation Act and its regulations (16 U.S.C.470 et seq.; 36 CFR Part 800), the program has focused on repatriating human remains from collections, developing a database, and developing a long-term monitoring program to ensure the preservation of significant resources (DOE/RL-98-10 Rev. 0 2003). DOE maintains extensive records on the history of Hanford Site, including the artifacts removed from areas at Hanford, and oversees its collection of artifacts.

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[92] See footnote 83 for definition of the term "historic property."

[93] "An adverse effect is found when an undertaking may alter, directly or indirectly, any of the characteristics of historic property that qualify the property for inclusion in the National Register in a manner that would diminish the integrity of the property/s location, design, setting materials, workmanship, feeling, or association" (36 CFR 800.5(a)(1) 2004).

DOE regularly consults with four Tribes (Nez Perce, Confederated Tribes of the Umatilla Indian Reservation, Wanapum, and Confederated Bands of the Yakama Nation) about the historical, religious, and/or cultural importance that each of these Tribes has attached to Hanford Site (DOE/RL-98-10 Rev. 0 2003). DOE accepts information provided orally from these Tribes and has agreed to keep certain information confidential, such as the exact location of a sensitive cultural resource. Tribal consultation is mandated under federal law (16 U.S.C. 470 et seq.; DOE/RL-98-10 Rev. 0 2003) and regulations prescribed under the National Historic Preservation Act (36 CFR Part 800). Tribal representatives from one or more of the four Tribes have actively participated in many cultural resources reviews.

8.2. EVALUATING CULTURAL RESOURCES

Evaluating Impacts during the Active Cleanup (50 Years or until 2064) and Near-Term Post-Cleanup (until 2164) Periods

Understanding the potential risks and impacts to cultural resources is predicated on the following assumptions.

1. A determination of the presence of cultural resources is made either from existing documentation maintained by the DOE or SHPO or from information obtained from Tribes and or historical societies, or both.
2. Cultural resources include structures, geologic features, landscapes, and living resources (i.e., flora, fauna) and impacts to resources can be direct or indirect, or both.
3. Many cultural resources rely heavily on intact, functioning ecosystems for cultural and religious integrity.
4. Cultural resources may be exposed to contamination prior to or during cleanup or from contamination sources left in place.
5. A pathway must exist for contaminant uptake for flora and fauna (Chapter 7 of this methodology) and at sufficient contaminant concentrations for ecological resources also considered cultural resources to be at risk.
6. Cultural resources may be adversely impacted by the release of contaminants during cleanup or additional exposure may occur after active cleanup has ended.
7. Extensive inventories have been conducted to identify and document the historical importance of all buildings and structures at Hanford, and to determine from these inventories which buildings and structures will remain after active remediation ends.
8. Not all cultural resources have been mapped or identified at the time an undertaking (i.e., project or activity) is being considered; this is especially true for resources located just below the surface.
9. The four Tribes having historical ties to Hanford have had an affinity for the Hanford Site for thousands of years and consider the entire site to be historically and culturally important.
10. Existing cultural resources records often are not compiled or organized in ways that would be helpful to planning for cleanup at a particular location.

In addition to the above, it should be emphasized that while the Manhattan Project/Cold War Era built environment at Hanford is well understood and documented, and mitigation actions have been identified to limit or compensate for the damage the planned remediation activity will cause to the building or structure, archaeological artifacts and other cultural resources continue to be discovered at the Hanford Site. Indeed, as of 2004, 75% of the entire Hanford Site had not been surveyed for the existence of cultural resources (ed. Neitzel DA 2004).[94] This means DOE, Tribes having historical ties to Hanford, and other interested parties including historical societies are unaware of the extent to which many EUs that either are undergoing or will undergo remediation contain archaeological and/or other sensitive artifacts or resources. And, as important, even when a cultural resources review has been completed for an undertaking and mitigation has occurred, so that the risk to cultural resources is considered to have been lessened, the remediation still may inadvertently expose, affect, disturb, or even destroy cultural resources.

Assigning a cultural resources risk rating of Not Discernible, Low, Medium, High, or Very High, as is the case for ecological resources (Chapter 7), will not occur during the active cleanup and near-term post-cleanup evaluation periods. This is because before any characterization of remedial action may begin, the required cultural resources review must be completed to determine if the remedial action has the potential to affect cultural resources, so that identified, potential impacts on cultural resources can be taken into account (16 U.S.C. 470, et seq.; 36 CFR Part 800). The review process also provides Washington State, Tribes, and interested parties with the opportunity to participate. Thus, instead of a rating, risks or impacts to cultural resources are considered Known, Unknown, or None based on whether written or oral documentation gathered on the entire EU and buffer area establishes the existence or presence of cultural resources within the EU.[95]

Because an actual risk rating does not occur, cultural resources information compiled on the entire EU from the literature review and any other data provided are intended to help guide planning for future project activities at those Hanford Site operable units that are located within or adjacent to a unit being evaluated in this Risk Review Project.

Expressing cultural resources as Known, Unknown, or None consists of the following. A determination of the current impact and impact during active cleanup and near-term post-cleanup time periods to cultural resources within the EU (and the buffer area) is made using existing records to establish whether cultural resources have been present or are present within the EU in the three overlapping landscapes that comprise the cultural resource setting at Hanford Site (i.e. Native American, Pre-Hanford, and Manhattan Project and Cold War). Using that information as well as data gathered on remediation options for the EU, state the impact (direct and indirect) to cultural resources during both the active cleanup and near-term post-cleanup evaluation periods as Known, Unknown, or None for each of the three landscapes. The process is described more fully below.

Determine the current impact and impact during active cleanup and near-term post-cleanup periods to cultural resources within the EU from documentation establishing whether cultural resources have been or are present. An analysis of units being evaluated is made for each of the three cultural

[94] It is clear many cultural resources reviews (all of which have been conducted in compliance with federal law) have been completed in the 10 years since the Neitzel report was published. However, a report similar to the Neitzel report that provides a compilation providing such information as the percent of Hanford Site that has been surveyed has not been published. Anecdotally, information gathered and reviewed on EUs for this Risk Review Project confirms the lack of surveys, as there are several EUs that have been only partially surveyed.

[95] It bears repeating that the scope of the Risk Review Project is limited. While the Risk Review Project is considered site-wide, the units being evaluated under this methodology include only those where cleanup or waste management activities will continue past October 1, 2015 or where cleanup activities will occur beginning October 1, 2015 or later (see Chapter 1).

resources landscapes at Hanford Site: Native American (pre-contact to present), historic pre-Hanford (1805-1943), and the Manhattan Project/Cold War Era (1943-1990). This analysis consists of an extensive review of the literature related to cultural resources as well as other sources of information, including information (written or oral) that Tribes and/or local historical societies may be willing to disclose about the unit being evaluated.

The literature review is composed of a survey of relevant cultural resources records gathered on the units being evaluated for the Risk Review Project for the purpose of 1) providing information on the extent to which the EU previously has been surveyed for cultural resources, 2) identifying documented cultural resources, and 3) providing details on the resources that have been identified. The literature review does not include fieldwork because of the assumption that necessary fieldwork will occur at the time an undertaking (i.e., project or activity) has been proposed. For each EU, the literature review is conducted by a professional archaeologist who is authorized to review Hanford Site cultural resources records, including maps, surveys and archaeological site forms, and other information that is available either electronically or in paper form. The scope of the literature review is as follows.

1. After determining the exact location of the EU, the information analyzed for each EU includes existing DOE cultural resources records and data on the entire EU itself as well as DOE records and data from EUs located within 500 m of the boundary of the EU.
2. Data from the Washington State Department of Archaeology and Historic Preservation is reviewed for comparative data search purposes.
3. Relevant information is reviewed to determine the extent to which the EU has been surveyed (if such information is available) for documented evidence of the existence of cultural resources, and also whether any cultural resource identified within the EU or near the EU (a) is or contains an historic property eligible for listing in the National Register of Historic Places, and/or (b) contains cultural resource information of note. If the EU is or contains an historic property eligible that is contributing to the Manhattan Project/Cold War Era district, then the information is reviewed to determine if the property is a non-contributing or contributing property[96] to the district with or without documentation requirements.

A written report is prepared on the results of the literature review. In addition to providing a map showing the location of the EU, the report includes 1) a summary of the cultural resources inventories; 2) for each of the three cultural landscapes, a description of the archaeological site types, buildings, and the presence/absence of any TCPs; 3) archaeological site types and presence/absence of any TCPs located within 500 m of the EU; 4) presence/absence of any recorded TCPs visible from the EU; and 5) historic map and aerial photograph indicators, geomorphology indicators, ground disturbance indicators, and a summary of the cultural resources literature review for that EU. References are also provided. Copies of the literature review reports for EUs are included as appendices to the reports prepared for the Risk Review Project.

The methodology used to develop the report for each EU follows the summary (and before Section 8.4, References, of this chapter) and is identified as Table 8-5. Methodology for Completing the Cultural Resources Literature Review. (Source: PNNL 2014).

If the literature review establishes the presence of cultural resources, then both the current impact and impact during active cleanup to resources are considered Known. If the review reveals an uncertainty about whether a cultural resource is present or has been present, such as an incomplete review or eligibility determination for the National Register has not been completed, then the current impact and

[96] See discussion in Section 8.1 on the Manhattan Project/Cold War Era.

impact during active remediation to cultural resources are considered Unknown. If the review establishes no presence of a cultural resource, then the current impact and impact during active cleanup are considered None. The same analysis is made for both direct and indirect impacts. Refer to Table 8-1. Analysis for rating impacts to cultural resources under current conditions and during active cleanup. Analysis is identical for all three landscapes. for the analysis.

For the near-term post-cleanup period, the table identifying remediation options for each EU is used (Appendix C). For example, if the option is D&D, as it will be for Manhattan Project/Cold War Era buildings and structures, then the impact is considered None as it is presumed all buildings and structures from that landscape will be removed from the EU.

For purposes of this chapter, the definitions of "direct" and "indirect" effect or impact are derived from regulations prescribed under the National Historic Preservation Act for finding an "adverse effect" (36 CFR 800.5 (2004)). Under the regulations, "an adverse effect is found when an undertaking may alter, directly or indirectly any of the characteristics of a historic property that qualify the property for inclusion in the National Register in a manner that would diminish the integrity of the property's location, design, setting, materials, workmanship, feel, or association" (36 CFR 800.5(a)(1)(2004)). Consistent with the above quoted regulation, direct effects or impacts to cultural resources include but are not limited to physical destruction (all or part) or alteration such as diminished integrity. And, indirect impacts include but are not limited to the introduction of visual, atmospheric, or audible elements that diminish the cultural resource's significant historic features (36 CFR 800.5(a)(2)2004). For example, a TCP that is visible from an EU would create a view shed that could be impacted under certain remediation options such as capping.

As noted, while much is known about the Hanford Site, a significant portion has yet to be inventoried for surface archaeological resources. In the case of subsurface archaeological resources, even less is known. Further, surface archaeological surveys will not identify all the resources that are present with an EU, specifically those located in the subsurface (e.g., burial items and artifacts). This means that a review of the documentation only allows for a determination of the presence/absence of surface cultural resources at a specific location with an EU, and that is only when a surface investigation has been completed. Only in very rare instances is there documentation of subsurface archaeological resources. This is because only surface investigations are routinely conducted during cultural resources reviews. This lack of data creates uncertainty about the potential for both surface and subsurface archaeological resources to be present with EUs.

Supplemental archaeological field surface and/or subsurface field investigations will not be conducted as part of this Risk Review Project. However, if during the project other information on the unit being evaluated is provided and authorized to be disclosed, such as from Tribes having historical ties to Hanford Site and/or historical societies, then that information may be added to the data from the literature review described above and included as part of the evaluation for the EU contained in the final report submitted on the Risk Review Project.

Table 8-1. Analysis for rating impacts to cultural resources under current conditions and during active cleanup. Analysis is identical for all three landscapes.

(INDIRECT IMPACT ANALYSIS IN BOLD)

	Current Conditions/Operations	During Active Cleanup
Known	• Literature review includes documentation establishing the presence of cultural resources, or • Documentation regarding eligibility of cultural resources for the National Register of Historic Places within EU has been completed • **EU is within landscape/setting of TCP**	• Literature review includes documentation establishing the presence of cultural resources, or • Documentation regarding eligibility of cultural resources for the National Register of Historic Places within EU has been completed • **EU is within landscape/setting of TCP**
Unknown	• Literature review indicates uncertainty in the presence of cultural resources (e.g., reviews are incomplete or indicators are present but actual presence of resources not documented) • Documentation regarding eligibility of cultural resources for the National Register of Historic Places within EU has not been completed • **Unknown if there are TCPs within EU or view shed**	• Literature review indicates uncertainty in the presence of cultural resources (e.g., reviews are incomplete or indicators are present but actual presence of resources not documented) • Documentation regarding eligibility of cultural resources for the National Register of Historic Places within EU has not been completed • **Unknown if there are TCPs within EU or view shed**
None	• Literature review does not indicate the presence of cultural resources	• Literature review does not indicate the presence of cultural resources

Activities supporting remediation vary in intensity and level, and as such may vary in their potential impact to cultural resources, particularly those that would not be exposed until the remediation.

Table 8-2 is arranged from lowest to highest effects to a unit being evaluated and is provided as a planning guide where activities supporting remediation are considered along with the cleanup itself. Determinations are qualitative, considering the likelihood that the identified activity involves or may involve subsurface disturbance that would expose the cultural resource to damage or otherwise cause an adverse effect. As an example, activities associated with soil removal increase the likelihood that removal will expose a resource and cause it to be adversely affected. For each EU, remediation effects to cultural resources are specifically described in the Evaluation Template for that specific EU. These effects are based on what is known about the range of cleanup actions for that EU as listed in the Existing Cleanup Decisions document (see Disposition Table in Appendix C to this methodology document).

Table 8-2. Potential effects to cultural resources from associated activities during active cleanup (to 2064) evaluation period. (This list is arranged from lowest to highest impacts.)

Type of Disturbance from Remediation	Cultural Resources Effects
A. Personnel traffic through non-target area	May inadvertently expose resources close to the surface.
B. Personnel traffic through target (remediation) area	May inadvertently expose resources close to the surface; may be disruptive if trails are made that decrease view shed value.
C. Car and pick-up traffic adjacent to the site	May inadvertently expose resources close to the surface; may lead to the introduction of invasive species and/or decrease presence of native plants used for medicinal or tribal religious purposes; view shed may be affected by increased dust, etc.
D. Car and pick-up traffic through remediation site	Depends on level of traffic and whether permanent roads are made, which may lead to the introduction of invasive species and/or decrease presence of native plants used for medicinal or tribal religious purposes; view shed may be affected by increased dust, etc.
E. Truck traffic on roads through non-target area	Depends on level of traffic and whether permanent roads are made, which lead to the introduction of invasive species and/or decrease presence of native plants used for medicinal or tribal religious purposes; view shed may be affected by increased dust, etc.
F. Truck traffic on roads through remediation site	Depends on level of traffic; depends on whether permanent roads are made, which may lead to the introduction of invasive species and/or decrease presence of native plants used for medicinal or tribal religious purposes; view shed may be affected by increased dust, etc.
G. Heavy equipment	Depends on whether resource may be exposed by work, view shed may be impacted by increased dust, etc.; landscape may be altered.
H. Drilling rigs	Depends on whether resource close to the surface may be exposed by work; heavy equipment could introduce invasive species that displace native species used for medicines, food, or cultural purposes; may result in permanent compaction, changing the aspect of the landscape and view shed.
I. Construction of buildings	Act of construction may destroy resource; may permanently preclude access to resource; may cause an indirect effect by altering view shed.
J. Caps, other containment	Containment act may destroy resource located close to surface; if resource is not destroyed, containment may disturb or adversely affect resource.
K. Soil removal	Act of removal may destroy resource; if resource is not destroyed, then, soil removal may disturb or adversely affect resource; complete destruction of view shed, plants and animals used for food, medicines, or cultural purposes; possible introduction of invasive species that preclude restoration.
L. Contamination	During remediation, radionuclides or other contamination released or spilled on the surface could have long-term effects if the contamination remains and resources become contaminated and/or plants having cultural importance to Tribes do not recolonize or thrive.

After the cleanup period ends in 2064, it is presumed that land use designations[97] for the Hanford Site will be in place. However, those designations are largely irrelevant for evaluating cultural resources during the near-term post-cleanup period because it also is presumed that the unit being evaluated will remain under federal jurisdiction. This means the federal agency having jurisdiction over the unit, whether DOE or another agency, will not only continue to have authority to maintain and keep in place institutional and/or engineered controls for that unit, but also will be responsible for adhering to all applicable federal and state laws (e.g., the National Historic Preservation Act). As an example, those properties currently either listed or eligible for listing in the National Register of Historic Places will be presumed to continue to be protected as required under federal law and also will continue to be subject to the cultural resources review process set out under the National Historic Preservation Act during the entire near-term post-cleanup period.

Source documents cited in the Reference section reveal that the majority of cultural resources considered important and which are present after active cleanup ends and the near-term post- cleanup begins in 2064 either have been or are present within land use areas currently designated as "conservation" or "preservation." In the future, it is possible such areas will instead be designated "unrestricted use" or "residential use" (see footnote above). Many of the areas currently designated "conservation" or "preservation" are located along the Columbia River, which coincides with the location of many of the properties listed or eligible for listing in the National Register of Historic Places. So, whether the designation ultimately is unrestricted or residential use or conservation or preservation is of no consequence for this Risk Review Project because, as stated above, it is presumed that these specific areas still will be under the jurisdiction of federal agencies at least until at least 2164 (near-term post-cleanup period ends) and federal agency or agencies will have the authority to protect cultural resources actually present or likely to be present from any human activities that may lead to their exposure or cause an adverse effect, such as destruction.

Finally, Tribal treaty rights relating to fishing, hunting, and gathering may be invoked during the near-term post-cleanup period (2064 to 2164). This may mean, as an example, that certain ecological resources located within certain EUs considered also to be cultural resources by Tribes could be impacted. However, as noted above, these resources are presumed to remain under federal jurisdiction, and thus are subject to continued protection in ways that would not adversely affect treaty rights. (See also discussion of tribal exposures in Chapter 5 and risks to ecological resources in Chapter 7.)

Table 8-3 addresses residual effects from associated cleanup activities that may still be present during the 100-year period following active remediation (2064-2164). Table 8-3 is provided as a guide or resource only. For purposes of the information provided in Table 8-3, it is presumed properties either listed or eligible for listing in the National Register of Historic Places that still remain at the Hanford Site will continue to be maintained during the entire evaluation period. It also is presumed that if jurisdiction has not been transferred out of federal control, the land management agency will have authority to protect cultural resources either known or likely to be present from harmful human intrusion or activities. Residual effects to cultural resources from remediation are described in the Evaluation Template for each EU. This description is based on an evaluation of what is known about the type of

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[97] For purposes of this methodology document, only two land use designations are relevant: the DOE identified land use designation of industrial (e.g., on the Central Plateau) (DOE-EIS-0222-F 2008) and a land-use designation called "unrestricted" (also called "residential"). This term is designed to be consistent with an anticipated future land use designation that the EPA recently identified in the record of decision for part of the Hanford 300 Area (DOE/RL and EPA/Region 10 Hanford Site 300 Area 2013). See also Washington Administrative Code, 173-340-200; 173-340-740.

cleanup for that EU as listed in the Existing Cleanup Decisions document (see Appendix C to this methodology document).

Table 8-3. Residual effects to cultural resources from associated cleanup activities during near-term post-cleanup evaluation period. (Residual effects after cleanup is complete.)

Type of Disturbance From Remediation	Effects to Cultural Resources
A. Personnel traffic through non-target area	Effects no longer present assuming resource not disturbed during remediation.
B. Personnel traffic through target (remediation) area	Effects no longer present assuming resource not disturbed during remediation.
C. Car and pickup traffic adjacent to the site	Effects no longer present assuming resource not disturbed during remediation; however, it is possible there are indirect effects depending on whether landscape altered by traffic (e.g., ruts, changes in vegetation).
D. Car and pickup traffic through remediation site	Effects no longer present assuming resource not disturbed during remediation; could cause permanent paths in vegetation, some invasive species, changes in plants used for food, medicines, or cultural purposes; possibility of indirect effects depending on whether landscape altered by traffic (e.g., ruts, changes in vegetation).
E. Truck traffic on roads through non-target area	Effects no longer present assuming resource not disturbed during remediation; however, it is possible there are indirect effects depending on whether landscape altered by traffic.
F. Truck traffic on roads through remediation site	Effects no longer present assuming resource not disturbed during remediation; similar to car traffic (see above).
G. Heavy Equipment	Permanent effects possible in areas of heavy equipment use.
H. Drilling Rigs	Permanent effects in the area of drill rig construction. Possible permanent effects in area surrounding rigs, depending on traffic and current activities.
I. Construction of Buildings	Permanent effects in the area of the construction, if resource was exposed thereby creating a possibility that other resources around the construction may be exposed and possibly even destroyed depending on traffic and current activities. Indirect effects such as loss of view shed may be impacted.
J. Caps, Other Containment	Permanent effects in the area of cap site, if resource was exposed thereby creating a possibility that other resources around the cap may be exposed depending on traffic and current activities. Periodic monitoring of cap will involve effects due to personnel, car, and truck traffic (see above for effects).
K. Soil Removal	Permanent effects in the area of soil removal, if resource was exposed thereby creating a possibility that other resources are near and/or adjacent to the area where soil was removed depending on traffic and current activities. Periodic monitoring of cap will involve effects due to personnel, car, and truck traffic (see above). Degree of effect depends also on restoration activities (potential for further exposure of resources). Indirect effects also possible to view shed.
L. Contamination	Permanent effects if contamination remains and/or resources are contaminated; resources may be destroyed and/or have to be removed; plants having cultural importance to Tribes may not recolonize or thrive; if contamination remains, access to and/or use of resources may be prohibited.

INITIATING EVENTS

Human or natural caused initiating events could strike the Hanford area at any time, although certain events such as fire are more likely than others (e.g., earthquake; see Chapter 4). And, any of the events could destroy a cultural resource, including a property listed or eligible for listing in the National Register of Historic Places. Obviously, the range of effects these hazard events could have on cultural resources extends from no disturbance to destruction and may even expose the resource to contamination. Even if the resource is not destroyed, access to or use of the resource may be denied (e.g., gathering berries). After the event, remediation may occur, which may further jeopardize cultural resources not already destroyed by the event. The immediate effects from remediation are described in Table 8-4 and are offered as a guide or resource.

Table 8-4. Types of cleanup effects after an initiating event.

Initiating Event	Effects from Remediation
Loss of institutional controls (means loss of active controls)	Increased human activities depending on whether resource is present. Use of/access to resource may be precluded.
Loss of engineered controls	Increased human activities depending on whether resource is present. Use of/access to resource may be precluded.
Structural decay	Increased human activities depending on whether resource is present. Use of/access to resource may be precluded.
Fire	Increased human activity related to firefighting, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity. Use of/access to resource may be precluded.
Earthquake	Increased human activity related to addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity. Use of/access to resource may be precluded.
Dam failure (flooding)	Potential increases of human activity related to addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on-site. Effects can vary depending on degree of human activity. Use of/access to resource may be precluded.
Ash fall (Volcanic)	Potential increases of human activity related to addressing any damage to engineered controls and buildings, and to remediation needed to repair any engineering controls or structures on-site. Effects vary depending on degree of human activity. Potential loss of resource.
Drought	Long term: potential loss of resource that cannot be restored.
Plane crash	Potential increases of human activity resulting from immediate rescue and human safety activities, as well as those addressing any damage to engineered controls and buildings and to remediation needed to repair any engineered controls or structures on-site. Effects may vary depending on degree of human activity, both immediately and over longer period. Use of/access to resource may be precluded.
Climate change	Long-term shifts in use of resource that cannot be restored.
Water table decreases	Increased human activity as a result of increased need for engineered controls or remediation of existing facilities. Long term: potential loss of resource that cannot be restored.

8.3. SUMMARY

In summary, an overall rating for each EU is not provided. Instead, the EU's cultural resources evaluation provides information on whether an impact (both direct and indirect) is Known (presence of cultural resources established), Unknown (uncertainty about presence of cultural resources), or None (no cultural resources present) based on written documentation gathered on the entire EU and buffer area and following the methodology developed for the literature review (see Table 8-1 and Table 8-5). For the near-term post-cleanup period (until 2164), the assignation will be adjusted to reflect the cleanup that has occurred. For example, there may be no Manhattan Project/Cold War Era buildings and structures at an EU because D&D has occurred. Direct impacts include but are not limited to physical destruction (all or part) or alteration such as diminished integrity. Indirect impacts include but are not limited to the introduction of visual, atmospheric, or audible elements that diminish the cultural resource's significant historic features. Impacts to cultural resources as a result of proposed future cleanup activities will be evaluated in depth under Section 106 of the National Historic Preservation Act (16 U.S.C. 470, et seq.) and include formal consultation and necessary field investigations during the planning for remedial action.

Each EU's Evaluation Template includes the assignation above as well as a summary of the documentation on the presence of resources within the EU and/or within 500 m of the EU, together with information on the types of disturbances that may occur during cleanup and the remaining effects in the 100-year period after remediation (Table 8-2 and Table 8-3). The impacts to each EU along with summary comments are included in that EU's Evaluation Template for current conditions, during active cleanup, and in the near-term post cleanup period (2064–2164). Both tables are offered to help guide future project activities, such as remediation that may take place at Hanford Site operable units, which are located within or adjacent to units being evaluated under this Risk Review Project.

Potential cleanup effects after an initiating event also are identified (Table 8-4).

Table 8-5. Methodology for Completing the Cultural Resources Literature Review. (Source: PNNL 2014)

Methodology for Completing the Cultural Resource Literature Review for the Hanford Site-Wide Risk Review

CONSULT U. S. DEPARTMENT OF ENERGY, HANFORD CULTURAL RESOURCES DATABASE (ARCGIS SHAPEFILE DATA) AND RECORDS ROOM TO GATHER RELEVANT CULTURAL RESOURCES INFORMATION FOR EACH EVALUATION UNIT. [98]

1. Utilize ArcGIS to overlay Evaluation Units over DOE cultural resources data last updated in December 2013.
2. DOE cultural resources data analyzed include:

   a) Archaeological site location information (point, linear and polygon data). Contains information of all archaeological sites recorded on the Hanford Site that are associated with all three landscapes on the Hanford Site (Native American Pre-contact and Ethnographic, Pre-Hanford Settlers and Farming and Manhattan Project and Cold War)
   b) Archaeological <u>survey</u> data. Distinct from cultural resource <u>review</u> data. (Archaeological surveys consist of reports written documenting the results of archaeological field inventories of the surface of the ground. Sometimes subsurface archaeological investigations are done and documented within these reports).
   c) Contributing Manhattan Project and Cold War Era Buildings with no documentation required (verified that this data was compiled using LMSI 2011 information which includes only those buildings have not been demolished as of 2011).
   d) Contributing Manhattan Project and Cold War Era Buildings with documentation required (verified that this data was compiled using LMSI 2011 information which includes only those buildings have not been demolished as of 2011).
   e) Archaeological District information. (These are comprised mostly of the archaeological districts that have been either determined National Register-eligible or State Register-eligible. These districts are associated with the Native American Pre-contact and Ethnographic landscape).
   f) Polygon information includes recorded traditional cultural properties (TCPs) as well as fenced Native American cemeteries.[99]
3. Identify those resources and surveys that overlay the evaluation units. For surveys, only those that occur within or overlap the Evaluation Units were identified. For archaeological resources and recorded historic buildings only those that occur within the Evaluation Units or are located within 500 meters of the Evaluation Units are included.

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[98] GIS data and associated records contained in the DOE Cultural and Historic Resources database and records room can be accessed only by those meeting the Secretary of Interior requirements for professional archaeologist.

[99] Traditional cultural property has been defined by the National Park service as "a property, a place, that is eligible for inclusion on the National Register of Historic Places because of its association with cultural practices and beliefs that are (1) rooted in the history of a community, and (2) are important to maintaining the continuity of that community's traditional beliefs and practices" (NPS 1992).

4. Attempt to find the NHPA Section 106 review completed for each Evaluation Unit. The way the database is set up, it is not always easy to do this because many reviews do not require field surveys.
5. Using PHOENIX 2012 aerial imagery establish and describe the general disturbance of the lands contained within the Evaluation Unit and how that correlates to the potential for archaeological resources to be present within the EU.
6. Identify nearby TCPs that may be indirectly affected by each remediation activities occurring within each Evaluation Unit.
7. Consult historic maps and imagery available at the DOE Cultural and Resources Records Room to understand pre-Hanford Settler land use and as an indicator for the potential for there to be pre-Hanford Settler cultural resources present within each Evaluation Unit. These include 1880 General Land Ordinance maps, 1943 aerial photographs, 1917 topographic maps, and 1943 Hanford Site Engineer Works Real Estate maps. Identify landowners.
8. Identify if there are Holocene of Pleistocene deposits within each Evaluation Unit as an indicator for the potential for there to be both Native American pre-contact/ethnographic and pre-Hanford Settler and Farming archaeological resources.
9. Visit DOE cultural resources records and archives room to obtain copies of cultural resources survey and archaeological site forms that are not electronically available on WISSARD.
10. Review archaeological site forms and related information to establish if any of the cultural resources identified in or near the Evaluation Units are eligible for listing in the National Register of Historic Places. Review survey reports for any other cultural resources information of note.
11. Review the *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan* to confirm status of contributing properties with and without documentation requirements.

CONSULT WASHINGTON STATE DEPARTMENT OF ARCHAEOLOGY AND HISTORIC PRESERVATION (WISSARD) TO ACCESS CULTURAL RESOURCES AND SURVEY DATA.[100]

1. Access DAHP WISSARD database for comparative data search purposes. DAHP WISSARD database contains documentation of recorded cultural resources and cultural resources surveys completed within the state of Washington. Using aerial imagery, approximate location of Evaluation Units in relation to cultural resources report and archaeological site information. Follow steps outlined in steps 3 through 5.
2. Download relevant cultural resources survey and archaeological site form information available on WISSARD.
3. Query WISSARD for electronic copies of cultural resources survey and archaeological site information identified during search of the DOE ArcGIS data.

[100] GIS data and associated records contained in the DAHP WISSARD database can be accessed only by those meeting the Secretary of Interior requirements for professional archaeologist.

REVIEW DOCUMENTS AND COMPILE INFORMATION ON TO DATASHEETS CREATED FOR EACH EVALUATION UNIT FOR "CULTURAL RESOURCES REVIEW AND SETTING" SECTION (SEE ATTACHMENT FOR AN EXAMPLE).

1. Compile list of archaeological sites, standing structures and TCPs as well as the relevant landscape they are associated with for each Evaluation Unit.
2. Compile a list of cultural resource surveys and any archaeological field work completed within each Evaluation Unit. State if the cultural resources survey is synonymous with a Section 106 review for the Evaluation Unit. List groups that may have been consulted with as part of the Section 106 process (in most instances this is Hanford Tribes and SHPO. Rarely have consulting parties associated with the Early Settlers and Farming Landscape been consulted with).
3. Compile a list of traditional cultural properties, archaeological sites, buildings and their associated landscape that are located within 500 meters of the Evaluation Unit. Describe closest recorded TCP and relative location from each Evaluation Unit.
4. Provide a "Cultural Resources Review Summary" for each Evaluation Unit based on completeness of cultural resources information. This includes summary of all cultural resources (archaeological sites, TCPs and buildings) and a statement about National Register-eligibility of each located within the EU and within 500 meters of the EU, potential for significant resources to be present and the cultural landscape they are associated with based on geomorphology, historic maps and evidence of soil disturbance, and if consultation with Native Americans and Pre-Hanford Settlers would be helpful based on the presence and potential for cultural resources of concern to be present as well as potential for both indirect and direct impacts to these resources.

REFERENCES

National Park Service. 1990. *National Register Bulletin 38: Guidelines for Evaluating Traditional Cultural Properties.* Written by Patricia L. Parker and Thomas F. King. U.S. Department of the Interior. Washington D.C.

8.4. REFERENCES

DOE/EIS-0222-F 1999, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/EIS-0222-SA-01 2008, *Supplemental Analysis, Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/RL-98-10, Rev. 0 (issued to public 2003), *Hanford Cultural and Historic Resources Management Plan*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/RL and EPA/Region 10 Hanford Site 300 Area 2013, *Record of Decision for 300-FF-2 and 300FF-5, and Record of Decision Amendment for 300 FF-1*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/RL-RIMS-EM-PD 2010, *Hanford Cultural and Historical Resources*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/RL-96-77, Rev 0 1996, *Programmatic Agreement Among the U.S. Department of Energy, Richland Operations Office, the Advisory Council on Historic Preservation , and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration, and Demolition of the Built Environment on the Hanford Site, Washington*, U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE/RL-97-56 Rev 1 1998, *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan*, U.S. Department of Energy, Richland Operations Office, Richland, Wash.

Neitzel DA (ed.) 2004, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, PNL-6415, Rev. 16, Pacific Northwest National Laboratory, Richland, WA.

Statutes and Regulations

Archaeological Resources Protection Act of 1979, 16 U.S.C. 470aa et seq.

Archeological and Historic Preservation Act of 1974, 16 U.S.C. 461 et seq.

American Indian Religious Freedom Act, 42 U.S.C. 1996 et seq.

National Historic Preservation Act of 1966, 16 U.S.C. 470 et seq.

Native American Graves Protection and Repatriation Act, 25 U.S.C. 3001 et seq.

36 CFR 800 2004, Protection of Historic Properties, U.S. Department of the Interior, Code of Federal Regulations.

WAC 173-340 2007, *Model Toxics Control Act – Cleanup*, Washington Administrative Code, Olympia, WA.

Executive Orders, Proclamations, Memoranda of Understanding, and Legislation

Executive Order 13007, Indian Sacred Sites, 61 FR 26771-26772 (1996).

Memorandum of Understanding Regarding Interagency Coordination and Collaboration for the Protection of Indian Sacred Sites (2012).

National Defense Authorization Act for Fiscal Year 2015, HR 3979, Section 3039, pp. 1245-1257, 113 Cong., 2d Sess. (2014).

Presidential Proclamation 73019, Establishment of the Hanford Reach National Monument (June 9, 2000), 3 CFR Vol. 1 2001-01-01.

CHAPTER 9. PRESENTING SUMMARY INFORMATION

9.1. INVENTORY DATA

Inventory data, as well as other metrics, have been compiled for EUs and will be provided in detail within each evaluation template and then summarized in the interim and final reports. Bar charts are to provide comparisons, with the y-axis on a $\log_{10}$ scale to provide relative context. Each entry in the figure includes a reference to a note in parenthesis to describe the type of barriers currently preventing release of the inventory to the environment. Figure 9-1 provides an example inventory summary figure for illustration purposes only.

9.2. TANK WASTE AND FARMS DATA

Results for tank waste and farms data are to be illustrated using pie diagrams to reflect the amount of each constituent or metric (e.g., groundwater threat metric) that is present within each tank and in the vadose zone or ancillary equipment within each specific EU. Each slice within the pie is scaled by the total inventory or metric over the entire EUs presented. Anticipated results after tank waste retrievals are also indicated as partial pie diagrams of the residuals. These detailed pie diagrams for individual contaminants and tank farms will be included in the evaluation templates (Figure 9-2 provides an example for illustration purposes). A summary level collection of pie diagrams that integrates results across all tank waste and farms EUs will be included in the interim and final reports (Figure 9-3 provides an example for illustration purposes). Each pie within the overall figure is scaled by the total inventory or metric over the entire set of EUs presented, with each slice within each pie scaled to the fraction of the pie within the EU indicated.

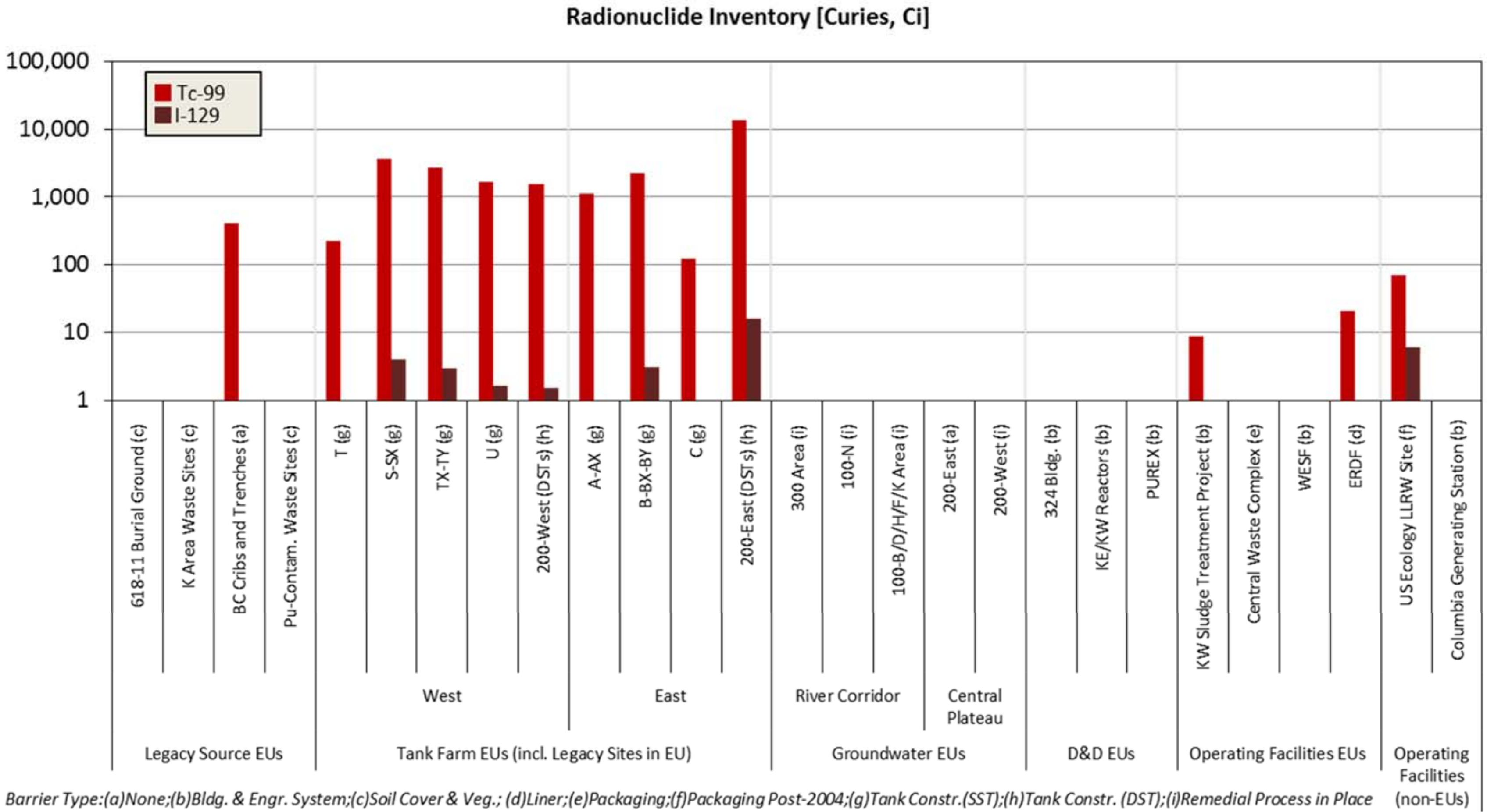


Figure 9-1. Example inventory bar chart (draft for illustration only): Radionuclide inventories – Tc-99 and I-129: Comparison of inventories for each EU.

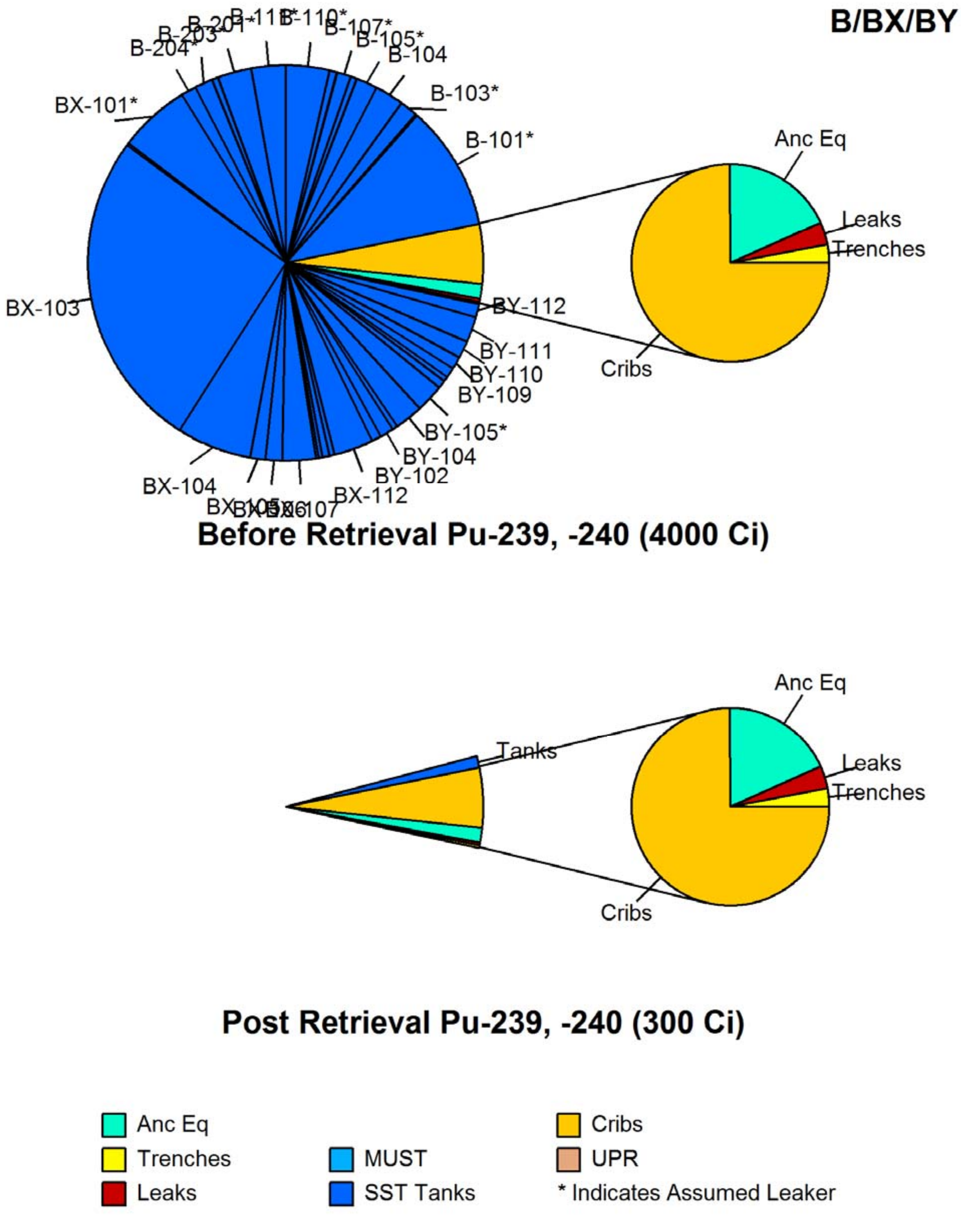


Figure 9-2. Example detailed tank waste and farm pie diagram (draft for illustration only): B-BX-BY Tank Farm Evaluation Unit Inventory Estimates for Plutonium Before and After 99% Retrieval

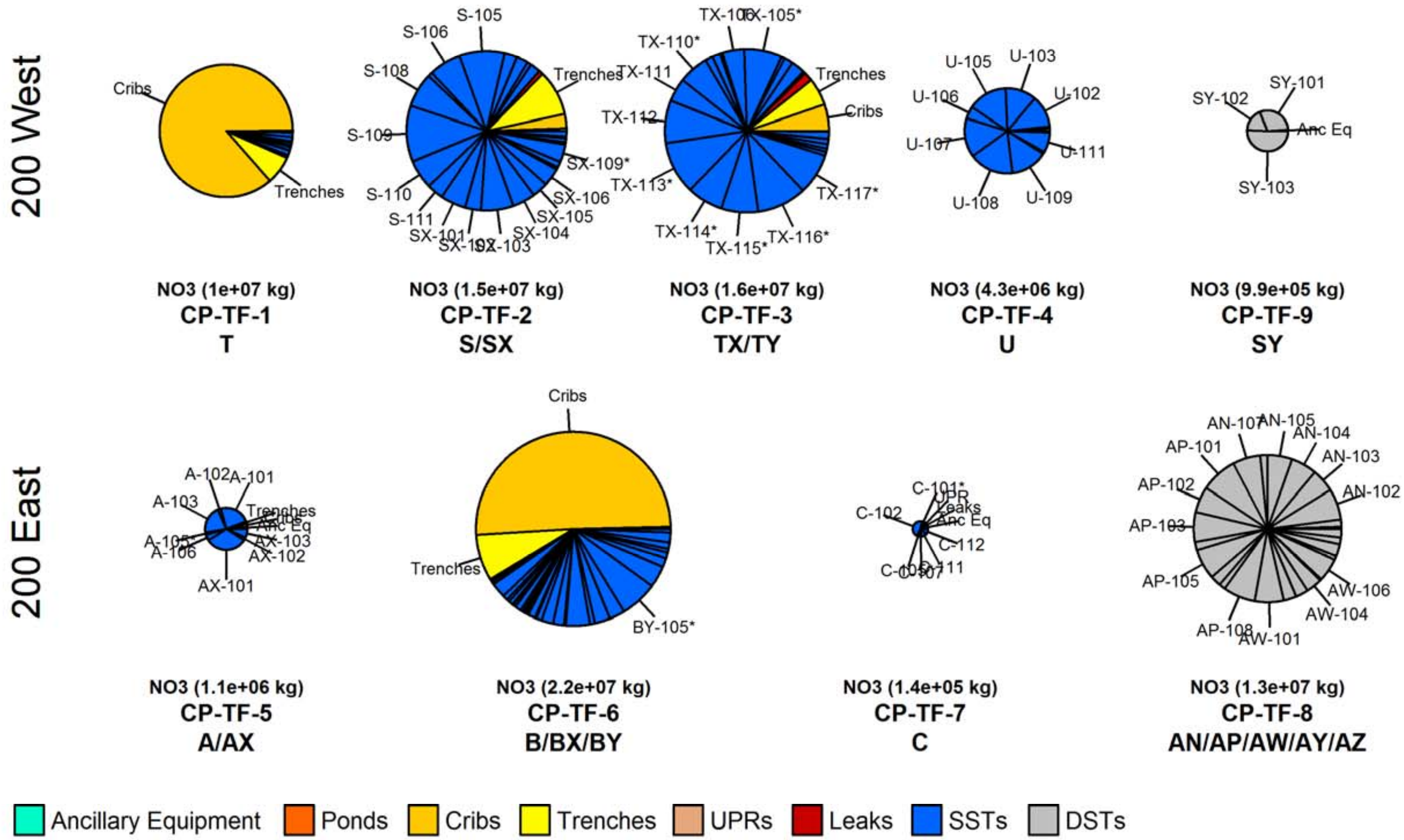


Figure 9-3. Example summary pie diagram of Tank Waste and Farms Inventory (draft for illustration). Nitrate: Inventory distribution between waste within tanks and existing environmental contamination from past disposal practices (i.e., discharges to cribs and trenches), leaks, and UPRs. The relative amount of inventory within each EU is scaled by relative area for each pie. Asterisk (*) indicates an assumed leaker tank.

9.3. RISK REVIEW RATINGS

Risk review ratings for each receptor are to be tabulated in summary tables using a combination of text summaries and symbolism. Specific symbology was developed for the Risk Review Project and is defined in Table 9-1. Symbols used in the rating tables indicate the highest rating when a rating range is present, although the accompanying text will indicate the risk rating range, when a range of ratings is possible, to reflect uncertainty. Symbols within each entry in rating tables are a combination of a risk rating symbol and additional symbols used to indicate 1) the presence of engineered barriers to prevent release to the environment or further dispersion of radionuclides and chemicals, 2) when treatment, waste retrieval or remediation is in progress, and 3) if interim stabilization has occurred (only applicable to single-shell tanks through removal of pumpable liquid). Table 9-2 provides example combinations of symbols used to represent individual table entries. Absence of an engineered barrier or treatment symbol indicates that a barrier is not present or that treatment is not currently occurring respectively. Table 9-3 provides an example summary table for illustration purposes, and should not be taken as the final actual risk ratings indicated.

Table 9-1. Symbology to be used for risk ratings in the summary tables. Individual table entries will be a combination of a risk rating symbol, a barrier symbol, and treatment, remediation and waste treatment symbol.

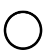
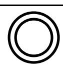
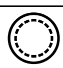
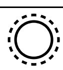
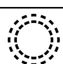
Symbol	Meaning
	Risk Rating Symbols
○	ND Rating
◔	Low Rating
◑	Medium Rating
◕	High Rating
●	Very High Rating
	Barrier Symbols
	One engineered barrier, Intact (barriers include tanks, covers, liners, buildings, etc.)
	One engineered barrier, barrier compromised (e.g., leaking tank)
	Two engineered barriers, both barriers intact
	Two engineered barriers, inner barrier compromised and outer barrier intact
	Two engineered barriers, inner barrier intact and outer barrier compromised
	Two engineered barriers, both barriers compromised.
	Treatment, Remediation and Waste Treatment Symbols
[ ]	Treatment, remediation or waste retrieval in progress
ǂ	Interim stabilized (single shell tank, stabilization through removal of pumpable liquid)

Table 9-2. Examples of combined risk rating, barrier and treatment symbols that are combined to form a single summary table entry. Absence of a barrier or treatment symbol indicates that a barrier is not present or that treatment is not currently occurring, respectively.

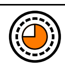
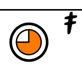
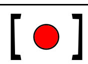
Symbol	Meaning
	Examples of Combined Rating, Barrier and Treatment Symbols
	Low rating, no engineered barriers or treatment present
	Medium rating, no engineered barriers or treatment present
	High rating, no engineered barriers or treatment present
	High rating, one engineered barrier that is compromised (i.e., leaking)
	High rating, two engineered barriers, inner barrier compromised, outer barrier intact
	High rating, one engineered barrier present (i.e., single shell tank) with interim stabilization
	Very high rating, currently undergoing treatment

Table 9-3. Example (draft for illustration only) - Partial Summary of Risk Review Project ratings threats to groundwater from contaminants currently in the vadose zone (includes current vadose zone inventory in Tank Waste and Farms EUs but not inventory within the tanks themselves).

EU Name	EU	Risk Driver	Current	Risk Driver	Active Cleanup	Risk Driver	Near-term Post-cleanup
Legacy Site EUs							
618-11 Burial Grounds	RC-LS-1	Sr-90	Low	Sr-90	Low	Sr-90	Low
K–Area Waste Sites	RC-LS-2	C-14	Medium	C-14	Medium	C-14	Medium
BC Cribs and Trenches	CP-LS-1	I-129, Tc-99, Cr(a)	High	I-129, Tc-99, Cr(a)	High	I-129, Tc-99, Cr(a)	High
Pu-Contam-inated Waste Sites	CP-LS-2	CCl4	Very High	CCl4	Very High	CCl4	Very High
Tank Waste and Farms							
T Tank Farm	CP-TF-1	Cr(a)	High ǂ	Cr(a)	High ǂ	Cr(a)	High
S-SX Tank Farms	CP-TF-2	Cr(a)	High ǂ	Cr(a)	High ǂ	Cr(a)	High
TX-TY Tank Farms	CP-TF-3	Tc-99, CCl4, Cr(a)	High ǂ	Tc-99, CCl4, Cr(a)	High ǂ	Tc-99, CCl4, Cr(a)	High
U Tank Farm	CP-TF-4	Various(b)	Low ǂ	Various(b)	Low ǂ	Various(b)	Low
A-AX Tank Farms	CP-TF-5	Cr(a)	Medium ǂ	Cr(a)	Medium ǂ	Cr(a)	Medium
B-BX-BY Tank Farms	CP-TF-6	I-129, Tc-99, Cr(a)	High ǂ	I-129, Tc-99, Cr(a)	High ǂ	I-129, Tc-99, Cr(a)	High
C Tank Farms	CP-TF-7	I-129	Medium ǂ	I-129	Medium ǂ	I-129	Medium
200 East (DSTs)	CP-TF-8	Various(b)	Low	Various(b)	Low	Various(b)	Low
200 West (DSTs)	CP-TF-9		ND		ND		ND

a. Cr represents both total and hexavalent chromium

b. The various non-zero inventory PCs are C-14, I-129, Sr-90, Tc-99, Cr(a), U-Total

APPENDIX A

HANFORD SITE-WIDE RISK REVIEW PROJECT DIRECTION MEMORANDUM

Department of Energy
Washington, DC 20585
January 16, 2014

MEMORANDUM FOR DAVID G. HUIZENGA
SENIOR ADVISOR
FOR ENVIRONMENTAL MANAGEMENT

DAVID S. KOSSON
PRINCIPAL INVESTIGATOR, CONSORTIUM FOR RISK
EVALUATION WITH STAKEHOLDER PARTICIPATION

FROM: DAVID M. KLAUS
DEPUTY ~~UNDER~~ SECRETARY
FOR MANAGEMENT AND PERFORMANCE

SUBJECT: Hanford Site-Wide Risk Review Project

The purpose of this memo is to request the conduct of a Hanford site-wide evaluation of human health, nuclear safety, environmental and cultural resource risks (Risk Review Project). The goal of the Risk Review Project is to identify and characterize potential risks and impacts to the public, workers, and the environment at the Hanford Site and to inform the efficient use of Department of Energy (DOE) Environmental Management (EM) resources. The project shall be independently led by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) and shall involve the active cooperation and participation of senior management at DOE-EM, DOE-Office of River Protection (ORP) and DOE-Richland (RL) as well as by U.S. Environmental Protection Agency (EPA) and the State of Washington Departments of Ecology and Health as participants in a Core Team to be established as part of the execution of the project. Additionally, the Pacific Northwest National Laboratory will provide assistance in a supporting role to CRESP during the Project.

The purpose of the Risk Review Project is to review existing information and to develop a summary level catalogue of risks and impacts to the environment and to rate or bin those risks and impacts according to the magnitude of potential risks to the members of the public, workers, and to the environment. The Risk Review Project should take into consideration: current and potential future impacts to human health (public and workers), land and river ecology, nuclear safety, natural resources, and cultural resources. This effort is to focus on risks associated with cleanup work that is currently on-going and remaining at the Hanford Site, and therefore recommendations should be prospective in nature. On-going and future cleanup work to be considered includes tank waste treatment and tank closure; soils, vadose zone and groundwater remediation; facility decommissioning; on-site near-surface disposal; and on-site risks from transuranic and high level wastes projected for off-site disposition for which formal regulatory completion of the remedy or corrective action has not been achieved. The review should place Hanford environmental and nuclear safety hazards and risks in context with currently designated future uses of the Hanford site and nearby land uses and activities that have a potential to impact risks, natural resources, and cultural resources. Additional context should be provided on impacts to on-site and nearby economic resources.

The participation of EPA Region 10 and EPA Headquarters and Washington Department of Ecology (Ecology) and Washington Department of Health (Health) is an important component of the Risk Review Project. Toward that end, please ensure that EPA, Ecology and Health are provided the opportunity to have representation on the Core Team, which will be established to oversee the development of risk characterization metrics and templates for determining risk ratings, the analysis and integration of rating results and to develop conclusions and recommendations regarding the risks and impacts evaluated. Additionally, please consult with appropriate tribal nations and give other stakeholders and agencies an opportunity to provide input during the execution of the Risk Review Project.

To help ensure efficient completion of the Project, I am directing the following:

1. EM, ORP, and RL will make the necessary staff and resources available to assist CRESP in conducting the review in a timely manner. This includes active senior management participation on the Core Team; and
2. EM, ORP, and RL will provide CRESP with all appropriate written reports, investigations, reviews, maps, charts, surveys, summaries or other communications or documents and access to electronic databases that CRESP may request as needed for the Risk Review Project. Documentation and electronic data may include mapping or other geographic information system data and overlays.

CRESP is responsible for scheduling meetings and/or teleconferences as needed, with cooperation from RL, ORP and EM. CRESP is to carry out the Risk Review Project based on the following schedule:

1. Within 2 months, initiate Core Team meetings to be held in Richland, WA;
2. Within 9 months, provide for review a set of approximately half of the draft summaries and specific evaluations to be completed and an interim progress report; and
3. Within 18 months, provide a draft final report.

A more detailed schedule is to be developed and updated quarterly. Quarterly progress summaries are to be provided by CRESP as well as progress briefings, as requested.

APPENDIX B

[Name of Evaluation Unit]
EVALUATION UNIT SUMMARY TEMPLATE

Table of Contents

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Part I. Executive Summary

EU Location: [i.e. 100 Area]

Related EUs: [i.e. groundwater EU]

Primary Contaminants, Contaminated Media and Wastes:

[Provide a listing of the primary contaminants that are risk drivers, associated wastes and their physical/chemical form. Note that the terminology "primary contaminants" is used to differentiate from a regulatory list of "contaminants of potential concern." For this Risk Review Project, a shorter list of primary contaminants is used to focus on the risk drivers in each EU as well as contaminants that are considered iconic for the Hanford Site (uranium, plutonium, technetium, etc.). This is a brief summary of the key contaminants, media, wastes, and forms (should be given as a comma delimited list).]

Brief Narrative Description:

[Limit to 2-3 concise paragraphs]

Summary Tables of Risks and Potential Impacts to Receptors

Table 1 provides a summary of nuclear and industrial safety related risks to humans and impacts to important physical Hanford Site resources.

Human Health: A Facility Worker is deemed to be an individual located anywhere within the physical boundaries of the EU; a Co-located Person (CP) is an individual located 100 meters from the facility; and Public is an individual located at the closest point on the Hanford Site boundary not subject to DOE access control, which in this instance is the west bank of the Columbia River. The nuclear related risks to humans are based on unmitigated (unprotected or controlled conditions) dose exposures expressed in a range from Non-Discernable (ND) to Very High. The estimated mitigated exposure that takes engineered and administrative controls and protections into consideration is shown in parentheses.

Groundwater and Columbia River: Direct impacts to groundwater resources and the Columbia River have been rated based on available information for the current status and estimates for future time periods. These impacts are also expressed in a range from ND to Very High.

Ecological Resources: The risk ratings are based on the degree of physical disruption (and potential additional exposure to contaminants) in the current status and as a potential result of remediation options.

Cultural Resources: No risk ratings are provided for cultural resources. The table identifies the three overlapping cultural resource landscapes that have been evaluated: Native American (approximately 10,000 years ago to the present), Pre-Hanford Era (1805 to 1943), and Manhattan/Cold War Era (1943 to 1990); and provides initial information on whether an impact (both direct and indirect) is KNOWN (presence of cultural resources established), UNKNOWN (uncertainty about presence of cultural resources), or NONE (no cultural resources present) based on written or oral documentation gathered on the entire EU and buffer area. Direct impacts include but are not limited to physical destruction (all or part) or alteration such as diminished integrity. Indirect impacts include but are not limited to the introduction of visual, atmospheric, or audible elements that diminish the cultural resource's significant historic features. Impacts to cultural resources as a result of proposed future cleanup activities will be evaluated in depth under Section 106 of the National Historic Preservation Act (16 USC 470, et. seq.) during the planning for remedial action.

Table 1: Risk Rating Summary (for human health, unmitigated nuclear safety basis indicated, mitigated basis indicated in parenthesis (e.g., " High" (Low)).

Population or Resource		Evaluation Time Periods	
		Active Cleanup (to 2064)	
		Current Condition/ Operations	**From Cleanup Actions**
Human	Facility Worker		
	Co-located Person		
	Public		
Environmental	Groundwater		
	Surface Water		
	Ecological Resources*		
Social	Cultural Resources*	**Native American**: Direct: Indirect: **Historic Pre-Hanford**: Direct: Indirect: **Manhattan/Cold War**: Direct: Indirect:	**Native American**: Direct: Indirect: **Historic Pre-Hanford**: Direct: Indirect: **Manhattan/Cold War**: Direct: Indirect:

*For ecological and cultural resources see Appendices J and K, respectively, for a complete description of ecological field assessments and literature review for cultural resources.

Support for Risk and Impact Ratings for Each Population or Resource

HUMAN HEALTH

Current

[Briefly describe each hazardous radiological initiating event that could cause an unmitigated dose consequence of greater than Low risk to Co-located Person]

[Event 1]: [Unmitigated hazard description]

Unmitigated Risk: Facility Worker – [rating]; CP – [rating]; Public – [rating]

Mitigation: [Description of mitigation measures that reduce risk to Low]

Mitigated Risk: Facility Worker – [rating]; CP – [rating]; Public – [rating]

[Event 2]: [Unmitigated hazard description]

Unmitigated Risk: Facility Worker – [rating]; CP – [rating]; Public – [rating]

Mitigation: [Description of mitigation measures that reduce risk to Low]

Mitigated Risk: Facility Worker – [rating]; CP – [rating]; Public – [rating]

Industrial Safety: [Briefly describe each potential industrial accident that could cause an unmitigated risk to the Facility Worker of greater than Low]

Unmitigated Risk: Facility Worker – [rating]; CP – [risk]; Public – [risk]

Mitigation: [Description of mitigation measures that reduce risk to Low]

Mitigated Risk: Facility Worker – [rating]; CP – [rating]; Public – [rating]

Risks and Potential Impacts from Selected or Potential Cleanup Approaches

[Discuss the risks and potential impacts to human health from selected or potential cleanup approaches]

ECOLOGICAL RESOURCES

Current

[Briefly describe current risks to ecological resources at the EU]

Risks and Potential Impacts from Selected or Potential Cleanup Approaches

[Briefly describe risks to ecological resources during cleanup work at the EU]

CULTURAL RESOURCES

Current

[Briefly describe current risks to cultural resources at the EU]

Risks and Potential Impacts from Selected or Potential Cleanup Approaches

[Briefly describe risks to cultural resources during cleanup work at the EU]

CONSIDERATIONS FOR TIMING OF THE CLEANUP ACTIONS

[Discuss the concerns if remediation is deferred until late in the cleanup period. For example, for D&D cases it may point to the loss of the building envelope integrity, resulting in more complex D&D and increased worker risk. For HLW tanks, this may point towards future leakage from specific tanks that may be important. In some cases, delay may be beneficial because of radioactive decay. For Operating Facilities, this section may not be applicable and should just be indicated as "NA".]

NEAR-TERM, POST-CLEANUP RISKS AND POTENTIAL IMPACTS

[Discuss the risks and potential impacts to human health, ecological and cultural resources in the near term after completion of the proposed cleanup]

Part II. Administrative Information

OU and/or TSDF Designation(s):

Common name(s) for EU:

Key Words:

Regulatory Status

Regulatory basis: [CERCLA, RCRA, WA MOTCA?]

Applicable regulatory documentation: [i.e., baseline risk assessment, RI/FS, NEPA EIS, records of decision, etc.]

Applicable Consent Decree or TPA Milestones:

Risk Review Evaluation Information

Completed (revised): [date]

Evaluated by: [name]

Ratings/Impacts Reviewed by: [names]

Part III. Summary Description

Current Land Use:

Designated Future Land Use: [This should be the land use designation from the Comprehensive Land Use EIS]

Primary EU Source Components [These next subsections should be a listing/brief identification/ description of the major components within the EU by source component types, or N/A if not applicable]

Legacy Source Sites:

High-Level Waste Tanks and Ancillary Equipment:

Groundwater Plumes:

D&D of Inactive Facilities:

Operating Facilities:

Location and Layout Maps

[Provide a map/figure illustrating the location of the EU within the Hanford Site and one or more “zoom ins” that illustrates the layout of sources within the EU]

Part IV. Unit Description and History

EU Former/Current Use(s)

[Discuss the current and historical use of the EU being evaluated, using the list of questions as a guide. Provide additional diagrams where appropriate. Only use the subsections that are applicable to the EU being considered. This section, in combination with the inventory in Part V, should provide all of the information needed to carry out the risk ratings with respect to each type of receptor. For groundwater, the range of concentrations within the plume or plume maps are appropriate, as well as the estimated rate of expansion/contraction of impacted groundwater. For surface soils and vadose zone, travel times and concentrations needed to describe impacts to groundwater should be included.]

Legacy Source Sites –

[Includes soils, cribs, trenches, vertical pipe units, buried TRU, etc.]
What is the origin and history of the contamination (e.g., accidental release, intentional discharge, multiple discharges)?

What are the primary contaminants (risk drivers)?

Are there co-contaminants that will affect mobility of the primary contaminants?

What is the depth of contamination and soil type/stratigraphy associated with the contamination? Is the soil profile primarily natural or heavily disrupted?

What is the physical state of the primary contaminants (i.e., adsorbed in contaminated soil, as debris, in subsurface piping)?

Is information available indicating the partition coefficients and other important transport parameters for the primary contaminants with the type of soil (if yes, provide table)?

What is the source and reliability of the information available to describe the contaminants (risk drivers) and materials present?

High-Level Waste Tanks –

Which processes produced the waste contained in the tanks within the farm?

How is the waste contained in the tanks classified (e.g., HLW, CH-TRU, RH-TRU)?

What nuclear safety concerns exist for the tanks/tank farm (e.g., adequate dispersal of hydrogen)?

[The response to this question can be a table indicating the tank IDs, hydrogen generation rate, time to LFL in the absence of active controls, and summary of fissile materials]

What types of tanks (i.e., tank construction/configuration) are located in the tank farm?

[The response to this question can be a table indicating the tank IDs, tank type, type of waste, and quantity of each waste type]

What is the origin of the contamination (e.g., spills, intentional discharges, disposal areas)?

Does the tank farm have known or suspected leaks from specific tanks? If yes, describe the extent and period of known or suspected leakage.

What are additional sources of contamination in the tank farm (e.g., spills, intentional discharges, disposal areas)? Describe the extent and period of intentional and unintentional discharges.

What is the current assessment of the integrity of each tank?

What ancillary infrastructure is contained within the tank farm (i.e., transfer pits, transfer piping, etc.)?

What is the depth of contamination and sediment types/stratigraphy associated with the contamination associated with past releases or leakage?

When is the waste in the tank farm scheduled for retrieval?

What measures have been taken to reduce migration of past contamination?

Groundwater Plumes –

What is the source and reliability of the information available to describe the contaminants (risk drivers) and materials present?

What is the origin of the contamination (e.g., spills, intentional discharges, disposal areas)?

What are the primary contaminants (risk drivers)?

Are there co-contaminants that will affect mobility of the primary contaminants?

What is the depth of the groundwater table from the ground surface? Has the depth to groundwater changed significantly since the contamination was emplaced? How is the depth to groundwater expected to change over the period of evaluation?

What is the depth of contamination and sediment types/stratigraphy associated with the contamination?

What is the physical state of the primary contaminants (e.g., adsorbed in contaminated sediments, dissolved in groundwater, present in or as non-aqueous phase fluids)?

Are perched water or contaminated hydrologic lenses present?

Are there continuing contaminant sources that are currently adding to the extent of contamination or may in do so in the future over the evaluation period? (Can the source concentrations be defined for the primary contaminants?)

Is there information on the site contamination and hydrology with respect to interpreting current and future plume migration (e.g., temporal history of plume to estimate rate of spread)?

D&D of Inactive Facilities –

What is the footprint and size of the facility?

What are the physical components and their sizes?

What is the current status of components?

What are the forms of the residual contamination (i.e., in process piping and tanks, on facility walls and surfaces, contained in hot cells or glove boxes, etc.)?

What is the primary construction of the facility (i.e., concrete, steel shell, etc.)? Does it contain asbestos or PCBs?

Are there particular elements of the facility that are considered to have high radionuclide inventory relative to the rest of the facility or risk drivers?

What is the integrity of the building and structural containment envelope (i.e., is the building fully intact, in a state of decay such that leakage into or out of the building is occurring or imminent, are safety systems such as ventilation and fire suppression fully functional)?

What is the proposed end-state for the building (i.e., demolition, entombment, other)?

Are there tanks currently containing wastes associated with the facility? If yes, what is the nature and volume of the waste, the construction of the tank, and the tank integrity?

Is the surrounding area or area under the facility adequately characterized with respect to contamination, contaminants, and contaminant transport processes?

Operating Facilities –

What processes produced the radioactive material and waste contained in the facility?

What are the primary radioactive and non-radioactive constituents that are considered risk drivers?

What types of containers or storage measures are used for radioactive materials at the facility?

How is the radioactive material and waste contained or stored within the facility classified?

What are the average and maximum occupational radiation doses incurred at the facility?

What processes and operations are conducted within the facility?

What is the process flow of material into and out of the facility?

What effect do potential delays have on the processes, operations, and radioactive materials in the facility?

What other facilities or processes are involved in the flow of radioactive material into and out of the facility?

Is shipping of material involved, and if so, how often and by what means?

What infrastructure is considered a part of the facility?

Ecological Resources Setting

[Briefly describe the ecological setting of the EU and the resources at risk within or adjacent to the EU. Keep in mind that this will be in context with the earlier report chapter that provides a detailed description of the Hanford Site ecological resources.]

Cultural Resources Setting

[Briefly describe the cultural resource setting of the EU and the resources at risk within or adjacent to the EU. Keep in mind that this will be in context with the earlier report chapter that provides a detailed description of the Hanford Site cultural resources.]

Part V. Waste and Contamination Inventory

[This section is intended to be a summary of contaminants and contaminated media. Results in this section may be best described in table or narrative form and figures (such as relative inventories of specific radionuclides for individual sources as developed for the Tank Farm pilot) may be applicable here. The discussion should be broken out by the type of sources and specific units (tanks, ancillary piping, near-surface soils, vadose zone, etc.) where applicable.]

Brief description of contaminated media and materials
What are the primary contaminants (risk drivers)?
What is the physical state of the primary contaminants (e.g., adsorbed in contaminated soil, as debris, in subsurface piping)?

Contamination within Primary EU Source Components

Legacy Source Sites:

High-Level Waste Tanks and Ancillary Equipment:

Vadose Zone Contamination:

Groundwater Plumes:

Facilities for D&D:

Operating Facilities:

Part VI. Potential Risk/Impact Pathways and Events

Current Conceptual Model

[Provide a narrative description of the pathways and barriers to receptors and conditions/events that can lead to completed pathways or specific forms of risks or impacts. The barriers discussion should include (1) a description of institutional, natural, and engineered barriers (including material characteristics) that currently mitigate or prevent risk or impacts; and (2) time scale from loss of each barrier to realization of risk or impacts. Each major source type needs to be considered and discussed (hence, subsections for each applicable source type). For EUs with multiple types of sources, these questions need to be answered for each source type. The questions are to be repeated in the narrative and should serve as the basis for the response. Subsections that are not applicable should be deleted.]

Pathways and Barriers: (1. description of institutional, natural, and engineered barriers (including material characteristics) that currently mitigate or prevent risk or impacts; 2. time scale from loss of each barrier to realization of risk or impacts)

Briefly describe the current institutional, engineered, and natural barriers that prevent release or dispersion of contamination, risk to human health, and impacts to resources:

1. What nuclear and non-nuclear safety accident scenarios dominate risk at the facility? What are the response times associated with each postulated scenario?
2. What are the active safety class and safety significant systems and controls?
3. What are the passive safety class and safety significant systems and controls?
4. What are the current barriers to release or dispersion of contamination from the primary facility? What is the integrity of each of these barriers? Are there completed pathways to receptors or are such pathways likely to be completed during the evaluation period?
5. What forms of initiating events may lead to degradation or failure of each of the barriers?
6. What are the primary pathways and populations or resources at risk from this source?
7. What is the timeframe from each of the initiating events to human exposure or impacts to resources?
8. Are there current ongoing releases to the environment or receptors?

Populations and Resources Currently at Risk or Potentially Impacted

[In the following sections, briefly describe the receptors that may be impacted or at risk. Be quantitative/descriptive to the extent possible but do not repeat earlier information. This is considering a 50-year timeframe and assuming the area remains under DOE control at least until cleanup of the EU is complete. Indicate "not applicable" where appropriate (the 50-year timeframe assumes that cleanup of an individual EU will not be completed for 50 years to establish a comparison for risks and potential impacts and thus provide input for sequencing of cleanup). For example, if a groundwater plume is not capable of reaching the Columbia River from the Central Plateau, then indicate "not applicable". Similarly, if the public does not have access, the result would be "not applicable" for many/most evaluation units. Institutional controls are assumed to be effective for the purposes of this review.]

Facility Worker:

Co-located Person:

Public:

Groundwater:

Columbia River:

Ecological Resources: Summary

Cultural Resources: Summary

Cleanup Approaches and End-State Conceptual Model

Selected or Potential Cleanup Approaches

What are the selected cleanup actions or the range of potential remedial actions?

[If a particular cleanup or end-state has been selected (e.g., through an EIS or CERCLA ROD) then this should be the assumed baseline cleanup approach and/or end state. If not, then the range of potential cleanup actions should be considered. For each type of source, the Overall Methodology section of the report will define a range of potential cleanup approaches and their general impacts (i.e., degree of disturbance of the area, change in contamination inventory, etc.). For buildings, decontamination, entombment, demolition; for soils, excavation, capping or in-situ immobilization, indicate estimated timeframe and quantity of effort to achieve assumed remediation.]

What is the sequence of activities and duration of each phase?

What is the magnitude of each activity (i.e., cubic yards of excavation, etc.)?

Contaminant Inventory Remaining at the Conclusion of Planned Active Cleanup Period

Risks and Potential Impacts Associated with Cleanup

Populations and Resources at Risk or Potentially Impacted During or as a Consequence of Cleanup Actions

[In the following sections, briefly describe the receptors that may be impacted or at risk. Be quantitative/descriptive to the extent possible but do not repeat earlier information. This is considering a 50-year timeframe and assuming the area remains under DOE control at least until cleanup of the EU is complete. Indicate "not applicable" where appropriate (the 50-year timeframe assumes that cleanup of an individual EU will not be completed for 50 years to establish a comparison for risks and potential impacts and thus provide input for sequencing of cleanup). For example, if a groundwater plume is not capable of reaching the Columbia River from the Central Plateau, then indicate "not applicable". Similarly, if the public does not have access, the result would be "not applicable" for many/most evaluation units. Institutional controls are assumed to be effective for the purposes of this review.]

Facility Worker:

Co-located Person:

Public:

Groundwater:

Columbia River:

Ecological Resources:

Cultural Resources:

Additional Risks and Potential Impacts if Cleanup is Delayed

[Describe any additional risks or impacts if the cleanup is delayed, such as increased D&D complexity if the building envelope is compromised and would result in increased D&D complexity, cost, and worker risk. Note that for the purposes of sequencing, we are assuming that all of the cleanup actions occur at the end of the 50-year cleanup period.]

Near-Term, Post-Cleanup Status, Risks and Potential Impacts

Populations and Resources at Risk or Potentially Impacted after Cleanup Actions (from residual contaminant inventory or long-term activities)

[Provide risk rating and short explanatory comment in this table for the timeframe]

Table 5.

Population or Resource		Risk/Impact Rating	Comments
Human	Facility Worker		
	Co-located Person		
	Public		
Environmental	Groundwater		
	Columbia River		
	Ecological Resources*		
Social	Cultural Resources*	**Native American:** Direct: Indirect: **Historic Pre-Hanford:** Direct: Indirect: **Manhattan/Cold War**: Direct: Indirect:	

*For ecological and cultural resources see Appendices J and K, respectively, for a complete description of ecological field assessments and literature review for cultural resources.

Long-Term, Post-Cleanup Status – Inventories and Risks and Potential Impact Pathways

[Provide a narrative description of the remaining contamination/wastes, the physical form, and potential initiating events and pathways that may result in exposure or disruption. This information will be used to paint a picture of the site and its surroundings relative to long-term legacy.]

Part VII. Supplemental Information and Considerations

[Provide tables and any other relevant information – do not use appendices]

Bibliography

APPENDIX C

LIST OF REMEDIATION OPTIONS USED AS PLANNING BASIS

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
RC-LS-1 (Interim)	618-11 Burial Ground	300-FF-2	DOE/RL-2013-02 Table A-1 ROD (Final, 2013)	Record of Decision (ROD) for 300-FF-2 and 300-FF-5, and Record of Decision Amendment for 300-FF-1 The major components of the selected remedy for the 300-FF-2 Operable Unit (OU) are: - Remove, Treat, and Dispose (RTD) at waste sites - Temporary surface barriers and pipeline void filling - Enhanced attenuation of uranium using sequestration in the vadose zone, periodically rewetted zone (PRZ), and top of the aquifer - Institutional controls (ICs)
RC-LS-2 (Interim)	K Area Waste Sites: legacy waste sites within the fence at 100-K, where remediation is post 2015	100-KR-1	DOE/RL-2013-02 Table A-1	ROD (Interim Action): Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units (EPA/ROD/R10-99/039): *Remove Treat Dispose for 46 sites; disposal of debris from B, D, H, and K reactors to ERDF; provides decision framework for leaving waste in place, generally below 15-ft depth.*
		100-KR-2	DOE/RL-2013-02 Table A-1	ROD (Interim Action): Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units (EPA/ROD/R10-99/039): *Remove Treat Dispose for 46 sites; disposal of debris from B, D, H, and K reactors to ERDF; provides decision framework for leaving waste in place, generally below 15-ft depth.*
			DOE/RL-2013-02 Table A-1	Declaration of the Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2 and the 100-KR-2 Operable Units (EPA/ROD/R10-00/121): Remove contaminated soil, structures, and debris; treat as needed; dispose at ERDF; backfill and revegetate.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-LS-1 (Interim)	BC Cribs and Trenches: cribs, trenches and tank located to the south of the 200-E Area	200-BC-1 (Note: Utilized 200-WA-1)	DOE/RL-2010-49, DRAFT A	These sites are covered under DOE/RL-2000-38, 200-TW-1 Scavenged Waste Group Operable Unit and 200-TW-2 Tank Waste Group Operable Unit RI/FS Work Plan, but are included in this work plan for consistency in information collection and storage. These sites will also be covered in the 200-WA-1 FS.
			DOE/RL-2013-02 (Table B-3 CP-15)	**CP-15 – Remediate Remaining 200 West Inner Area Contaminated Soil Sites (200-WA-1 OU)** Cleanup Decision Summary and Relevant Decision Documents Several action memoranda are in place to remove contaminated soil, structures, and debris from 200 West Inner Area soil sites with disposal at ERDF. Range of Alternatives - RTD of approximately half of waste sites and cap remainder. - RTD of all waste sites; backfill and revegetate. - Cap and maintain under long-term stewardship (LTS) with monitoring and appropriate institutional controls. If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including institutional control ICs and 5-year reviews of remedy effectiveness.
CP-LS-2 (Interim)	Plutonium (Pu) contaminated cribs and trenches associated with PFP in central part of 200-W Area	200-PW-1,3,6 200-CW-5	DOE/RL-2013-02 (Table A-1) CERCLA Final ROD	Record of Decision, Superfund Site 200-CW-5 and 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units (EPA 2011c): - RTD of soil and debris to specified depths or specified cleanup levels for plutonium-contaminated soils and subsurface structures and debris. - Soil vapor extraction at three 200-PW-1 waste sites will continue until vadose zone cleanup levels are met. - Soil covers will be used to provide coverage to a depth of at least 15 ft over cesium-contaminated soils. Removal of sludge followed by tank stabilization for two tanks. - No action for two waste sites. - ICs and long-term monitoring for waste sites where contamination is left in place and an unrestricted land use is precluded.

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-TF-1 (Interim)	T tank farm, ancillary structures, associated liquid waste sites, and soils contamination	200-DV-1, WMA T, 200-WA-1	DOE/RL-2013-02 (Table B-3 TW-1)	**TW-1 Tank Waste – Tank Retrieval and Single-Shell Tank Farm Closure** Tank Closure and Waste Management EIS Record of Decision (78 FR 75913, December 13, 2013) sets the following requirements for tank retrieval and closure: • 99% retrieval of waste by volume from the single-shell tanks (SSTs). • Leak detection monitoring and routine maintenance. • New and existing storage facilities. • Operations and necessary maintenance, waste transfers and associated operations, and upgrades to existing tanks or construction of waste receipt facilities. • SST closure operations include filling the tanks and ancillary equipment with grout to immobilize the residual waste. • Disposal of contaminated equipment and soil would occur on site. • Decisions on the extent of soil removal or treatment would be made on a tank farm or waste management area basis through the Resource Conservation and Recovery Act (RCRA) closure permitting process. • The tanks would be stabilized, and an engineered modified RCRA Subtitle C barrier put in place followed by post-closure care. Existing decisions for tank retrieval are also present within the Tri-Party Agreement (TPA) and the Consent Decree [State of Washington v. DOE, No. 08-5085-FVS (E.D. Wa.)]: • TPA milestone M-45-00 states “Closure will follow retrieval of as much tank waste as technically possible, with tank waste residues not to exceed 360 cubic feet in each of the 100 series tanks, 30 cubic feet in each of the 200 series tanks, or the limit of waste retrieval technology, whichever is less.” A procedure for gaining an exemption from this requirement is outlined in Appendix H of the TPA. • The Consent Decree defines retrieval requirements for 10 tanks in C Farm and 9 additional tanks. Up to three retrieval technologies may be required to their “limits of technology” in an effort to obtain the waste residue goal of 360 cubic feet of waste or less. Provisions are provided to determine the “practicability” of continued use of a retrieval technology including matters “such as risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval mission.”

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-TF-2 (Interim)	S-SX tank farms, ancillary structures, associated liquid waste sites, and soils contamination; includes 242-S Evaporator	WMA S/SX, 200-DV-1, 200-WA-1		Same as CP-TF-1
CP-TF-3 (Interim)	TX-TY tank farms, ancillary structures, associated liquid waste sites, and soils contamination; includes 242-T Evaporator	WMA TX/TY, 200-DV-1, 200-WA-1		Same as CP-TF-1
CP-TF-4 (Interim)	U tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA U, 200-WA-1		Same as CP-TF-1

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-TF-5 (Interim)	A-AX tank farms, ancillary structures, associated liquid waste sites, and soils contamination	WMA A/AX, 200-EA-1, 200-PW-3		Same as CP-TF-1
CP-TF-6 (Interim)	B-BX-BY tank farms, ancillary structures, associated liquid waste sites, and soils contamination	WMA B/BX/BY, 200-DV-1, 200-EA-1		Same as CP-TF-1
CP-TF-7 (Interim)	C tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA C		Same as CP-TF-1
CP-TF-8 (Interim)	200-East DSTs: AN, AP, AW, AY, AZ tank farms, ancillary structures, associated liquid waste sites, and soils contamination	Not Applicable	DOE/RL-2013-02 (Table B-3 TW-4)	**TW-4 Tank Waste – Double-Shell Tank Closure** Cleanup Decision Summary and Relevant Decision Documents No cleanup decisions have been made. Decisions have been deferred to future decision-making processes. <u>Range of Alternatives</u> - Retrieve double-shell tank (DST) wastes consistent with RCRA; achieve designated retrieval objectives or limits of technology; remediate structures and soil and install cover/cap to meet closure performance standards; maintain post-closure care and monitoring consistent with RCRA Permit. - Close under RCRA.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-TF-9 (Interim)	200-West DSTs: SY tank farm, ancillary structures, associated liquid waste sites, and soils contamination	WMA S/SX	DOE/RL-2013-02 (Table B-3 TW-4)	**TW-4 Tank Waste – Double-Shell Tank Closure** Cleanup Decision Summary and Relevant Decision Documents No cleanup decisions have been made. Decisions have been deferred to future decision-making processes. <u>Range of Alternatives</u> - Retrieve DST wastes consistent with RCRA; achieve designated retrieval objectives or limits of technology; remediate structures and soil and install cover/cap to meet closure performance standards; maintain post-closure care and monitoring consistent with RCRA Permit. - Close under RCRA.
RC-GW-1 (Interim)	300 Area uranium and associated contaminant plumes	300-FF-5	DOE/RL-2013-02 Table A-1 ROD (Final, 2013)	Record of Decision for 300-FF-2 and 300-FF-5, and Record of Decision Amendment for 300-FF-1 The major components of the selected remedy for the 300-FF-2 OU are: - Remove, Treat and Dispose (RTD at waste sites - Temporary surface barriers and pipeline void filling - Enhanced attenuation of uranium using sequestration in the vadose zone, Periodically Rewetted Zone (PRZ, and top of the aquifer - Institutional Controls (ICs
RC-GW-2 (Interim)	100-N Strontium strontium and associated contaminant plumes	100-NR-2	DOE/RL-2013-02 (Table A-1) CERCLA Interim Action ROD	Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, (EPA/ROD/R10-99/112) - ICs for shoreline site; in situ and RTD with ex situ bioremediation for petroleum sites - RTD for remainder of sites in 100-NR-1 - Maintain ERA pump and treat (P&T) for 100-NR-2 Deploys the apatite sequestration technology for remediating strontium-90 in the 100-NR-2 OU by extending existing apatite permeable reactive barrier.
			DOE/RL-2013-02 (Table B-2 RC-4.3)	**RC-4.3– Restore 100-NR-2 Groundwater OU to Beneficial Use** An action memorandum, interim ROD, and Explanation of Significant Differences (ESD) are in place to clean up strontium-90 in the groundwater using P&T and physical barriers. An in situ apatite barrier and phytoremediation treatability tests are being evaluated for use in the cleanup of strontium-90 in groundwater.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
				Range of Plausible Alternatives - Resume operation of existing P&T system; operate and expand system as necessary until cleanup objectives are achieved; transition to surveillance and maintenance (S&M) for post-treatment groundwater monitoring. - Construct an impermeable barrier along the shoreline to redirect groundwater flow and increase travel times for radioactive decay to achieve cleanup objectives. - Expand the apatite permeable reactive barrier to promote sequestration of strontium-90. - Incorporate phytotechnology. - Use sequestration and immobilization technologies for inner portion of strontium-90 plume. - Allow monitored natural attenuation to proceed under LTS with institutional controls. - If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including institutional control ICs and 5-year reviews of remedy effectiveness.
RC-GW-3 (Interim)	100-B/D/H/F/K Area chromium and associated contaminant plumes, includes pump and treat systems	100-BC-5	DOE/RL-2013-02 (Table B-2 RC-4.1)	**RC-4.1– Restore 100-BC-5 Groundwater OU to Beneficial Use** No cleanup decisions have been made for this OU. Groundwater monitoring and reporting continue to track groundwater contamination in this OU. Range of Plausible Alternatives - Install P&T system in 100-BC-5; transition to S&M for post-treatment groundwater monitoring. - Incorporate bioremediation for chromium. - Allow monitored natural attenuation to proceed under LTS with institutional control ICs. If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including institutional controls and 5-year reviews of remedy effectiveness.

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
		100-KR-4	DOE/RL-2013-02 Table A-1 CERCLA Interim Action ROD	Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units: - Remove hexavalent chromium from groundwater; 30 extraction wells; ion exchange treatment; reinject treated effluent. - Implement in situ redox manipulation barrier for second chromium plume. - Monitor. - Institute ICs
			DOE/RL-2013-02 (Table B-2 RC-4.2)	**RC-4.2– Restore 100-KR-4 Groundwater OU to Beneficial Use** An interim ROD is in place to clean up hexavalent chromium in the groundwater using P&T <u>Range of Plausible Alternatives</u> - Expand the P&T system in 100-KR-4; transition to S&M for post-treatment groundwater monitoring. - Continue operation of P&T system with incorporation of bioremediation for chromium. - Allow monitored natural attenuation to proceed under LTS with ICs. If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including ICs and 5-year reviews of remedy effectiveness.
		100-HR-3	DOE/RL-2013-02 Table A-1 CERCLA Interim Action ROD	Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units: - Remove hexavalent chromium from groundwater; 30 extraction wells; ion exchange treatment; reinject treated effluent. - Implement in situ redox manipulation barrier for second chromium plume. - Monitor. - Institute ICs.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
			DOE/RL-2013-02 (Table B-2 RC-4.4)	**RC-4.4– Restore 100-HR-3 Groundwater OU to Beneficial Use** An interim ROD, ROD amendment, and ESDs are in place to clean up hexavalent chromium in the groundwater using P&T and an in situ reduction/oxidation ("redox") manipulation barrier. <u>Range of Plausible Alternatives</u> - Expand P&T system in 100-HR-3; transition to S&M for post-treatment groundwater monitoring. - Maintain and repair in situ redox manipulation barrier. - Incorporate bioremediation. - Allow monitored natural attenuation to proceed under LTS with institutional controls. - If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including institutional control ICs and 5-year reviews of remedy effectiveness.
		100-FR-3	DOE/RL-2013-02 (Table B-2 RC-4.5)	**RC-4.5 – Restore 100-FR-3 Groundwater OU to Beneficial Use** No cleanup decisions have been made for this OU. <u>Range of Plausible Alternatives</u> - Install P&T system in 100-FR-3; transition to S&M for post-treatment groundwater monitoring. - Incorporate bioremediation for chromium. - Allow monitored natural attenuation to proceed under LTS with institutional controls. If residual contamination remains after cleanup actions are completed, cleanup work will transition to LTS, including institutional controls and 5-year reviews of remedy effectiveness.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-GW-1 (Interim)	Existing groundwater plumes emanating from 200-E Area	200-BP-5, 200-PO-1	DOE/RL-2013-02 (Table B-3 CP-22)	**CP-22 – Restore 200 East Groundwater to Beneficial Use (200-PO-1/200-BP-5 OUs)** Cleanup Decision Summary and Relevant Decision Documents No cleanup decisions have been made for the 200 East groundwater. <u>Range of Alternatives:</u> - Install P&T system for 200-BP-5 OU; implement monitored natural attenuation for 200-PO-1 OU; perform well support and maintenance activities. - Allow monitored natural attenuation to proceed under LTS with appropriate institutional control ICs. - Install P&T system for 200-BP-5 and selective P&T for 200-PO-1 hot spots. Note: 400 Area groundwater cleanup actions are included as part of 200-PO-1 OU.
CP-GW-2 (Interim)	Existing groundwater plumes emanating from 200-W Area; includes pump and treatment systems	200-ZP-1,	DOE/RL-2013-02 Table A-1	ROD (200-ZP-1 Final): - Pump and Treat P&T to address carbon tetrachloride, nitrate, chromium, trichloroethylene, I-129, Tc-99, and tritium - Monitored natural attenuation - Flow-path control through injection of treated water - ICs
		200-UP-1	DOE/RL-2013-02 Table A-1 ROD (Interim Action): EPA 2012	*Record of Decision for Interim Remedial Action, Hanford 200 Area Superfund Site 200-UP-1 Operable Unit* (12-AMRP-0171) AR/PIR Accession Number 0091413 The major components of the selected remedy for the 200-UP-1 OU are: - Groundwater extraction/treatment - Monitored natural attenuation - I-129 hydraulic containment and treatment technology evaluation - Remedy performance monitoring - Institutional Control ICs
RC-DD-1 (Interim)	324 Building and associated soil contamination under the building	324 Building	DOE/RL-2013-02 Table A-2	**Action Memorandum #2 for the 300 Area Facilities** Provides for D4 of the 324 and 327 Buildings and ancillary facilities in the 300 Area with D4 waste going to ERDF. The AM provides a list of the ancillary facilities. In general, slabs and subsurface structures would be removed along with about 1 m of surrounding soil; however, on a case-by-case basis, the slabs and/or below-grade structures and soils can be deferred to CERCLA actions associated with the 300-FF-2 OU.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
			DOE/RL-2013-02 Table C-21 (PBS RL-0041)	The D4 process includes deactivating the facility by removing loose hazardous materials and equipment; decontaminating the facility to allow open-air demolition; and decommissioning the facility by disconnecting utilities and services. The structure is then demolished using techniques such as track hoe, processor, loader, cranes, explosives, cutting equipment, or other methods, and the demolition debris are disposed, generally to ERDF. Following demolition, samples are collected to verify that cleanup criteria are met, and the sites are backfilled and revegetated.
		300-FF-2	DOE/RL-2013-02 Table A-1 CERCLA Interim Action ROD	Declaration of the Interim Record of Decision for the 300-FF-2 Operable Unit (EPA/ROD/R10-01/119): - Remove contaminated soil, structures, and debris; treat as needed; dispose at ERDF, WIPP, or other. - Backfill and revegetate. - Establish ICs. - Continued groundwater monitoring EPA 2004b: - Uranium soil cleanup level from 350 to 267 pCi/g based on engineering study to ensure protectiveness of the groundwater and river - Modified land use assumption for eight outlying waste sites from industrial to unrestricted changed cleanup levels for these sites to those consistent with 100 Area cleanup.
			DOE/RL-2013-02 Table A-1 ROD (Final)	Record of Decision for 300-FF-2 and 300-FF-5, and Record of Decision Amendment for 300-FF-1 (Hanford Administrative Record Accession Number: 0087180, 2013) The major components of the selected remedy for the 300-FF-2 OU are: - Remove, Treat and Dispose (RTD at waste sites - Temporary surface barriers and pipeline void filling - Enhanced attenuation of uranium using sequestration in the vadose zone, Periodically Rewetted Zone (PRZ, and top of the aquifer - Institutional Controls (ICs

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
RC-DD-2 (Interim)	KE/KW Reactors, basin, ancillary buildings, and associated soil contamination	*105-K Reactor*	DOE/RL-2013-02 Table A-2	**Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities (DOE and EPA 2007)** Identifies ISS for 105-KE and 105-KW reactor cores, decontamination and decommissioning (D&D) of reactor components up to the cores and for remaining buildings and structures in 100-K Area. Subsurface structures will be removed 3 ft bgs; substructures and soil beneath facilities that exceed cleanup levels will be evaluated through source OU cleanup activities that are considered final for the ancillary facilities and demolished portions of the reactors. Further decisions are expected on reactor cores in ISS.
		100 K Basins	DOE/RL-2013-02 Table A-1 CERCLA Interim Action ROD	Declaration of the Record of Decision for the 100-KR-2 Operable Unit, (EPA/ROD/R10-99/059) - Remove spent nuclear fuel from basins. - Remove sludge from basins, including sludge treatment prior to interim storage. - Treat and remove water from the basins. - Remove debris from the basins, including grouting in place. - Deactivate and remove the basins. - Institute ICs.
			DOE/RL-2013-02 (Table B-2 RC-2)	**RC-2 – Disposition 100 Area K West Basin** An interim ROD, ROD amendment, and action memorandum are in place for the removal, treatment, and interim onsite storage of spent nuclear fuel and sludge from the K Basins. **Range of Plausible Alternatives** - Remove, treat, and transfer sludge for interim storage at T Plant. - Transfer fuel scrap for interim storage at Canister Storage Building. - D4 K West Basin and ancillary structures. - Remediate below-grade portions consistent with 100 Area contaminated soil sites.* * May require removing K Reactors to access below-grade contaminated soils. K East Basin was demolished in 2009.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
		100-KR-1 (includes 100-K Ancillary Bldgs and legacy sites)	DOE/RL-2013-02 Table A-1	ROD (Interim Action): Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units: (EPA/ROD/R10-99/039) *Remove Treat Dispose for 46 sites; disposal of debris from B, D, H, and K reactors to ERDF; provides decision framework for leaving waste in place, generally below 15-ft depth.*
		100-KR-2 (includes 100-K Ancillary Bldgs and legacy sites)	DOE/RL-2013-02 Table A-1	ROD (Interim Action): Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units: (EPA/ROD/R10-99/039) *Remove Treat Dispose for 46 sites; disposal of debris from B, D, H, and K reactors to ERDF; provides decision framework for leaving waste in place, generally below 15-ft depth.*
			DOE/RL-2013-02 Table A-1	Declaration of the Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2 and the 100-KR-2 Operable Units (EPA/ROD/R10-00/121) Remove contaminated soil, structures, and debris; treat as needed; dispose at ERDF; backfill and revegetate.
		100-K Ancillary Bldgs	DOE/RL-2013-02 Table A-2	**Action Memorandum for the Non-Time-Critical Removal Action for the 100-K Area Ancillary Facilities (DOE and EPA 2005b)** Provides for D4 of 27 buildings/structures in northern part of 100-K Area with D4 waste going to ERDF. In general, slabs and subsurface structures would be removed with about 1 m of surrounding soil; however, on a case-by-case basis, the slabs, below-grade structures, and soils can be deferred to CERCLA actions associated with 100-KR-1 and 100-KR-2 source OUs.
			DOE/RL-2013-02 Table A-2	**Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities (DOE and EPA 2007)** Identifies ISS for 105-KE and 105-KW Reactor cores, D&D of reactor components up to the cores **and for remaining buildings and structures in 100-K Area**. Subsurface structures will be removed 3 ft bgs; substructures and soil beneath facilities that exceed cleanup levels will be evaluated through source OU cleanup activities that are considered final for the ancillary facilities and demolished portions of the reactors. Further decisions are expected on reactor cores in ISS.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-DD-1 (Interim)	PUREX Canyon, tunnels, ancillary buildings, structures, and associated near-surface contaminated soils	200-CP-1 - Canyon	DOE/RL-2013-02 (Table B-3 CP-5)	**CP-5– Disposition PUREX Canyon Building/Associated Waste Sites (200-CP-1 OU)** Several action memoranda are in place to remove contaminated soil, structures, and debris from waste sites with disposal at ERDF. Future cleanup decisions for remaining buildings and waste sites will be included in decision documents (e.g., action memoranda, RODs). <u>Range of Alternatives:</u> - Remove all contents and D4 PUREX Canyon Building including below-grade foundation; remove all contaminated materials, associated waste sites and contaminated soils to achieve RAOs; dispose all wastes and debris at approved facility. - Condition contents to place in spaces below canyon deck level; stabilize and fill voids; remove contaminated wastes and soils from associated waste sites and dispose at approved facility; partially demolish building to canyon deck level; place engineered barrier over demolished structure; maintain ICs and perform post-closure monitoring and caretaking. - Condition contents, retrieve associated waste site contaminated soils and debris, and place in PUREX Canyon for entombment (option to allow other wastes); stabilize and fill voids; surround with clean fill and place an engineered barrier over the canyon building; maintain institutional control ICs and perform post-closure monitoring and caretaking.

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
		200-CP-1 - Tunnel	DOE/RL-2013-02 (Table B-3 CP-6)	**CP-6– Disposition PUREX Storage Tunnels (200-CP-1 OU)** Cleanup Decision Summary and Relevant Decision Documents No cleanup decisions have been made for the PUREX storage tunnels. <u>Range of Alternatives:</u> - Maintain safe storage, perform hazardous waste facility closure consistent with RCRA Permit, remediate radionuclides consistent with CERCLA, and conduct post-closure monitoring. - Stabilize waste and prepare tunnels for in-place disposal, install barrier, perform post-closure care, and transition to LTS. - Remove and dispose waste and contaminated equipment from tunnels, evaluate tunnels for residual contamination and remediate tunnels consistent with 200 East Inner Area contaminated soil sites.
		200-MG-1	DOE/RL-2013-02 (Table B-3 CP-5)	DOE/RL-2009-48; DOE/RL-2009-86 Action memoranda to remove contaminated soil, structures, and debris from waste sites with disposal at ERDF.
		200-MG-2	DOE/RL-2013-02 (Table B-3 CP-5)	DOE/RL-2009-37 Action memoranda to remove contaminated soil, structures, and debris from waste sites with disposal at ERDF.

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
RC-OP-1 (Interim)	KE/KW fuel storage and sludge	*105-K Reactor*	DOE/RL-2013-02 Table A-2	**Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities" (DOE and EPA 2007)** Identifies ISS for 105-KE and 105-KW Reactor cores, D&D of reactor components up to the cores and for remaining buildings and structures in 100-K Area. Subsurface structures will be removed 3 ft bgs; substructures and soil beneath facilities that exceed cleanup levels will be evaluated through source OU cleanup activities that are considered final for the ancillary facilities and demolished portions of the reactors. Further decisions are expected on reactor cores in ISS.
		100 K Basins	DOE/RL-2013-02 Table A-1 CERCLA Interim Action ROD	Declaration of the Record of Decision for the 100-KR-2 Operable Unit, (EPA/ROD/R10-99/059) - Remove spent nuclear fuel from basins. - Remove sludge from basins, including sludge treatment prior to interim storage. - Treat and remove water from the basins. - Remove debris from the basins, including grouting in place. - Deactivate and remove the basins. - Institute ICs.
			DOE/RL-2013-02 (Table B-2 RC-2)	**RC-2 – Disposition 100 Area K West Basin** An interim ROD, ROD amendment, and action memorandum are in place for the removal, treatment, and interim onsite storage of spent nuclear fuel and sludge from the K Basins. <u>Range of Plausible Alternatives:</u> - Remove, treat, and transfer sludge for interim storage at T Plant. - Transfer fuel scrap for interim storage at Canister Storage Building. - D4 K West Basin and ancillary structures. - Remediate below-grade portions consistent with 100 Area contaminated soil sites.* * May require removing K Reactors to access below-grade contaminated soils. K East Basin was demolished in 2009.

Appendix C: List of Remediation Options Used as Planning Basis
(Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
		100-KR-2 (includes 100 K Ancillary Bldgs and legacy sites)	DOE/RL-2013-02 Table A-1	ROD (Interim Action): Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units: (EPA/ROD/R10-99/039) *Remove Treat Dispose for 46 sites; disposal of debris from B, D, H, and K reactors to ERDF; provides decision framework for leaving waste in place, generally below 15-ft depth.*
			DOE/RL-2013-02 Table A-1	Declaration of the Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2 and the 100-KR-2 Operable Units (EPA/ROD/R10-00/121) Remove contaminated soil, structures, and debris; treat as needed; dispose at ERDF; backfill and revegetate.
CP-OP-1 (Interim)	Central Waste Complex (CWC) operations, closure, and D&D		DOE/RL-2013-02 (Table B-3 CP-12)	**CP-12– Disposition Remaining Waste Treatment, Storage and Disposal Facilities*** No cleanup decisions have been made for the remaining waste treatment, storage, and disposal facilities. <u>Range of Plausible Alternatives:</u> - Closure of facilities will be according to approved operating plans and closure plans (e.g., RCRA Closure Plans); consequently, cleanup actions will be determined and accomplished in accordance with applicable regulatory and permit/license requirements. **No other alternatives are being considered.** * Includes LERF/ETF, WESF, WRAP, 222-S Lab, IDF, and Inert Waste Landfill/Pit 9. (Note: CWC not specifically mentioned but would fall into this category.)
CP-OP-3 (Interim)	Waste Encapsulation and Storage Facility (WESF): Evaluate for the storage and removal of Cs/Sr capsules; D&D included with B Plant EU	Not Applicable	DOE/RL-2013-02 (Table B-3 CP-9)	**CP-9 – Disposition Cesium/Strontium Capsules** No cleanup decisions have been made for final disposition of the cesium/strontium capsules. Decisions have been deferred to future decision-making processes. <u>Range of Plausible Alternatives:</u> - Package and transport capsules from WESF to dry storage; store capsules pending final disposition; direct dispose of capsules at a geologic repository. - Incorporate capsules into immobilized high-level waste glass at WTP. Store capsules at Hanford for 300 years (approximately 10 half-lives); after natural decay, direct dispose of capsules as mixed low-level radioactive waste.

Appendix C: List of Remediation Options Used as Planning Basis (Interim Report EUs only)

Evaluation Unit (EU) ID*	Description & Comments	Operable Unit Cross-Walk	Reference	Existing Cleanup Decisions
CP-OP-6 (Interim)	Environmental Restoration Disposal Facility (ERDF) operations and closure	Not Applicable	DOE/RL-2013-02 (Table A-1) FINAL ROD	Declaration of the Record of Decision for the Environmental Restoration Disposal Facility (EPA/ROD/R10- 95/100) - Landfill construction in accordance with RCRA - Capped at completion
			DOE/RL-2013-02 (Table B-6)	Central Plateau–Manage ERDF - ERDF was approved according to a CERCLA Final ROD and closure and post-closure care are part of the operating documentation. Alternatives need not be analyzed unless future decisions are made that modify the current final ERDF decisions.

APPENDIX D

SHORT BIOGRAPHIES OF

CRESP and PNNL PARTICIPANTS

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*CRESP Management Board member

1. CRESP Leadership

David S. Kosson*

David Kosson, PhD (CRESP Principal Investigator) is Cornelius Vanderbilt Professor of Engineering at Vanderbilt University, where he has appointments as Professor of Civil and Environmental Engineering, Chemical Engineering, and Earth and Environmental Sciences. Professor Kosson also is the Principal Investigator for the multi-university Consortium for Risk Evaluation with Stakeholder Participation (www.CRESP.org), supported by the Department of Energy to improve the risk-informed basis for remediation and management of nuclear waste from former defense materials production and nuclear energy. Professor Kosson's research focuses on management of nuclear, energy production, and industrial wastes, including process development and contaminant mass transfer applied to groundwater, soil, sediment, waste, and cementitious materials systems. Dr. Kosson in collaboration with other Vanderbilt researchers, U.S. Environmental Protection Agency, and the Energy Research Centre of The Netherlands has developed the Leaching Environmental Assessment Framework (LEAF) for understanding the release of contaminants from wastes and construction materials under a wide range of use and disposal scenarios (www.vanderbilt.edu/Leaching). Dr. Kosson leads the Cementitious Barriers Partnership (www.CementBarriers.org), which is a multi-institution initiative focused on developing advanced tools for predicting the long-term performance of cementitious materials in nuclear applications. Professor Kosson has participated in or led many external technical reviews on nuclear waste processing for the Department of Energy including for tank wastes and a range of technology approaches at Hanford, Savannah River, and Idaho sites. Dr. Kosson served as a member of U.S. DOE Secretary Chu's team to address design challenges associated with the Hanford Waste Treatment Plant. Professor Kosson also has provided expertise and leadership for the National Academies, and as an advisor to the Department of Defense, for two decades on demilitarization of chemical weapons in the United States and abroad. Professor Kosson has authored more than 100 peer-reviewed professional journal articles, book, book chapters, and other archival publications. He received his PhD in Chemical and Biochemical Engineering from Rutgers University, where he subsequently was Professor of Chemical and Biochemical Engineering.

Charles W. Powers*

Charles W. Powers, PhD (CRESP Co-Principal Investigator), is Professor of Environmental Engineering at Vanderbilt where he is co-PI (with David Kosson) of CRESP, which he co-founded in 1995. This many-discipline consortium exists to advance cost-effective, risk-informed cleanup and disposition of nuclear waste by carrying out independent scientific evaluation and fostering decisions based on the informed consent of affected publics.

Dr. Powers' early academic career was spent at Yale University where, as associate professor of social ethics, he led the University's multi-disciplinary graduate program in ethics. He has been an environmental officer in the private sector (Cummins Engine Company), the founding chair or CEO of eight environmental institutions and consortia including the Health Effects Institute, Clean Sites, the NY/NJ Harbor Consortium, and he was the custodial trustee of the nation's then #5 Superfund site (Industri-plex). In addition to Yale and Vanderbilt, he has been on the faculties of Robert Wood Johnson Medical School, Tufts, Harvard, Princeton, and Haverford. He is an author of some 85 peer reviewed articles on diverse scientific and policy issues and an author of The Ethical Investor: Universities and Corporate Responsibility (New Haven) and The Great Experiment: Brownfields Pilots Catalyze Revitalization (New Brunswick). Dr. Powers received his BA with honors from Haverford College, and holds graduate degrees from Oxford University, Union Theological Seminary, and two from Yale University, including his PhD.

*CRESP Management Board member

Jennifer A. Salisbury

After graduating from the University of New Mexico School of Law, Jennifer A. Salisbury, JD, spent the first part of her career working in the United States Congress, including as Director of Legislation for a senator. Then, she served as a trial lawyer in such positions as Assistant United States Attorney and General Counsel of a state agency. Later, her career shifted away from legal jobs and toward executive management positions in government, such as at the Department of the Interior, where she provided management oversight as Deputy Assistant Secretary of such federal agencies as the Minerals Management Service and National Park Service. This was followed by a seven-year stint as the Cabinet Secretary of New Mexico's natural resources agency. While Secretary, Salisbury coordinated the state's efforts to ensure New Mexico's radioactive waste transportation safety program had been completely implemented by the time shipments of transuranic waste to the Waste Isolation Pilot Plant began in March 1999.

Since leaving government, Salisbury has served as a consultant on such issues as environmental cleanup, nuclear waste transportation, and natural resource development on public lands. Salisbury also mediates legal disputes. She recently ended ten years of service as a member of the Department of Energy’s Environmental Management Advisory Board and currently serves as board chair of a non-profit that fosters collaborative processes to develop concrete recommendations for tackling important state policy concerns.

2. CRESP

Craig H. Benson*

Craig H. Benson, PhD, PE, DGE, is Wisconsin Distinguished Professor and Chair of Geological Engineering at the University of Wisconsin-Madison. He also serves as Director of the Recycled Materials Resource Center (RMRC), a federally funded research center focused on sustainable construction of transportation infrastructure, and the Bioreactor Partnership, an industry-academic partnership on sustainable solid waste management. He is a member of the Management Board of CRESP. Dr. Benson has a BS from Lehigh University and MSE and PhD degrees from the University of Texas at Austin. Dr. Benson has been conducting experimental and analytical research in geoenvironmental engineering for 27 years, with the primary focus in environmental containment, beneficial use of industrial byproducts, and sustainable infrastructure. His research has included laboratory studies, large-scale field experiments, and computer modeling. Dr. Benson has received several awards for his work, including the Huber Research Prize, the Alfred Nobel Prize, and the Croes (twice), Middlebrooks, Collingwood, and Casagrande Awards from the American Society of Civil Engineers. Dr. Benson is a member of the ASCE Geo-Institute (GI) and is former Editor-in-Chief of the ASCE/GI Journal of Geotechnical and Geoenvironmental Engineering. He currently serves as Treasurer for the ASCE/GI Board of Governors and is a member of the Executive Committee of ASTM Committee D18 on Soil and Rock. Dr. Benson is a member of the University of Texas Academy of Distinguished Alumni.

Kevin G. Brown

Kevin Brown, PhD, is Senior Research Scientist in the Department of Civil and Environmental Engineering at Vanderbilt University. His research has been supported by CRESP. Dr. Brown’s current research focuses on life-cycle risk evaluation, model integration, and waste management issues related to proposed advanced nuclear fuel cycles and cementitious materials and barriers for nuclear applications. Between 1986 and 2002 at the Savannah River Laboratory, he was recognized as a DOE Complex-wide authority in process and product control for high-level waste vitrification. Dr. Brown spent 2002-2003 at the International Institute for Applied Systems Analysis in Laxenburg, Austria, where he estimated potential transboundary radiation doses resulting from hypothetical accidents at Russian Pacific Fleet sites. Dr. Brown led the CRESP evaluation of life-cycle risks for the DOE Idaho Site Subsurface Disposal Area, where wastes contaminated with radioactive and hazardous materials were buried in pits, trenches, and soil vaults before 1970. The Idaho results were presented to the Idaho Site Citizens Advisory Board, who strongly endorsed the clarity of the approach and the results. In 2009, Dr. Brown was a member of the External Technical Review Team chartered by DOE-HQ to evaluate the system-level modeling and simulation tools in support of Savannah River Site and Office of River Protection liquid waste processing and disposal. In 2010 and 2011, Dr. Brown participated on the Tank Waste Subcommittee of the DOE Environmental Management Advisory Board charted to provide independent technical reviews of liquid waste capital and operations projects related to DOE-EM's tank waste cleanup program at major DOE sites. He participated in Construction Project Reviews for the Hanford Tank Waste Treatment and Immobilization Plant in 2011 and 2013 and the Savannah River Salt Waste Processing Facility in 2011, 2012, and 2013. In 2011 and 2012, Dr. Brown applied the prioritization model developed by CRESP to prioritize remediation and associated projects at DOE sites to Melton Valley, Experimental Molten Salt Reactor Experiment, East Tennessee Technology Park, and Bear Creek Burial Grounds at the Oak Ridge National Laboratory. He holds a BE in Chemical Engineering, an MS in Environmental and Water Resources Engineering, and a PhD in Environmental Engineering all from Vanderbilt University.

Joanna Burger *

Joanna Burger, PhD, is a Distinguished Professor of Biology at Rutgers University and a professor in the School of Public Health, where she teaches ecology, behavior, and ecological risk to undergraduate and graduate students. Her primary research has been in ecotoxicology, risk assessment, behavioral ecology, biomonitoring, and stakeholder involvement, especially at Department of Energy Sites, including Savannah River Site, Oak Ridge, Brookhaven, Idaho National Laboratory, Los Alamos, Amchitka Island, and Hanford. She has studied the interactions of ecosystems and people for over 30 years, including monitoring levels of radionuclides, mercury, and other contaminants on environmental health. Additional research involves public perceptions and attitudes, inclusion of stakeholders in solving environmental problems, and the efficacy of conducting stakeholder-driven and stakeholder-collaborative research. Professor Burger has participated in reviews for the Department of Energy, as well as the educational program of the Nuclear Regulatory Commission. She has edited a book on science and stakeholders, aimed at understanding the role of a full range of stakeholders in energy-related decisions, focusing on several case studies of Department of Energy sites. She is on the Editorial Board for Journal of Nuclear Energy and Power Generation Technologies, Environmental Research, Science for the Total Environment, Environmental Monitoring and Assessment, and Journal of Toxicology and Environmental Health. Professor Burger has participated on many National Academy of Sciences committees, including serving on the Board of Environmental Science and Toxicology and Board of Biology, as well as several committees for the U.S. Environmental Protection Agency (most recently on unique exposures for environmental justice communities). Professor Burger has authored more than 400 peer-reviewed professional journal articles, books, and book chapters. She received the Lifetime Distinguished Achievement Award from the Society of Risk Analysis, as well as being a Fellow of several societies. She received her BS in Biology from the State University of New York at Albany, her MS in Zoology and Science Education from Cornell University, her PhD in Ecology from the University of Minnesota in Minneapolis, Minnesota, and an Honorary PhD from the University of Alaska at Fairbanks.

James H. Clarke*

Jim Clarke, PhD, is Professor of the Practice of Civil and Environmental Engineering and Professor of Earth and Environmental Sciences at Vanderbilt University. Prior to joining the faculty of Vanderbilt University in the Fall of 2000, he was Chairman, President, and CEO of Eckenfelder, Inc., an environmental engineering and consulting firm focusing on services to the private sector in the areas of hazardous waste management, contaminated site investigation, and remediation and wastewater treatment. Jim's experience includes the investigation, risk assessment, technology evaluation, and remediation of over 30 Superfund sites. His research at Vanderbilt focuses on the investigation, remediation, and long-term management of legacy hazardous chemical and radioactive waste sites and the energy – environment interface.

Jim was a member of the former Nuclear Regulatory Commission (NRC) Advisory Committee on Nuclear Waste and Materials and advised the Commission and the Office of Nuclear Materials Safety and Safeguards on issues concerning the Yucca Mountain project, risk-informed performance-based approaches to site decommissioning and remediation (lead Committee member), and the overall nuclear waste regulatory program. He is a consultant to the NRC Advisory Committee for Reactor Safeguards and its subcommittee on Radiation Protection and Nuclear Materials. Jim is a member of the American Academy of Environmental Engineers and Scientists and has served on committees of the National Academies (the Committee on Remediation of Buried and Tank Waste). He is a peer reviewer for the National Academy, the U.S. Environmental Protection Agency, the Department of Energy, and several journals and book publishers.

Dr. Clarke received his PhD in theoretical physical chemistry from The Johns Hopkins University and a BA in chemistry with honors from Rockford College.

Allen G. Croff

Allen G. Croff has a BS in chemical engineering from Michigan State University, a Nuclear Engineer Degree from the Massachusetts Institute of Technology, and an MBA from the University of Tennessee. He worked at Oak Ridge National Laboratory (ORNL) for 29 ½ years and retired in 2003. While employed at ORNL, Mr. Croff was involved in technical studies and program development focused on waste management and nuclear fuel cycles, including development of the ORIGEN2 computer code and study of actinide partitioning-transmutation. Mr. Croff chaired a committee of the National Council on Radiation Protection and Measurements that produced the 2002 report titled "Risk-Based Classification of Radioactive and Hazardous Chemical Wastes" and the Nuclear Energy Agency's Nuclear Development Committee from 1992 to 2002. He was also vice-chairman of the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste and Materials from 2004 until its merger with the Advisory Committee on Reactor Safeguards in 2008. Mr. Croff was a member of the DOE Nuclear Energy Research Advisory Committee from 1998 to 2005 and seven previous committees of the National Academies. He is currently a member of the National Council on Radiation Protection and Measurements, the National Academies' Nuclear and Radiation Studies Board, and a National Academies committee on a development of a DOE cleanup technology roadmap.

Lyndsey Fern Fyffe

Lyndsey Fyffe is a graduate research assistant with CRESP and PhD Candidate in Environmental Engineering at Vanderbilt University in Nashville, Tennessee. Her research area is nuclear and chemical safety, with a dissertation focused on analyzing trends (qualitative and quantitative) from accidents in both the nuclear industry and the chemical industry to improve safety and efficiency of operations at nuclear chemical facilities. Ms. Fyffe has an MS in Environmental Engineering from Vanderbilt and a BS in Civil and Environmental Engineering from Duke University.

Michael Gochfeld

Michael Gochfeld, MD, PhD, is an environmental toxicologist and occupational physician who is Professor in the Department of Environmental and Occupational Medicine at Rutgers-Robert Wood Johnson Medical School in the Environmental and Occupational Health Sciences Institute (Piscataway, New Jersey). He is one of the founding members of CRESP, which provides a variety of research endeavors supporting the Department of Energy's management of nuclear and chemical contamination from the manufacture and testing of nuclear weapons. His research has focused on ecological and human health consequences of occupational and environmental exposure to heavy metals, particularly mercury. From 1999 to 2001, he chaired New Jersey's Mercury Task Force. His work on mercury included investigating cultural practices resulting in exposure to elemental mercury as well as mercury risks from fish consumption.

He has been active in exploring unique environmental exposure pathways, and environmental justice. He has also chaired the international Cadmium Working Group for the Scientific Group on Methodology for Safety Evaluation of Chemicals, part of the International Scientific Committee on Problems of the Environment. He is also a clinician seeing patients exposed to heavy metals and other contaminants in their home, community, or workplace environments, one aspect of which is evaluation of high-end fish consumers exposed to methylmercury. He received the Health Achievement Award from the American College of Occupational and Environmental Medicine. He is author of over 200 peer-reviewed papers on environmental and occupational health and has contributed book chapters on toxicology and risk assessment.

Kathryn A. Higley*

Kathryn Higley, PhD, is a Professor in the Department of Nuclear Engineering. She holds a BA in Chemistry (1978) from Reed College, an MS in Radiological Health Sciences (1992), and a PhD in Radiological Health Sciences (1994) from Colorado State University. Her fields of interest include environmental transport and fate of radionuclides, radiochemistry, radiation dose assessment, neutron activation analysis, nuclear emergency response, and environmental regulations.

She has held both Reactor Operator and Senior Reactor Operator's licenses, and is a former Reactor Supervisor for the Reed College TRIGA reactor. She has held research positions at three research reactors including Reed College, Washington State University (Pullman), and Oregon State University. She has fourteen years with Battelle, Pacific Northwest Laboratories as an environmental health physicist at the Hanford Nuclear Reservation, and three years' experience in environmental radiation monitoring at the Trojan Nuclear Power Plant in Oregon. She is a consultant to the U.S. Department of Energy's Office of Air, Water and Radiation Protection. She is a member of the Health Physics Society and a certified Health Physicist. Dr. Higley has been at Oregon State University since 1994 teaching undergraduate and graduate classes on radioecology, dosimetry, radiation protection, radiochemistry, societal aspects of nuclear technology, and radiation biology.

George M. Hornberger

George Hornberger, PhD, is Distinguished University Professor at Vanderbilt University where he holds appointments as the Craig E. Philip Professor of Civil & Environmental Engineering and Professor of Earth & Environmental Sciences. Professor Hornberger is the Director of the Vanderbilt Institute for Energy and Environment, which fosters research, teaching and outreach on social, economic, legal, and technical aspects of critical issues at the energy-environment intersection. For many years he was a member of the faculty at the University of Virginia, where he held the Ernest H. Ern Chair in Environmental Sciences. He received a PhD in Hydrology from Stanford University in 1970. In addition to interdisciplinary research underway through VIEE, he continues his longstanding research on the transport of dissolved and suspended constituents through soils, groundwater, and catchments. Hornberger is a Fellow of the American Geophysical Union, of the Association for Women in Science, and of the Geological Society of America. He is a recipient of the Robert E. Horton Award of the Hydrology Section of AGU, the Biennial Medal for Natural Systems of the Modelling and Simulation Society of Australia, the John Wesley Powell Award for Citizen's Achievement from the USGS, the Excellence in Geophysical Education Award from AGU, and the William Kauala Award from AGU. He was the 2002 Langbein Lecturer of the American Geophysical Union. He was selected as Outstanding Scientist in Virginia in 2007. He is a member of the U.S. National Academy of Engineering.

Kimberly L. Jones*

Kimberly L. Jones, PhD, is a professor of Environmental Engineering and Chair of the Department of Civil and Environmental Engineering at Howard University in Washington, DC. She holds a BS in Civil Engineering from Howard University, an MS in Civil and Environmental Engineering from the University of Illinois in Champaign, and a PhD in Environmental Engineering from The Johns Hopkins University. Dr. Jones' research interests include developing membrane processes for environmental applications, physical-chemical processes for water and wastewater treatment, remediation of emerging contaminants, and environmental nanotechnology.

Dr. Jones currently serves on the Chartered Science Advisory Board of the U.S. Environmental Protection Agency, and as chair of the Drinking Water Committee of the Science Advisory Board. She has served on the Water Science and Technology Board of the National Academy of Sciences, and the Board of Association of Environmental Engineering and Science Professors, where she was Secretary of the Board. She has served on several committees of the National Academy of Science and the Institute of Medicine. She served as the Deputy Director of the Keck Center for Nanoscale Materials for Molecular Recognition, one of the first centers to bring nanotechnology research to Howard University. She also serves on the Center Steering Committee of the Center for the Environmental Implications of Nanotechnology (CEINT), a National Environmental Nanotechnology Center. Dr.

Jones has received a Top Women in Science Award from the National Technical Association, the Outstanding Young Civil Engineer award from University of Illinois Department of Civil and Environmental Engineering, a NSF CAREER Award, an Outstanding Leadership and Service award from the College of Engineering, Architecture and Computer Sciences at Howard, Outstanding Faculty Mentor award from the American Society of Civil Engineers HU Student Chapter and Top Women Achievers award from Essence Magazine. She also served as an associate editor of the Journal of Environmental Engineering (ASCE).

Steven L. Krahn*

Steven Krahn, PhD, is Professor of the Practice of Nuclear Environmental Engineering in the Department of Civil and Environmental Engineering at Vanderbilt University. Immediately prior to coming to Vanderbilt, he served in the U.S. DOE as the Deputy Assistant Secretary for Safety & Security in the Office of Environmental Management (EM). He is performs research as part of CRESP in the areas of nuclear and environmental risk assessment and risk management and the insertion of advanced technology into nuclear facilities. While at DOE, Dr. Krahn served as the Deputy Chair of the Nuclear Safety Research and Development Committee, which provided oversight and direction to safety-related research; directed the technology development program for the nuclear waste processing; chaired the EM Technical Authority Board, charged with providing final technical approval of new facilities and major modifications to nuclear facilities; and was selected by the Deputy Secretary to serve on the Risk Assessment Working Group, DOE's technical leadership team for overseeing the development of improved quantitative risk analysis in the department. He has led or served on dozens technical reviews of nuclear facilities and radioactive waste processing systems for DOE sites including Savannah River, Hanford, Idaho, Oak Ridge, and others. He has also provided nuclear/environmental engineering and risk assessment consultation to the U.S. nuclear industry for more than a dozen years and to NASA for five years. He received his Doctorate in Public Administration from the University of Southern California and holds an MS in Materials Science from the University of Virginia. He previously taught systems engineering at The George Washington University and the University of Maryland.

Eugene J. LeBoeuf

Eugene J. LeBoeuf, PhD, PE, is an Associate Professor of Civil and Environmental Engineering at Vanderbilt University. He also serves as the Associate Chair for the Department of Civil and Environmental Engineering and Director of Undergraduate Studies. His teaching and research interests include water resources engineering, surface and groundwater hydrology, and physicochemical processes of environmental systems, including fate and transport of contaminants in the environment.

Dr. LeBoeuf received his BS in civil engineering from Rose-Hulman Institute of Technology in 1985, MS in industrial engineering and management science from Northwestern University in 1986, MS in civil engineering from Stanford University in 1993, and a PhD in environmental engineering from The University of Michigan in 1998. He has over 40 archival peer-reviewed publications and one U.S. patent. He is a registered professional engineer in the states of Tennessee and Missouri, and a member of the American Academy of Environmental Engineers and Scientists as a Board Certified Environmental Engineer. Dr. LeBoeuf also serves as a Colonel in the U.S. Army Reserve, having served in a number of Army and joint military positions both on active duty and in the Reserve. He is currently serving as Chief of Staff, 416th Theater Engineer Command, Dairen, Illinois.

Henry J. Mayer

Henry J. Mayer, PhD, is Executive Director of the Environmental Analysis & Communications Group, Director of the Bloustein-CAIT Ports Program, and a Faculty Fellow at the E.J. Bloustein School of Planning & Public Policy, Rutgers University. Dr. Mayer has extensive experience in the corporate, academic, and government arenas, with a focus over the past fifteen years on the large and complex environmental, infrastructure, and capital financing issues associated with the redevelopment of many of the country's older cities and towns. His recent work has included examining the policies, programs and decisions that have influenced the development and life-cycle costs of the U.S. Department of Energy's environmental management cleanup efforts at the nation's former nuclear weapons sites over the past fifteen years. He recently completed a Background Forensics Analysis of the Portsmouth and Paducah Gaseous Diffusion Facilities Decontamination and Demolition.

Richard B. Stewart*

Richard B. Stewart, LLB, is a world-recognized scholar in environmental, administrative, and regulatory law, having published over 10 books and nearly 100 articles in these fields. He is University Professor, John E. Sexton Professor of Law, New York University. He is Director of the Frank T. Guarini Center on Environmental and Land Use Law, and of the Hauser Global law School program at NYU. His recent work has included a major forthcoming book, with Jane Stewart, that provides the first comprehensive history and account of U.S. nuclear waste law and regulatory policy, several articles on nuclear waste policy, and a co-authored book that sets forth a general program for reform of U.S. environmental law. Before joining NYU in 1992, Stewart was Byrne Professor of Administrative Law at Harvard Law School and, from 1989-91, Assistant Attorney General in charge of the Environment and Natural Resource Division of the U.S. Department of Justice, where he formulated the U.S. government's position on the Rio Climate Convention, prosecuted Exxon for the Exxon Valdez oil spill, and was responsible for legal issues relating to DOE's defense facilities and wastes, including representing the U.S. in Nevada's unsuccessful litigation challenge to the constitutionality of the Nuclear Waste Policy Act. Stewart is Advisory Trustee and former Chairman, Environmental Defense Fund. Stewart is a graduate of Yale University, Harvard Law School, and Oxford University, where he was a Rhodes Scholar. He is a member of the American Academy of Arts and Sciences and the American Law Institute. He holds honorary degrees from the University of Rome "La Sapienza" and Erasmus University, Rotterdam.

Hamp Turner

Dr. Hamp Turner has more than 25 years' experience in software development, data management, and engineering process modeling. He is the owner of Turner Technology, LLC (Nashville, TN), a software and engineering consulting company founded in 2001. He previously worked for OLI Systems, Inc. (Morris Plains, NJ).

Interests include the development of systems and interfaces that provide a bridge between complex modeling and software technology and the skill sets of less sophisticated computer users. This includes the integration of engineering computer models with internet interfaces and with Microsoft Excel and the management and presentation of complex data sets.

Dr. Turner has a PhD in chemical engineering from Rutgers University.

3. PNNL

Wayne Johnson
PNNL Lead and Core Team Liaison

Mr. Johnson, PE, is the Director of the Earth Systems Science Division within Pacific Northwest National Laboratory's Energy and Environment Directorate, overseeing six technical groups and approximately 250 staff. ESSD conducts a wide range of environment-related research in support of waste cleanup, natural resource management, and energy production. Mr. Johnson possesses more than 29 years of management experience in the fields of nuclear engineering and radiological science, environment and earth sciences, and energy systems. Specific areas of expertise include complex project planning and strategic analysis, systems engineering, radiological controls, threat detection, environmental remediation, and waste management. This includes serving as an Officer in the U.S. Navy at Naval Reactors, management responsibilities for environmental restoration and technology deployment projects at the Hanford Site, and project management and consulting support to multiple radiological facilities at various DOE and International sites, including the development and implementation of reactor accident cleanup and stabilization plans at the Chernobyl Site in the Ukraine. He currently has the assignment to be PNNL's lead in providing support to Japan in response to the Fukushima disaster. He is a registered Professional Engineer, Nuclear in the State of Washington. Mr. Johnson holds an MS in Engineering Management from Washington State University (1995) and a BS in Nuclear Engineering from Oregon State University (1983). Mr. Johnson is a member of the American Nuclear Society (since 1981).

Robert Bryce

Mr. Bryce has 34 years of experience managing or performing applied environmental research. He has managed environmental programs and major ground-water monitoring and hydrologic characterization and risk assessment projects for U.S. Department of Energy contractors. He has also assisted DOE, regulators, and contractors with the development of groundwater protection and risk assessment strategies for Hanford and was the contractor lead for developing the Hanford End State Vision in 2005. In addition to his experience with Hanford site monitoring and risk assessment, he has participated in the geochemical and hydrologic characterization of regional ground-water flow systems.

Mr. Bryce was also member of the leadership team for the Hanford Site Groundwater Vadose Zone integration project and led the development of the System Assessment Capability. The System Assessment Capability was designed to assess the impact of Hanford waste on human health, ecological health, cultures, and the regional economy. The capability represented Hanford waste inventory, simulated the transport of contaminants through the environment, and estimated the resulting impact. The capability was developed through an open process with regulator, stakeholder, and Tribal Nation participation.

Mr. Bryce managed the Hanford Probabilistic Seismic Hazard Analysis (PSHA) project. The objective of the project was to assess future hazard to Hanford facilities from seismic events. The products of a PSHA include seismic hazard curves, uniform hazard spectra, and other products that serve as the input to ground motion site response analyses at a particular facility. The PSHA team is made up of international experts in seismic hazard analysis. The effort is performed with oversight from a participatory peer review panel.

Mr. Bryce also currently supports the Nuclear Regulatory Commission in performing environmental reviews of applications for new nuclear power plants. He has led the review team for several new applications and performed the review of groundwater and surface water aspects for a number of plant sites.

Amoret Bunn

Amoret Bunn, PhD, has 20 years of experience as an environmental engineer performing applied environmental research. Her experience ranges from remediation activities for contaminated soil and groundwater, to development of ecological risk assessment software, to working with groups of people with various technical training and cultural backgrounds on environmental impact assessments. In addition, she has extensive experience in preparing and leading field surveys for hazard assessments of metal and organic contaminants in terrestrial and aquatic environments. Dr. Bunn has reviewed and prepared environmental compliance documentation for CERCLA, RCRA, and NEPA, and participated in all phases of CERCLA RI/FS process. Her research areas of interest include pharmacokinetic studies of aquatic organisms, health assessments for nanomaterials, and ecological risk assessments of radionuclides and hazardous chemicals. Many of these assessments have focused on fate and transport in hyporheic systems using large-scale mesocosms.

Mickie Chamness

Ms. Chamness has worked at the Hanford Site for most of the past 34 years. For the first 15 years she worked on projects related to hydrogeologic characterization of sites for storage, monitoring, and cleanup of radioactive and mixed waste sites. After a brief hiatus, she returned to PNNL to work on wide range of environmental projects including environmental monitoring, ecological surveys at Hanford and around the country, and compilation of data on biological receptors at the Hanford Site. Work on ecological surveys gives her the opportunity to work with cultural resource experts.

Currently, Ms. Chamness is working on geologic energy storage and energy and water conservation projects. She holds a BS in Geology from Washington State University.

Janelle Downs

Janelle Downs, PhD, has 30 years of experience as an ecologist performing ecological surveys, habitat analysis and restoration, and using remote sensing data in landscape condition analyses. Her work includes managing and collecting environmental and biological field survey data for a variety of DOE, DOI, and DOD projects and programs over the past twenty-five years. She has lead teams involved in field data collection and analysis for baseline risk evaluations associated with chemical and radionuclide contaminants for DOD and DOE, field surveys at military installations in Maryland, Louisiana, and southern California, and ecological data collection and analysis to map invasive species, delineate habitat suitability/availability, and rank range conditions at locations across the Pacific Northwest. She has also led efforts to develop eco-hydrological information needed for performance assessment of various waste disposal actions for the DOE at Hanford. Areas of expertise include the collection and analysis of environmental and vegetation data and application of GIS analysis and image analysis for mapping and development of environmental decision tools using spatial information. Dr. Downs has also worked as a subject matter expert providing NEPA analysis and support for various projects including EIS preparation for new reactor licensing for the Nuclear Regulatory Commission and development of Environmental Assessments and information for geologic carbon sequestration.

Vicki Freedman

Vicki Freedman's, PhD, research activities have included theoretical and numerical studies of coupled hydrodynamics, contaminant transport, and geochemistry in environmental systems since joining PNNL in 2000. She has been involved in both forward prediction and inverse modeling of tank farm wastes at the Hanford Site, and has been a major contributor to the vadose zone modeling for field investigations of past leaks, as well as tank closure performance assessments investigating potential leak scenarios. She is currently providing technical oversight to the baseline risk assessment performance assessment being performed for Waste Management Area C. Dr. Freedman has also led the demonstration of a new high performance computing capability currently under development by ASCEM (Advanced Simulation Capability for Environmental Management). This demonstration included using supercomputers to model subsurface discharges and evaluate potential remediation technologies in the deep vadose zone at Hanford.

Elizabeth Golovich

Elizabeth Golovich, PhD, is a project manager at the Pacific Northwest National Laboratory. Since joining the laboratory in 2005, Dr. Golovich has collaborated on a wide variety of research activities involving standoff chemical detection using laser-based detection methods, performance testing of light-emitting diode lamps, and analysis of radionuclide complexes formed from the alkaline degradation products of cellulosic materials. Elizabeth began working on projects investigating concerns associated with the operation of the Hanford Waste Treatment and Immobilization Plant in 2007 and continues to support these activities. She currently manages multiple projects associated with remediation activities on the Hanford Site, including the investigation of radionuclide migration through concrete materials. Dr. Golovich also provides technical support to Washington River Protection Solutions as part of the Hanford Vapor Monitoring, Detection and Remediation Project.

Alicia Gorton

Alicia Gorton, EIT, PhD, is an environmental risk and decision analyst at the Pacific Northwest National Laboratory, which is operated by Battelle Memorial Institute for the US Department of Energy. Alicia combines a diverse and interdisciplinary background of environmental, ocean, and coastal engineering with her deep respect and admiration of the environment and natural resources to provide technical insight and management for remediation efforts at the Hanford Site and evaluations of marine and hydrokinetic energy projects. Specifically, Dr. Gorton's experience at the Pacific Northwest National Laboratory includes significant responsibilities for authoring the Construction and Operations Plan (COP) and Safety Management System (SMS) for the Principle

Power WindFloat Pacific Project, a 30 MW floating windfarm 18 miles off the coast of Oregon which is planned to be fully commissioned by the end of 2017; managing the Client and User Interface Strategy and Action Plan for PHOENIX, a gallery of web-based GIS applications for rapidly accessing and visualizing Hanford environmental monitoring data; integrating subsurface science and technology initiatives at the Pacific Northwest National Laboratory with the Hanford Site Deep Vadose Zone Implementation Schedule and Strategy to identify key capabilities and potential impacts of vadose zone and groundwater related projects; collaborating with Consortium for Risk Evaluation with Stakeholder Participation on the Hanford Site-Wide Risk Review to identify current and potential future impacts to human health, land and river ecology, and both natural and cultural resources.

As an active member of several professional associations, she holds leadership positions with the Columbia Section of the American Society of Civil Engineers, and is a peer reviewer of the American Shore and Beach Preservation Association's technical journal Shore and Beach. In 2014, Dr. Gorton was selected as one of ten New Faces of Civil Engineering by the American Society of Civil Engineers, who recognize "young, diverse, and talented engineers who demonstrate a clear vision, good managerial and technical skills, and who possess inspirational leadership qualities and a desire and willingness to change the world for the better." Alicia is also a co-leader of a Girl Scout troop in the Eastern Washington and Northern Idaho Council, and is an active member of the Mid-Columbia Mastersingers Chamber Ensemble.

Kris Hand

Kris Hand has 24 years of experience as a biologist and ecologist, with much of her work taking place on the Hanford Site. She has conducted work in terrestrial and aquatic ecology, wildlife biology, fisheries, and environmental compliance. From 2003-2011, she held a major role in the Ecological Monitoring and Compliance Project as a leader and project reviewer, where her responsibilities included managing and conducting ecological surveys on the Hanford Site, supervising technical staff, and writing compliance assessments. From 2006-2009, she was a task leader for laboratory research on the effects of total dissolved gas on incubating chum salmon. Ms. Hand is currently an environmental permitting specialist on the Environmental Protection and Regulatory Programs' centralized permitting team. As a subject matter expert in environmental permitting, she has been integral in the development, organization, and maintenance of a centralized permitting database and process for PNNL. She obtains and manages environmental permits from numerous local, state, and federal agencies for research projects. Her other project focus areas include applying skills in Geographic Information Systems and cartography to support environmental reviews for nuclear power applications, conducting habitat assessment surveys on the Hanford Site, and assessing fish condition for Juvenile Salmon Acoustic Telemetry System studies being conducted in the Snake and Columbia Rivers. She holds a BS in Wildlife Biology from Washington State University.

Ellen Kennedy

Ellen Kennedy has over twenty years' experience working in the field of cultural resources management and joined the Pacific Northwest National Laboratory in 2000 as the lead subject matter expert for NHPA Section 106 activities for DOE and DOE contractors at Hanford Site. In this role Ms. Kennedy was responsible for managing and leading cultural resources compliance for complex clean-up projects requiring facilitation of tribal and public input on cultural resources concerns as well as long-term protection of cultural resources at Hanford. Additional clients include the DOE- Pacific Northwest Site Office, DOE-Office of River Protection, Bonneville Power Administration, Benton County, and miscellaneous private industry. Ms. Kennedy has expertise in ethnography and oral history and led efforts to interview individuals who lived and farmed at Hanford prior to 1943 and worked extensively with American Indian tribes to document traditional cultural resources on the Hanford Site. Between 2007 and 2011, Ms. Kennedy was the project manager for PNNL's Cultural Resources Project providing program-wide technical and contractor support to the U.S Department of Energy's Cultural and Historic Resources Program at the Hanford Site. Ms. Kennedy also worked on a variety of other projects including cultural risk assessment activities for to the Groundwater Protection Program and served as the cultural and historic resources subject matter expert (SME) for Nuclear Regulatory Commission (NRC) NEPA compliance activities.

During 2011, Ms. Kennedy had the opportunity to work for the Confederated Tribes of the Umatilla Indian Reservation's Cultural Resources Protection Program where she provided technical support on cultural resource issues of concern at the Hanford Site. Ms. Kennedy rejoined PNNL in late 2012 to support PNNL's NEPA and NHPA compliance work for the NRC. Ms. Kennedy has provided technical cultural resource compliance support for a variety of PNNL projects and to the Hanford Site-Wide Risk Assessment project. Additionally, Ms. Kennedy is conducting policy-related research to support to NRC's "Fitness for Duty" Program. Ms. Kennedy obtained her Master's Degree in Anthropology from Western Washington University in 1998 and her Bachelor's Degree in Anthropology and Historic Preservation from Mary Washington College in 1993. Ms. Kennedy meets the Secretary of the Interior Standards for Professional Archaeologists.

Kyle Larson

Kyle Larson has 15 years of experience doing environmental research, monitoring, and compliance activities. His experience at PNNL has been diverse, ranging from conservation and management of ecosystems, protection of sensitive/rare species, contaminant exposure/uptake in aquatic and terrestrial biota on the Hanford Site, remote sensing and landscape ecology, and passage and survival of juvenile salmonids at hydroelectric dams. He has extensive experience with Geographic Information Systems (GIS) and spatial analysis, which has allowed him to work a variety of multidisciplinary projects. Kyle holds a Master's degree in environmental science from Washington State University and bachelor's degree in Wildlife Biology from the University of Idaho.

George Last

Mr. Last has 38 years of experience in applied geology and hydrogeologic research, project management, and line management. He joined PNNL in February 1984, where he managed the Site Characterization Group from 1988 to 1993, and the Hanford Cultural Resources Program from 1993 to 1994. He has managed many environmental projects for the U. S. Department of Energy (and its contractors), the Bonneville Power Administration, the U.S. Army, U.S. Air Force, U.S. Nuclear Regulatory Commission, and the private sector. He has led or participated in a broad range of geology, hydrogeology, and environmental studies supporting facility siting, hazardous waste site investigations, vadose zone research, and groundwater hydrology. His experience includes project scoping and management, drilling and sampling, geophysics, geologic mapping, field and laboratory experimentation, and data analysis. He has authored or coauthored over 130 technical reports and journal articles. He is a licensed geologist and hydrogeologist in the State of Washington. Mr. Last holds an MS in Environmental Sciences (Hydrogeology) from Washington State University (1997) and a BS in Geology from Washington State University (1976). Mr. Last is a member of a number of professional organizations including the Geological Society of America, American Geophysical Union, American Association of Petroleum Geologists, and the Northwest Scientific Association (Board of Directors).

Peter Lowry

Peter Lowry is a safety engineer with over 20 years of experience in supporting nuclear licensing, hazard and accident analyses and safety control development, system engineering, and project management.

Mr. Lowry has performed and supported hazards and safety analysis for several Hanford Facilities and projects including the Plutonium Finishing Plant, PUREX Deactivation, Spent Nuclear Fuels Project Canister Storage Building and Sludge Treatment Project, Tank Waste Remediation System (Tank Farms), and the Waste Treatment Plant (Nuclear Safety Lead for Low-Activity Waste, High Level Waste Vitrification, and Pretreatment facilities). Mr. Lowry supported the Hanford Tank Operations Contractor (TOC)/Waste Treatment Plant (WTP) - One System Team in the comparative evaluation of documented safety analyses performed on TOC and WTP facilities. In addition, he has conducted and supported hazards and safety analysis at nuclear power plants, U.S. Department of Energy nuclear and non-nuclear facilities at Pacific Northwest National Laboratory, Savannah River Site, Idaho National Laboratory, and Rocky Flats Site, and for Petróleos Mexicanos petroleum pump and transfer systems.

Mr. Lowry currently supports the Nuclear Regulatory Commission as part of the PNNL team to review the Risk Informed Fire Protection Amendment Requests for existing U.S Light Water Reactor Nuclear Power Plants and has supported DOE-NE and NRC in the evaluation of aging of passive components in nuclear power plants.

Mr. Lowry serves on the writing groups for both ANS 53.1 Nuclear Safety Criteria and Safety Design Process for Modular Helium-Cooled Reactor Plants and ASME/ANS, Standard for Probabilistic Risk Assessment for Advanced Non-Light Water Reactor Nuclear Power Plants.

Jennifer L. Mendez

Jennifer Mendez, MA, joined PNNL in 2015 as a Cultural Resource Scientist in the Environmental Assessment Group. Mrs. Mendez was hired to provide cultural resources support and technical assistance for several PNNL projects.

Mrs. Mendez has been working in the field since 2005, serving as a field archaeologist at several small cultural resource management firms and working on various field projects. The last 5 years of her professional career have focused on Hanford Site cultural resources and regulatory compliance; providing support for both DOE-RL and PNSO's Cultural Resources programs. Additionally, a large portion of her prior work focused on the management, maintenance and improvement of Cultural Resource database systems (GIS & Access/SQL) and records management.

Jennifer has extensive experience in leading and performing all phases of NHPA Section 106 reviews including fieldwork, reporting and consultation. Additionally, Jennifer has experience with the review and preparation of NEPA documentation. She holds a BA in Anthropology from the State University of New York at Stony Brook (2005) and an MA in Anthropology from the University of Tulsa (2008). Additionally, she meets the Secretary of the Interior Standards for Professional Archaeologists.

Mary Peterson

Since joining Battelle in 1982, Ms. Peterson has held positions as a deputy sector manager, line manager of 60 technical people, key client account manager, program manager and project manager for projects totaling over $20 M, technical contributor, and principal investigator. The focus of her activities has been on strategy development, sales/business growth with government and industrial clients, building and managing relationships, lab-wide capability development, and program/project execution.

She is currently working with multiple sectors including Environmental Management and Homeland Security to establish new business opportunities and develop business and capability strategies. In addition, she is engaged in a breadth of programmatic activities and client relationships associated with sector management.

Reid Peterson

Reid Peterson, PhD, has worked largely in the field of waste processing for treatment of high-level waste. Dr. Peterson has extensive background in managing large research programs. In addition, Dr. Peterson has experience in taking projects from inception to pilot scale proof of concept. Through his experiences at PNNL, WTP, and SRNL, Dr. Peterson has developed working relationships with key staff across the National Lab complex including ANL, INEL, LANL, and SRNL as well as the site contractors for waste processing at both SRS and Hanford. Past activities include leading research teams in the areas of separation processes for nuclear applications. Current focus areas include dissolution reaction, cesium removal technologies, and solid/liquid separation techniques; organized and led team to identify, select, and demonstrate backup ion exchange resin for cesium separation; supervised research programs that mitigated all key technology risks associated with separation processing for the WTP; and led preparation.

Christine Ross

Christine Ross joined Battelle Memorial Institute in 1995 and transferred to Pacific Northwest National Laboratory in March of 2009. She has extensive experience in knowledge management activities and has led this effort for several projects both internal and external to the laboratory. In addition, Ms. Ross manages a SharePoint Support team that provides ongoing maintenance and support for a wide-range of projects.

Ms. Ross also supports the Nuclear Regulatory Commission in their combined license and license renewal programs as the Knowledge Management Task Lead. Other work activities include Database Administrator and Lead for the NRC's Comment-Response Database hosted by PNNL, Knowledge Management Lead and Non-Spatial Database Manager for projects that support the U.S. Department of Energy, and Deputy Project Manager supporting NRC's Office of Federal and State Materials and Environmental Program.

Mark Triplett

Mark Triplett is a Senior Advisor at Pacific Northwest National Laboratory. He has more than 30 years of experience at PNNL in waste management systems analysis, decision analysis for environmental restoration, and risk communication. Mr. Triplett has worked on many aspects of the Hanford site cleanup, including soil, groundwater, and tank waste cleanup, and has expertise in planning and prioritizing cleanup activities. During 2013, he participated in a two-month assignment with Japan's Ministry of Environment sponsored by the U.S. State Department's Embassy Science Fellowship program. In that assignment, he reviewed Japan's environmental remediation activities for offsite Fukushima cleanup.

Michael Truex

Mr. Truex has 21 years of experience at Pacific Northwest National Laboratory in subsurface remediation research and field applications. His experience includes providing clients with technical support for remediation decisions through technology assessments, applications of numerical fate and transport modeling, and feasibility and treatability assessments. He specializes in evaluation and application of in situ remediation and attenuation-based remedies. Field experience includes work at Department of Energy, Department of Defense, and private remediation sites.

At the Department of Energy Hanford Site, Mr. Truex was a technical liaison between PNNL and the Environmental Restoration Contractor (1997-2005) and River Corridor Closure Contractor (2005-2007). Mr. Truex provided technical and programmatic support for assessing and implementing improved remediation and characterization technologies. Mr. Truex has also been a principal investigator for several treatability tests and has provided input to feasibility studies at the Hanford Site. Currently, he is a leading contributor to PNNL's effort for development and testing of technologies addressing deep vadose zone contamination and for development of analyses and approaches to support selection and implementation of remediation strategies for the Hanford Site and other sites with complex subsurface contaminant plumes.

4. SRNL

Jeannette Hyatt

Ms. Hyatt has 23 years of experience at DOE sites in leadership, management, and technical direction of diverse organizations. In her current position she is responsible for project management of deployment of innovative technical approaches to complex operational conditions involving multiple organizations and facilities. As the Director of Regulatory Integration and Environmental Services at the Savannah River Site, she was responsible for ensuring proper environmental risk assessment, operational compliance, and successful decommissioning and demolition. During the execution of the American Recovery and Reinvestment Act project, she implemented innovative approaches to environmental risk reduction, effective deployment of new programs, and data rich reporting systems. Her area of expertise ranges between development of rapid deployment analytical techniques and mobile laboratories, radioanalytical laboratory operations, quality assurance, client services, business management and delivery of environmental services to nuclear operations, environmental remediation, and Federal Emergency Management Act project direction. Projects requiring extensive negotiation and facilitation between parties of diverse technical and socio-economic interests are her area of special interest. Ms. Hyatt holds a BS in Chemistry (Montana State University, 1990), an MBA in Engineering & Technology (City University-Bellevue, 1995), and maintains professional certification as a Project Management Professional. She is a member of the Savannah River Site Leadership Association and is the past VP of Programs for the local PMI Chapter.