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PNNL-32055 Rev 0
DVZ-RPT-076 Rev 0

Adaptive Site Management Strategies for the Hanford Central Plateau Groundwater

September 2021

Inci Demirkanli
Vicky Freedman

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Abstract

Adaptive site management (ASM) is a systematic and iterative management approach that can be used to expedite the remediation of large and/or complex sites. ASM is defined as a formal and systematic project or site management approach centered on rigorous site planning and a firm understanding of site conditions and uncertainties, using science and technology to routinely re-evaluate and prioritize site remedial actions and characterization activities. The goal of the approach is to create a framework of structured and continuous planning, implementation, and assessment processes that accommodates new information and changing site conditions to develop effective and efficient cleanup approaches that achieves the required outcome(s) while optimizing costs, cleanup timeframe, and performance. Central to ASM is an evolving conceptual site model (CSM). Over time, incremental reductions in uncertainty associated with the CSM will occur, while supporting continued progress toward site cleanup and closure through remedy optimization and evaluation.

ASM has the potential to expedite cleanup for the Central Plateau area at Hanford through a planned and systematic approach for reducing uncertainty with targeted characterization activities, while continuing remediation activities that advance cleanup for key risk-driving contaminants. A core component of cleanup within the Central Plateau is the 200 West Pump-and-Treat (P&T) system. Even with an active P&T remedy, uncertainty exists with respect to plume distributions, total mass in the aquifer, and currently known continuing sources. Additional uncertainty is associated with multiple contaminant source locations in the vadose zone, which have the potential to create new groundwater plumes in the absence of any source control measures, although not all contaminant fluxes to groundwater will result in contaminant concentrations above cleanup levels. Collectively, these uncertainties need to be addressed in the CSM to support effective and efficient site progress toward cleanup goal(s).

Other nontechnical factors that may warrant an ASM approach at the Hanford Central Plateau are associated with the formation of operable units (OUs) used to manage cleanup. With the exception of the 200-ZP-1 OU, the three remaining groundwater OUs only have interim action records of decision. Nine vadose zone source area OUs are also in the early stages of the remedial investigation and feasibility study process, with pending characterization and technology identification activities.

A set of proposed site objectives for the Central Plateau are provided in this document as an initial consideration/example and basis for discussion for ASM implementation. These example site objectives were selected with the goal of maintaining protectiveness at the Columbia River through confinement of contaminant plumes within an administratively controlled area below existing surface waste sites and waste disposal facilities. Although site decision makers and regulators need to provide concurrence, these site objectives are used in this document to describe the elements of an ASM approach, including selection of interim objectives and a long-term adaptive management plan. Interim objectives are also defined to yield measurable incremental progress toward the overall site goals.

This document identifies initial technical considerations for developing an ASM framework for the Central Plateau cleanup decisions. These considerations are intended to facilitate more specific decisions, such as objectives, near- and long-term actions, and performance metrics, to develop an overall approach that maintains protectiveness but recognizes the uncertainty, long timeframe, and technical challenges that need to be considered in selecting, implementing, and managing remediation at the Hanford Central Plateau.

Acknowledgments

Funding for this work was provided by the U.S. Department of Energy Richland Operations Office under the Deep Vadose Zone – Applied Field Research Initiative. The Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the Department of Energy under Contract DE-AC05-76RL01830.

We would also like to acknowledge our mentor, Mike Truex, whose vision and knowledge sharing on adaptive site management will accelerate cleanup not just at Hanford, but at environmental sites worldwide.

Acronyms and Abbreviations

ARAR	applicable or relevant and appropriate requirements
ASM	adaptive site management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
HCZ	high-conductivity zone
IDF	Integrated Disposal Facility
ITRC	Interstate Technology & Regulatory Council
MNA	monitored natural attenuation
NPL	National Priorities List
NQAP	Nuclear Quality Assurance Program
OU	operable unit
P&T	pump-and treat
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
ROD	record of decision
Rwia	Ringold Formation Wooded Island Unit A
Rwie	Ringold Formation Wooded Island Unit E
Rlm	Ringold Formation Wooded Island Lower Mud
SMART	specific, measurable, attainable, relevant, and time-bound
TI	technical impracticability
WMA	Waste Management Area

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1.0 Introduction

Adaptive site management (ASM) is a systematic and iterative site management approach recognized for the potential benefits of improving and expediting cleanup of large and/or complex hazardous waste sites, and ultimately reducing cleanup costs. The U.S. Environmental Protection Agency (EPA) Superfund program defines ASM as a formal and systematic project or site management approach centered on rigorous site planning and a firm understanding of site conditions and uncertainties (EPA, 2020). It is defined as a technique, rooted in the sound use of science and technology, that encourages routine re-evaluation and management prioritization of site cleanup activities to account for new information and changing site conditions. The goal of the approach is to create a framework of structured and continuous planning, implementation, and assessment processes that targets management and resource decisions to incrementally reduce site uncertainties and support effective and efficient site progress that achieves the required outcome(s) while optimizing costs, cleanup timeframe, cleanup performance, and risks.

Remediation at complex sites is typically affected by issues of competing site priorities, uncertainties associated with conceptual site models (CSM), lack of systematic uncertainty management approaches, and linear cleanup decision making, as well as other factors such as contracting and funding challenges. These sites are typically characterized by difficult subsurface access, deep and widely spread (vertically and laterally) zones of mixed contamination, significant subsurface heterogeneity, and uncertainty associated with source distribution that limit the effectiveness of remediation (NRC 2013).

The ASM framework is intended to address these challenges through stepwise actions identified under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process and allows feedback from these actions to guide the decision making. In some specific cases the Resource Conservation and Recovery Act (RCRA) may be the governing regulatory framework, but it entails a similar process to CERCLA. Figure 1.1 highlights the typical stages of the CERCLA cleanup process, with the colored curved arrows showing how a nonlinear progression of cleanup can occur while still adhering to the CERCLA structure. For example, early or interim response actions implemented during the remedial investigation/feasibility study (RI/FS) stage can support the development of dynamic work strategies and/or characterization plans to address key site uncertainties and reduce data collection costs, and ultimately result in more informed cleanup decisions. Similarly, ASM approaches can help develop flexible remedial action strategies, allowing for continuous remedy performance evaluation and optimization with input from supplemental site characterization activities.

The Central Plateau on the U.S. Department of Energy (DOE) Hanford Site is one of the most complex environmental remediation sites in the world, presenting challenges associated with:

- Shallow sources (e.g., waste tanks)
- Persistent and recalcitrant deep vadose zone residual sources, including key risk drivers such as Tc-99, I-129, U, nitrate, and chromium comingled with other contaminants, posing long-term risk of continued contaminant flux into groundwater
- Large-scale, comingled groundwater plumes (e.g., carbon tetrachloride, Tc-99, U, I-129) with significant uncertainty in plume distribution and total mass in the aquifer

- Subsurface heterogeneity, including both geological and geochemical factors, affecting plume distribution, remedy design (implementation and operational strategies), and the impact on contaminant fate and transport outside the Central Plateau

These complexities represent the principal uncertainties that will influence cleanup timeframes. They collectively limit applicability and effectiveness of conventional technologies and approaches at the site due to technical impracticability (TI) (e.g., limitations due to unsaturated zone properties) or prohibitive costs of application (e.g., well installation and treatment). In addition to technical challenges, the Hanford Central Plateau cleanup actions are still early in the remediation decision process. For example, many of the vadose zone source operable units (OUs) are still awaiting CERCLA remedial decisions, and all groundwater OUs, except 200-ZP-1, have only interim action records of decision (RODs). Overall cleanup efforts at Hanford are estimated to last decades and cost tens of billions of dollars in life-cycle schedule and budget (DOE 2016a). More information on the Hanford Site is given in Section 3.0.

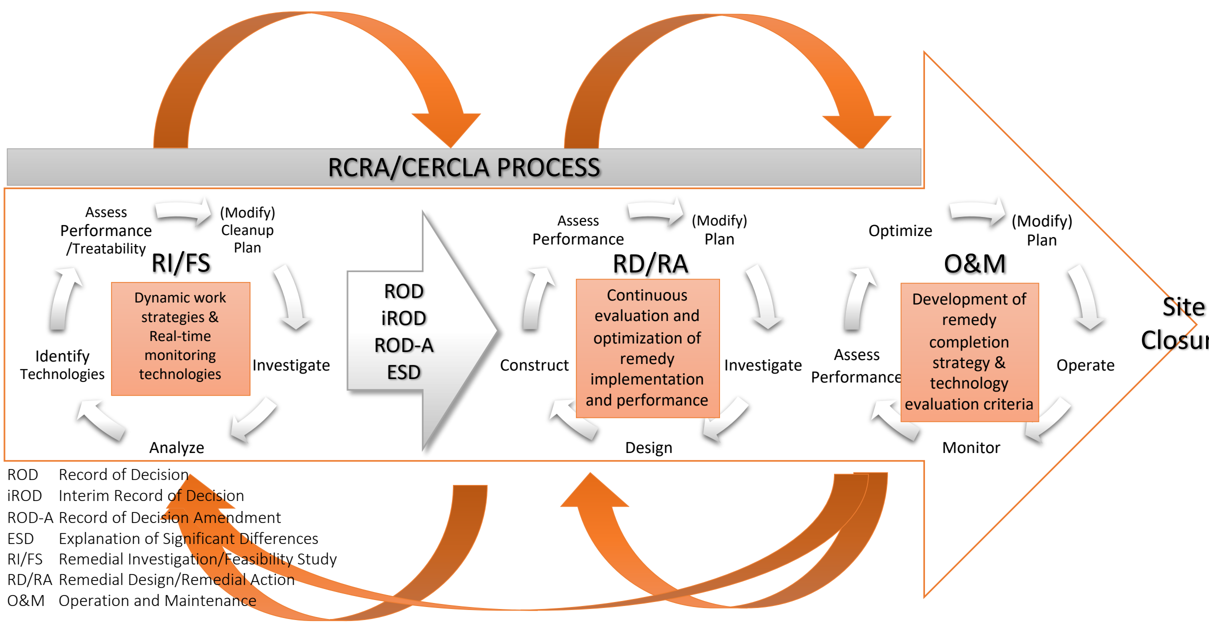


Figure 1.1. Application of adaptive site management at complex sites (adapted from EPA 2018).

Site-specific challenges present a unique opportunity to use the nationally recognized ASM approach for remediation management of the Hanford Central Plateau groundwater cleanup to achieve federal- and state-mandated regulatory cleanup goals (ITRC, 2017). To that end, this document identifies technical considerations for developing an ASM approach/framework for the Central Plateau groundwater cleanup decisions. Within this framework, site decision makers and regulators need to determine specific objectives, regulatory strategy, cleanup actions, performance metrics, and timeframes to streamline and expedite the cleanup while reducing cost, achieving protectiveness, and moving toward site closure. The considerations in this document are intended to facilitate this process by identifying an overall approach that maintains protectiveness, but recognizes the uncertainty, long timeframe, and technical challenges that need to be considered in selecting, implementing, and managing remediation at the Hanford Central Plateau.

In addition to the background information about ASM discussed above, Section 2.0 summarizes the current Central Plateau cleanup strategy and regulatory framework and Section 3.0 discusses a set of technical considerations important to an ASM approach for Central Plateau cleanup. Section 4.0 provides example site objectives for the Central Plateau as an initial proposal and basis for discussion for ASM implementation, including interim objectives that support achieving cleanup goals. Finally, key points from this work are summarized in Section 5.0.

2.0 ASM Framework

A framework for adaptive management provides the necessary structure for planning, prioritizing, and implementing remedial actions based on new site information and changing site conditions. There are two important aspects of developing an effective ASM framework: (1) identification of technical and programmatic elements that will define the key remedial actions and strategies to reduce uncertainty, address site complexities, and accelerate cleanup; and (2) identification of mechanisms and timelines for new site information or changing site conditions to be periodically incorporated into remedial decisions.

A recent guidance document, developed by the Interstate Technology & Regulatory Council (ITRC 2017), outlines the necessary steps for an ASM process when it is applied to cleanup at complex sites, such as Hanford. Figure 2.1 represents the main structure of this guidance, with some general modifications. In the ITRC guidance document, adaptive management is recommended for sites with significant technical and non-technical complexities that result in uncertainties affecting the selection, implementation, and optimization of remedial approaches and transitioning to long-term management within a reasonable timeframe. A site with substantial challenges typically requires a longer remediation timeframe with a higher remediation cost due to these uncertainties. However, these sites may also have greater potential for cost savings and remedial timeframe reductions if managed strategically and adaptively within an ASM framework, as shown in Figure 2.1.

The ASM framework recognizes the need for changing interim remediation objectives in different phases of a cleanup process to achieve the ultimate end goal. Initial goals at a cleanup site are typically to establish bulk, site-level control, achieve protectiveness (e.g., institutional controls, targeted actions for exposure pathways), and reduce future risks. However, it is common that the initial remedy reaches a point of diminishing returns (plateau of decreasing effectiveness) before the end goal is achieved, necessitating more focused approaches in later phases of site remediation to address limitations due to site complexities (NRC 2013). In the ASM framework, the initial remedy provides information for the evaluation of subsequent actions and advances toward the end goal through three general activities: (1) remedy design, implementation, and/or optimization; (2) integrated site characterization to address key uncertainties; and (3) remedy monitoring and performance assessment. In this framework, the key element that integrates all information and supports improved decision making is the CSM, which is expected to be updated frequently based on the critical information received from these activities. The CSM supports the development of a site-wide, living strategy document to plan long-term management activities and facilitate decision making (Figure 2.1).

In the ASM framework, the initial step of an adaptive management process is to establish appropriate **site objectives** (i.e., end goals) or to confirm that existing objectives are still appropriate at the time of planning based on the current CSM. Site objectives are overall expectations for the site remediation to protect public health and the environment. They could represent an end state as the final restoration goal for a site corresponding to a defined future use of the site (e.g., land and groundwater use). However, for a complex cleanup effort, a site objective could also be an end state for a component of the cleanup (e.g., Central Plateau component of the Hanford Site cleanup) that is consistent with the overall desired end state.

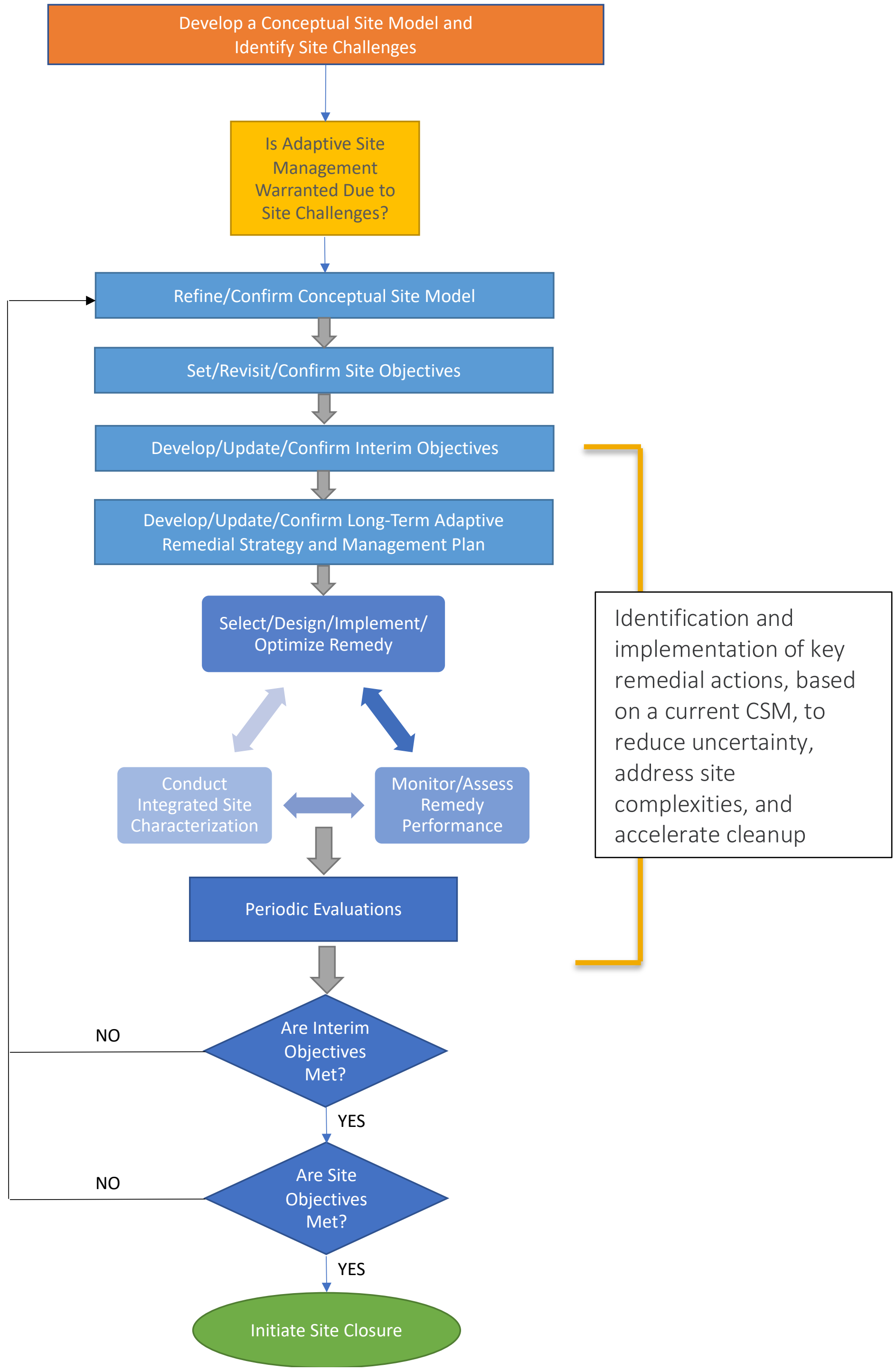


Figure 2.1. Framework for application of adaptive site management at complex sites (adapted and modified from ITRC 2017).

Site objectives typically are established based on regulatory requirements, regardless of the technical practicability to meet them (ITRC 2017). These objectives may include applicable or relevant and appropriate requirements (ARARs), other federal and state standards, or target risk levels that are protective of human health and the environment [40 CFR 300.430(e)(2)(i)]. For certain sites, these goals may include alternative site objectives where TI is demonstrated. Determination of an appropriate end state for a site guides the selection of the appropriate regulatory approach and site objectives for different cleanup components in a manner that is consistent with the desired endpoint. With identification and frequent evaluation of site objectives, ASM supports the development of effective and efficient technical and regulatory approaches to achieve these objectives, while providing stepwise progress toward the final restoration end state selected.

For complex sites with significant uncertainties, implementation of an adaptive framework and establishing site objectives do not require resolving all key site uncertainties at the beginning of the cleanup process. Identification and resolution of these uncertainties are embedded into the progress of the cleanup. Through an adaptive approach, the estimates for overall cleanup timeframe are expected to be reduced as the cleanup progresses and uncertainties are addressed strategically.

While site objectives are needed for the overall remediation approach, they represent a required, collective outcome of many components of a complex cleanup process requiring implementation over a long timeframe, such as source management/containment/control, or plume containment/remediation. Therefore, site objectives are usually not considered functional, and they are not easy to translate into contaminant, plume, technology, or source-specific near-term actions or remedy performance metrics. An adaptive management process requires identification of **interim objectives** that, when implemented or achieved, would yield measurable incremental progress toward the overall site goals. These near-term targets are specific, measurable, attainable, relevant, and time-bound (SMART) objectives that help develop a step-by-step implementation approach for the overall cleanup strategy (ITRC 2017). One of the main purposes of using interim objectives is to identify key near-term remedial actions within the CERCLA and/or RCRA (where applicable) processes to address site-specific complexities and reduce the associated uncertainty that drives the overall timeframe for cleanup. Selected interim objectives for a site must be linked to the agreed-upon site objectives and the end state, and where the regulatory approach is determined, these must also consider regulatory elements for decision making (removal action, interim ROD, TI waiver, etc.).

Setting site objectives requires consideration of the final restoration goal that is appropriate for defined future use of the site. While identification of types of appropriate objectives (e.g., mass removal, concentration reduction, plume area reduction targets, or pursuing a TI waiver for a plume) for interim targets may be more of a qualitative approach, setting the actual targets typically requires use of predictive tools alongside an updated CSM. At an appropriate, site-specific frequency, these objectives need to be updated or replaced with new interim objectives based on the collected data and updated CSM. Conversely, the site objective(s) is typically expected to remain unchanged because it represents the required end state.

As can be seen in Figure 2.1, interim objectives are the product of an overall adaptive remedial strategy specifically developed for the site and are expected to be achieved/updated/replaced within shorter periods of time to provide stepwise and iterative progress. These interim objectives are generally developed to support identification and/or implementation of **key remedial actions** to reduce uncertainty, address site-specific technical and non-technical complexities, and accelerate cleanup. These key remedial actions typically include (1) selection, design, or implementation of a remedy or optimization of a selected remedy; (2) site characterization activities to address key uncertainties associated with the CSM; and/or (3) monitoring and assessment of remedy performance to measure progress toward achieving both interim and overall site objectives. Data collected from these key remedial actions conducted under the interim objectives must be periodically evaluated to update the CSM and to measure the progress toward the interim targets, as well as the site objectives.

2.1 Role of the CSM in Identifying Key Remedial Actions

The CSM is an iterative, "living representation" of a site that provides a platform for integrating and summarizing all information relevant to a cleanup activity (EPA 2011). Therefore, the CSM is a critical tool for providing the ability to efficiently access and interpret site data and for supporting decision-making throughout the entire cleanup process. It is a foundational element that is used to identify site-specific challenges for remediation, to develop a defensible basis for predictive analysis of contaminant fate and transport, and to assess remediation performance for supporting remedy decisions and stepwise implementation via ASM.

The project life cycle of a CSM mirrors the common progression of the environmental cleanup process, as shown in Figure 2.2 (EPA 2011). For a traditional, linear cleanup approach, the focus of a CSM starts with remedial investigation, and then shifts toward remedial technology evaluation and selection, and later, remedy implementation and optimization. Preliminary and baseline CSMs are developed to support identification of project milestones, stakeholder communications, systematic planning, and identification of data gaps and uncertainties. The characterization CSM provides an iterative improvement of the CSM as new data become available during remedial investigation efforts. It also supports technology selection and remedy decision making. Design and remediation and post-remedy CSMs are iteratively updated to support remedy design, implementation, and optimization efforts, and provide documentation for long-term management and attainment of cleanup objectives. CSMs become increasingly quantitative during the cleanup process as more data are collected and data gaps are addressed. Fate and transport models are typically used to integrate data and develop quantitative CSMs and provide predictive analyses for remedy selection, performance, and optimization.

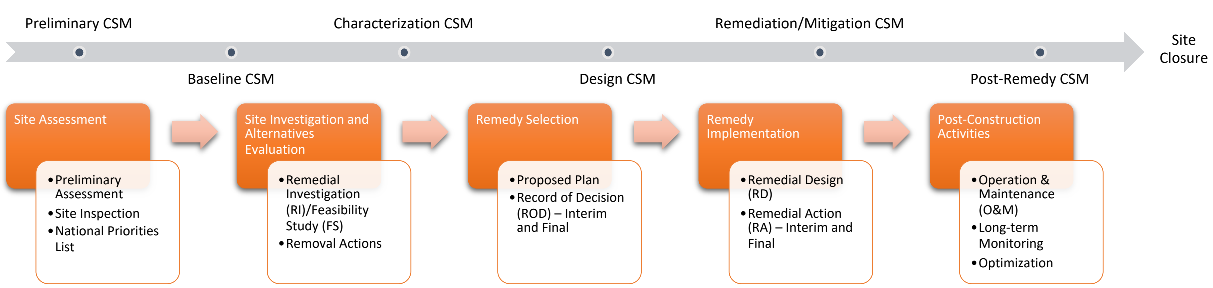


Figure 2.2. Six stages of the project life cycle CSM in relation to environmental cleanup activities (adapted from EPA 2011).

While site restoration is typically envisioned as a linear process, for complex sites where adaptive management is applied, it is anticipated to be a highly dynamic and iterative approach with CERCLA activities of different stages happening simultaneously (e.g., characterization and remedy optimization) under a regulatory framework (Figure 1.1). Like traditional cleanup approaches, ASM also uses the CSM as the main tool to support decision making and to identify key remedial actions that can reduce uncertainty and address site complexities. Because ASM requires repeated remedy evaluations and assessment of progress, the decisions must be based on a current CSM, as well as the state-of-the-science and -practice (ITRC 2017). Therefore, an ASM approach requires frequent updates to the site CSM to integrate data from the key cleanup activities that reduce uncertainties affecting the selection, implementation, and optimization of remedial approaches and the transition to long-term management. Specifically, the CSM allows for the development of focused strategies to support refinement of the cleanup decisions.

Under ASM, frequent and periodic refinements to a suitable quantitative CSM are needed to support identification of interim objectives and associated stepwise remediation and monitoring elements. However, for complex sites, recognize that site knowledge will evolve over time and some aspects may not become apparent until some time has passed (e.g., slow migration from vadose zone sources). Thus, a fully comprehensive CSM is not required to initiate an ASM approach. During ASM, the CSM will be refined frequently as new information is gained or conditions change, facilitating adjustment of the remedy.

2.2 Role of Characterization, Monitoring, and Performance Assessment in ASM

Monitoring is as an integral component of an ASM strategy, with goals explicitly tied to both short- and long-term remedial objectives (i.e., site and interim objectives under the ASM approach) for site cleanup and closure. Monitoring information is needed to address data gaps, reduce uncertainty, and support decision-making. Monitoring can be classified into four phases (described below), with each phase testing and verifying both the remedy and the CSM, while providing insights on features, events, and processes that can impact remedy performance (Bunn et al. 2012).

- **Characterization monitoring (i.e., site characterization).** Characterization monitoring at the Hanford Site supports the identification of the nature and extent of contaminants in both the vadose zone and groundwater, as well as physical and geochemical heterogeneities impacting contaminant transport. Initial characterization activities serve as the basis for the CSM, but additional activities may be needed in later stages of a cleanup process to close data gaps and refine the CSM. For example, in Hanford Central Plateau, data obtained during the first 5 years of the 200 West P&T remedy operations provided improved estimates of carbon tetrachloride mass and distribution, indicating that the total mass is greater than the baseline estimate and a greater portion lies with the Ringold Formation Wooded Island – unit A (Rwia) and Ringold Formation Wooded Island – lower mud unit (Rlm) (DOE 2020a). This information suggests that additional characterization is needed to address carbon tetrachloride contamination below the main unconfined aquifer in the Ringold Formation Wooded Island Unit E (Rwie; the focus of the current remedy) to support remedy optimization efforts.
- **Process monitoring.** Process monitoring is defined as a monitoring activity conducted during the remedial design and remedial action to verify remedy effectiveness. For example, process monitoring of source controls, using either direct (e.g., degradation products) or indirect measures (e.g.,

geophysical surveys), can verify that remedial amendments have been successfully delivered to the vadose zone. Analysis of P&T pumping rates and groundwater concentrations can provide process monitoring support to better understand the impacts of continuing sources, providing capture performance analysis as feedback to operational changes in remedy execution.

- **Performance monitoring.** Performance monitoring is conducted during and after the remedial action implementation, assessing remediation effectiveness based on short- and long-term goals. Performance monitoring can be data-intensive until the site achieves stability after active cleanup activities cease (e.g., termination of the 200 West P&T). Performance monitoring can provide data needed to optimize remedy and/or transition to passive remedy approaches, such as monitored natural attenuation (MNA). For example, assessment of plume capture performance for P&T can lead to re-design of the well network or operational strategy. Performance monitoring can also indicate where additional uncertainties may impact remedy performance. For example, recent data around Waste Management Area (WMA) T-TX-TY in the 200-ZP-1 OU, or WMA S-SX in the 200-UP-1 OU, indicate effects of potential continuing sources on the 200 West P&T remedy performance, highlighting the need for further information and source containment/operational strategy to optimize capture (DOE 2021).
- **Long-term monitoring.** Long-term monitoring occurs after performance monitoring has confirmed attainment of remediation objectives and is conducted to verify contaminant stability, remedy stability, and site maintenance (e.g., institutional controls are in place). Since the 200-ZP-1 remedy is planned to transition to MNA, conducting efficient and effective long-term monitoring in the Hanford Central Plateau will be critical to confirm contaminant behavior based on predicted and/or documented attenuation mechanisms in the CSM. Another example of long-term monitoring needs at Hanford may be related to issuance and implementation of a TI waiver. Although a TI waiver allows for a TI zone to be established where monitoring does not need to occur (subject to a 5-year review), long-term monitoring is still required outside the TI zone (Deeb et al. 2011). For example, a TI waiver may be applicable to radioiodine (I-129) at the 200-UP-1 OU, because no practical remediation technologies have been identified to treat I-129 in groundwater (Truex et al. 2019).

MNA is a prevalent passive remedy when remedial objectives can be achieved (as documented with sufficient lines of evidence) and may be an important component of an ASM strategy at Hanford. MNA is often used after active remediation techniques have been terminated, but MNA guidance typically interprets reasonable timeframes for remedy completion as 30 to 50 years. When passive remediation extends beyond that timescale, targeted and less frequent cost-effective monitoring is needed to support the remedy as described below.

A long-term, practical approach for monitoring large, slow-moving plumes has been recently described in Fritz et al. (2021). This document provides guidance for implementing an extended-scale monitoring (ESM) approach appropriate for long-duration MNA, which may be needed at a complex site. Extended-scale is defined with respect to time (i.e., a long duration of remediation) and a large enough physical scale such that receptors will not be impacted within the remediation timeframe. Sentinel wells placed between a known area of groundwater contamination and a receptor zone provide advanced warning of movement to a downstream receptor. ESM recommends less frequent sampling than standard MNA guidance, but with sufficient frequency to verify the CSM and confirm remedy objectives. Sites where ESM would be applicable would support natural attenuation processes that are sufficiently rapid to prevent contaminant migration past site boundaries or a defined containment zone. This strategy may be appropriate for contaminant plumes within the Central Plateau at Hanford, as long as specific criteria are met, such as (1) a robust CSM with minimal uncertainty; (2) implementation of efficient and effective source control and/or mitigation measures; (3) a demonstration of attainment of Hanford Site final remedial objectives (e.g., river protection, with considerations of future land use decisions) as they apply to the Central Plateau; (4) an ability to control exposure pathways during the remediation time period; and (5) an agreement by site regulators and stakeholders to support the ESM approach.

2.3 Documenting an Adaptive Remedial Approach

For implementation of ASM, a long-term management plan is needed as a "living document" to outline important components of the approach for supporting the decision making and forward planning (Figure 2.1). This document must provide a summary of the selected regulatory approach for the site or various components of the cleanup efforts. Some of the key elements of a long-term management plan include discussions of site objectives, interim objectives, remedy components, key site complexities and uncertainties that govern cleanup timeframes/decisions based on the current CSM, performance metrics and predictions, schedule and basis for periodic evaluations, and decision logic for remedy evaluation, optimization, modification, or transition (ITRC 2017). Furthermore, the document should outline the necessary monitoring activities to support periodic evaluations and updates to the CSM. As part of the ASM approach, the long-term management plan is to be revised based on these periodic performance evaluations and CSM updates.

A periodically updated (i.e., "living") long-term management plan will enable the necessary continuity in decision-making at a complex site, where cleanup timeframes may take decades, and will allow integration with other site cleanup components (e.g., the long-term management plan for Central Plateau groundwater remediation would support the integration with tank waste retrieval/remediation).

In addition to a long-term management plan, it is important to recognize that access to new site information and CSM updates are critical elements of an ASM approach. Therefore, regular reporting activities at Hanford need to support the implementation of this approach. Hence, a key goal of annual monitoring, characterization, and remedy performance reports is to evaluate and interpret data for use in updating the CSM and in guiding remedy adaptation.

3.0 The Hanford Central Plateau Contamination and Current Cleanup Strategy

The Hanford Site was established in 1943 to produce nuclear materials for national defense. These production activities resulted in the generation and disposal of significant amounts of hazardous wastes and/or radioactive materials at the site (DOE 2016b). In 1989, with the cessation of plutonium production at Hanford and in anticipation of the site's addition to the National Priorities List (NPL), the site's mission shifted to waste management and environmental cleanup, resulting in a cleanup agreement between DOE, EPA, and the Washington State Department of Ecology: the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989), known as the Tri-Party Agreement.

The Tri-Party Agreement is a legally binding federal facility agreement based on CERCLA, a RCRA corrective action order, and a *Hazardous Waste Management Act* (RCW 70.105) consent order (DOE 2013). It creates a framework for implementing these regulations, as they apply to Hanford, through establishing a set of enforceable milestones for achieving regulatory compliance and remediation.

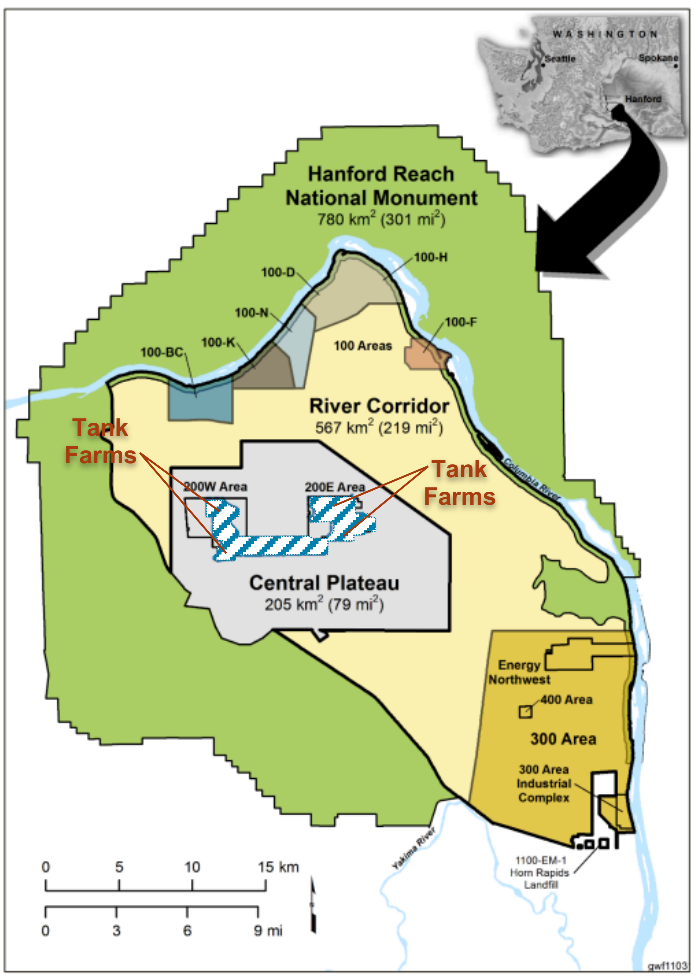


Figure 3.1. Major areas of the Hanford Site, including River Corridor and Central Plateau (adapted from DOE 2019b).

In 1989, the EPA placed four areas of the Hanford Site on the NPL pursuant to the CERCLA requirements, including the 100, 200, 300, and 1100 Areas (Figure 3.1). The 100, 300, and 1100 Areas are in the River Corridor and the 200 Areas are located on the Central Plateau, which are the two main geographic areas of the Hanford Site. Each NPL site was divided into OUs (i.e., a grouping of individual waste sites based primarily on geographic area or common waste sources) to simplify the response actions (DOE 2016b).

During the production activities, the Central Plateau's 200 Areas, 200 East and 200 West, were primarily used for waste management activities and separation and processing of plutonium. This area had approximately 1,000 facilities, structures, and buildings, including the Plutonium Finishing Plant and Plutonium/Uranium Extraction Plant. Although the processing activities ended at Hanford in 1989, they generated large volumes of radioactive, chemically hazardous, and mixed wastes that either were disposed of to the soil column as liquid effluent via engineered structures (e.g., cribs, trenches), or entered the soil column as spills and leaks in the Central Plateau. In addition, high-radioactivity liquid effluents generated during processing operations were sent to 177 single- or double-shell underground tanks in tank farms. Approximately 67 single-shell tanks are known or suspected to have leaked up to 1 million gallons of waste into the soil column (DOE 2013). To minimize the probability of future leaks, all single-shell tanks have been interim stabilized, with the pumpable liquid in each tank being transferred to double-shell tanks.

Overall, the intentional disposal and/or inadvertent release of waste in the Central Plateau during the processing activities created more than 800 waste sites with deep vadose zone contamination and large-scale, comingled groundwater plumes generally flowing from west to east toward the Columbia River (Figure 3.2). Central Plateau groundwater contaminants include tritium, iodine-129, nitrate, technetium-99, uranium, total and hexavalent chromium, cyanide, strontium-90, carbon tetrachloride, and trichloroethene. In some areas, contaminants in the deep vadose zone continue to migrate into the groundwater, resulting in increasing concentrations of contaminants in these regions (DOE 2021).

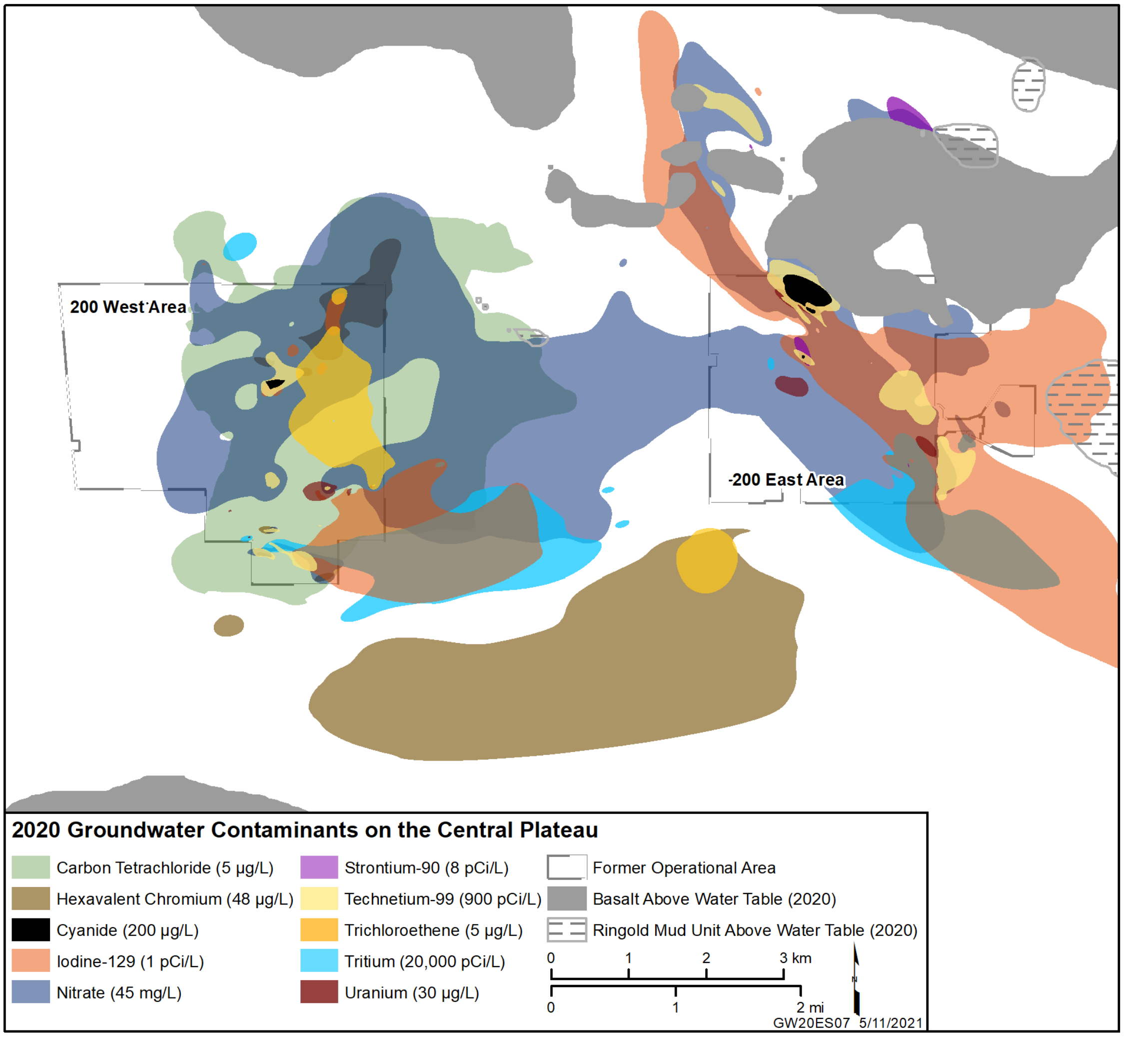


Figure 3.2. Groundwater contaminant plumes in the Central Plateau in 2020 (DOE 2021).

3.1 Goals of Central Plateau Cleanup Strategy

Hanford cleanup operations are governed by a main goal of protecting the Columbia River. To this end, a set of overarching goals were developed, as shown in Table 3.1, by dialogue among Tri-Party Agencies, Tribal nations, the State of Oregon, stakeholders, and the public to address the main components of the cleanup operations.

Table 3.1. Overarching Goals for Hanford Site Cleanup

Hanford Cleanup Goals	
Goal 1	Protect the Columbia River
Goal 2	Restore groundwater to its beneficial use to protect human health, the environment, and the Columbia River
Goal 3	Clean up the River Corridor Protect groundwater and the Columbia River Shrink the active cleanup footprint to the Central Plateau Support anticipated future land uses
Goal 4	Clean up Central Plateau waste sites and facilities Protect groundwater and the Columbia River Minimize the footprint of areas requiring long-term waste management activities Support anticipated future land uses
Goal 5	Safely mitigate and remove the threat of Hanford's tank waste Safely store tank waste until it is retrieved for treatment Safely and effectively immobilize tank waste Close tank farms and mitigate the impacts from past releases of tank waste to the ground
Goal 6	Safely manage and transfer legacy materials scheduled for off-site disposition, including special nuclear material (including plutonium), spent nuclear fuel, transuranic waste, and immobilized high-level waste
Goal 7	Consolidate waste treatment, storage, and disposal operations on the Central Plateau
Goal 8	Develop and implement institutional controls and long-term stewardship activities that protect human health, the environment, and Hanford's unique cultural, historical, and ecological resources after cleanup activities are completed

As described in the Hanford Site Cleanup Completion Framework (DOE 2013) and the goals shown in Table 3.1, cleanup of the Hanford Central Plateau is a highly complex and challenging undertaking due to large number of waste sites, tank farms, excess facilities, and deep vadose zone and groundwater contamination. Furthermore, the cleanup strategy must also be consistent with the future land use decisions as described in the *Hanford Comprehensive Land-Use Plan* (DOE 1999). Figure 3.3 shows the final land-use designations for the Hanford Site as established by this plan. The Central Plateau is designated for Industrial-Exclusive land use, allowing for continued waste management operations consistent with regulatory commitments at waste management facilities. CERCLA documents for the Inner Area use an Industrial land-use designation to set exposure scenarios and establish cleanup levels (DOE 2013).

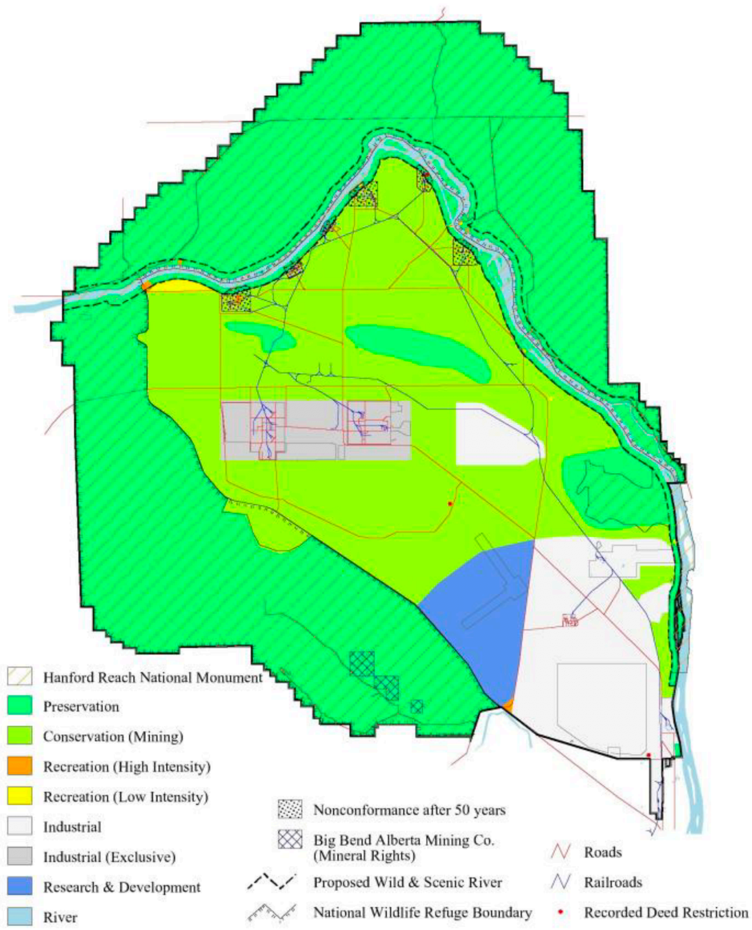


Figure 3.3. Final designation from the *Hanford Comprehensive Land-Use Plan* (DOE 2013).

Based on previous decision documents, the current cleanup strategy for Central Plateau involves the following activities (DOE 2013):

- Implement groundwater treatment systems to contain contaminant plumes within the footprint of the Central Plateau, thereby protecting the Columbia River.
- Implement groundwater treatment alternatives, including active treatment, to restore the groundwater to beneficial use.
- Make and implement cleanup decisions in a geographic approach analogous to the geographic approach applied to the River Corridor.
- Develop and apply deep vadose zone treatment technologies to protect the groundwater.
- Make and implement cleanup decisions that are protective of human health and the environment and that support anticipated future land use.
- Address residual contamination in the outer portion of the Central Plateau to further reduce the active cleanup footprint of the Hanford Site.
- Remediate the inner portion of the Central Plateau attain an area for long-term waste management activities that is as small as practical.

3.2 Regulatory Process and Remediation Management

The primary regulatory processes that must be implemented and integrated at the Hanford Site are (1) the CERCLA process guiding the cleanup decisions for most waste sites and groundwater for radioactive contamination or other hazardous substances, in conjunction with the Atomic Energy Act requirements for radionuclides and the RCRA requirements for a subset of waste sites designated as “RCRA past-practice” sites; (2) the RCRA closure process guiding decisions about active RCRA treatment, storage, and disposal facilities; and (3) the National Environmental Policy Act for evaluating potential environmental impacts of major cleanup and closure actions (DOE 2013).

To support waste site remediation in the Central Plateau, more than 15 source OUs, including one vadose zone OU (200-DV-1) with a highly contaminated perched water zone, have been established, encompassing more than 800 waste sites (DOE 2016b) (Figure 3.4). While the source OUs in the Central Plateau are in various stages of the CERCLA process, RODs have been published for interim or final remedial action at the 200-CU-1 (U-Plant), 200-CW-3; 200-DF-1 (Environmental Restoration Disposal Facility [ERDF]), 200-PW-1/3/6, and 200 CW-5 (a grouping of primarily plutonium and cesium-contaminated waste sites) OUs. The remaining OUs are in their early stages of RI/FS process for site investigations.

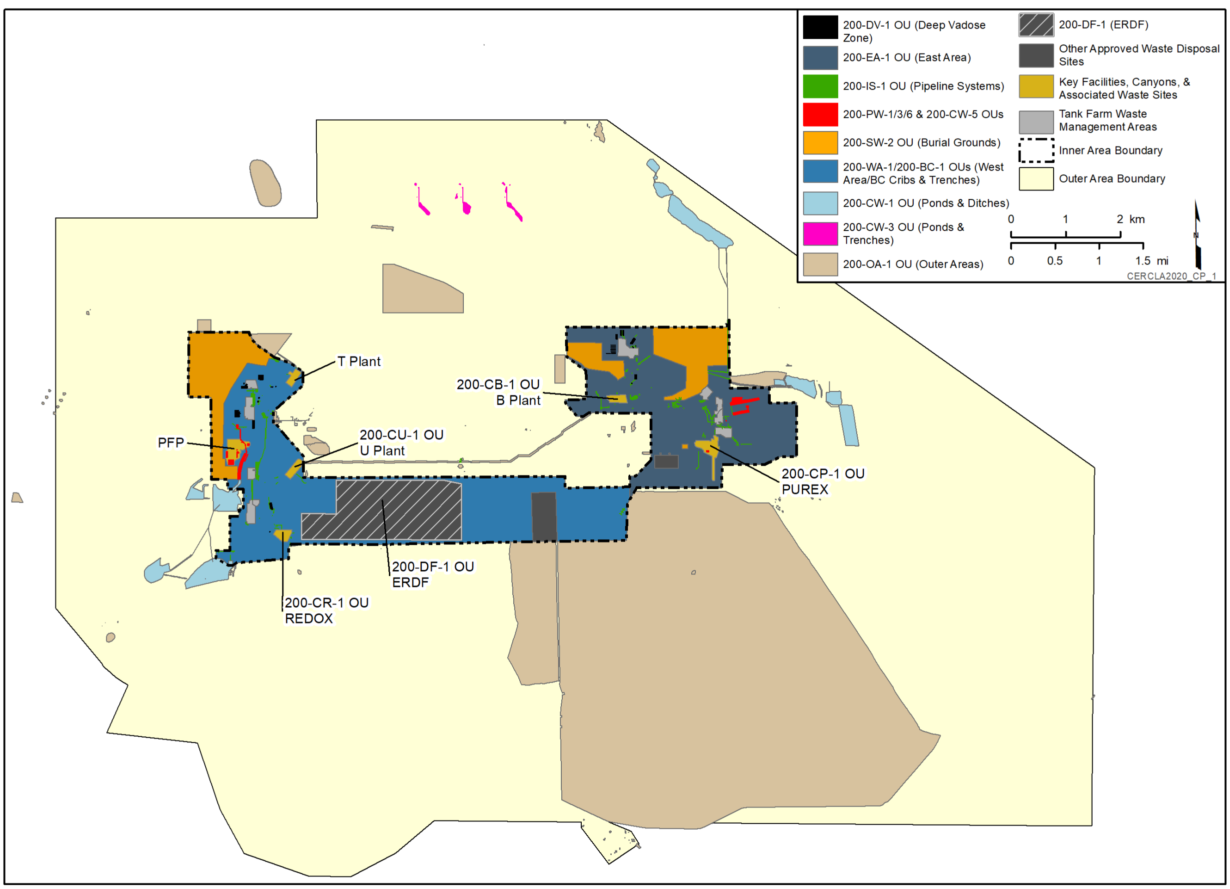


Figure 3.4. Source operable units in the Central Plateau (DOE 2016b).

To support groundwater remediation in the Central Plateau, four groundwater OUs have been established: 200-BP-5, 200-PO-1, 200-UP-1, and 200-ZP-1 (Figure 3.5). These OUs encompass groundwater contamination of radionuclides and hazardous contaminants from the 200 East and 200 West Areas and regions where these contaminants have migrated beyond the Central Plateau.

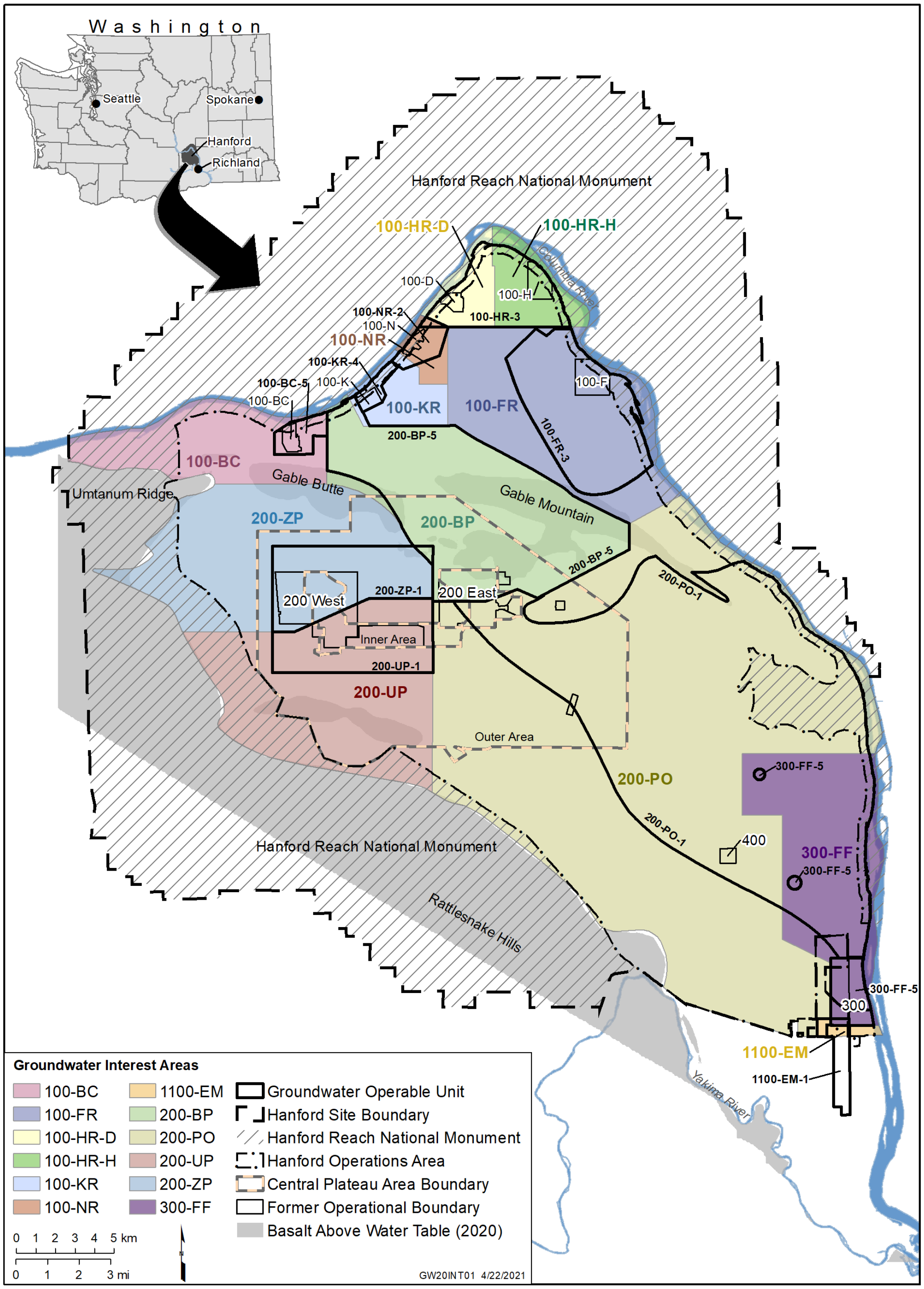


Figure 3.5. Hanford groundwater operable units (DOE 2021).

Although the 200 West P&T system is the principal remedy for Central Plateau groundwater, vadose zone sources that can impact P&T treatment have not yet been addressed because their remedy decisions are still pending. The 200 West P&T remedy, originally designed and implemented for the 200-ZP-1 OU plumes under a final ROD (EPA et al. 2008), is currently addressing additional plumes in the U Plant and WMA S-SX areas for the 200-UP-1 OU under an interim ROD (EPA et al. 2012), a perched water extraction at the B Complex for the 200-DV-1 OU under a removal action (DOE 2014), and the plumes in the B Complex area in the 200-BP-5 OU under a removal action (DOE 2016c). It is anticipated that the use of this remedy will continue to evolve to address pending remedial decisions (e.g., interim ROD for 200-BP-5 and 200-PO-1, including an extraction system at WMA C and WMA A-AX), and potentially for developing source control and management strategies at the tanks farms with continuing fluxes into groundwater.

The 200-ZP-1 OU, located in the northern and central portions of the 200 West Area and the surrounding region, is the only groundwater OU in the Central Plateau with a final ROD (EPA et al. 2008) with the remedial action objectives to (1) return the groundwater to beneficial use within the entire footprint of the groundwater plumes by achieving cleanup levels; (2) apply institutional controls to prevent the use of groundwater until cleanup levels have been achieved; and (3) protect the Columbia River and its ecological resources from degradation and unacceptable impact caused by contaminants originating from the 200-ZP-1 OU. As discussed above, a P&T remedy combined with MNA and flow-path control (i.e., hydraulic containment) was selected to achieve the cleanup levels identified in the ROD within a 125-year period (i.e., 25 years of active pumping and 100 years of MNA). Since remedy operation began in 2012, new information has emerged that impacts the technical assumptions used to support the issuance of the final ROD in 2008. This includes updated estimates of the abiotic degradation rate for carbon tetrachloride and the total contaminant mass and its distribution in the subsurface.

The new findings regarding the carbon tetrachloride resulted in a revised CSM that indicates unfavorable conditions for attaining the remedial action objectives for carbon tetrachloride within the timeframe defined in the ROD. As a result, a remedy optimization study was initiated in 2019 to evaluate an increase in removal and treatment capacity for carbon tetrachloride within the 200 West P&T system and a transition to MNA for nitrate treatment (DOE 2019a). Additional activities, such as further characterization of contaminant distribution, were also initiated for the Rwia aquifer. Furthermore, the new information indicates significant impact on P&T effectiveness and efficiency from continuing sources, such as around the T-TX-TY tank farms, warranting potential source containment measures in these areas.

The evolution of remedial actions and decisions for the 200-ZP-1 OU demonstrates the complexity of the Central Plateau and highlights the major uncertainties (e.g., plume distribution, heterogeneity, source impact). These uncertainties affect the selection, implementation, and optimization of remedial approaches and transition to long-term management within a reasonable timeframe. An ASM approach can be used to address these uncertainties and support both short- and long-term decision-making at Hanford.

3.3 Hanford CSM Elements and Key Uncertainties for an Application of ASM

Although groundwater is divided into separate management units and contains different mixtures of co-located contaminants, the Hanford Central Plateau site is considered to be a complex site due to several technical challenges associated with achieving cleanup, as well as the challenges associated with the integration of cleanup approaches for different management units.

- **Geologic heterogeneities.** The unconsolidated sediments of the Hanford and Ringold formations beneath the Central Plateau can exhibit significant heterogeneities that influence subsurface contaminant transport. Less-permeable zones, such as the Ringold A formation beneath the ZP-1 OU, can contain a large portion of the dissolved-phase contamination, thereby limiting remedy effectiveness. Small-scale vadose zone heterogeneities in areas like the B-Complex can cause contaminants to migrate laterally and inhibit the effective delivery of amendments to treat contaminants in the deep vadose zone.
- **Geochemical heterogeneities.** Remediation of soil and groundwater contaminants is influenced by the geochemical and physical properties of the formation, as well as the chemical properties of the contaminant and co-located contaminants. Hence, the effectiveness of the remedy approaches designed to immobilize contaminants in situ may present variations due to subsurface conditions as well as co-located contaminants. Combined technologies or treatment train approaches may be required for remediating contaminant mixtures, using remedy combinations that collectively are more efficient and robust in mitigating contaminant issues, such combining hydrologic controls and contaminant sequestration/degradation to meet goals for sustainable contaminant flux reduction.
- **Continuing sources.** Several contaminant sources located deep within vadose zone will influence groundwater cleanup and closure decisions, yet limited information exists regarding the depth of contamination, source strength, and potential risk to groundwater. Decisions and approaches to protect and remediate groundwater must be linked to contaminant sources and key risk-drivers, such as technetium-99, uranium, iodine-129, and chromium in the vadose zone. Remedy selection for waste sites will require technically defensible descriptions of sources and their relative strength and temporal contributions to groundwater contamination to support future feasibility studies and remedy optimization efforts. The majority of waste sites with deep vadose zone contamination in the Central Plateau are assigned to the 200-DV-1, 200-EA-1, 200-WA-1, and 200-BC-1 OUs (Figure 3.4).
- **Large-scale site.** Although the large areal extent of Hanford (586 square miles) does not necessarily make Hanford a complex site, the vast nature and extent of subsurface contamination, the inaccessibility of contaminants located deep within the vadose zone, and the existence of co-located plumes limits cleanup that can be accomplished within a reasonable timeframe (ITRC 2017). The large scale also means that there exist multiple uncertainties associated with geologic and source characterization. For example, deep borehole characterization is limited at Hanford due to the high costs of drilling.
- **Tank farms.** Tank waste is a complex and costly challenge at Hanford. Wastes within tanks will be retrieved, and once the Hanford Tank Waste Treatment and Immobilization Plant is operational, it will vitrify tank wastes, with the most highly radioactive portion of the waste to be disposed in a deep geologic repository and the less radioactive portion to be buried at the Integrated Disposal Facility

(IDF) in the 200 East Area. Remedy selection and implementation for waste sites within the Central Plateau will need to be coordinated with tank farm activities. In addition, the soil beneath tank farms has been contaminated through tank leaks, accidental spills, and intentional releases, serving as additional sources to groundwater.

These complexities translate into a pervasive uncertainty in the subsurface at Hanford. The inherent natural heterogeneity and incomplete knowledge of vadose zone sources, groundwater plume distributions, and natural attenuation mechanisms for subsurface contaminants make it difficult to predict remedy performance and cleanup timeframes. The 200-ZP-1 OU optimization study (DOE 2019a), for example, has already identified some key uncertainties impacting the 200 West P&T system. This includes recent data indicating that more carbon tetrachloride mass resides within the Rwia and Rlm units than previously estimated, engendering additional uncertainty about the total carbon tetrachloride mass in the aquifer. The carbon tetrachloride abiotic degradation rate is also slower than initially estimated, which is another source of uncertainty associated with the cleanup timeframe (DOE 2019a).

Other conceptual model uncertainties for the Hanford Central Plateau exist, including multiple, interacting contaminant sources in the vadose zone that will continue to contribute to groundwater contamination in the absence of any source control measures. In the 200 East Area, a significant inventory of contaminants in the vadose zone exists at the B-Complex (e.g., Tc-99, uranium, nitrate), with uncertainty in multiple source locations, volumes, and intensities (Oostrom et al. 2013; Serne et al. 2010). The perched water zone beneath the B-Complex also lacks sufficient characterization with respect to its lateral extent and contaminant inventory and its potential dewatering capacity (DOE 2020b). Technically defensible descriptions of the hydraulic and geochemical properties influencing contaminant transport are also not known, due to small-scale heterogeneities beneath the B-Complex. In the 200 West Area, ongoing contaminant fluxes to groundwater continue to impact the P&T remedy, such as the expansion of the technetium-99 plume at WMA T-TX-TY.

The current ROD at 200-ZP-1 has identified an active P&T remedy for 25 years, followed by an MNA period of 100 years. As with most P&T systems, contaminant mass removal rates are initially high but eventually experience a decline due to an increased influence of small-scale mass transfer limitations. The P&T system at the 200 West Area needs to reach cleanup standards to support a transition to natural attenuation that achieves protectiveness of downstream receptors at the Columbia River. Given that there are no significant biogeochemical attenuation mechanisms for the recalcitrant contaminants (carbon tetrachloride, Tc-99, uranium, etc.), plume dispersion and mass removal are critical to bringing contaminant concentrations below cleanup goals. A high hydraulic conductivity zone (HCZ) inferred to exist between the 200 Areas in the Central Plateau (and extending south and east) is key to attenuating contaminant concentrations. However, the configuration of the HCZ has not yet been fully characterized, because borehole coverage is still sparse in those areas. Although a sampling and analysis plan is under development (CPCCo 2021) and geophysical methods are currently being used to delineate the HCZ (Robinson et al. 2020), there is still uncertainty associated with the impact of the HCZ on attenuation of contaminants migrating from the Central Plateau. Until the HCZ configuration can be confirmed, the hydraulic connection between the Central Plateau and the Columbia River is a considerable source of uncertainty.

4.0 Considerations for an ASM Approach for Central Plateau Groundwater

Challenges stemming from site complexity, uncertainties, and the administrative/regulatory context shape the objectives of ASM, whose site-specific implementation is embodied in a long-term management plan, as discussed in Section 2.3.

Given the long-time frames associated with remedy decisions, an evolving site CSM, and the primary objective of Columbia River protection, a flexible and iterative approach with multiple intermediate steps is needed to manage site uncertainty and achieve effective and efficient progress toward the required end state. An ASM approach for the Hanford Site Central Plateau will include:

- identification of site objectives that are consistent with the overall Hanford Site goals and that support the development of a long-term management approach,
- interim goals that provide quantifiable, stepwise progress for achieving site objectives, and
- remedial actions that address key uncertainties and data gaps.

It is important to note that effective and efficient progress refers to the cleanup approach that achieves the required outcome(s) while optimizing costs, cleanup timeframe, and performance. For example, a non-optimized P&T approach might achieve the required outcome, but at a longer timeframe and a greater cost than an optimized system. Therefore, an ASM application for Hanford must also consider an evaluation of alternative approaches (e.g., interim objectives, cleanup strategies) through cost-benefit evaluations.

4.1 Factors Influencing the ASM Approach for the Central Plateau

The technical and nontechnical challenges presented in prior sections serve as barriers to effective remedy implementation until uncertainties are reduced, and therefore they influence the nature of the ASM approach that is taken. The relevant factors are summarized as follows:

- Hundreds of contaminated soil sites, with both shallow (e.g., waste tanks) and deep vadose zone recalcitrant contaminant sources present long-term risk (e.g., Tc-99, I-129, U, and chromium), with uncertainty in multiple source locations, volumes, and intensities
- Uncertainty exists about co-located plume distributions and total mass in the aquifer
- Uncertainty exists about the natural attenuation capacity of both the vadose zone and aquifer
- Subsurface heterogeneity, including the nature and extent of the HCZ, impacts contaminant transport to the Columbia River
- TI and prohibitive costs of application are associated with conventional technologies (e.g., excavation of deep vadose sources, limited treatment access because ERDF is located above the I-129 plume in the 200-UP-1 OU)

- Central Plateau groundwater OUs (200-BP-5/200-PO-1/200-UP-1) still require final CERCLA remedial decisions
- Nine source area OUs are in early stages of the RI/FS process, with pending characterization and/or technology identification efforts (e.g., 200-WA-1 and 200-BC-1, 200-DV-1 OUs)

4.2 Consideration for Central Plateau Site Objectives

A key first element of implementing ASM for the Hanford Central Plateau is to identify appropriate remediation management objectives to serve as the site objectives. While final site objectives are tied to the yet-to-be-determined Hanford end state, functional site objectives and associated interim objectives for the Central Plateau will facilitate remediation management via ASM.

The proposed site objectives for the Central Plateau described below are provided as an initial considerations/examples for ASM implementation. These site objectives were selected with the goal of maintaining protectiveness through confinement of contaminant plumes within an administratively controlled area below existing surface waste sites and waste disposal facilities. Although site decision makers and regulators need to provide concurrence, these site objectives are used in this document to describe the elements of an ASM approach, including selection of interim objectives and a long-term adaptive management plan. Although not strictly necessary, consolidated administrative management of the Central Plateau groundwater (e.g., a single OU for the Central Plateau defined by an alternative point of compliance) is consistent with these objectives and implementable at the scale of the entire Central Plateau.

4.2.1 Long-Term Central Plateau Site Objectives

As described in Section 3.0, overall existing objectives for Hanford Site groundwater are protection of the Columbia River and enabling future beneficial use of groundwater consistent with the site end state (Table 3.1). Within an ASM framework, it is necessary to identify an overall goal for the Central Plateau that is consistent with the Hanford Site objectives and procedures. This overall goal facilitates management of Central Plateau remediation and identifies interim objectives. For the purposes of this document, two site objectives are identified for the Central Plateau. While the first site objective provides remediation management and regulatory framework guidance for the Central Plateau, the second objective aligns the first objective with the overall Hanford Site objective.

1. **No sustained contaminant migration outside the Central Plateau at concentrations above the identified cleanup standard.**

A principal objective in managing Central Plateau remediation is that no sustained contaminant migration occurs outside the Central Plateau boundary at concentrations above the identified cleanup standard. Regardless of the groundwater management framework (i.e., single versus multiple OUs), confining contaminants to the Central Plateau is a necessary objective to comply with the protection of the Columbia River. This objective includes the recognition of (1) the long timeframe to reach an ultimate groundwater end state due to overlying waste sites and infrastructure (e.g., IDF, ERDF) and (2) the anticipated long timeframe for remediation due to spatial extent of existing plumes within the Central Plateau.

The containment objective supports the identification of an appropriate regulatory approach, establishing interim objectives for remedy optimization in both the short- and long-term. Alternative remedial approaches need to be considered for confining contaminants within the Central Plateau boundary, based on a life cycle cost-benefit analysis that evaluates compliance with this goal and also results in the most effective and efficient remedial approach. The ability for the alternatives to achieve containment needs to be considered in identifying the appropriate boundary location under the selected regulatory framework and contaminant levels of concern (e.g., considering attenuation mechanisms beyond the boundary prior to reaching the Columbia River, if applicable). The scale of operations and future remedy needs are important considerations during decision making.

The identified boundary is not to be viewed as an absolute point of compliance, but as a management objective with some flexibility. Any instances of contaminant migration past this boundary would need to be temporary and/or with demonstrably negligible impacts to the river. For example, a small distal portion of the plume can temporarily extend beyond the boundary before receding, or contaminant concentrations migrating beyond the boundary can naturally attenuate.

Predictive analysis should be used to determine the nature, extent, and timeframe of acceptable temporary excursions outside the Central Plateau boundary or the plume conditions that create a level of concern. Determination of the impacts to the river and the time period of impact need to be based on plume mass, plume size, and evidence of any continuing sources. This determination needs to be updated and confirmed periodically based on CSM updates, as uncertainty diminishes.

2. **Achieve steady-state groundwater conditions within the Central Plateau boundary, consistent with "the future beneficial use" that is linked to the final Hanford Site end state.**

The final, long-term objective after remediation is to permanently achieve steady-state groundwater conditions within the Central Plateau boundary consistent with "the future beneficial use" for the Hanford Site end state. This objective is consistent with the current overall approach to return Hanford Site groundwater to future beneficial use, which is currently defined as restoring the aquifer to achieve drinking water standards. However, there is a need for a final Hanford end state decision to finalize the specific conditions of the ultimate objective. Furthermore, evaluations for Central Plateau are needed, within a life cycle assessment of remedial approaches, for determining technical practicability and future beneficial use (e.g., drinking water, industrial use). An ASM approach for the Central Plateau can be initiated using the first site objective of "No sustained contaminant migration outside the Central Plateau" to guide remediation while an end state is being developed and the future target groundwater conditions are determined. This approach controls the groundwater contamination and limits the magnitude of source flux such that any necessary adjustments can be made in the future if the final objective requires different conditions.

4.3 Considerations for Central Plateau Interim Objectives

For implementing an ASM approach, Central Plateau interim objectives will need to create a stepwise remediation approach to achieve the "site" objectives. Therefore, a remediation strategy defined by a progression of revised/updated interim objectives for steps is needed to meet the first and second site objectives described above. These interim objectives are more specific and functional than the site objectives and need to consider individual contaminants of concern, contaminants of potential concern, plumes, and sources to groundwater. Predictive analyses conducted for determining the overall site objectives, boundaries, and cleanup timeframes will need to be used to prioritize plumes and potential sources and to identify the characterization needed to support remedial approaches. These targets will be reevaluated and revised periodically based on an evolving understanding of CSM, a reduction in uncertainty, and remedy performance.

Appropriate target categories for interim objectives can be waste-site-specific or plume-specific and may include measures such as mass recovery and treatment, concentration reduction, plume containment, plume reduction, source control, and/or selection of alternative cleanup approaches under appropriate regulatory framework (e.g., a TI waiver for I-129 cleanup). These interim objectives will also define the key remedial actions or strategies (e.g., remedy optimization, characterization) needed to address site uncertainties and complexities. The anticipated timeframe for interim objectives should be 3 to 5 years to create an iterative, stepwise ASM process and better quantify progress toward the overall site objectives.

4.3.1 Central Plateau Interim Objectives

The interim objective categories and steps identified below are proposed as considerations to support future discussions for Central Plateau remedy decision making. Consistent with implementing ASM and the state of the CSM, the interim objectives are progressive in time, though overlap may occur over different timescales for different plumes and waste sites. Site decision makers and regulators will need to define a “plume of concern” for ASM management, to guide decisions about an appropriate remedy, transitioning source control to source actions, and for evaluating actions in the vadose zone. For the purpose of this document and as an aid for future discussion, a plume of concern is a plume that (1) has the potential to migrate outside the Central Plateau and/or (2) will not attenuate within the Central Plateau to meet ultimate site objective 2 (Section 4.2.1). Consistent with current interim and groundwater OU regulatory decisions, the ASM approach discussed here broadly encompass the Central Plateau and use the legally defined Central Plateau boundary as a controlled zone for active remediation, long-term monitoring, and with respect to decisions for any associated remediation actions.

1. **Reduce current or emerging groundwater plumes so they cannot sustain migration outside the Central Plateau**

Interim objectives that aim to reduce plumes of concern must consider the point of compliance or the boundaries, the contaminant levels evaluated for the overall site objectives, and the continuing sources contributing to the groundwater plumes; where continuing sources exist, those can be addressed under a separate interim objective (as proposed below). Plume reduction requires quantifiable targets (e.g., mass removal, concentration reduction, plume area reduction, source control) to prevent migration of contaminants outside the Central Plateau. For instance, the current application of P&T followed by MNA as part of final and interim remedies on the Central Plateau uses this basic approach. However, many assumptions (i.e., the amount and distribution of total carbon tetrachloride mass, the abiotic degradation rate for carbon tetrachloride) that supported the estimated concentration levels and remedy timeframes determined in the 200-ZP-1 ROD are no longer valid. In an ASM approach, these targets must be reviewed and updated routinely based on any new information and updates to the CSM (Figure 2.1). These targets also need to directly correlate the remedy performance to progress toward achieving interim and site objectives. Assessment of plume reduction requires conducting ongoing performance monitoring and periodic performance assessments. This information supports any updates to the CSM as well as optimization efforts to maintain removal effectiveness and efficiency.

Where MNA is selected as a remedy component, monitoring supports periodic evaluation of attenuation mechanisms and their impact on the plumes. Like many contaminated sites using P&T, the 200 West P&T remedy in the Central Plateau was originally designed to address immediate risks at the site, such as large-scale containment of carbon tetrachloride plume and bulk treatment. However, performance of these systems depends on complex factors such as heterogeneous geology, large capture zones requiring multiple pore-volume flushes, the presence of source zones, diffusion-limited mass transfer, co-located and/or recalcitrant contaminants, and dispersed contaminant distributions (Guo et al. 2017; NRC 2013). As the remedy progresses from initial implementation through continued operation over time, contaminant removal effectiveness needs to be monitored and, if needed, the remedy needs to be optimized to avoid suboptimal operations. Plume reduction objectives and targets allow stepwise assessment of optimization needs.

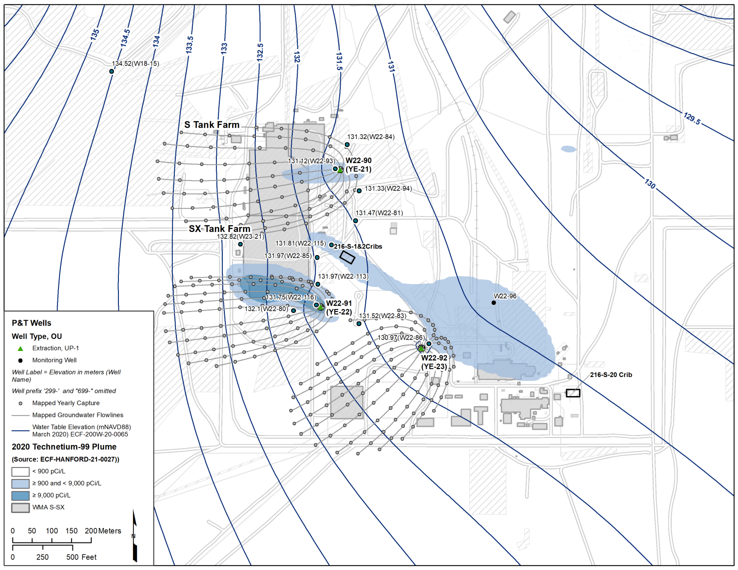
2. **Efficiently contain existing, known source contributions to groundwater if they can lead to a plume of concern**

For Central Plateau groundwater cleanup, existing contaminant sources, typically identified around the tank farm areas and underneath disposal facilities, are a significant uncertainty in the current CSM in terms of their impact on the groundwater plumes and on the cleanup timeframe. Where these sources can lead to a plume of concern, the optimization of the groundwater remedy to contain these sources at or near the source area may be needed to provide effective and efficient control (e.g., higher concentration/mass removal with relatively lower flow rate of pumping). Furthermore, additional studies or monitoring activities may provide a better understanding of the current and future impacts of sources on the groundwater to support predictive analyses.

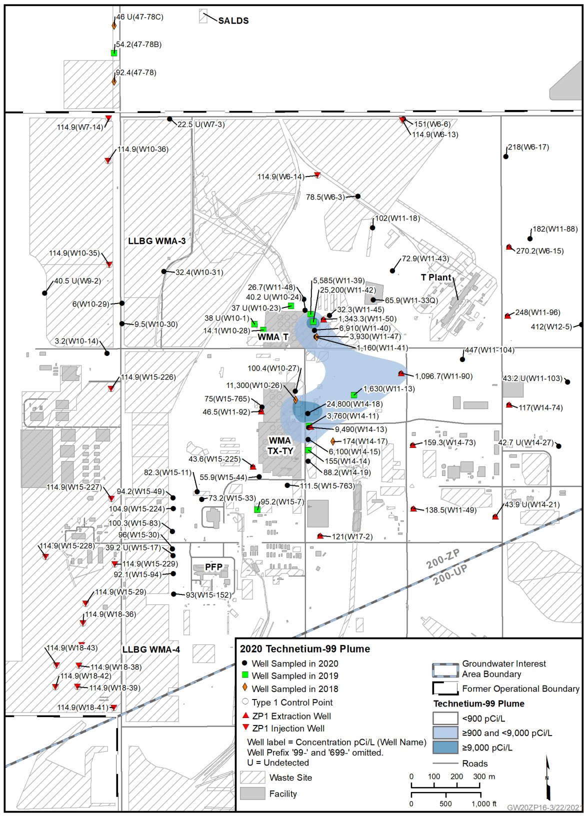
In the Central Plateau, examples of continuing sources include Tc-99 contamination at the WMA S-SX and WMA T-TX-TY. As can be seen in Figure 4.1, Tc-99 plumes around these areas are continuing to evolve due to fluxes into groundwater and current pumping strategies. Around the S-SX tank farm, the application of P&T relatively close to the source zones achieves better containment of the plumes versus observed plume behavior at the T-TX-TY tanks farms. However, at the S-SX tank farm, part of the plume still continues to migrate beyond the existing capture zones, highlighting the importance of continued analyses and optimization consistent with an ASM approach. The current pumping strategy around the T-TX-TY tank farms does not include targeted efforts for source containment, resulting in more dilute and spread-out plume distribution, potentially requiring pumping for longer time periods and at a higher capacity.

3. **Identify and apply effective source actions to replace source containment and treat the source sufficiently to prevent emergence of a plume of concern in the future**

Addressing sources by a source action (e.g., in situ treatment) may be necessary to enable termination of P&T source containment, which is inefficient over long time periods. Therefore, appropriate targets need to be identified to provide stepwise progress toward achieving this interim goal and to simultaneously support decision making for the second interim objective specified above. Evaluating and deploying



(a)



(b)

Figure 4.1. Tc-99 plumes in groundwater near (a) S-SX tank farms, and (b) T-TX-TY tank farms.

viable treatment methods for deep vadose zone contamination to provide long-term protection of the groundwater is a key component of the current Central Plateau cleanup strategy. For example, as discussed in Section 2.0, the 200-DV-1 OU was established to address challenging liquid waste sites with vadose zone contamination across Central Plateau, primarily the cribs and trenches associated with the B-BX-BY, T-TX-TY, and S-SX tank farm WMAs. It also includes the highly contaminated perched water zone under the B Complex (200-BP-5 OU), which is a source of contaminant mass flux into groundwater. As a result of a long history of technology evaluations, eight potential in situ treatment technologies were recently identified, and a treatability study test plan was developed to address the contamination within 200-DV-1 waste sites (DOE 2019b). These efforts are intended to provide information on potential source actions that could be applied in conjunction with the groundwater P&T source control strategies.

4. **For emerging plumes, apply source containment or source actions so that a plume of concern is not created**

At a complex system with hundreds of waste sites, such as the Central Plateau, an ASM approach provides the necessary framework and flexibility to address changing conditions and an evolving CSM. It is possible that new plumes may emerge in the groundwater; for example, a new area with high Tc-99 concentrations (> 900 pCi/L) has recently been observed in wells southeast of the main plume at the 200-PO-1 OU. The decision for action and the type of action for these conditions needs to be based on an identified “trend of concern” that is a trigger for needing action beyond MNA and/or long-term passive management (e.g., with ESM). Actions for this interim objective are similar to those that are appropriate for addressing interim objectives 1 and 2 and may need further consideration for interim objective 3.

5. **Identify major future sources of concern that could create a plume of concern**

Appropriate characterization of expected major vadose zone sources is needed to estimate the potential “plumes of concern” that could emerge from these areas. The focused should be on source characterization, but tailored to focus only on major sources, depending on an understanding of the site inventory and past operations. In an ASM approach, other smaller sources are managed by interim objective 4. While current characterization activities are ongoing for the 200-DV-1 OU under the RI/FS process, lessons learned from this process need to be integrated into future RI/FS actions for the other liquid-disposal waste sites in the 200-EA-1, 200-WA-1, and 200-BC-1 OUs to support implementation of this objective.

6. **Apply appropriate source actions to address future sources of concern identified by interim objective 5 so that they don’t create a plume of concern**

This objective calls for preemptive remediation (pending characterization data under interim objective 5) of major sources that are expected to create plumes of concern. For ASM, this action is similar to the P&T action that has been applied in the near term to address existing plumes that have sufficient concentration and mass such that they are predicted to migrate beyond the Central Plateau without application of active remediation.

7. **Apply long-term passive management with ESM to verify meeting site objectives**

This objective recognizes that, for the Central Plateau, there will be a long-term passive management component of the remediation (e.g., I-129 beyond the Central Plateau boundary). Based on the large physical scale, long timescale of the contamination, and site complexities (e.g., heterogeneity, potential sources, and TI waiver applications), ESM is recommended as suitable for this portion of ASM implementation.

4.4 Periodic Evaluations and Reporting

As discussed in Section 2.2, monitoring for characterization, process effectiveness and efficiency, long-term management, and performance assessments are important components of an ASM framework. These activities are typically conducted and reported annually at the OU level in the Central Plateau (e.g., annual groundwater monitoring and P&T remedy performance reports). Within the approach and objectives provided above, the current activities and any additional identified remedial actions should still be reported annually to support CSM updates and provide the needed evaluations for achieving or progress toward the interim and site goals.

5.0 Summary

ASM is a systematic and iterative management approach recognized for the potential benefits of improving and expediting cleanup of large and/or complex sites, such as Hanford Central Plateau. The Central Plateau is one of DOE's most complex environmental remediation sites, presenting challenges associated with the following:

- Hundreds of contaminated soil sites, and potential shallow sources (e.g., waste tanks)
- Persistent and recalcitrant deep vadose zone residual sources, including key-risk drivers such as Tc-99, I-129, U, nitrate, and chromium comingled with other contaminants, posing long-term risk of continued contaminant flux into groundwater, with significant data gaps on the total amount of contaminants in the vadose zone and quantifiable flux into groundwater
- Extensive co-mingled groundwater plumes (e.g., carbon tetrachloride, Tc-99, U, I-129) with uncertain total mass and contaminant distribution
- Uncertainty associated with subsurface heterogeneity, including both the geological framework (e.g., within the Central Plateau and for the hydraulic connections to the Columbia River) and biogeochemical factors (e.g., attenuation mechanisms)

In addition to the specific technical challenges, the administrative and remediation management aspects of the Hanford Site Central Plateau area are consistent with a need to consider ASM. Many of the cleanup actions on the Central Plateau are still early in the remediation decision process. For example, many of the source OUs still require CERCLA remedial decisions, and all groundwater OUs, except 200-ZP-1, only have interim action RODs. Overall cleanup efforts are estimated to last decades and cost tens of billions of dollars in life cycle schedule and budget (DOE 2016a).

The framework and proposed considerations discussed in this document identify an ASM approach for selecting, implementing, and managing remediation at the Hanford Central Plateau to achieve an effective and efficient progress toward the required end state. Key elements of an ASM approach will include identification of appropriate site objectives that are consistent with the overall Hanford Site goals and that support the development of a long-term management approach; interim goals that provide a quantifiable, stepwise progress for achieving site objectives; and key remedial actions that address key uncertainties and data gaps. For implementation of ASM, a long-term management plan needs to be developed to capture these elements and to support decision making and forward planning. Furthermore, application of an ASM approach for Central Plateau groundwater cleanup may enhance integration with the tank waste cleanup activities as the focus becomes addressing key uncertainties and data gaps in the near- and long-term.

The proposed considerations in this document are intended to facilitate the application of an ASM process by identifying an overall approach that maintains protectiveness but recognizes the uncertainty, long timeframe, and technical challenges that need to be considered in selecting, implementing, and managing remediation at the Hanford Central Plateau.

6.0 Quality Assurance

This work was performed in accordance with the Pacific Northwest National Laboratory Nuclear Quality Assurance Program (NQAP). The NQAP complies with DOE Order 414.1D, *Quality Assurance*. The NQAP uses NQA-1-2012, *Quality Assurance Requirements for Nuclear Facility Application*, as its consensus standard and NQA-1-2012, Subpart 4.2.1, as the basis for its graded approach to quality.

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Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

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