

# Remediation Strategy for Uranium in Groundwater at the Hanford Site 300 Area, 300-FF-5 Operable Unit

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Prepared for the U.S. Department of Energy  
Assistant Secretary for Environmental Management



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Department of Energy**  
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## EXECUTIVE SUMMARY

Uranium concentrations in some portions of the groundwater beneath the Hanford Site 300 Area remain above the 30- $\mu\text{g/L}$  drinking water standard. The persistence of this plume is not consistent with expectations presented in the Record of Decision for interim remedial action, which assumed significant attenuation of the uranium plume within 10 years of 1993.<sup>a</sup> In 2005, the U.S. Department of Energy (DOE) embarked on a comprehensive re-evaluation of the remedy for uranium contamination in the groundwater beneath the 300 Area, which is part of the 300-FF-5 Operable Unit. A multiple-task program was conducted consisting of a limited field investigation, assessment of current risk, hydrogeologic and geochemical modeling, updating the conceptual model, and re-evaluation of prospective remedies for uranium. The objectives of the re-evaluation effort are to "...identify, develop, and select remedial actions that have the potential to 1) restore, to the extent possible, the 300-FF-5 groundwater aquifer to its highest and best beneficial use, and 2) reduce risk to human health and the environment."<sup>b</sup>

New information developed from the renewed characterization efforts has provided a better understanding of the possible inventories of residual contamination in various subsurface regions, and the possible mechanisms by which those inventories may contribute to groundwater contamination. Increased knowledge of 1) the processes associated with uranium transfer between sediments and groundwater (particularly the dynamics of river-induced water table changes), and 2) carbonate-related sorption changes between groundwater and river water have provided a new appreciation for the complex phenomena and dynamic subsurface characteristics that contribute to the persistence of the groundwater plume. One of the findings from the limited field investigation and new conceptual model is that the quantity of uranium remaining in the unsaturated vadose zone and periodically re-wetted sediments near the water table is considerably greater than the amount estimated to be in the contaminated aquifer. The persistently elevated concentrations of uranium in groundwater are symptomatic of the remaining contamination on sediments at and above the water table. Consequently, the remediation strategy that originally focused on the always saturated aquifer must now also consider potential treatment of the vadose zone and water table zone sediments to effectively mitigate the uranium plume.

Laboratory and field treatability tests of phosphate-based remedial technologies to provide in-situ treatment of uranium have also been conducted.<sup>c,d</sup> These efforts demonstrate that in-situ stabilization of uranium with phosphate minerals may be an effective treatment for uranium entering the aquifer from wetted sediments at the water table. Direct groundwater treatment was shown to be less effective in attaining groundwater cleanup goals. Additional testing is necessary, however, to evaluate means to implement phosphate-based uranium immobilization at the water table interface.

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<sup>a</sup> EPA. 1996. *Record of Decision for USDOE Hanford 300-FF-1 and 300-FF-5 Operable Units Remedial Actions*. U.S. Environmental Protection Agency, U.S. Department of Energy, and Washington State Department of Ecology, Olympia, Washington.

<sup>b</sup> DOE-RL. 2005. *Work Plan for Phase III Feasibility Study 300-FF-5 Operable Unit*. DOE/RL-2005-41, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

<sup>c</sup> Vermeul VR, MD Williams, BG Fritz, RD Mackley, DP Mendoza, DR Newcomer, ML Rockhold, BA Williams, and DM Wellman. 2007. *Treatability Test Plan for 300 Area Uranium Stabilization Through Polyphosphate Injection*. PNNL-16571, Pacific Northwest National Laboratory, Richland, Washington.

<sup>d</sup> Wellman DM, JS Fruchter, VR Vermeul, and MD Williams. 2008. *Challenges Associated with Apatite Remediation of Uranium*. PNNL-17480, Pacific Northwest National Laboratory, Richland Washington.

New information developed through the field investigations, treatability studies, hydrologic model development, and uranium geochemistry research conducted by DOE's Office of Science continues to enhance the understanding of the uranium distribution, uranium transport, and potential remediation processes at the Hanford Site. This report on a strategy to remediate uranium contamination was prepared to synthesize the new information in terms of 1) identifying promising remediation alternatives, and 2) conducting an initial comparative evaluation of these alternatives. The alternatives developed and compared in this report are considered prototype alternatives because additional information is needed before the alternatives can be developed and evaluated at the level of detail necessary for a feasibility study and subsequent proposed plan for action. The intent of the strategy in this report is to provide a context for the additional characterization and treatability testing that will support a complete feasibility study. Final evaluation of the environmental problem and remedial action alternatives for uranium contamination in 300 Area groundwater will be deferred to a more comprehensive feasibility study that will develop and evaluate remedies for all contaminants of concern in the 300-FF-5 Operable Unit. The comprehensive feasibility study and proposed plan will support a Record of Decision in the 2012 timeframe for remedial actions for the entire 300 National Priorities List site, in accordance with the *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act of 1986*.<sup>e,f</sup>

The remediation strategy analysis is consistent with the initial steps of the feasibility study process outlined by U.S. Environmental Protection Agency (EPA) guidance.<sup>g</sup> The remedial action objectives, general response actions, identification of applicable technologies and management strategies, and screening of appropriate technologies built upon a prior technology screening report.<sup>h</sup> Three treatment zones targets were identified: unexcavated vadose zone sediments, occasionally wetted sediments in immediate proximity to the fluctuating water table, and the saturated aquifer containing both saturated sediments and groundwater. The remediation strategy study developed prototype alternatives for these targets and conducted a preliminary screening of these alternatives. The remediation strategy study concludes with the results of this preliminary screening and suggestions for additional site characterization and testing. Additional remedial alternative evaluation is deferred to the subsequent feasibility study after additional characterization and technology information is collected.

Two general remediation strategies were considered:

- Decrease the flux of uranium from the vadose zone to the groundwater
- Directly decrease the concentration of uranium in the groundwater.

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<sup>e</sup> *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*. Public Law 96-510, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

<sup>f</sup> *Superfund Amendments and Reauthorization Act (SARA) of 1986*. Public Law 99-499, 100 Stat. 1613, Title 10, et seq.

<sup>g</sup> EPA. 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*; Interim Final. EPA/540/G-89/004, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

<sup>h</sup> Nimmons MJ. 2007. *Evaluation and Screening of Remedial Technologies for Uranium at the 300-FF-5 Operable Unit Hanford Site, Washington*. PNNL-16761, Pacific Northwest National Laboratory, Richland, Washington.

Initial technology screening indicates that large scale use of pump-and-treat technology, use of a mobilizing agent with hydraulic capture, and reduction-oxidation manipulation techniques were not suitable for uranium remediation at the 300 Area. In addition to passive alternatives, such as no-action and monitored natural attenuation, seven active prototype alternatives were formulated and evaluated in this remediation strategy study. Each prototype alternative was screened using the three criteria of effectiveness, implementability, and relative cost in the manner of a preliminary alternative screen in a CERCLA feasibility study.<sup>f</sup> An ordinal ranking scheme was employed to compare prototype alternatives in a qualitative, not quantitative, comparison.<sup>i</sup> The ranking analysis is a relative comparison of the prototype alternatives. The relative cost comparison between alternatives is “order of magnitude” using an approximate estimate of capital, time-discounted operating costs, and closing costs using procedures prescribed by the EPA.<sup>j</sup>

Considering only effectiveness and implementability, but excluding relative cost, the relative ranking of the prototype alternatives is shown in Table ES-1 where the ranking order is from most desirable to least desirable.

Table ES-1. Relative Ranking of the Prototype Alternatives Using Effectiveness and Implementability.

1	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone
2	Focused Excavation and Disposal of Contaminated Sediment
3	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone
4	Polyphosphate Application to Groundwater Beneath Original Source Areas
5	Polyphosphate Application to Groundwater along Source Area Perimeters
6	Monitored Natural Attenuation
7	Polyphosphate Application to Groundwater to Form Linear Reactive Barrier Parallel to River
	<i>Tied for Lowest Ranking</i>
8	No Action
8	Extensive Excavation and Disposal of Contaminated Sediment

When relative cost is added to the consideration, the two passive alternatives—no action and monitored natural attenuation—have very low costs relative to all of the active remedies. Consequently, although they have low ranking in terms of effectiveness and implementability, the relatively minimal cost of the passive alternatives tends to skew the combined ranking. Also, with regard to a monitored natural attenuation remedy, evidence to date indicates the time period to achieve the remedial action goal of restoring the aquifer would be too long for this remedy to be a viable alternative. Therefore, combined ranking of only the active prototype alternatives is considered to be useful in this remediation strategy study. The summary ranking in order of desirability for the active prototype alternatives according to

<sup>i</sup> The Integrated Field-Scale Subsurface Research Challenge (known also as the Integrated Field Challenge) is managed by DOE’s Office of Biological and Environmental Research – Remediation, Sciences Division. Its objective is to use state-of-the-science field experiments to resolve the geochemical, biophysical, and microbiological factors that control uranium migration at the Hanford Site 300 Area.

<sup>j</sup> U.S. Environmental Protection Agency. 2000. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*. EPA 540-R-00-002 OSWER 9355.0-75. U.S. Army Corps of Engineers, Hazardous, Toxic and Radioactive Waste, Center of Expertise, Omaha, Nebraska. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

the combined criteria of effectiveness, implementability, and relative cost is shown in Table ES-2 where the ranking order is from most desirable to least desirable.

Table ES-2. Summary Ranking of Active Prototype Alternatives  
Using Effectiveness, Implementability, and Relative Cost.

1	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone
2	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone
3	Polyphosphate Application to Groundwater Beneath Original Source Areas
	<i>Next Three Rank Similarly</i>
4	Polyphosphate Application to Groundwater to Form Linear Reactive Barrier Parallel to River
4	Focused Excavation and Disposal of Contaminated Sediment
4	Polyphosphate Application to Groundwater along Source Area Perimeters
	<i>Significantly Lowest Rank</i>
5	Extensive Excavation and Disposal of Contaminated Sediment

Available field data and current interpretations indicate the largest inventory of contaminant uranium beneath the 300 Area is in the sediments above the groundwater. The portion of inventory that is available for transport to groundwater is not fully defined, and is the subject for additional laboratory and field research activities. The conceptual model postulates that fluctuations in the water table play a role in the re-supply of uranium to the aquifer. Preliminary screening indicates treatment of this uranium source area is preferred compared to treatment of groundwater. Treating the source has the advantage of reducing uranium concentrations in the groundwater in a relatively shorter timeframe than by treatment of groundwater alone. Thus, efforts to 1) refine the location(s) of the source(s) that continue to supply uranium, and 2) to test methods for effectively implementing remediation in the smear zone, are critical for developing an effective remediation approach.

The set of active treatment actions essentially consists of two strategies: chemically stabilize uranium with a form of phosphate, or physically remove the uranium-contaminated sediments situated above the water table. Both courses of action have fundamental advantages and disadvantages. The chemical stabilization approach has the advantages of appearing to be an order of magnitude less costly than excavation and having the flexibility to possibly treat lateral contamination outside the contaminant source "footprint." However, the delivery technology for chemical stabilization has yet to be fully developed and proven. Additionally, effective delivery of phosphate reagent to groundwater has yet to be perfected. Furthermore, formulation and application of a phosphate reagent to the vadose zone is only in its preliminary development stage. Additional treatability testing is needed to verify the implementability of the phosphate-based technologies for the targeted smear zone (vertical zone of fluctuating groundwater elevation) contamination. The excavation approach has the advantage of being a mature and relatively certain technology. It has fundamental disadvantages of appearing to be more expensive than phosphate stabilization and of removing only uranium directly encountered. As with the phosphate-based technology, to be effective, excavation must target the contamination source.

The path forward from this remediation strategy for uranium toward a future feasibility study involves additional characterization of contamination in various subsurface regions where uranium may be sequestered. The characterization would focus on identifying the locations of where contaminant uranium is sequestered, and on determining the inventory and form of that uranium (i.e., is it labile). A second

element of the path forward involves additional testing of promising technologies for immobilizing uranium in the environment.

Information presented in this report will be used in a future feasibility study report that will address all contaminants of concern for groundwater associated with the 300 Area National Priorities List site. Systematic planning efforts leading toward additional remedial investigation and feasibility study activities are underway in summer 2008.

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## LIST OF TERMS

ARAR	Applicable or Relevant and Appropriate Requirement
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CFR	<i>Code of Federal Regulations</i>
COC	contaminants of concern
DART	directed applied reagent technology
DCE	dichloroethene
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ESD	explanation of significant difference
FRTR	Federal Remediation Technologies Roundtable
FS	feasibility study
LFI	limited field investigation
MCL	maximum contaminant level
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act Cleanup Regulations
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	operations and management
PNNL	Pacific Northwest National Laboratory
PV	present value
RAO	remedial action objective
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
RI	remedial investigation
ROD	Record of Decision
SARA	<i>Superfund Amendments and Reauthorization Act of 1986</i>
TCE	trichloroethene
WAC	Washington Administrative Code
WIDS	Waste Information Data System
VOC	volatile organic compound
ZVI	zero-valent iron

**MEASUREMENTS**

°C	degrees Celsius
Ci	curies
pCi	picocuries
cm	centimeter(s)
°F	degrees Fahrenheit
ft	foot/feet
gal	gallon(s)
gpm	gallon(s) per minute
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
km <sup>2</sup>	square kilometer(s)
L	liter(s)
lb	pound(s)
m	meter(s)
mg	milligram(s)
mi	mile(s)
mi <sup>2</sup>	square mile(s)
min	minute(s)
µg	microgram

## 1.0 INTRODUCTION

The persistence of uranium in groundwater beneath the Hanford Site 300 Area at levels that exceed the drinking water standard (Figure 1-1) has prompted efforts to re-evaluate potential remedies that were described during the initial feasibility study for the 300-FF-5 Operable Unit (DOE-RL 1994). As described in the work plan for this re-evaluation, the objectives are to "...identify, develop, and select remedial actions that have the potential to 1) restore, to the extent possible, the 300-FF-5 groundwater aquifer to its highest and best beneficial use, and 2) reduce risk to human health and the environment" (DOE-RL 2005a). The work plan included a multi-pronged program of focused site investigation and characterization of the subsurface, development of better hydrologic models, an updated risk assessment, an updated conceptual model, and consideration of remediation alternatives in a new Phase III feasibility study focused on uranium remedies. That Phase III feasibility study was intended to supplement and complete the earlier Phase I and Phase II feasibility studies conducted in the early 1990s, with consideration of recent technology developments focused on uranium cleanup activities.

The conceptual model for uranium contamination beneath the 300 Area has evolved since the initial remedial investigation for the 300-FF-5 Operable Unit (DOE-RL 1995). An expanded groundwater report for fiscal year 2004 provided updated information on trends for plume parameters and a revised conceptual model (Peterson et al. 2005). A limited field investigation was conducted in 2006 that included detailed characterization of sediment and water samples from the vadose zone and unconfined aquifer at four strategic locations (Williams et al. 2007). A revised description of the conceptual model for uranium was prepared in 2007 (Peterson et al. 2008) that included the results of the limited field investigation, an investigation of the groundwater/river interface (Fritz et al. 2007), and the most recent monitoring results. Based on these efforts, the current conceptual model indicates that to effectively remediate the groundwater plume, potential sources in the overlying vadose zone must also be considered.

Laboratory and field treatability tests of phosphate-based remedial technologies to provide in-situ treatment of uranium have also been conducted (Vermeul et al. 2007, Wellman et al. 2008). These efforts demonstrate that in-situ stabilization of uranium with a phosphate mineral may be a viable alternative for immobilization of contaminant uranium at the water table interface. The new information developed through the field investigations, treatability studies, hydrologic model development, and uranium geochemistry research conducted by the U.S. Department of Energy's (DOE) Office of Science improved the understanding of uranium distribution, uranium transport, and potential remediation processes at the Hanford Site. This document synthesizes the new information in terms of identifying promising remediation alternatives and conducting an initial comparative evaluation of these alternatives.

### 1.1 OBJECTIVES

The remediation strategy described in this report is intended to capture and organize information and evaluations conducted since 2005 as part of developing a remedy for uranium in groundwater beneath the Hanford Site 300 Area, a part of the 300-FF-5 Operable Unit. The report integrates recent characterization information related to the source of uranium groundwater contamination and presents the partially complete feasibility process of developing and screening remedial action alternatives for



cleanup. One objective of this report is to provide a remediation strategy based on chosen general response actions. The intent of the strategy is to provide a context for the subsequent additional characterization and treatability testing that will be required prior to conducting the feasibility study. This secondary objective intends to foster a remediation orientation with the site characterization and remediation technology development efforts. Final evaluation and decisions for the remedy to the uranium contamination in 300 Area groundwater will be deferred to a comprehensive 300 Area feasibility study scheduled for 2011.

## 1.2 SCOPE

The scope of this report reflects the iterative nature of the remedial investigation process and is focused on the following:

- The contaminant of concern is uranium.
- The geographic extent is the subsurface beneath the 300 Area, including the vadose zone and unconfined aquifer (the latter a part of the 300-FF-5 Operable Unit).
- The media included are 1) groundwater contaminated by uranium in the uppermost aquifer, and 2) sediments associated with the uranium contamination in the subsurface. The sediments may be saturated, unsaturated, or periodically saturated and unsaturated by the cyclic rise and fall of the water table in response to Columbia River stage fluctuations.

## 1.3 ORGANIZATION OF REPORT

This report is structured similar to a feasibility study focused on identification and evaluation of remedies for uranium contamination. However, it proceeds no further than formulation of candidate prototype alternatives with preliminary screening of those prototype alternatives. The prototype alternatives are subject to significant technical uncertainty because further site characterization is required to define the extent of the contamination source, and there is incomplete remediation technology development.

The beginning of the report describes the site in Section 2.0, the regulatory context in Section 3.0, and methodology in Section 4.0. The core of the report presents identification and screening of remediation technologies in Section 5.0, assembly of applicable technologies into prototype alternatives in Section 6.0, and preliminary screening of prototype alternative using three criteria in Section 7.0. A brief discussion of the strategy and the path forward is in Section 8.0.

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## 2.0 SITE DESCRIPTION

This section describes the 300-FF-5 Operable Unit at the Hanford Site, which includes groundwater affected by releases from the 300-FF-1 and 300-FF-2 Operable Units (EPA 1996, EPA 2000a). The description includes the physical setting, site history, waste sources, meteorology, topography, hydrogeology, ecology, and land use. This section includes information collected in the original remedial investigation in the early 1990s, and information from recent site characterization activities conducted as part of the limited field investigation for uranium.

### 2.1 PHYSICAL SETTING

The Hanford Site occupies an area of approximately 1,517 km<sup>2</sup> (586 mi<sup>2</sup>) in Benton County, north of the confluence of the Yakima River with the Columbia River in south-central Washington State (Figure 2-1). The Hanford Site extends north to south over a distance of about 50 km (30 mi) and 40 km (24 mi) from east to west. The 300 Area, in the southeastern corner of the Hanford Site, is located north of the city of Richland and covers approximately 1.5 km<sup>2</sup> (0.6 mi<sup>2</sup>). Locations of the operable units associated with the 300 National Priorities List (NPL) site are shown in Figure 2-2.

### 2.2 SITE HISTORY

The Hanford Site was established in 1943 to produce plutonium for nuclear weapons and was the first plutonium production facility in history. The Hanford Site is divided into several operational areas (e.g., 100, 200, 300, and 400 Areas) associated with specific steps in the plutonium production process (DOE-RL 1998a, b). Plutonium production continued throughout the Cold War and ended in 1988. Presently, the Hanford Site is undergoing cleanup/removal of contaminated facilities and environmental restoration.

Most of the 300 Area was used for industrial activities associated with fabrication of nuclear fuel rods and test materials related to plutonium production processes. The nuclear fuel rods were fabricated from uranium with various degrees of enrichment over time. The fuel rod manufacturing process included encasing or cladding the uranium within various metal alloys containing aluminum, zirconium, tin, iron, chromium, and nickel. Additionally, laboratories for nuclear fuel research, and development and support facilities operated in the 300 Area.

Wastes generated in the 300 Area resulted from fuel fabrication operations and a variety of support operations, such as electric power generation from coal or oil, laboratory wastes, water treatment residuals, and sanitary waste disposal (DOE-RL 1993). These wastes were disposed in a variety of liquid and/or solid forms to cribs, ponds, and trenches located in the vicinity of the 300 Area. Typical waste streams discharged to the environment through the various ponds and trenches included uranyl nitrate hexhydrate, ammonium nitrate, hexone, neutralized waste acids containing metallic and chemical compounds of the fuel fabrication process, as well as process chemicals and solutions used in the numerous fuel reprocessing and separation technologies employed in the laboratories and test facilities (Gerber 1992). The largest volume of waste was generated from fuel fabrication operations. As a result of these activities, contaminated sediments and groundwater containing significant quantities of uranium exist near and beneath the historic 300 Area disposal facilities (cribs, trenches, and ponds) (Peterson et al. 2008). The focus of this remediation study centers on this uranium contamination.

Figure 2-1. Location Map of the Hanford Site in South-Central Washington State.

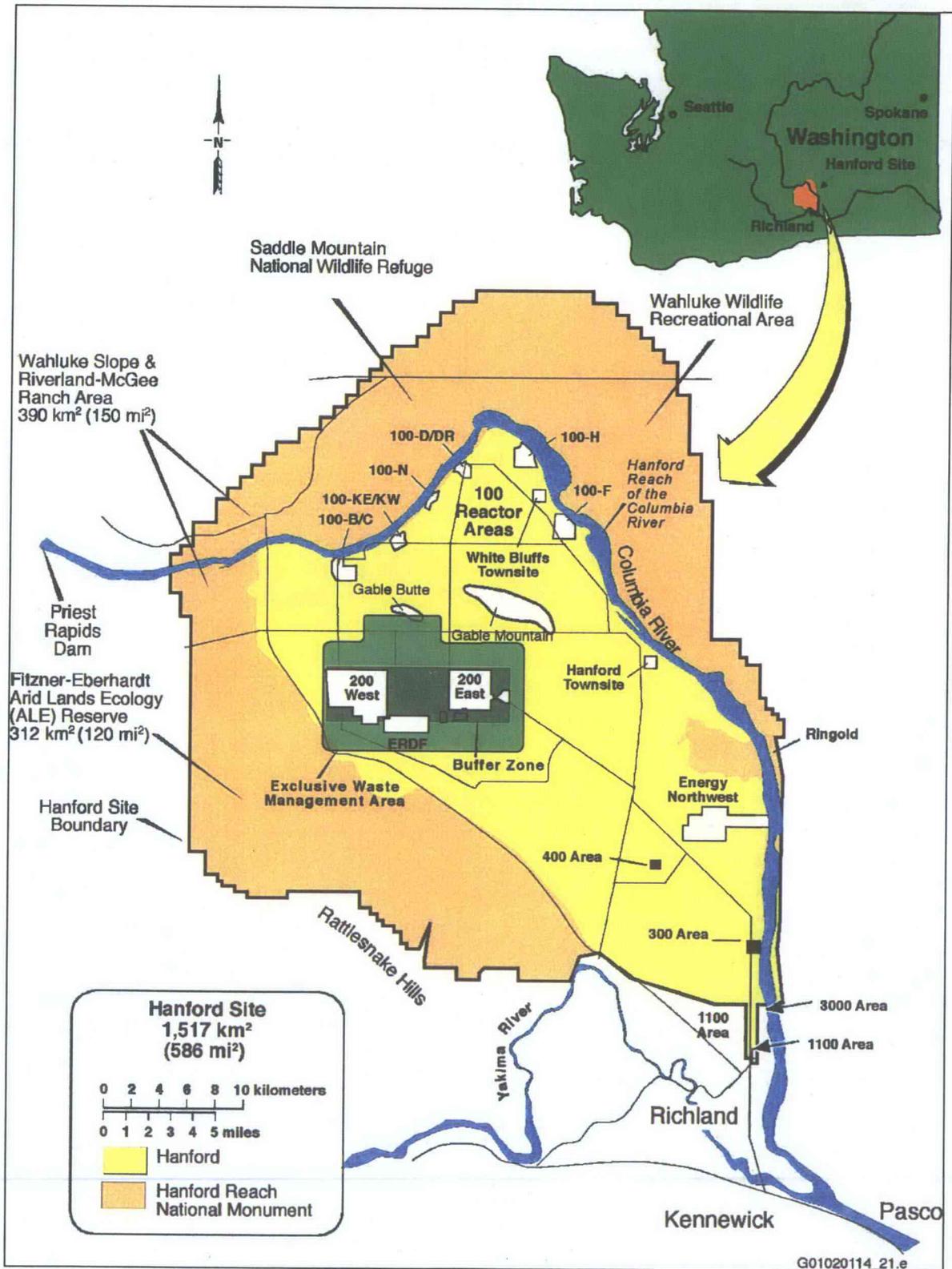
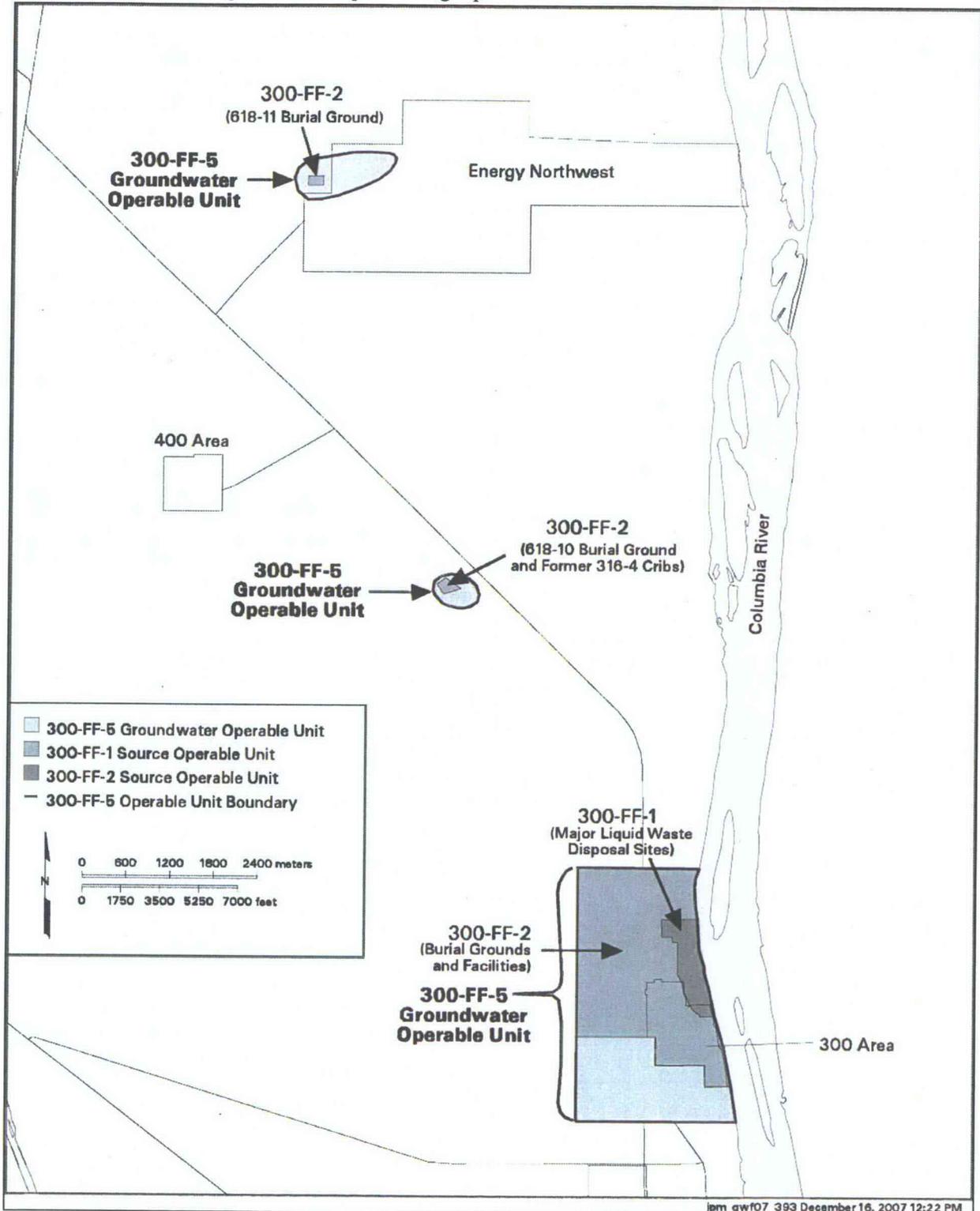


Figure 2-2. Map Showing Operable Units of the 300 NPL Site.



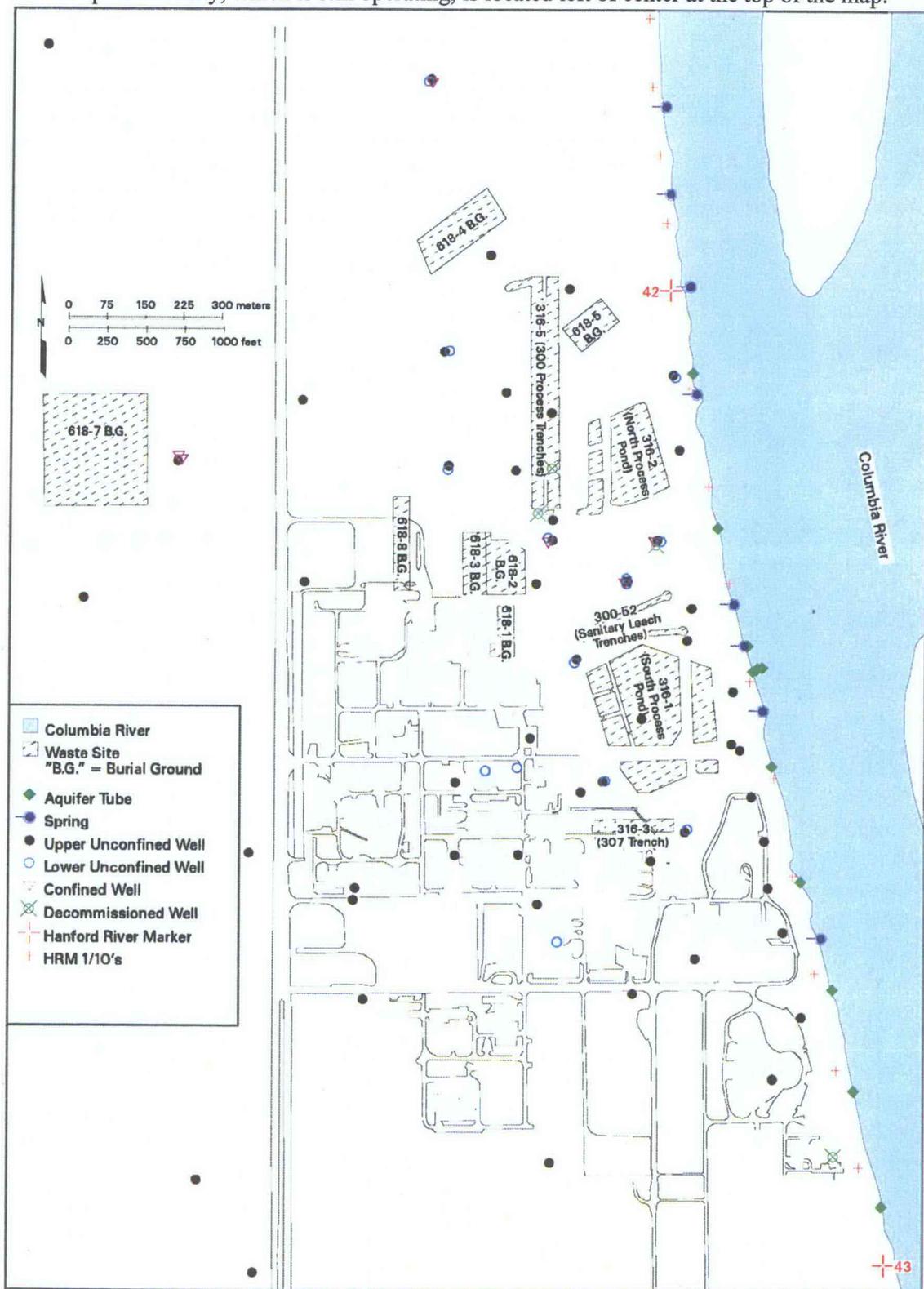
## 2.3 WASTE SOURCES

Historical operations involving fuel fabrication and research activities at the 300 Area have contaminated engineered liquid waste-disposal facilities, the underlying vadose zone, and the uppermost aquifer with uranium. Principle reports describing historical operations for the purpose of supporting remedial action decisions are Young et al. (1990), Young and Fruchter (1991), and DeFord et al. (1994). The greatest impact to groundwater from disposal of waste containing uranium probably occurred during the Hanford Site's peak plutonium production period in the 1950s through the mid-1960s. During this period, effluent was directed to the South and North Process Ponds and a lesser amount to the 307 Process Trenches. Contaminated process wastes continued to be generated during the 1970s and 1980s, with disposal shifting to the 300 Area Process Trenches in the mid-1970s. Table 2-1 lists the principle waste-disposal units and chronology of their use. Figure 2-3 provides a location map for these waste-receiving facilities. Additional contamination of the 300 Area subsurface occurred because of leakage from the process sewer system (Waste Information Data System [WIDS] Code 300-15), which delivered fuel fabrication and other process/research waste effluents to the various disposal sites (Lindberg and Bond 1979).

Table 2-1. Operating Periods for Principle Liquid Waste Disposal Facilities.

Disposal Facility	WIDS <sup>(a)</sup> Code	Period of Use for Effluent	Comments
South Process Pond	316-1	1943 to 1975	Removal of contaminated soil completed in 2000; excavation backfilled in 2004.
North Process Pond	316-2	1948 to 1974	Removal of contaminated soil completed in 1999; excavation backfilled in 2004.
307 Process Trenches	316-3	1953 to 1963	Backfilled with contaminated soil in 1965; remedial action to be completed by December 2009 (TPA milestone M94-07).
300 Area Process Trenches	316-5	1975 to 1985; 1985 to 1994	Received nonhazardous liquid effluent after 1985 through December 1994. Expedited Response Action to remove contaminated soil in 1991, followed by more extensive soil and infrastructure removal actions in 1997/98; backfilled in 2004.
310 Treated Effluent Disposal Facility (TEDF)	--	1994 to present	Receives 300 Area effluents via the process sewer system. Treated effluent is then discharged to the Columbia River via an NPDES permit.
(a) Waste Information Data System.			
Reference: 300-FF-1 Operable Unit Remedial Action Report (DOE-RL 2005b)			

Figure 2-3. Map of Former Waste Disposal Facilities in the 300 Area. The 310 Treated Effluent Disposal Facility, which is still operating, is located left of center at the top of the map.



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## 2.4 300 AREA CLIMATE

The climate of the 300 Area is semi-arid, influenced by the rain shadow created by the Cascade Range located approximately 130 km (80 mi) to the west. The resulting climate is characterized by low precipitation, high evapotranspiration, and relatively high winds. Observations at the Hanford Meteorological Station, located approximately 32 km (20 mi) northwest of the 300 Area at an elevation of 223 m (733 ft) above mean sea level, indicate the total annual precipitation averages approximately 16 cm (6 in.). Rain is the usual form of precipitation, but snow also falls in winter. Winter is the wettest season. Summer is the driest season; however, the greatest intensity of precipitation occurs in summer with occasional thunderstorms. Summer is typically hot and dry, and winters are moderately cold. The average temperature in July is 24.7°C (76.4°F), and the average temperature in January is -1.5°C (29.3°F). In the Hanford Site climate, most of the water available for recharge to soil comes in winter months during periods of low evaporation (Hulstrom 1992).

Based upon observations at the 300 Area monitoring station operated by Pacific Northwest National Laboratory (PNNL), wind direction at the 300 Area varies over 360 degrees, with a prevailing wind direction from the southwest (11% of the time). Winds from the north, southeast, south-southwest, and north-northwest occur with approximately equal frequency (approximately 8%) (DOE-RL 1989).

## 2.5 TOPOGRAPHY

The ground surface overlying the 300 Area aquifer has generally flat topography with an absence of clearly defined drainages. The 300 Area is approximately 119 m (390 ft) above mean sea level, and the eastern boundary is defined by the Columbia River. The river shoreline consists of a steep embankment with an approximate rise of 12 m (40 ft) up to the 300 Area.

## 2.6 HYDROGEOLOGY

The stratigraphy beneath the 300 Area consists of sedimentary deposits with a total thickness ranging between 40 and 60 m (131 and 196 ft) overlying basalt bedrock. The principle units of the sedimentary layers consist of—from lower to upper—the fluvial and lacustrine sediments of the Ringold Formation, the glaciofluvial deposits of the Hanford formation, and a relatively thin layer of eolian sand and silt at the surface. However, the surface eolian deposits have been removed by excavation over most of the 300 Area, and up to 10 m (32 ft) of backfill material is at the surface in some places. The Cold Creek Unit, which lies between the Hanford and Ringold Formations in other portions of the Hanford Site, is apparently not present beneath the 300 Area. Figure 2-4 is a schematic representation of the hydrologic and stratigraphic units present at the 300 Area. A comprehensive discussion of the hydrogeology is included in the most recent description of the conceptual model for uranium (Peterson et al. 2008).

The water table beneath the 300 Area continuously fluctuates near the Columbia River in response to changing river stage. Nominally, depth to water at the 300 Area ranges between 8 and 17 m (26 and 56 ft) below the ground surface, depending on the topographical location. The unconfined aquifer beneath the 300 Area, which contains the bulk of groundwater contamination, flows through glacially deposited gravels and sands. Groundwater flow and direction are very dynamic near the river, but generally flow is west to east and toward the river. Groundwater in the unconfined aquifer flows preferentially through the saturated Hanford formation sediment, although the unconfined aquifer system does include sediments of the underlying Ringold Formation. The aquifer solids in the Hanford



The goal is to reduce uranium concentrations in groundwater; however, the source zone(s) for supplying uranium that maintains the groundwater plume appear to be related to the unsaturated sediment above and immediately in contact with groundwater. Consequently, vadose sediments in the Hanford formation could be important in implementing a remedy for uranium contamination in groundwater.

The thickness of the vadose zone varies as the water table moves up and down in response to changes in the Columbia River stage. However, the water table is usually within the Hanford formation throughout most of the 300 Area. Therefore, the vadose zone is composed predominantly of Hanford formation sand and gravel, recent eolian silt and sand, and, in some places, backfill. The backfill typically consists of reworked sand and gravel of the Hanford formation, or at the former 307 Process Trenches, of scrapings from the former South Process Pond and coal plant fly ash. In summary, the hydrogeologic framework controls the groundwater contact with uranium residuals in the vadose sediment at the dynamic groundwater interface, and determines the convective and diffusive flow path of mobilized uranium in the saturated zone.

## 2.7 DESCRIPTION OF URANIUM CONTAMINATION

The background uranium concentration in groundwater beneath the Hanford Site is estimated to range between 0.5 to 12.8  $\mu\text{g/L}$ , depending on location (DOE-RL 1997). At the 300 Area, natural background is estimated to range from 3 to 8  $\mu\text{g/L}$  (Peterson et al. 2008). The subsurface beneath the 300 Area contains uranium contamination above soil and groundwater background levels as a result of the discharges of liquid wastes containing uranium. The following sections describe the nature and extent of the uranium contamination in the groundwater, vadose zone, and water table interface. Table 2-2 provides a summary of earlier estimates for the inventory of uranium sequestered in various subsurface "compartments" beneath the 300 Area, as prepared for an update to the conceptual model.

Table 2-2. Summary of Uranium Inventory Estimates for Various Subsurface Repositories in the 300 Area (from Peterson et al. 2008). (2 sheets)

Compartment	Description	Uranium Inventory (kg)
A	Vadose zone sediment above highest water-table elevation; beneath footprint of former liquid-waste disposal facilities	2,100
B	Vadose zone pore water above highest water-table elevation; beneath footprint of former liquid-waste disposal facilities	75
C	Vadose zone sediment above highest water-table elevation; outside footprint of former liquid-waste disposal facilities	560
D	Vadose zone pore water above highest water-table elevation; outside footprint of former liquid-waste disposal facilities	6
	<i>Vadose Zone Subtotal:</i>	2,700
E	Sediment in intermittently wetted zone through which water table rises and falls; beneath footprint of disposal facilities	1,100
F	Pore water in intermittently wetted zone through which water table rises and falls; beneath footprint of disposal facilities	37
G	Sediment in intermittently wetted zone through which water table rises and falls; outside footprint of disposal facilities	120

Table 2-2. Summary of Uranium Inventory Estimates for Various Subsurface Repositories in the 300 Area (from Peterson et al. 2008). (2 sheets)

Compartment	Description	Uranium Inventory (kg)
H	Pore water in intermittently wetted zone through which water table rises and falls; outside footprint of disposal facilities	2
	<i>Water Table Zone Subtotal:</i>	<i>1,300</i>
I	Aquifer sediment; within area of greater than 30 µg/L uranium (average concentrations for 2002 to 2007)	120
J	Groundwater; within area of greater than 30 µg/L uranium (average concentrations for 2002 to 2007; total porosity of 26%)	60
	<i>Aquifer Subtotal:</i>	<i>180</i>
	<b>TOTAL:</b>	<b>4,200</b>
Notes: Modified from PNNL-17034, Table 7.1 (Peterson et al. 2008). Number of significant figures does not reflect accuracy.		

### 2.7.1 Groundwater Contamination

A detailed description of the history, extent, and nature of the groundwater contamination by uranium in the 300 Area is presented in Peterson et al. (2008). The conceptual model summarizes the results of historic groundwater monitoring, and includes the results from recent aquifer and sediment characterization activities. The groundwater beneath the 300 Area is currently contaminated with a variably shaped plume of uranium that extends over an area of approximately 0.5 km<sup>2</sup> (0.19 mi<sup>2</sup>). Monitoring of the plume since the late 1940s has indicated elevated uranium concentrations above background. Since 1992, groundwater monitoring has indicated temporal trends that exhibit variations in uranium concentrations around a relatively constant mean concentration that remains elevated with respect to background levels. However, uranium concentrations vary seasonally within the plume. Concentrations up to several hundred micrograms per liter have been observed at wells and aquifer tubes within the plume since 2005. (Note: The drinking water standard for uranium in groundwater is 30 µg/L.) As estimated from plume maps and the presumed thickness of the contaminated hydrologic unit, the volume of groundwater contaminated by uranium during the last several years is in the range of 1,500,000 to 2,800,000 m<sup>3</sup>, with the mass of uranium dissolved in those volumes in the range 77 to 105 kg (Peterson et al. 2008, Table 3.3). For the portion of the plume that exceeds the drinking water standard, the volume range is 940,000 to 1,280,000 m<sup>3</sup> and the mass range is 65 to 78 kg. Other methods for estimating the mass of uranium in groundwater produce similar values; i.e., many tens of kilograms.

### 2.7.2 Uranium Contamination in Vadose Zone Sediment

Estimates for the inventory of uranium sequestered in various subregions of the vadose zone were also developed as part of updating the conceptual model (Peterson et al. 2008, Section 6.0). Sediments and associated pore water beneath the footprints of former liquid waste disposal facilities may contain over half the uranium inventory at the 300 Area, with additional contamination in the zone through which the water table rises and falls. This rough inventory estimate is based on newly acquired but spatially limited data from characterization of subsurface sediments. It appears the quantity of uranium in unsaturated (or

periodically wetted) sediments above the always saturated aquifer exceeds the quantity of uranium within the aquifer by a significant factor.

Completed source remedial actions have removed significant volumes of contaminated sediment from the major liquid waste disposal facilities, such as the North and South Process Ponds, and the 300 Area Process Trenches (DOE-RL 2005b). The maximum depths for the excavations were a result of pre-determined soil cleanup values and concurrence to backfill excavated areas by the cognizant regulatory agency. Residual uranium contamination remained at the bottom of some excavations; lesser understood inventories may also remain at greater depths under the vadose zone. The mobility characteristics of these residual inventories under current hydrologic conditions are only beginning to be understood (Zachara et al. 2005, 2007), and the relationship between the inventories and the re-supply of the groundwater plume is considered a key data gap for any renewed remedial investigation activities. Also, work in progress under DOE's Integrated Field-Scale Research Challenge program is partially focused on the transport of uranium through the vadose zone at the 300 Area (Freshley 2008). The preponderance of available evidence does suggest that the persistence of the uranium plume in groundwater is related to a continuing supply of uranium from the overlying vadose zone, as opposed to the alternatives of release from uranium sequestered in aquifer solids, or migrating into the 300 Area from outside sources (Peterson et al. 2008).

The total estimated area of vadose contamination based on the sum of all the disposal unit footprints (ponds and trenches) is approximately 76,000 m<sup>2</sup> (19 acres). Assuming that the contaminating fluid releases extended uniformly downward towards the water table, that acreage would represent a minimum area of contaminated sediment source at the groundwater interface. However, sediment characterization southeast of the south end of the 300 Area Process Trenches indicates some lateral spread of uranium contamination in the 1- to 2-m (3.2- to 6.5-ft) vertical zone of fluctuating groundwater elevation (i.e., "smear zone"). Consequently, the source area of sediment contributing to the groundwater contamination may extend to some unknown distance outside the "footprint" margins of the ponds and trenches that received uranium-bearing waste effluent.

Uranium concentrations in the unsaturated sediments beneath the disposal areas vary according to depth, based on sampling and laboratory work conducted under the limited field investigation (Williams et al. 2007). Uncontaminated Hanford Site sediments contain a range of relatively immobile background of total uranium ranging between approximately 1.5 to 5 mg/kg of sediment. Contaminated 300 Area sediments may contain between 5 to 25 mg/kg of sediment. However, the geochemical form of the contaminant uranium is variable, which affects the potential for the uranium to be mobilized (i.e., is the form "labile"). For those forms that can be mobilized under geochemical conditions that might exist beneath the 300 Area, a transporting medium such as water is also required for further dispersion along environmental pathways. Currently, a weak nitric-acid leach procedure is used to extract uranium from sediment; the procedure provides a conservative estimate for the amount of labile uranium available. Contact time and the rate of exchange between the sediment and transporting medium are also parameters used in estimating the time it might take to exhaust the inventory of uranium sequestered in a particular subsurface compartment.

Preliminary uranium results for samples of vadose zone sediment at a borehole through the former South Process Pond range between 1 and 5 mg/kg of sediment, and some stratification of the uranium in the vadose zone has been observed. The highest uranium concentrations are associated with samples from the lower portion of the vadose zone and near the water table (i.e., "smear zone"). Backfill material at the

South Process Pond borehole site revealed a concentration of 3 mg/kg of sediment. Other preliminary results suggest that sediments beneath the former North Process Pond may have slightly higher concentrations of labile uranium.

### **2.7.3 Sediment in the Intermittent Wetted Groundwater Interface Zone**

The lowermost portion of the vadose zone is of particular significance to the exchange of uranium between the vadose zone and the groundwater system. The sediments in this zone are periodically contacted by groundwater at times when the water table is raised because of elevated Columbia River stages during early summer. This zone, which currently extends as much as 2 m (6.5 ft) above typical low groundwater elevations, is a pathway and possible sequestration region for uranium that contributes to the groundwater plume. Concentrations of labile uranium in this interface zone are generally higher than in the sediments above. Areas extending laterally beyond the "footprints" of the waste sites above are also suspected locations for residual amounts of the contaminant uranium. Sediments and associated pore water in this smear zone may contain an appreciable portion of the uranium inventory in the subsurface, possibly approaching a third of the total. Remedial action that prevents or limits the release of uranium from the interface zone between groundwater and the vadose zone will directly reduce uranium flux into the groundwater.

### **2.7.4 Conceptual Model of 300 Area Subsurface Uranium**

The rough estimates for inventories of uranium stored in various subsurface compartments, and the relative paths by which the mobile component of that inventory may be transported, are shown schematically in Figure 2-5. Figure 2-6 provides a graphical key to the locations of the various compartments defined for the inventory estimates. The path arrows suggesting fluxes between the various compartments reflect long-term net conditions. Short-term reversals of flux are possible, particularly in the lower vadose zone where there are fluctuations in groundwater elevation. This conceptual representation of subsurface inventory and exchange was developed as part of an update to the conceptual model for uranium (Peterson et al. 2008). Numerous uncertainties remain in quantifying this subsurface regime of contamination, although it does provide a qualitative framework that is useful in formulating remediation strategies.

With currently available information, fluxes between the various subsurface compartments can only be discussed in a semi-quantitative manner. Research being conducted as part of the Integrated Field-Scale Research Challenge program (Freshley 2008) will help in quantifying the transfer of uranium among the various compartments. As indicated in Figure 2-5, the continuing input of uranium to groundwater involves release from the sediments and pore water in the smear zone, which in turn may be replenished with uranium from the overlying unsaturated zone sediments. Unexcavated sediments directly beneath former liquid waste disposal facilities (compartment A) are a possible source region, assuming the inventory includes labile forms of uranium and that a medium is available to transport the uranium downward.

Figure 2-5. Estimated Inventory of Uranium in the Subsurface at the 300 Area.

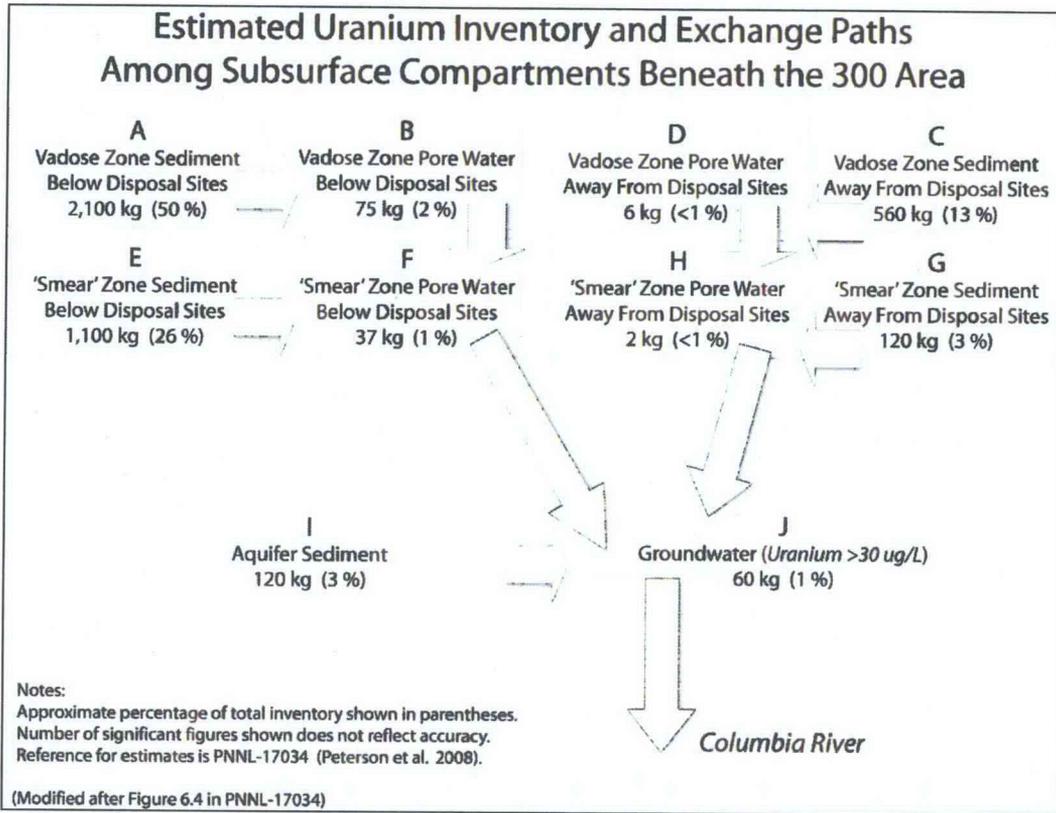
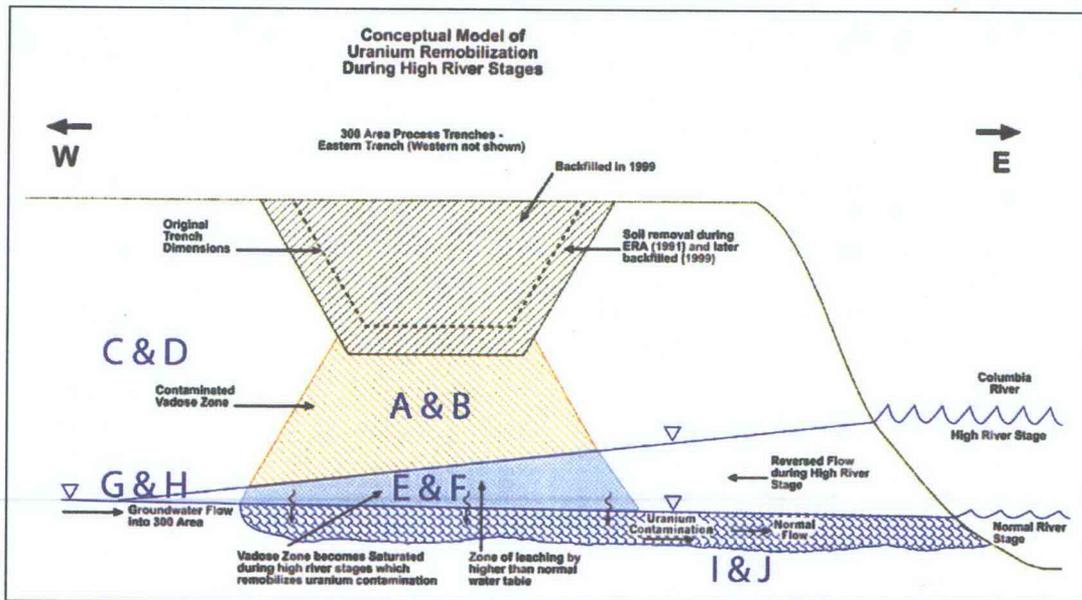


Figure 2-6. Schematic Cross Section Beneath Waste Site, Showing Locations for Compartments Defined for Uranium Inventory and Exchange Model (modified after Lindberg and Chou 2001).



Recent sediment sampling results conducted after the limited field investigation suggest that the smear zone away from the former disposal site footprints (compartment G) may contain higher amounts of uranium than indicated in Figure 2-5, with as yet unpublished estimates suggesting as much as 10% of the total uranium inventory. If so, such sediments extending beyond the disposal site footprints could be a significant source for supplying uranium to groundwater. The rate of transfer between the individual compartments has a direct influence on the uranium concentrations in the groundwater. Remedial actions that reduce the flux of uranium to groundwater may have a greater effect on groundwater concentrations than actions that reduce concentrations directly in the aquifer.

Under current land use and meteorological conditions, and in the absence of waste disposal activities, the availability of a transporting medium for labile uranium in the upper portion of the vadose zone appears to be limited. However, uranium in the interface zone between the aquifer and vadose systems may be of sufficient quantity to maintain the uranium plume in the upper aquifer for a future period of time. Remedial treatments that interrupt the transport pathways or reduce the fluxes along these pathways will result in corresponding reductions in groundwater concentrations and the level of contamination.

With suitable uranium flux reduction, a new uranium equilibrium may develop under natural processes that would result in attainment of cleanup goals, i.e., groundwater concentrations lower than the 30- $\mu\text{g/L}$  drinking water standard.

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### 3.0 REGULATORY CONTEXT

With the end of nuclear fuel production operations at the Hanford Site, the DOE initiated a process of evaluating and responding to the contamination present in the subsurface associated with the 300 Area. This environmental response is governed by environmental regulations applied by the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), and DOE. In November 1989, the EPA placed the Hanford Site, including the 300 Area, on the National Priorities List (NPL) pursuant to the *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act of 1986* (SARA). The 300 Area has been divided into three operable units. The 300-FF-1 Operable Unit includes the former major liquid waste disposal facilities, such as the North and South Process Ponds, while the 300-FF-2 Operable Unit includes solid waste burial grounds and other facilities. The 300-FF-5 Operable Unit includes groundwater affected by releases from the various waste sites. The focus of this document is on contamination in groundwater beneath the 300 Area portion of the 300-FF-5 Operable Unit. Because of the possibility that residual, mobile uranium in the vadose zone is still contributing to the groundwater plume, portions of the vadose zone are also discussed.

As required for NPL sites, remedial investigation and feasibility study (RI/FS) were conducted in the early 1990s. These efforts were specified by the *Hanford Federal Facility Agreement and Consent Order*, which was negotiated and approved by Ecology, the EPA, and DOE in May 1989 (Ecology et al. 1989). This agreement, known as the Tri-Party Agreement, governs all CERCLA efforts at the Hanford Site.

A Phase I and II Feasibility Study Report for the 300-FF-5 Operable Unit (DOE-RL 1994) documented the evaluation and selection of an interim action that imposed restrictions on the use of groundwater until natural attenuation processes reduce concentrations of uranium, trichloroethene, and 1,2-dichloroethene to health-based criteria. The ongoing interim remedy selected was adopted in 1996 by the *Declaration of the Record of Decision, USDOE Hanford Area 300-FF-1 and 300-FF-5 Operable Units, Hanford Site, Benton County, Washington* (ROD) [DOE-RL et al. 1996]. The rationale for interim action included an anticipated decline in groundwater concentrations of uranium and halogenated solvents within 10 years of 1993, and assumed that upcoming excavation and removal actions involving presumed sources for groundwater contamination would support that decline.

Subsequent groundwater monitoring revealed that uranium concentrations did not decline as anticipated, and that concentrations persisted above the 30- $\mu\text{g}/\text{L}$  target level through 2004. Therefore, a renewed effort to develop and implement groundwater cleanup was initiated in 2005. This renewed effort is outlined in the *Work Plan for Phase III Feasibility Study, 300-FF-5 Operable Unit* (DOE-RL 2005a).

This report, as required by the work plan, will complete this remediation strategy study and will supplement and complete earlier evaluation of remedial actions evaluated by the earlier feasibility study (DOE-RL 1994). This present remediation strategy report provides updated information resulting from a limited field investigation (Williams et al. 2007), an updated conceptual site model (Peterson et al. 2008), recent hydrologic study and analysis, new remediation technology testing (Wellman et al. 2008), and recent research in the geochemical behavior of uranium (Bond et al. in press).

Section 4.0 of this document describes the CERCLA process as applied to the 300-FF-5 Operable Unit groundwater. This remediation strategy report for addressing uranium contamination in groundwater is a

prelude to a full feasibility study to address all of the contaminants of concern (COC) in groundwater in the 300 Area. The COC list has changed since the original RI/FS (DOE-RL 1995) was published based upon the original ROD and 5-year reviews. The COCs presently considered to be addressed in the comprehensive RI/FS include cis-1,2-dichloroethene, trichloroethene, as well as uranium.

Section 121 of CERCLA, as amended, establishes cleanup criteria for remedial actions at NPL sites such as the 300-FF-5 Operable Unit. Section 121 also requires that any applicable or relevant and appropriate requirement (ARAR), standard, criteria, or limitation under any federal environmental law, or any more stringent state requirement be met for any contaminant that will remain onsite after completion of the remedial action.

Consideration of potential ARARs for the 300-FF-5 Operable Unit is based upon CERCLA guidance (EPA 1988a, 1988b). Preliminary ARARs will be contained in the final feasibility study and final ARARs will be contained in the final record of decision for 300-FF-5 Operable Unit.

Section 3 of the Phase I/II feasibility study (DOE-RL 1994) compiled a complete identification of potential ARARs in 1994. As of the writing of this report, this inventory remains relevant. However, updates and revisions to regulations, such as the *Washington Model Toxic Control Act* regulations and the 2000 establishment of the uranium maximum contaminant level (MCL) of 30 µg/L in groundwater (Title 40 *Code of Federal Regulations* [CFR] Part 141), have supplemented the original ARAR analysis. Therefore, the evaluation of remedial alternatives in Section 7.0 of this remedial strategy report is conducted using updated ARARs.

Section XI of the 1996 ROD (EPA 1996) summarizes the statutory requirements determined by the EPA to be applicable or relevant and appropriate for the interim remedies selected at that time for the 300-FF-5 Operable Unit. Additionally, in November 2001, the EPA issued a directive specifying the cleanup level for uranium in groundwater as 30 µg/L. The chemical-specific ARARs identified are as follows:

- *Safe Drinking Water Act*, 40 CFR Part 141, establishes MCLs for public drinking water supplies and provides the basis for establishing cleanup goals for trichloroethene (TCE) and 1,1-dichloroethene (DCE) that are protective of groundwater.
- EPA Directive No. 9283.1-14, *Use of Uranium Drinking Water Standards Under 40 CFR 141 and 40 CFR 192 as Remediation Goals for Groundwater at CERCLA Sites* (EPA 2001).
- “Model Toxics Control Act Cleanup Regulations” (MTCA), *Washington Administration Code* (WAC) Chapter 173-340-745, provides risk-based cleanup levels applicable to establishing cleanup levels for soil.
- “Water Quality Standards for the State of Washington,” WAC Chapter 173-201A-040, applies to the identification, treatment, storage, and land disposal of hazardous and dangerous wastes.

Action-specific ARARs that place technology-based or activity-based regulation on remedies include the following:

- “State of Washington Dangerous Waste Regulation,” WAC Chapter 173-303, applies to the identification, treatment, storage, and land disposal of hazardous and dangerous wastes.
- “Hazardous Waste Recycling; Land Disposal Restrictions; Final Rule” (40 CFR 268) applies to the disposal of materials contaminated by metals that are hazardous or dangerous wastes.

Location-specific ARARs that restrict activities from sensitive or unique areas include the following:

- *Archeological and Historic Preservation Act* (16 USC Section 469), regulates the recovery and preservation of artifacts in areas where a remedy may cause irreparable harm, loss, or destruction.
- *National Historic Preservation Act* (16 USC 470, et. seq.), 36 CFR Part 800, applies to actions for preserving historic properties controlled by a federal agency.
- *Endangered Species Act of 1973* (16 USC 1531, et seq.), 50 CFR Part 200 and 50 CFR Part 402, applies to the conservation of critical habitat upon which endangered or threatened species depend and requires consultation with the Department of Interior.

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#### 4.0 METHODOLOGY OF REMEDIATION STRATEGY STUDY

This remediation strategy study is a prelude to the future Phase III feasibility study. The Phase III feasibility study will supplement and complete the Phase I and Phase II feasibility study report for the 300-FF-5 Operable Unit (DOE-RL 1994). The Phase III study will be conducted using the process specified by EPA regulations (EPA 1989) associated with implementation of CERCLA, as amended by SARA. The feasibility study process is guided by *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA; Interim Final* (EPA 1988a), which prescribes a process that includes the following steps:

1. Establish remedial action objectives (RAOs).
2. Develop general response actions.
3. Inventory applicable technologies and management strategies.
4. Screen appropriate technologies.
5. Combine technologies into alternatives.
6. Conduct preliminary screening of alternatives.
7. Evaluate selected alternatives with seven criteria.
8. Compare alternatives.
9. Present final alternatives and the preferred remedy in report for public comment.

Steps 1-4 are documented in the evaluation of remedial technologies (Nimmons 2007). The RI/FS work plan activities included additional characterization and treatability testing to provide the information needed to proceed with the subsequent steps. Additional characterization and treatability testing activities are recommended based on these initial efforts prior to completing the feasibility study. However, to guide these subsequent activities, this remediation strategy study uses currently available information to proceed through step 6 of the feasibility study process. Evaluating the potential remedial alternatives provides a basis to determine the detailed objectives for additional characterization and treatability testing. This remediation strategy study also demonstrates that technologies undergoing treatability testing are supporting the leading remedial alternative candidates. Because additional characterization and treatability testing is needed to enable full evaluation in a feasibility study, the remediation strategy study uses estimated characterization and technology performance parameters and a relative comparison of prototype alternatives. Additional detailed evaluation will be conducted for the subsequent 300-FF-5 Operable Unit feasibility study programmed for 2011.

#### 4.1 REMEDIAL ACTION OBJECTIVES

The primary RAOs of the 300-FF-5 Operable Unit were established in the *Work Plan for Phase III Feasibility Study* (DOE-RL 2005a) based upon the objectives stated in the ROD for the 300 Area in 1996. RAOs are as follows:

1. Return groundwater to its beneficial uses wherever practicable, within a time frame that is reasonable given the particular circumstances of the Hanford Site.

2. Restore, to the extent possible, the groundwater aquifer to its highest and best beneficial use, which is presumed to be a drinking water supply.
3. Reduce risk to human health and the environment.

The EPA has established a federal MCL of 30 µg/L uranium in drinking water. This MCL forms the reference concentration for evaluating groundwater contamination by uranium. Correspondingly, the efficacy of remedial actions is evaluated by the degree of reduction in volume and concentration of uranium in groundwater relative to 30 µg/L over time. The point of compliance for measuring remedial cleanup is defined as the groundwater at the surface of the water table, the groundwater at the shoreline interface, and river channel at the boundary of the Columbia River where the aquifer intercepts the river channel.

The conceptual site model provides the basis for determining performance objectives for the remedial alternatives to meet these overall RAOs. The conceptual site model for groundwater contamination in the 300-FF-5 Operable Unit has evolved over the past 17 years as a result of the remedial investigation (DOE-RL 1993), periodic groundwater monitoring, the limited field investigation (Williams et al. 2007), and multiple research and testing that has been conducted. A recent compilation of characterization work is presented in Peterson et al. 2008. Section 2.0 of this document summarizes the present understanding of the conceptual site model. Based on the conceptual model and, in particular, the presence of persistent uranium contamination in the vadose zone that is periodically contacted by groundwater, the remedial alternatives are configured with performance objectives to achieve one of the following objectives:

1. Decrease the flux of uranium from the vadose zone to the groundwater such that groundwater concentration remains below 30 µg/L
2. Directly decrease the concentration of uranium in the groundwater and maintain the concentration below 30 µg/L.

## 4.2 GENERAL RESPONSE ACTIONS

General response actions include those that meet performance objectives. General response actions that remove or sequester contamination in the vadose zone include excavation and some types of in-situ treatment. General response actions that directly decrease the concentration of uranium in groundwater include some types of in-situ treatment and monitored natural attenuation (MNA). Subsequent identification, evaluation, and selection of remedial technologies must contend with the high permeability of the aquifer, high-groundwater flow rate, variable groundwater flow direction, water table fluctuations, and the distributed nature of the uranium source material. The screening of prospective remediation technologies follows from this fundamental view of the problem.

## 4.3 IDENTIFICATION, EVALUATION, AND SCREENING OF TECHNOLOGIES

A comprehensive survey of treatment technologies was conducted within the *Evaluation and Screening of Remedial Technologies for the 300-FF-5 Operable Unit* (Nimmons 2007). Section 5.0 of this report summarizes the technology screen process within the context of contemporary knowledge.

A wide spectrum of candidate treatment technologies for reducing concentrations of uranium in groundwater has been considered. More traditional technologies involving pump-and-treat, hydraulic management, or flushing were identified in the earlier Phase I and Phase II feasibility study

(DOE-RL 1994). These older technologies have been supplemented with more recent treatment technologies that involve manipulation of geochemical conditions in groundwater and sediments to reduce the mobility or stabilize uranium. Sources for the technology inventory included literature searches and Internet remediation technology search tools maintained by DOE, EPA, and other organizations. These prospective treatment technologies were classified according to the applicable media or zone (i.e., sediment, wetted sediment near the fluctuating water table, or groundwater) in accordance with the conceptual site model. Secondary classification of the technologies was made according to the mode of action: passive, physical, chemical, or biological.

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## 5.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

Persistent uranium contamination in groundwater beneath the 300 Area is a result of uranium residuals in the unsaturated sediments above the uppermost aquifer being mobilized primarily by excursions of the water table into those sediments. Section 2.0 describes this contaminant conceptual model. Earlier feasibility studies in the 1990s focused on the groundwater per se (DOE-RL 1994 and 1995b). Better understanding of the conceptual model describing the contamination process (Peterson et al. 2008) suggests that treatment of the source of the groundwater contamination in sediments may be more effective than groundwater treatment alone. Consequently, a comprehensive inventory of potentially applicable remedial practices and technologies to control or remove uranium contamination from several zones in the subsurface has been conducted (Nimmons 2007). This evaluation of remedial technologies forms the basis for the screening analysis developed in this section of the remedial strategy.

A comprehensive search of literature and the Internet identified prospective technologies that might be used to remove, control, stabilize, or mitigate uranium in the subsurface. The identification procedure was subdivided according to the matrix and location of uranium contamination. Consistent with the conceptual model, three potential treatment zones were identified: the upper aquifer (groundwater and sediment), sediment within the extent of the fluctuating groundwater interface (smear zone), and the vadose zone sediment (unexcavated sediments below former uranium disposal facilities).

The mode of action of prospective remedial technologies was also considered in the identification process. Uranium can be physically removed by excavation of uranium on sediment or pumping of uranium dissolved in groundwater. Treatment and disposal of the removed media are conducted ex-situ at the ground surface. Uranium contamination may also be stabilized or treated in-situ within the subsurface. In the earlier feasibility studies conducted in the 1990s, 40 technologies for geohydraulic management of contaminated groundwater were identified. Most of these technologies involved emplacement of hydraulic barriers or large-scale groundwater pumping to contain or capture contaminated groundwater. Some of the early technologies focused on removal and treatment of contaminated groundwater by ex-situ treatment. Recent developments in remedial technology have focused on promising geochemical processes to treat uranium in groundwater. Therefore, the technology inventory for groundwater identified an additional 13 in-situ treatment technologies to the original technologies considered in the previous feasibility studies.

Previous feasibility study work (DOE-RL 1994) did not consider the smear zone where fluctuating groundwater elevations periodically contact sediment in the lowermost vadose zone. Physical excavation along with five in-situ technologies are identified and evaluated in this evaluation.

The previous feasibility study (DOE-RL 1994) did not address the lower vadose zone but assumed that remedies implemented in the 300-FF-1 Operable Unit upper vadose zone would protect groundwater. Ten candidate technologies are considered for the vadose zone beneath the extent of the previous excavation. Eight in-situ treatment technologies were identified in addition to two physical technologies involving excavation or surface capping.

Consideration of the new in-situ treatment technologies is organized according to the chemical mode of interaction with the uranium contamination. Screening of the in-situ chemical treatment technologies is conducted within the following geochemical classifications.

- *Redox technologies* – These technologies attempt to manipulate oxidation-reduction conditions of the subsurface to reduce uranium to uranous (uranium IV) forms. Techniques include in-situ redox manipulation using sodium dithionite, zero-valent iron, microbial-induced reduction, and calcium polysulfide technologies. The common deficiency of technologies in this category is that the reduced environment and corresponding uranium precipitate is easily reoxidized over time. Consequently, over time the “treated” uranium is remobilized. It may be possible, depending upon the kinetics of the remobilization oxidation, to meet remediation goals in the saturated zone for groundwater if remobilization were slow enough to result in uranium concentrations below cleanup criteria.
- *Co-precipitated iron oxyhydroxide* – This technology stabilization coprecipitates uranium in a composite precipitate. However, the precipitate is not permanent because the reaction is reversed as the precipitate ages.
- *Phosphate precipitation technologies* – These technologies apply and modify phosphate with uranyl (uranium VI) forms that immobilizes the uranium and prevent further dissolution of uranium by sequestration, immobilization, or precipitation. The resulting reaction seeks to create a stable, long-lasting reaction that removes the source of ongoing uranium contamination to the groundwater. Newly developed and developing approaches offer a variety of application techniques and reagent types. However, this group of technologies requires further development.
- *Flushing technologies* – This group of remediation technologies uses a variety of leaching solutions to dissolve solid-phase uranium and hydraulic extraction techniques to remove the solubilized uranium with lixiviant residuals. This technology group is basically an extension of in-situ mining that has been practiced since the 1960s. Carbonate flushing solutions are typically employed.

## 5.1 INITIAL INVENTORY OF POTENTIAL REMEDIATION TECHNOLOGIES

Table 5-1 lists the general response actions and associated technologies considered in the technology screening. The table includes the source of information for each technology (e.g., the original RI/FS, the work plan, or recent developments). No additional screening was conducted for those technologies rejected by the original RI/FS unless there have been relevant updates to the technology since 1995. New technologies or changed assessments on older technologies listed in the original 1994 feasibility study (DOE-RL 1994) are highlighted in yellow in Table 5-1.

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
No Action	No action	No action	FS (DOE-RL 1992)	Retained as "baseline" case.	Yes
Institutional Controls	Land-use restrictions	Deed restrictions	FS (DOE-RL 1992)	Retained to be used in conjunction with other process options.	Yes
--	Access controls	Signs and/or fences	FS (DOE-RL 1992)	Retained to be used in conjunction with other process options.	Yes
--	Monitoring	Monitoring	FS (DOE-RL 1992)	Retained to be used in conjunction with other process options.	Yes
MNA	MNA	MNA	EPA (1999)	Not explicitly listed in RI/FS but implied in 1995 ROD.	Yes
Containment	Horizontal barriers	Subsurface barrier or surface cap	FS (DOE-RL 1992) and FRTR Version 4.0	NOT retained in RI/FS. Surface barriers not applicable to groundwater per se, but applicable to vadose zone.	No for groundwater; yes for vadose zone technology
--	Vertical barriers	Slurry walls	FS (DOE-RL 1992)	Proven and feasible technology.	Yes
--	--	Grout walls - grout injection	FS (DOE-RL 1992)	Less effective and more costly than slurry walls.	Yes
--	--	Grout walls - deep-soil mixing	FS (DOE-RL 1992)	No more effective than slurry walls but more expensive.	Yes
--	--	Sheet piling	FS (DOE-RL 1992)	Not implementable due to rocky subsurface.	No

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
Containment	Vertical barriers	Cryogenic walls	FS (DOE-RL 1992) and DOE-RL (1999)	More expensive than slurry walls. Contemporary assessment: difficult to implement for long-term.	No
--	Hydraulic containment	Pump to control or contain uranium plume	FS (DOE-RL 1992)	Feasible.	Yes
Removal	Groundwater extraction	Wells	FS (DOE-RL 1992)	Established and feasible.	Yes
--	--	Interceptor trench	FS (DOE-RL 1992)	Established and feasible.	Yes
--	Aquifer soil dredging/excavation	Excavation with dewatering	FS (DOE-RL 1992)	Well developed and feasible. Contemporary assessment: not relevant to saturated zone uranium.	No for groundwater; yes for vadose zone technology
--	--	Mechanical dredging	FS (DOE-RL 1992)	Well-developed and feasible. Contemporary assessment: not relevant to saturated zone uranium.	No for groundwater; yes for vadose zone technology
--	--	Hydraulic dredging	FS (DOE-RL 1992)	Not effective for large cobbles.	No

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
Disposal	Treated groundwater	Surface water discharge	FS (DOE-RL 1992)	Feasible to Columbia River.	Yes
--	--	Subsurface discharge	FS (DOE-RL 1992)	Feasible.	Yes
--	Sludge and soils	Onsite disposal	FS (DOE-RL 1992)	ERDF was planned. Contemporary assessment: ERDF not large enough. Moist solid not compatible.	No
--	--	Offsite disposal	FS (DOE-RL 1992)	Less preferred under CERCLA; no regional facility available.	No
Ex-situ Treatment of Groundwater	Separation	Gravity separation of suspended solids	FS (DOE-RL 1992)	Well established and feasible. Contemporary assessment: not relevant to dissolved uranium.	No
--	--	Filtration of suspended solids	FS (DOE-RL 1992)	Well established and feasible. Contemporary assessment: not relevant to dissolved uranium.	No
--	--	Ion exchange of uranium	FS (DOE-RL 1992)	Established: effective for low uranium concentrations.	Yes
--	--	Reverse osmosis	FS (DOE-RL 1992)	Effective for concentrating.	Yes
--	--	Ultrafiltration	FS (DOE-RL 1992)	Effective for high molecular weight compounds. Contemporary assessment: not effective with dissolved uranium.	No

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
--	--	Membrane-based coupled transport	FS (DOE-RL 1992)	Developmental.	No
--	--	Electrodialysis	FS (DOE-RL 1992)	Expensive, developmental.	No
--	--	Freeze/crystallization	FS (DOE-RL 1992)	Expensive, developmental.	No
--	--	Evaporation/distillation	FS (DOE-RL 1992)	Expensive.	No
--	--	Electrolysis	FS (DOE-RL 1992)	Expensive.	No
--	Chemical reaction	Precipitation	FS (DOE-RL 1992)	Effective for secondary waste stream.	Yes
--	Organic separation	Air stripping	FS (DOE-RL 1992)	Effective only for organics, not applicable to uranium.	No
Ex-situ Treatment of Groundwater	Organic separation	Carbon adsorption	FS (DOE-RL 1992)	Effective only for organics, not with uranium.	No
--	Chemical reaction	Enhanced oxidation	FS (DOE-RL 1992)	Not applicable to uranium.	No
--		Chemical oxidation/reduction	FS (DOE-RL 1992)	Expensive.	No
--	Biological	Biological treatment	FS (DOE-RL 1992)	Not effective for uranium.	No
--	Thermal	Thermal treatment	FS (DOE-RL 1992)	Not applicable to uranium.	No
In-situ Treatment	Physical	Vapor extraction	FS (DOE-RL 1992)	Not applicable to uranium.	No
--	Physical and chemical	In-situ flushing	FS (DOE-RL 1992) and FRTR Version 4.0	Potentially effective and feasible in so far as uranium is on sediments.	Yes

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
In-situ Treatment	In-situ precipitation/fixation	Generic precipitation/fixation	FS (DOE-RL 1992), FRTR Version 4.0 and recent DOE-sponsored research	Formerly unproven. Contemporary assessment: see below for recent developments.	Yes
--	--	Permeable reactive barrier – ZVI	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; reoxidation delayed but not prevented
--	--	Permeable reactive barrier-amorphous ferric oxyhydroxide	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	Yes
--	--	Permeable reactive barrier-hydroxyapatite	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	Yes
--	--	Permeable reactive barrier-zeolite	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; not effective at aquifer water pH
--	--	In-situ reactive barrier-injected polyphosphate	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	Yes
In-situ Treatment	In-situ precipitation/fixation	DART emplacement of ZVI and apatite pellets in wells	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; not applicable to Hanford formation
--	--	In-situ reactive barrier-nanoparticle injection	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; reoxidation delayed but not prevented

Table 5-1. Inventory of Remediation Technologies or Management Approaches for Uranium. (6 sheets)

General Response Action	Technology Type	Remediation Technology	Source of Information	Conclusion from 1992 RI/FS	Retained for Technology Screening
In-situ Treatment	In-situ precipitation/fixation	Colloidal ZVI injection	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; reoxidation delayed but not prevented
--	--	In-situ reactive barrier-calcium citrate and sodium phosphate injection	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	Yes
--	--	In-situ redox manipulation by dithionite injection	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; uranium reoxidizes and redissolves
--	Biological	Microbial dissimilatory reduction of U(VI)	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; uranium reoxidizes and redissolves
--	--	Anaerobic in-situ reactive zone	FRTR Version 4.0 and recent developments	New technology NOT addressed by RI/FS.	No, see Table 7-2; uranium reoxidizes and redissolves

Yellow highlighting indicates new technologies or changed assessments on older technologies listed in the original feasibility study (DOE-RL 1994).  
 CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act*.  
 DART = **Directed applied reagent technology**.  
 ERDF = Environmental Restoration Disposal Facility.  
 FRTR = Federal Remediation Technologies Roundtable: Screening Matrix and Reference Guide, Version 4.0: [http://www.frtr.gov/matrix2/top\\_page.html](http://www.frtr.gov/matrix2/top_page.html).  
 FS = Feasibility study.  
 MNA = Monitored natural attenuation.  
 RI = Remedial investigation.  
 ROD = Record of decision.  
 ZVI = Zero valent iron.

## 5.2 CRITERIA FOR TECHNOLOGY SCREEN

The potentially applicable technologies are screened in accordance with CERCLA criteria. The screening criteria include effectiveness, implementability, and relative cost as described in the following paragraphs.

A technology is considered effective if it is proven capable of, or there is relatively low technical uncertainty associated with performance of the technology in the targeted matrix over the time period necessary to effect a permanent reduction of dissolved uranium in groundwater.

A technology is considered implementable if proven capable of being constructed and deployed in the type of the sediments found in the Hanford and Ringold Formations at the required depths below ground surface and operating at the necessary scale. The technology also must not interfere with other technologies if it does not address all of the contaminated volume, and must not pose potentially significant administrative issues (e.g., use of potentially unacceptable reagents).

The third criterion, relative cost, is evaluated on technologies that passed the screen for effectiveness and implementability. The relative cost is considered by assessing whether the cost for a technology can be reasonably estimated, and whether high-cost factors for a technology render it grossly more expensive than other technologies with similar effectiveness and implementability.

Technologies are not required to address the entire volume of the operable unit if they do not operate in a way that prevents combination with another technology as part of a multiple technology approach to remediation.

## 5.3 SCREENING OF GROUNDWATER TECHNOLOGIES

Screening of both legacy and new technologies for groundwater is presented in Table 5-2. Technologies that originated in the Phase I and II feasibility study are italicized in the Table 5-2 listing. Those technologies passing the screen using the criteria of effectiveness and implementability were further screened according to the criterion of relative cost. The preliminary economic comparison of technologies is summarized in Table 5-3. Screening of technologies for application upon sediments is discussed in subsequent sections.

Fifty-three technologies or management techniques for groundwater are initially identified. Thirteen of the 53 technologies were additions to the 40 identified in the original feasibility study (DOE-RL 1994). The additions are new in-situ technologies that were not known earlier. Evaluation of these technologies on the basis of criteria from the 1994 feasibility study (DOE-RL 1994), including adjustments for 2006 conditions and with a focus on groundwater technologies, narrowed the original 53 technologies to 29 candidate technologies for groundwater. With the consolidation of 3 institutional control actions into 1 action, 27 actions and technologies are reduced to 12 using criteria of effectiveness and implementability. The 12 remaining technologies are reduced to 2 active technologies and 2 passive management strategies using the relative cost criteria.

The resulting active technologies for groundwater are as follows:

- in-situ polyphosphate treatment
- in-situ calcium citrate and sodium phosphate treatment.

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable ?	Rationale For Implementability Screen	Retain for Further Consideration?
Passive	No action	--	--	Yes	Retained as "Baseline" case.	Yes
--	Institutional controls	Yes	Institutional controls and monitoring is the present interim remedy.	Yes	Institutional controls and monitoring is the present interim remedy.	Yes
--	MNA	Yes	Presently operative, but not fully effective because of continuing releases from untreated sources.	Yes	Natural attenuation processes are occurring without intervention.	Yes
Physical	Slurry wall containment	?	If cut-off wall can be effectively inserted into less-permeable zones, either containment or flow restriction could be affected.	No	Large rocks and high hydraulic conductivity preclude slurry wall construction.	No
--	Grout walls - grout injection	?	Grout injection within a less-permeable zone can effectively reduce flow and effect hydraulic control or containment. Grout wall in highly permeable zones may not be effective.	?	Proven construction technology; however, quality assurance is difficult. Construction in very high-permeability Hanford aquifer would be problematic.	No
--	Grout walls - deep soil mixing	?	Depth and heterogeneity of Ringold Formation mud-base layer are problematic in assuring effective containment.	No	Depth-to-toe-in layer, large rocks, and high hydraulic conductivity preclude consistent auger placement of grout.	No
--	Selective hydraulic containment with pumping	No	Focused pump-and-treat can be effective where hydrogeology permits moderate pumping rates. Hanford aquifer conditions preclude effective containment even at very high pumping rates. Continuous pumping from water supply well did not appreciably reduce uranium concentrations.	Yes	Proven technology. Groundwater withdrawn will require ex-situ treatment before disposal. Extremely high pumping rates would be required even for small areas.	No

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Physical	<i>Groundwater extraction-wells</i>	?	Focused groundwater extraction can be effective where hydrogeology permits moderate pumping rates. Hanford aquifer conditions generally require very high pumping rates. Continuous pumping from water supply well did not appreciably reduce uranium concentrations. Very localized pumping may be effective to facilitate in-situ treatment or flushing technologies.	Yes	Proven technology.	Yes. Retained as groundwater flow management tool for in-situ treatment technologies. Very high permeabilities of Hanford aquifer preclude wide-scale deployment.
--	<i>Groundwater extraction-interceptor trench</i>	?	Hanford aquifer permeability and aquifer layers make effectiveness of trench questionable.	No	Rocky, high permeability of aquifer would make construction of trench very problematic.	No
--	<i>Treated water disposal to surface water (Columbia River)</i>	Yes	Proven technology. Very large flows may require special diffuser or distribution system to prevent excessive scour, erosion, or ecological issues.	Yes	Proven technology. Water quality of treated water discharge will control NPDES permitting.	Yes
--	<i>Treated water disposal to groundwater (re-injection)</i>	Yes	Proven technology. Care must be taken to not reinject in location where subsurface contamination could be mobilized.	Yes	Proven technology.	Yes

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Chemical	<i>Ex-situ ion exchange</i>	Yes	Effective for low concentrations of uranium. Limited by effectiveness of groundwater extraction.	Yes	Proven technology. Concentrated uranium solution resulting from resin regeneration will require treatment/disposal.	Yes
--	<i>Ex-situ reverse osmosis</i>	Yes	Effective for low concentrations of uranium. Limited by effectiveness of groundwater extraction.	Yes	Proven technology. Concentrated uranium solution resulting from process will require treatment/disposal.	Yes
--	<i>Ex-situ precipitation</i>	Yes	Effective only for high concentrations of uranium in secondary waste streams. Limited by effectiveness of groundwater extraction.	Yes	Proven technology. Resulting waste stream will require further processing.	Yes
--	<i>In-situ flushing</i>	Yes	Effective only on sorbed uranium where hydraulic contact and containment with flushing solution recovery can be obtained. Not effective on dissolved uranium per se.	No	High permeability of aquifer and focusing treatment to narrow, upper zone of saturated sediment are problematic. More properly applied to smear zone or vadose zone contamination.	Yes, for uranium on sediments only
--	Permeable reactive barrier-ZVI	No	Short-term effectiveness of iron removal by iron possible, but subject to dissolved oxygen, temperature, pH, and metal complexing agents. Long-term performance not effective due to buildup of precipitates of carbonate minerals on reactive surfaces.	No	Excavation of barrier trench precluded by large rocks.	No

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective ?	Rationale for Effectiveness Screen	Technically Implementable ?	Rationale For Implementability Screen	Retain for Further Consideration?
Chemical	Permeable reactive barrier-amorphous ferric oxyhydroxide	No	Uranium previously sorbed on amorphous ferric oxyhydroxide material tends to be desorbed with lower uranium concentrations, resulting in a re-release of uranium over the long term.	No	Excavation of barrier trench precluded by large rocks.	No
--	Permeable reactive barrier-hydroxyapatite	No	Least-effective media for uranium removal relative to amorphous ferric oxyhydroxide or zero-valent iron (Nafiz et al. 2002).	No	Excavation of barrier trench precluded by large rocks.	No
--	Permeable reactive barrier-zeolite	No	Efficiency and longevity of zeolite depends on sorptive capacity and specificity for uranium. Reactions that cause clogging and surface passivation are likely to be less significant because the chemical mechanism is primarily cation exchange. No uranium specific zeolites known.	No	Excavation of barrier trench precluded by large rocks.	No
--	In-situ treatment by injected polyphosphate	?	Effectiveness controlled by application design and groundwater flow. Rapid autunite formation immobilizes uranium. Longer-term apatite formation provides backup process. Promising but not fully developed.	Yes	Multiple linear arrays of application wells could allow deployment in sediments with large boulders. Implementability remains to be demonstrated.	Yes

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Chemical	DART emplacement of ZVI and apatite pellets in wells	No	The application of the solid-phase reagents requires close spacing (not more than two well diameters) of many wells. Long-term performance is compromised by buildup of deposits and precipitates on reactive media.	No	This technology assumes that the emplaced reagents have a higher permeability than the surrounding formation. The very high permeability of the Hanford formation, where most of the contamination exists, makes emplacement problematic.	No
--	In-situ reactive barrier-nanoparticle injection	No	Technology in development. Effectiveness, particularly over the long term, is problematic due to reoxidation and remobilization from ZVI.	Yes	Nanoparticle composition is unspecified, but ZVI is the principle candidate.	No
--	Colloidal ZVI injection	No	Technology in development. Effectiveness, particularly over the long term, is problematic. Long-term performance is not effective due to buildup of precipitates of carbonate minerals on reactive surfaces.	Yes	Combine with in-situ reactive barrier by nanoparticle/colloidal injection.	No
--	In-situ treatment-calcium citrate and sodium phosphate injection	?	Microbial degradation of citrate over time facilitates application of phosphate to form apatite immobilization of uranium. Experimental technology in field application.	Yes	Injection of reagents in multiple wells to form an in-situ reactive barrier avoids problems with excavated trench construction.	Yes

Table 5-2. Technology Screen for Groundwater Remediation. (6 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Chemical	In-situ redox manipulation by dithionite injection	No	Application effectiveness controlled by stratigraphy. Short-term effectiveness of redox reaction controlled by presence of available iron. Long-term maintenance of reduced conditions required to maintain immobilization is problematic.	Yes	Application and injection of reagent uses multiple injection wells. Number of wells is controlled by well spacing, which remains to be determined for site conditions. Follow-up application of reagent feasible with wells.	No
Biological	Microbial dissimilatory reduction of U(VI)	No	Though short-term stabilization is likely effective, long-term stability of uranium is not effective unless continuing biological treatment is applied periodically in perpetuity.	No	Long-term maintenance of biologically reduced zone is problematic.	No
--	Anaerobic in-situ reactive zone	No	Though short-term stabilization is likely effective, long-term stability of uranium is not effective unless continuing biological treatment is applied periodically in perpetuity. Addition of iron and/or sulfur additives delays but does not prevent reoxidation and remobilization of uranium.	No	Long-term maintenance of biologically reduced zone is problematic.	No
<p><i>Italic text indicates technologies that originated in the Phase I and II feasibility study (DOE-RL 1994).</i></p> <p>? = Insufficient data</p> <p>DART = Directed applied reagent technology</p> <p>MNA = Monitored natural attenuation.</p> <p>NPDES = National Pollutant Discharge Elimination System.</p> <p>ZVI = Zero valent iron</p>						

Table 5-3. Cost Screen for Groundwater Remediation Technologies. (4 sheets)

Technology Type	Technology	Effective?	Technically Implementable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
Passive	<i>No action</i>	--	Yes	Yes	Continued monitoring for indefinite period with continued uranium exposure to the environment. Retain for "baseline" case.	Yes
--	<i>Institutional controls</i>	Yes	Yes	Yes	Continued monitoring for indefinite period with continued uranium exposure to the environment. Incrementally higher operation and maintenance costs to maintain access controls; however, long-term risk of costly natural resources damage assessment.	Yes
--	MNA	Yes	Yes	Yes	Continued monitoring for indefinite period with continued uranium exposure to the environment. Effectively a continuation of the present interim action with the potential need for additional monitoring wells at additional expense.	Yes
Physical	Slurry wall containment	?	No	--	--	--
--	<i>Grout walls - grout injection</i>	?	?	--	--	--
--	<i>Grout walls - deep soil mixing</i>	?	No	--	--	--
--	<i>Selective hydraulic containment with pumping</i>	No	Yes	--	--	--
--	<i>Groundwater extraction-interceptor trench</i>	?	<i>No</i>	--	--	--

Table 5-3. Cost Screen for Groundwater Remediation Technologies. (4 sheets)

Technology Type	Technology	Effective?	Technically Implementable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
--	<i>Treated water disposal to surface water (Columbia River)</i>	Yes	Yes	Yes	Disposal to Columbia River is less costly than reinjection. However, pumping and treatment of groundwater ex-situ is at least one order of magnitude more costly than in-situ treatment.	No
--	<i>Treated water disposal to groundwater (re-injection)</i>	Yes	Yes	Yes	More costly than discharge to Columbia River unless combined with in-situ treatment as required for hydraulic control. Very expensive ex-situ treatment costs favor reinjection in combination with an in-situ treatment.	No, would only be used where appropriate for hydraulic control of in-situ process
Physical	<i>Groundwater extraction-wells with in-situ treatment (re-injection)</i>	Yes for make-up water	Yes	Yes	Retained only if in-situ treatment requires hydraulic control.	No, would only be used where appropriate for hydraulic control of in-situ process
Physical	<i>Groundwater extraction-wells with ex-situ treatment (see Treatments below)</i>	? For uranium capture in Hanford formation	Yes	Yes	A limited system of 7 wells (350 gpm) would cost ~\$800,000 without treatment. PV of 100 years operation with ion exchange ~ \$60 million. Not cost effective for more than 5 years of operation.	No
Chemical	<i>Ex-situ ion exchange of pumped groundwater</i>	Yes	Yes	Yes	Small unit ~ 300 gpm: PV of 100 years operation with ion exchange ~ \$60 million. Not cost effective for more than 5 years of operation. Large unit ~4000 gpm: prohibitively expensive-PV for 100 years on the order of \$250 million.	No
--	<i>Ex-situ reverse osmosis of pumped groundwater</i>	Yes	Yes	Yes	More costly than ex-situ ion exchange.	No

Table 5-3. Cost Screen for Groundwater Remediation Technologies. (4 sheets)

Technology Type	Technology	Effective?	Technically Implementable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
--	<i>Ex-situ precipitation</i> of pumped groundwater	Yes	Yes	Yes	More costly than ex-situ ion exchange.	No
--	<i>In-situ flushing</i>	Yes	No	Yes, for uranium on sediments only	In-situ flushing NOT cost effective, in high permeability aquifer due to poor control. Not applicable to thin interface zone deposits of uranium found in limited field investigation.	No
--	Permeable reactive barrier-ZVI	No	No	--	--	--
--	Permeable reactive barrier-amorphous ferric oxyhydroxide	No	No	--	--	--
--	Permeable reactive barrier-hydroxyapatite	No	No	--	--	--
--	Permeable reactive barrier-zeolite	No	No	--	--	--
Chemical	In-situ reactive barrier-injected polyphosphate	?	Yes	Yes	In-situ stabilization of uranium is generally one order of magnitude less than pump-and-treat technology. Approximately \$25 million depending upon extent of deployment.	Yes
--	DART emplacement of ZVI and apatite pellets in wells	No	Yes	--	--	--

Table 5-3. Cost Screen for Groundwater Remediation Technologies. (4 sheets)

Technology Type	Technology	Effective?	Technically Implementable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
	In-situ reactive barrier-nanoparticle injection	No	Yes	--	--	--
	Colloidal ZVI injection	No	Yes	--	--	--
	In-situ reactive barrier-calcium citrate and sodium phosphate injection	?	Yes	Yes	In-situ stabilization of uranium is generally one order of magnitude less than pump-and-treat technology. ~ \$25 million depending upon extent of deployment.	Yes
	In-situ redox manipulation by dithionite injection	No	Yes	--	--	--
Biological	Microbial dissimilatory reduction of U(VI)	No	No	--	--	--
	Anaerobic in-situ reactive zone	No	No	--	--	--
<p><i>Italic text indicates technologies that originated in the Phase I and II feasibility study (DOE-RL 1994).</i></p> <p>U = uranium  ? = Insufficient data  DART = Directed applied reagent technology</p> <p>MNA = monitored natural attenuation.  PV = present value  Redox = reduction and oxidation  ZVI = zero valent iron</p>						

The resulting passive management strategies for groundwater are as follows:

- institutional controls (land-use restrictions, access controls)
- monitored natural attenuation (MNA).

### 5.3.1 Discussion of Groundwater Technology Screening

Hydraulic control or groundwater extraction is very problematic in the very permeable Hanford aquifer. The permeability of the coarse sand and gravel formation exhibits hydraulic conductivity ( $K_h$ ) greater than 2,000 m/d ( $2.94 \times 10^6$  gal/d/ft<sup>2</sup>). Depending upon hydraulic gradients, groundwater flow velocities as high as 15 m/d (50 ft/d) result. Contaminated groundwater extraction is ineffective in such a permeable aquifer. Long-term pumping from a well in the south portion of the 300 Area demonstrates this lack of effect. The water supply well (399-4-12) supplies water for the aquariums in the 331 Building; this well has a pumping rate that typically varies in the range of 757 to 2,271 L (200 to 600 gal) per minute and has been in operation since approximately 1982. Assuming an average pumping rate of 1,235 L (350 gal) per minute for 27 years, and an average uranium concentration of 30 µg/L during that period, approximately 460 kg (1,014 lb) of uranium has been withdrawn through this well. However, monitoring of uranium concentrations of groundwater from the well has indicated no reduction of uranium concentrations over the years of extraction.

Similarly, attempts to either conduct wide-scale extraction or hydraulic control of dissolved uranium in the aquifer are not likely to mitigate the contamination. The rocky subsurface makes installation of sheet pile and slurry cut-off walls problematic. Effective hydraulic control by such barriers, even if constructed, is questionable.

The very high permeability of the formation also makes large-scale injection of water to form hydraulic containment impractical. During installation of well 399-4-12, pump testing at 3,027 L/min (800 gal/min) produced a drawdown of approximately 2.5 cm (1 in.).

In-situ treatment of uranium in groundwater involves either a fast one-time reaction or formation of a phosphate mineral, which adsorbs and stabilizes soluble uranium over an extended time period. The rapid, one-time instantaneous removal of soluble uranium occurs with injected phosphate reagents forming autunite. The resulting autunite mineral solid precipitates and sequesters uranium, thereby removing the formerly dissolved uranium from the groundwater. The stabilized uranium is permanently removed. If phosphate is applied to groundwater having adequate concentrations of dissolved calcium, another mineral, apatite, is formed. Apatite provides a long-term stabilizing agent for dissolved uranium. Consequently, application of phosphate sequentially with a calcium-chloride reagent may be used to establish long-term reactive zones to treat uranium in groundwater. The application of phosphate may be modulated by applying the phosphate using polymerized polyphosphate reagents that allow time-delayed release of the phosphate, thereby permitting extended emplacement through a down gradient volume relative to the injection point in the aquifer. Apatite placed over the treatment volume promotes the sorption of dissolved uranium that enters the treatment zone after the initial polyphosphate application. Sorbed uranium on apatite eventually is stabilized as autunite forms from the apatite-uranium complex. A second method for deploying phosphate uses calcium-citrate phosphate solutions. This technology uses in-situ biodegradation of the citrate to allow the phosphate and calcium reaction to apatite in the aquifer.

## 5.4 SCREENING OF TECHNOLOGIES FOR SMEAR ZONE

Screening of remediation technologies for the smear zone is presented in Table 5-4, while Table 5-5 presents the final selection of technologies based upon comparison of relative cost.

Because the 1994 feasibility study (DOE-RL 1994) did not address the groundwater interface zone (smear zone) where fluctuating water elevations produce a wetted layer of sediment, a new list of six prospective technologies is initially identified. These six technologies are reduced to two technologies using criteria of effectiveness and implementability. Two active technologies remained after applying relative cost criteria.

The resulting active technologies for the smear zone (Zone 3) are as follows:

- Selective excavation to the water table
- Stabilization by application of phosphate.

### 5.4.1 Discussion of Smear Zone Technology Screening

The smear zone is relatively thin (2.5 to 3 m [8.2 to 9.8 ft]), representing the extent of groundwater table fluctuation. The zone is overlain with approximately 9.7 to 12 m (32 to 40 ft) of sediment. It is the immediate source of ongoing uranium contamination when contacted with rising groundwater elevations during summer. Access to the smear zone, relatively thin-targeted dimension, and lateral extent of the uranium contamination in the smear zone are the principle challenges to applying a remedy.

Six active technologies were considered in the screening process. One of the six selective excavation, was identified as being effective and technically implementable. Slope stability set-back requirements, dewatering of contaminated sediment, and handling of vadose sediment overburden incur significant costs. Pressure grouting of the targeted smear zone is technically difficult to affect beyond a radius of 1 m (3.28 ft). Stabilization of the targeted zone by phosphate stabilization is judged to be potentially effective and implementable with low costs relative to other technologies. Application by infiltration of phosphate would be facilitated by the relatively porous, sandy sediment fill above the targeted residual zone. Ongoing development is being conducted to resolve issues with engineering the application and management of phosphate stabilization reagents. Other chemical and biological technologies are either ineffective because of high uncertainty, reaction reversibility, or application difficulties.

Table 5-4. Technology Screen for Smear Zone Remediation. (2 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Passive	No action	--	--	Yes	Retained as "baseline" case.	Yes
Physical	Selective excavation to water table	Yes	Deeper excavation removes uranium residuals where encountered.	Yes	Implementable only for focused, localized areas. Excavation side wall stability would require handling large soil volumes and soil moisture would require dewatering processes. However, excavation is feasible.	Yes
--	Pressure grout injection at water table with dense push rod well pattern	Yes	Grout can stabilize and isolate uranium from groundwater.	No	Efficacy of technology dependent upon site conditions. If smear zone is widespread, grout injection is too localized to be effective.	No
Chemical	Injection of reactive substance to form water barrier at water table	Yes	Physical mechanics of application and containment limit effectiveness. Reactive substance used determines effectiveness.	No	Physically feasible. Agent not yet identified or available.	No
--	Stabilization by application of polyphosphate solution	?	Application effectiveness controlled by stratigraphy. Rapid autunite formation immobilizes uranium. Longer-term apatite formation provides backup process. Promising but not fully developed.	Yes	Polyphosphate application may be configured for differential reaction rate and delivery conditions. Dual delivery modes: percolation from surface application or timed flooding with elevated water table techniques.	Yes

Table 5-4. Technology Screen for Smear Zone Remediation. (2 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Biological	Temporary bioremediation to anaerobically stabilize uranium	?	Though short-term stabilization is likely effective, long-term stability of uranium is questionable unless continuing biological treatment is applied periodically in perpetuity.	No	Maintenance of biologically reduced zone problematic.	No
	Anaerobic in-situ reactive zone	Yes	Anaerobic bioreduction has been demonstrated. However, long-term maintenance of reductive zone not yet proven.	No	Maintenance of biologically reduced zone problematic.	No

Table 5-5. Cost Screen for Zone 3 (Smear Zone) Remediation Technologies.

Technology Type	Technology	Effective?	Technically Implementable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
Passive	No action	--	Yes	Yes	Continued monitoring in perpetuity with continued uranium exposure to the environment. Retain for "baseline" case.	Yes
Physical	Selective excavation to water table	Yes	Yes	Yes	Higher relative cost compared to lowest-cost technology, polyphosphate stabilization (1.8) for treating relatively thin ~15-acre smear zone.	Yes; only for small focus areas
--	Pressure grout injection at water table with dense push rod well pattern	Yes	No	--	--	--
Chemical	Injection of reactive substance to form water barrier at water table	Yes	No	--	--	--
--	Stabilization by application of polyphosphate solution	Yes	Yes	Yes	Lowest-cost technology when applied over "prototype coverage area" based upon ~15-acre smear zone of north and south disposal areas. Relative cost factor 1.0, ~\$25 million.	Yes
Biological	Temporary bioremediation to anaerobically stabilize uranium	?	No	--	--	--
--	Anaerobic in-situ reactive zone	Yes	No	--	--	--

## 5.5 SCREENING OF TECHNOLOGIES FOR THE VADOSE ZONE

Screening of remediation technologies for the vadose zone is presented in Tables 5-6 and 5-7.

The 1994 feasibility study (DOE-RL 1994) did not address the lower vadose zone. Thus, a new list of 10 candidate technologies was considered. Using criteria of effectiveness and implementability, the 10 were reduced to 4 technologies. Three active technologies remained after applying relative cost criteria. The resulting active technologies for the vadose zone are as follows:

- excavation of sediment to the water table
- vadose sediment treatment with polyphosphate immobilizing agent
- vadose sediment treatment with calcium citrate and sodium phosphate.

### 5.5.1 Discussion of Vadose Zone Technology Screening

Uranium residuals remain in soil and sediments directly below former waste-disposal areas, such as the former discharge ponds. Some contaminated sediments were excavated from beneath the former ponds as part of the 300-FF-1 Operable Unit cleanup to a level of 267 pCi/g prior to backfill placement. However, the excavation depths in the pond areas did not extend to the water table. Consequently, residual uranium remains in this deeper portion of the vadose zone on sediment and in associated pore water that may migrate downward under some infiltration conditions.

Technologies that employ chemical reagents to either stabilize or mobilize uranium in situ, without direct excavation and removal of sediment, rely upon percolation through and contact of liquid reagent with uranium on unsaturated sediments. The reagents either stabilize the uranium in place or mobilize and transport the uranium to the groundwater, where attempts would be made to collect the leached uranium. Soil washing or leaching was judged inappropriate because the very permeable Hanford aquifer precludes assured hydraulic control and collection of the mobilized uranium. Among the multiple stabilization processes, only phosphate stabilization into autunite results in enduring stabilization resistant to long-term changes in redox conditions. Application, infiltration, and effective contact of phosphate reagent with the targeted sediment continue to be studied.

Focused excavation of the vadose zone, specifically in areas beneath former disposal facilities down to the groundwater table, is a proven but expensive (relative to in-situ technologies) remediation technology. Re-excavation of the backfill placed during the conclusion of the 300-FF-1 Operable Unit remedial action would be required to gain access to the remaining vadose zone sediments that pose a continuing risk of contaminating groundwater. Excavation would be scheduled during periods of low groundwater elevation to maximize contaminant removal. The excavation operation would use techniques and practices employed in open-pit surface mining. Real-time chemical analysis of the sediment would guide the excavation process.

In-situ treatment of vadose zone sediments using phosphate reagent appears to be less expensive relative to excavation. Application of the phosphate could be accomplished using two methodologies: phosphate/polyphosphate application, or application of calcium citrate-sodium phosphate. Because one-time uranium stabilization by autunite may be sufficient to remedy uranium in the vadose zone, emplacement of extended-action apatite may not be necessary.

Table 5-6. Technology Screen for Vadose Zone Sediment Remediation. (2 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Passive	No action.	--		Yes	Retained as "Baseline" case.	Yes
Physical	More extensive excavation to water table.	Yes	Deeper excavation removes uranium residuals where encountered.	Yes	Further excavation possible.	Yes
--	Impermeable surface cap	Yes, partially	Reduces infiltration and associated transport of uranium from sediments above influence of water table, but not at uncovered locations.	No	Wide-area hydraulic control not feasible because of very high permeabilities. Large rocks preclude cut-off walls.	No
Chemical	Vadose flushing with mobilizing agent and hydraulic extraction of solution.	?	Physical flow dynamics of application controls effectiveness. Chemical used determines effectiveness.	Yes	Consider as a groundwater technology because agent collection will be in groundwater.	Yes
--	Vadose infiltration with immobilizing agent-hydroxyapatite reaction	Yes	Application effectiveness controlled by stratigraphy. Hydroxyapatite reaction kinetics controls extent of effectiveness.	No	Application of hydroxyapatite in a reactive form through vadose zone not feasible.	No
--	Vadose infiltration with immobilizing agent-polyphosphate	?	Application effectiveness controlled by stratigraphy. Rapid autunite formation immobilizes uranium. Longer-term apatite formation provides backup process. Promising, but not fully developed.	Yes	Polyphosphate application may be configured for differential reaction rate and delivery conditions. Percolation from surface application may be conducted prior to or possibly after surface redevelopment.	Yes

Table 5-6. Technology Screen for Vadose Zone Sediment Remediation. (2 sheets)

Technology Type	Technology	Effective?	Rationale for Effectiveness Screen	Technically Implementable?	Rationale For Implementability Screen	Retain for Further Consideration?
Chemical	Vadose infiltration with colloidal ZVI.	?	Application effectiveness controlled by stratigraphy. Short-term effectiveness of redox reaction controlled by presence of water. Long-term maintenance of reduced conditions required to maintain immobilization questionable.	No	ZVI most appropriate for groundwater, not unsaturated soil. Nanoparticle ZVI will be considered as groundwater technology.	No
	Vadose infiltration with dithionite solution.	?	Application effectiveness controlled by stratigraphy. Short-term effectiveness of redox reaction controlled by presence of available iron. Long-term maintenance of reduced conditions required to maintain immobilization questionable.	No	Technology is proven but delivery of dithionite to unsaturated soil problematic.	No
	Vadose infiltration with calcium polysulfide.	No	Redox modification is not effective over the long term.	Yes	Application of calcium polysulfide appears to be feasible using infiltration methods.	No
	Vadose infiltration with calcium citrate and sodium phosphate.	?	Control and rate of microbial degradation of citrate in vadose problematic.	Yes	A form of apatite technology; however, delivery technology is not fully developed. Maintenance of moisture for citrate biodegradation not yet demonstrated.	Yes
Biological	Temporary bioremediation to anaerobically stabilize uranium.	No	Though short-term stabilization is likely effective, long-term stability of uranium is questionable unless continuing biological treatment is applied periodically in perpetuity.	No	Maintenance of biologically reduced zone problematic.	No

Table 5-7. Cost Screen for Vadose Zone Sediment Remediation Technologies.

Technology Type	Technology	Effective?	Technically Implem-entable?	Retain for Further Consideration?	Rationale for Cost Evaluation	Retain for Alternative Assembly?
Passive	No action	--	Yes	Yes	Continued monitoring over long term with continued uranium exposure to the environment. Retain for "baseline" case.	Yes
Physical	More extensive excavation to water table.	Yes	Yes	Yes	Higher relative cost compared to lowest-cost technology, polyphosphate stabilization. May be cost effective in conjunction with shallow, upper vadose zone excavation.	Yes, where other removal actions coincide
--	Impermeable surface cap	Yes, partially	No	--	--	--
Chemical	Vadose flushing with mobilizing agent and hydraulic extraction of solution.	Yes	Yes	Yes	Within high-permeability Hanford aquifer, groundwater pumping for withdrawal of lixiviant solution is at least three times the cost of immobilizing agent flushing.	No
--	Vadose infiltration with immobilizing agent-hydroxyapatite reaction.	Yes	No	--	--	--
--	Vadose infiltration with immobilizing agent, polyphosphate.	Yes	Yes	Yes	Lowest-cost technology, particularly if applied without wells.	Yes
--	Vadose infiltration with colloidal ZVI.	?	No	--	--	--
--	Vadose infiltration with dithionite solution.	?	No	--	--	--
--	Vadose infiltration with calcium polysulfide.	No	Yes	--	--	--
--	Vadose infiltration with calcium citrate and sodium phosphate	?	Yes	Yes	Low-cost technology, particularly if applied without wells. Comparable cost to polyphosphate percolation, depending upon application process.	Yes
Biological	Temporary bioremediation to anaerobically stabilize uranium	No	No	No	--	--

## 5.6 SUMMARY OF APPLICABLE TECHNOLOGIES

Two active technologies will form the basis of formulating direct treatment of groundwater contaminated with dissolved uranium:

- in-situ polyphosphate treatment to stabilize uranium to form autunite and apatite
- in-situ treatment with calcium citrate and sodium phosphate to stabilize uranium to form apatite.

Two passive management strategies will also be employed in formulating alternative remedies for mitigating dissolved uranium in groundwater:

- institutional controls (land-use restrictions, access controls, pumping restrictions)
- MNA.

Two active technologies will form the basis of defining treatment alternatives for remediation of uranium in smear zone sediment that contribute to groundwater contamination:

- selective excavation to the water table
- in-situ treatment of sediment with phosphate reagents to stabilize uranium.

Two active technologies will form the basis of defining treatment alternatives for remediation of potentially mobile uranium in the vadose zone sediments that can contribute to groundwater contamination:

- selective excavation to the water table
- in-situ treatment of sediment with phosphate reagents to stabilize uranium.

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## 6.0 ASSEMBLY OF TECHNOLOGIES INTO PROTOTYPE REMEDIATION ALTERNATIVES

This remediation strategy study for the 300 Area builds upon the site characterization, technology screen, and treatability study efforts conducted since 1990, but focuses primarily on work conducted since 2004. The evaluation and screening of remedial technologies for uranium at the site in this section forms the basis from which prototype remedial alternatives are developed.

Remedial alternatives are conceptual designs that incorporate one or more technologies in a specific configuration that has the potential to meet the RAOs and remediation performance objectives as described in Section 4.0. Each alternative includes a concept of the location(s), sequencing, and duration of applying remedial technology to the contaminated site sediments and/or groundwater.

The conceptual model guided the definition of the candidate remediation alternatives for treating the uranium contamination in the groundwater and sediments beneath the 300 Area. The conceptual model described in Section 2.0 presents the current understanding of the distribution, geochemistry, and transport of the uranium within the unsaturated sediment and aquifer.

### 6.1 REMEDIATION ALTERNATIVES CONSIDERED IN THE PREVIOUS FEASIBILITY STUDY

The 1995 feasibility study (DOE-RL 1995) identified and considered 16 alternatives to remediate the groundwater. At that time, groundwater remediation was considered distinct from the overlying vadose zone sediments. In addition, the conceptual model of the hydrogeology and contaminant transport were much simpler with significant differences compared to our present understanding described in Section 2.0. Table 6-1 lists the alternatives considered in 1995 before preliminary screening according to effectiveness, implementability, and cost.

Table 6-1. Initial List of Alternatives for 1995 Feasibility Study.

Alternative Number	Alternative Description
1995 Alternative 1	No action
1995 Alternative 2	Institutional controls
1995 Alternative 3	Selective hydraulic containment
1995 Alternative 4	Selective hydraulic containment with in-situ flushing
1995 Alternative 5	Extensive hydraulic containment
1995 Alternative 6	Extensive hydraulic containment with selective in-situ flushing
1995 Alternative 7	Selective slurry wall containment
1995 Alternative 8	Selective slurry wall containment with minimal extraction
1995 Alternative 9	Selective slurry wall containment with in-situ flushing
1995 Alternative 10	Extensive slurry wall containment
1995 Alternative 11	Extensive slurry wall containment with minimal extraction
1995 Alternative 12	Extensive slurry wall containment with in-situ flushing
1995 Alternative 13	Selective hydraulic containment with a river cut-off wall
1995 Alternative 14	Selective in-situ flushing with a river cut-off wall
1995 Alternative 15	Selective aquifer dredging
1995 Alternative 16	Extensive aquifer dredging

The 1995 feasibility study (DOE-RL 1995) further evaluated a reduced list of six alternatives following the preliminary screen. Table 6-2 lists the remediation alternatives evaluated in the detailed evaluations of the 1995 feasibility study.

Table 6-2. Final List of Alternatives for 1995 Feasibility Study

Alternative Number	Alternative Description
1995 Alternative 1	No action
1995 Alternative 2	Institutional controls
1995 Alternative 3	Selective hydraulic containment
1995 Alternative 5	Extensive hydraulic containment
1995 Alternative 8	Selective slurry wall containment with minimal extraction
1995 Alternative 11	Extensive slurry wall containment with minimal extraction

The 1995 feasibility study (DOE-RL 1995) concluded no unacceptable risk to human health or the environment would result if direct exposure to contaminated groundwater was prevented. The 1995 study identified negative effects for the four active remediation alternatives such as worker safety, environmental effects during implementation, and high costs relative to the passive, no-action remedy. With the expectation that natural groundwater processes would reduce the concentrations of uranium and other COCs by 2018, Alternative 2—institutional controls—was recommended as the preferred remedy. As of 2008, uranium concentrations have not declined as anticipated in 1995. Consequently, renewed evaluation of remediation strategy is pursued here.

## 6.2 REMEDIATION STRATEGIES

Remediation strategies describe broad categories of remedial actions. Also described as general response actions, these strategies describe the method or deployment goal of the technology assemblies a remediation action plan uses to affect cleanup.

As described in Section 4.0, to meet the RAOs, remedial alternatives can be configured with performance objectives to either achieve one of the following:

- decrease the flux of uranium from the vadose zone to the groundwater such that groundwater concentration remains below 30 µg/L
- directly decrease the concentration of uranium in the groundwater and maintain the concentration below 30 µg/L.

The first performance objective leads to a remediation strategy of source treatment. The goal of this strategy is to prevent further groundwater contamination. Uranium is stabilized or removed in unsaturated sediment above and in contact with the groundwater. The deployment treatment is focused on below areas or facilities where historic releases of waste-contaminated sediments reside, and provide ongoing potential for further groundwater contamination. Dissolved uranium presently in groundwater is not directly targeted.

There are two potential remediation strategies that could meet the second performance objective. One strategy is to treat the bulk of groundwater contamination. The groundwater is treated to reduce

concentrations in part or the entire contaminated plume. Contaminated sediments within the smear zone are treated only incidentally as the groundwater table fluctuates. The second potential strategy is to either contain high concentrations, or prevent concentrations of uranium in groundwater from flowing into the Columbia River.

These overall remediation strategies and the results of the technology screening were used to develop candidate remedial alternatives. These candidate alternatives are referenced as *prototype alternatives* because additional characterization and treatability testing efforts are needed to reduce technical uncertainty associated with the contaminant distribution and the mechanism for deployment of in-situ technologies within the smear zone of the fluctuating water table. Because additional characterization and treatability testing is needed to enable full evaluation in a feasibility study, the remediation strategy study uses estimated characterization and technology performance parameters, and a relative comparison of prototype alternatives.

### 6.3 POTENTIAL ALTERNATIVES HAVING FATAL FLAWS

Several potential prototype alternatives were examined because they are typically considered at other remediation sites, but were not carried forward because of significant issues with their application at the 300 Area. These prospective alternatives include pump-and-treat, various approaches of in-situ leach/extraction, and in-situ redox manipulation.

#### 6.3.1 Pump-and-Treat

Groundwater extraction to provide hydraulic control and/or extract contaminated groundwater is one of the earliest approaches to groundwater cleanup. It was considered and rejected in the 1995 feasibility study (DOE-RL 1995). The discussion below elucidates some of the reasons the pump-and-treat system is not viable for the 300 Area.

The overall net mean flux of groundwater exiting the Hanford aquifer to the Columbia River along the east periphery of the 300 Area, assuming 3 km (1.8 mi) of shoreline, using modeling of 1992 data is approximately  $3.5 \times 10^6$  m<sup>3</sup>/year (approximately 1,800 gpm). An additional net flux of  $4.9 \times 10^6$  m<sup>3</sup> per year is estimated to flow to the south of the site. Assuming the principal pathway for dissolved uranium is east through the river shoreline, it is conceivable a groundwater extraction system capable of pumping a total of 7,568 L/min (2,000 gpm) could be installed. However, the groundwater flux to the river is much higher at times and a 2,000-gpm extraction system would not provide capture during these high-flux periods. Additionally, a pump-and-treat system would not significantly increase removal of uranium from the aquifer or from the overlying vadose zone sediments. Pump-and-treat provides containment, but does not meet the RAOs related to restoration any faster than a no-action alternative.

#### *Description*

Thirty groundwater extraction wells operate continuously. Extracted groundwater is treated in an ion-exchange system with onsite regeneration. Uranium-laden water from the regeneration process is treated by precipitation, precipitate dewatering, and disposal.

### ***Targeted Extent of Application***

Approximately 30 wells are placed 45 m (147 ft) inland from the river shoreline, spaced 30 m (98 ft) apart. Groundwater upgradient of wells and beneath former waste-disposal areas would not be immediately withdrawn; thus, only uranium concentrations downgradient of wells would be reduced.

### ***Performance Metric***

CERCLA-required groundwater monitoring is performed to observe the response of dissolved uranium in the aquifer.

### ***Discussion***

Because the release rate of uranium to groundwater from the sorbed inventory above the water table is unaffected, the pump-and-treat alternative does not achieve restoration any faster than a no-action alternative.

## **6.3.2 Application of Mobilizing Agent with Hydraulic Capture**

In-situ extraction uses a chemical agent to mobilize uranium in sediment, flush the dissolved uranium into groundwater, capture and recover the burdened groundwater, and treat/separate the extracted uranium from the groundwater in an ex-situ process facility. This treatment is an extension of in-situ leach uranium-mining technology. This approach could be deployed using multiple five-spot or seven-spot well networks installed in areas of known uranium residuals approximately corresponding to the original discharge ponds and trenches. One center injection well and four or six extraction wells per network apply leaching solution and extract the resulting uranium solution. The leaching solution or lixiviant provides two functions: 1) it oxidizes and dissolves uranium from the sediments, and 2) it provides a ligand, which forms stable complexes with the uranium that may be extracted. Possible lixiviants may be alkaline solutions of ammonium or sodium bicarbonate to complex  $U^{6+}$  with carbonate/bicarbonate. The lixiviant-uranium solution is pumped to the surface for treatment. The anionic uranium complex  $UO_2(CO_3)_2^{2-}$  is removed from the solution by strong-base anionic (quaternary ammonium) exchange resins.

### ***Targeted Extent of Application***

The uranium extraction process targets within the extent of former waste-disposal ponds and trenches. It is unlikely this remedy could be efficiently deployed for treating an extended area of thin smear zone deposits outside of the original disposal areas.

### ***Performance Metric***

CERCLA-required groundwater monitoring is performed to observe the response of dissolved uranium in the aquifer.

### ***Discussion***

The 1995 feasibility study (DOE-RL 1995), considered but rejected a flushing approach in the preliminary screen because of problems also affecting in-situ leach/extraction. The primary challenge for

successful implementation of either approach is hydraulic control and capture of the leaching solutions. The fatal flaw of this prospective approach is that it risks uncontrolled release of mobilized contaminants to the Columbia River in a very challenging hydrogeologic environment. Increases of dissolved uranium in groundwater and river shoreline would be expected.

### 6.3.3 In-Situ Redox Manipulation

Considerable technical development and study of manipulating subsurface geochemical conditions to sequester or immobilize inorganic contaminants have been pursued over the past 20 years. The possibility of conducting such in-situ redox manipulations on uranium residuals has been studied extensively. Such modification of redox conditions can be affected by a variety of chemical or biological methods. The addition of reducing solutions, iron particles, and reducing microorganisms has been proposed. The fatal flaw of such approaches is that within the complex geochemistry of uranium, a permanent stable chemical form of uranium within Hanford Site conditions has neither been identified nor attained. Maintenance of a reduced, immobilized uranium form to prevent renewed contamination of groundwater in the high groundwater flow rate conditions would require frequent reinjection of barrier-forming reagents. Thus, this type of approach is problematic for application at the 300 Area.

The primary variable determining the mobility of uranium in environmental systems is oxidation state. Uranium can exist in the +3, +4, +5, and +6 oxidation states in aqueous environments. Uranium(VI) and U(IV) are the most common oxidation states of uranium in natural environments. Uranium will exist in the +6 oxidation state under oxidizing to mildly reducing environments. Uranium(IV) is stable under reducing conditions and is considered relatively immobile because U(IV) forms sparingly soluble minerals. Dissolved U(III) easily oxidizes to U(IV) under most reducing conditions found in nature. The U(V) aqueous species ( $UO_2^{2+}$ ) readily disproportionates to U(IV) and U(VI).

Reducing conditions that are characteristic of many deep-geologic environments are conducive to formation of sparingly soluble uranous [U(IV)] compounds, such as uraninite ( $UO_2$ ) and coffinite ( $USiO_4$ ). Such uranium stabilization could also be promoted by creating reducing conditions using anaerobic biological process to create a reducing environment. Oxidizing conditions that occur in near-surface environments such as the Hanford Site, in contrast, tend to release uranium precipitated or sorbed as U(IV) into shallow groundwater and surface waters as the more stable uranyl, U(VI), aqueous complexes. Therefore, the problem with attempting U(IV) stabilization in shallow groundwater, such as is present in the 300 Area, is long-term maintenance of anoxic, reducing conditions.

## 6.4 INITIAL LIST OF PROTOTYPE ALTERNATIVES

Two passive alternatives are considered. One alternative, no action, proceeds as the baseline case, which CERCLA guidance requires to provide a reference alternative for comparing the other alternatives. The second passive alternative, MNA, considers ongoing natural processes in conjunction with a plan of actively monitoring the effects of those processes without further application of active remedial technologies. The remaining prototype alternatives are engineered actions to remove, reactively treat, and stabilize uranium contamination.

#### **6.4.1 Alternative 1: No Action**

##### ***Description***

A no-action alternative is required under the "National Oil and Hazardous Substances Pollution Contingency Plan" (40 CFR 300). This plan is the result of the federal government to develop a coordinated response to clean up contamination in soil and groundwater. The no-action alternative is the baseline for comparison to other remedial alternatives. In accordance with the EPA definition, this alternative works if the institutional controls currently in place would be removed and that no remedial actions would be performed. As required under CERCLA, groundwater monitoring would be performed to verify the effectiveness of the alternative.

##### ***Targeted Extent of Application***

The entire extent of uranium contamination in the aquifer and sediments, as well as source sediments in the 300 Area, is included in this alternative. No remedial action would be applied to these unsaturated and saturated zones.

##### ***Performance Metric***

CERCLA-required groundwater monitoring is performed to observe the response of dissolved uranium in the aquifer.

##### ***Discussion***

Under this alternative, no active measures to remedy the cause, flow, or use of contaminated water would be applied. Concentrations of uranium dissolved in the groundwater, which exceed the 30 µg/L uranium MCL, would continue to discharge to the Columbia River and be diluted for the foreseeable future.

#### **6.4.2 Alternative 2: Monitored Natural Attenuation**

##### ***Description***

Natural attenuation relies on natural processes to clean up or attenuate uranium in soil and groundwater. Continuation of the ongoing monitoring of groundwater quality provides information for regulators to evaluate the efficacy and rate of clean up; therefore, the process is termed MNA. This alternative distinguishes itself from the no-action alternative, in that the site is managed to optimize natural processes and preclude development or land-use actions, which would impede the natural processes and includes other institutional controls as necessary to meet RAOs.

##### ***Rationale***

Soluble hexavalent uranium, U(VI), can be sorbed to iron-hydroxide minerals, precipitated in the presence of phosphate minerals, and reduced to much less soluble forms depending upon the pH, alkalinity, temperature, and sediment mineralogy. The current level of understanding for these natural processes is moderate and more research is required. The regulatory guidance to support consideration of natural attenuation as a remediation alternative is found in the EPA Directive

(OSWER 9200.4-17 [EPA 1999]) and DOE guidance (DOE-RL 1999). MNA would be deployed in conjunction with source removal or stabilization in accordance with EPA guidance.

#### *Targeted Extent of Application*

The entire extent of uranium contamination in the aquifer in the 300 Area is included in this alternative. Saturated and unsaturated sediments, not treated by source removal actions, would be indirectly addressed by the groundwater monitoring of natural process activity.

#### *Performance Metric*

By definition, groundwater monitoring would be performed to observe the response of dissolved uranium in the aquifer to natural attenuation processes. Seasonal monitoring (with possible monthly sampling from a subset of select well locations) of groundwater quality would be conducted according to a specific monitoring plan. Monitoring would include uranium and geochemical parameters such as pH, Eh, specific conductance, alkalinity, bicarbonate, iron, phosphate, calcium, and other relevant species.

#### *Discussion*

The natural attenuation processes of uranium in the 300 Area include periodic groundwater contact of contaminated sediment resulting from water-level fluctuations, dispersion, dissolution, and eventual transport and mixing in the Columbia River. The rate of natural removal of uranium from the subsurface system is complex and variable, and will likely extend for decades. MNA is a complementary component of the active remediation alternatives because the active remedial actions will likely be focused and probably limited to source areas. Remediation of the larger aquifer volumes outside the focused treatment areas will rely upon natural attenuation. Such attenuation is based upon the kinetics of the geochemistry, not the radioactive half-life of uranium. Source removal or stabilization of uranium expedites and facilitates natural attenuation processes to attain cleanup goals. For the purpose of this alternative analysis, MNA is considered without any further source treatment actions. Complementary natural attenuation as an adjunct to each of the active remediation alternatives is evaluated as part of each active alternative evaluation.

### **6.4.3 Alternative 3: Phosphate Stabilization**

Phosphate stabilization may be deployed in various modes of application to sediments and/or groundwater. Five deployment configurations of the alternative are considered. Each is identified as a sub-alternative by a letter designation.

#### *Description*

The addition of water-soluble phosphate compounds to a soil or groundwater system promotes the stabilization of mobile and soluble uranium(VI) contaminating the 300 Area. Orthophosphate ( $\text{PO}_4^{3-}$ ) in groundwater precipitates with dissolved uranyl ions [uranium(VI)] to form insoluble uranyl phosphate minerals. Injection of water-soluble phosphate compounds into contaminant plumes within aquifers stabilizes uranium in the groundwater, thereby sequestering the uranium and reducing concentrations of the contaminant. Such precipitation processes are superior to alternative reversible sorption mechanisms. However, the form of the phosphate reagent used has consequences. Application of some phosphate compounds, such as tribasic sodium phosphate [ $\text{Na}_3(\text{PO}_4)_n\text{H}_2\text{O}$ ] or phytic acid [ $\text{C}_6\text{H}_{18}\text{O}_{24}\text{P}_6$ ], result in

excessively rapid formation of phosphate precipitate that tend to occlude approximately 30% of the fluid-filled pore space within sediments. Such rapid reduction in hydraulic conductivity significantly affects subsequently applied reagents and perturbs the flow of the targeted groundwater plume by deflecting the natural flow path. Additionally, some compounds such as phytic acid can produce fine, highly mobile floccules that sorb aqueous uranium and enhance the uranium mobility within the subsurface. In contrast, application of soluble long-chain polyphosphate materials has been shown to delay the precipitation of phosphate phases. In addition, by formulating the reagent mixture with a range of phosphate polymers, the reaction rate of the treatment may be managed to promote treatment over a widespread treatment volume extending downgradient from the injection well. This capability is a function of the degree of reagent polymerization. The longer the polyphosphate polymer chain, the slower the hydrolysis reaction leading to formation and intermediate reaction of the orthophosphate that reacts with the contaminating U(VI).

The immobilization process with polyphosphate results in the formation of an insoluble uranyl phosphate mineral, autunite  $X_{1-2}[(UO_2)(PO_4)]_{2-1} \cdot nH_2O$  where X is any monovalent or divalent cation. Because autunite sequesters uranium in the oxidized form  $U^{6+}$ , rather than requiring reduction to  $U^{+4}$ , the possibility of reoxidation and remobilization is negated. Release of uranium sequestered in the autunite structure can only occur through dissolution of the autunite structure. Extensive testing demonstrates that autunite under Hanford formation conditions is very stable with very low solubility.

Autunite formation is applicable to uranium stabilization in groundwater or on sediments. The autunite formation is a rapid, one-time stabilization reaction. In groundwater situations a second reaction, assuming sufficient calcium is available, can be promoted to stabilize the long-term stabilization of uranium. In the presence of excess unreacted phosphorous, a second phosphate mineral, apatite  $[Ca_5(PO_4)_3OH]$  forms, which provides a secondary long-term agent for sorption of U(VI) over time at and onto the apatite-water interface. The extended apatite zone can, under favorable pH conditions (pH <7.0), temporarily adsorb additional concentrations of dissolved uranium after the initial application of phosphate reagents. The intent of the process is to facilitate the conversion of temporarily adsorbed uranium into permanently sequestered autunite. However, this reaction must be carefully facilitated by minimizing inhibiting carbonate reactions. The dynamics of high-carbonate concentrations in the 300 Area aquifer complicate the longer-term treatment of dissolved uranium in groundwater using polyphosphate application strategies to the groundwater per se (Wellman et al. 2008).

### *Discussion*

A variety of phosphate compounds are available. For direct application to groundwater via injection wells in the 300 Area, a polyphosphate reagent mixture consisting of a combination of compounds would be applied. The reagent mixture would allow the phosphate to react both instantly and over time, thereby allowing uranium treatment over a distance as the reagent spreads. The reagent application process will include pH control and calcium addition. The pH management will prevent premature degradation of the polymerized phosphate prior to reaction in the aquifer. The calcium will facilitate formation of apatite beyond the initial reaction zone to provide a secondary phosphate mineral to provide temporary uranium sorption capacity to allow more permanent sequestering of sorbed uranium to autunite mineral forms.

A multiple application protocol provides additional time-release phosphorus for lateral precipitation of amorphous calcium-phosphate as the in-situ treatment zone disperses in radial distribution from the well and moves downgradient in the aquifer. The amorphous calcium-phosphate precedes the formation of

hydroxyapatite. The sequential addition of reagent pulses provides additional hydraulic driving force to maximize lateral distribution. Formation of hydroxyapatite is dispersed throughout the aquifer treatment zone, thereby establishing a reactive sorption zone for follow-up uranium sequestration. Thus, the rapid sequestration of immediately available dissolved uranium in autunite is followed by establishment of a longer-term in-situ treatment zone in the aquifer to treat subsequent dissolved uranium.

Preliminary pilot testing of the triple-step polyphosphate demonstrated successful formation of autunite. However, the design of the application process was inadequate in forming extended action apatite. Factors, such as very high groundwater flow velocities and excessively rapid dosing procedures used in the pilot test, did not allow for effective long-term treatment. Additional treatability testing is planned to improve the formation of apatite.

Application of phosphate to stabilize uranium is not limited to groundwater. Phosphate may also be deployed in many configurations, depending upon the location of the targeted uranium located within the groundwater, fluctuating water level zone (smear zone), or lower vadose zone sediments. Consequently, several methods and arrangements of applying phosphate reagents to groundwater are considered in this remediation strategy study.

#### **6.4.4 Alternative 3A: Polyphosphate Application to Groundwater Beneath Original Source Areas.**

This alternative consists of injecting polyphosphate reagents in a three-application sequence through multiple wells within former source areas; i.e., disposal ponds and trenches. Figure 6-1 illustrates the coverage area of the multiple injection wells required for this alternative.

##### ***Rationale***

Form autunite and apatite within aquifer to provide both immediate stabilization and longer-term treatment of dissolved uranium beneath principal sources of groundwater contamination.

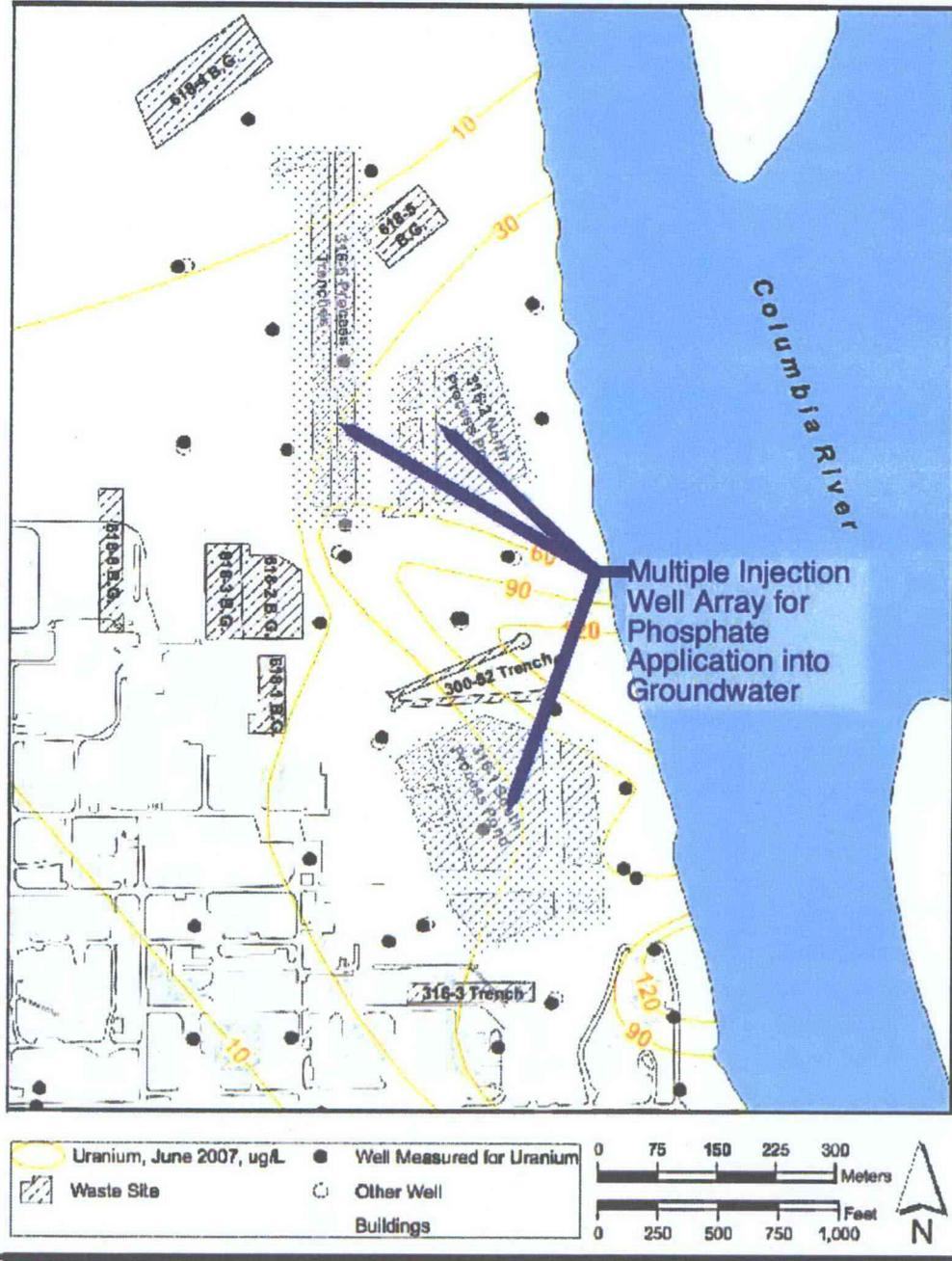
##### ***Extent***

Phased deployment would begin in the aquifer beneath the North and South Process Ponds and beneath the 300 Area Process Trenches. Subsequent treatment of residual groundwater plumes would be deployed as appropriate. Approximately 76,000 m<sup>2</sup> (19 acres) would be treated. This area is based upon coverage of the present WIDS site boundaries for the former South Process Pond (316-1), retired filter backwash pond, North Process Pond (316-2), and the 300 Area Process Trenches (316-5).

Injection wells would be installed in an array spaced approximately 20 m (65 ft) apart. Approximately 242 wells would be required to cover the 76,000 m<sup>2</sup> (19 acres). The phosphate reagent application remains to be determined, but likely multiple applications over an extended period would be conducted to maximize treatment effectiveness. The injections would be scheduled coincident to the high spring and summer Columbia River operating levels. This alternative would treat groundwater and saturated sediment during the high-water table season, thereby establishing a treatment zone with short-term lowering of mobile uranium concentration. Apatite formation within the zone would also provide longer-term capacity for intercepting and stabilizing uranium in the aquifer. To the extent the water table rises into the vadose zone sediments during reagent injection, uranium in the smear zone would be treated.

Because of the open framework, gravels of the aquifer may make uniform treatment problematic. Direct treatment of sediments in and above the fluctuating water table (smear zone) may be required to effect the desired clean up.

Figure 6-1. Map of Injection Well Application Areas for Phosphate Application.



**Expected Performance**

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs over the duration of the uranium source.

#### **6.4.5 Alternative 3B: Polyphosphate Application to Groundwater to Form Linear Barrier**

A linear subsurface reactive barrier geometry to intercept and treat groundwater is the design focus of this alternative. This alternative would install two or three lines of multiple wells with 20 m (65 ft) spacing approximately parallel to the Columbia River. Figure 6-2 illustrates a hypothetical configuration of injection wells for a linear in-situ treatment barrier.

##### *Rationale*

Place autunite and apatite within the aquifer downgradient of source areas to provide immediate stabilization and longer-term treatment of a large proportion of dissolved uranium groundwater contamination. The objective of this alternative is to form a reactive barrier to intercept and stabilize dissolved uranium flowing toward the Columbia River.

##### *Extent*

A linear reactive zone of apatite to be placed in the aquifer extending approximately 1,160 m (3,800 ft) from the north end of the North Process Pond, parallel to the Columbia River to the south end of the persistent plume. Alignment of the barrier is roughly along the subsurface ridge line formed by the top of the Ringold Formation. A double line of injection wells with 20-m (65-ft) spacing would require 135 wells.

The line of wells with the injection of polyphosphate would form a linear zone of interception to treat upgradient groundwater contaminated with uranium. The reactive zone of autunite and apatite would immediately, and over time, sequester and stabilize soluble uranium flowing through the reactive barrier toward the Columbia River. Deployment of this alternative would be similar to the area-wide application but would require fewer wells because the former pond and trench source areas would not be treated. Rather, groundwater uranium contamination resulting from the source releases would be treated only as the groundwater contacts the reactive barrier.

Technical emplacement of apatite along a reactive barrier may be difficult. Open-framework gravels and high groundwater flow velocities with frequent reversals of flow direction in the targeted zone may preclude successful emplacement of a continuous, effective reactive barrier. The position of the linear barrier is selected to minimize vertical coverage by using the Ringold Formation upper-surface ridge. This alignment does not intercept the eastern half of the process pond areas, thereby offering only partial coverage. Moving the alignment east, near the river shoreline, could increase the proportion of water treated but would be more difficult to construct because of its proximity to river-induced gradients.

##### *Expected Performance*

The alternative is expected to reduce uranium concentration in groundwater to meet the RAOs over the duration of the uranium source; however, this alternative focuses primarily on protection of the Columbia River, and does not accelerate restoration of the aquifer.



#### **6.4.6 Alternative 3C: Polyphosphate Application to Groundwater Along Source Area Perimeters**

This alternative consists of placing a linear reactive zone around each of the source areas using multiple well lines installed along the perimeter of each former discharge pond or trench. The procedures for application of the polyphosphate are similar to the method used for the other two polyphosphate application alternatives. Figure 6-3 illustrates a hypothetical configuration of injection wells for linear containment barriers.

##### ***Rationale***

Autunite and apatite is placed within the aquifer along the perimeter of source areas to provide immediate stabilization and longer-term treatment of dissolved uranium beneath principle sources of groundwater contamination. The objective of this alternative is to form a reactive barrier to contain the groundwater contamination to a limited aquifer volume associated with the "footprint" of the source area.

##### ***Extent***

A linear reactive zone of apatite is placed in the aquifer along the perimeters of the North Process Pond (316-2) and southern half of the adjoining 300 Area Process Trenches (316-5), along with the perimeter of the South Process Pond (316-1). A double line of injection wells with 20-m (65-ft) spacing would require 200 wells.

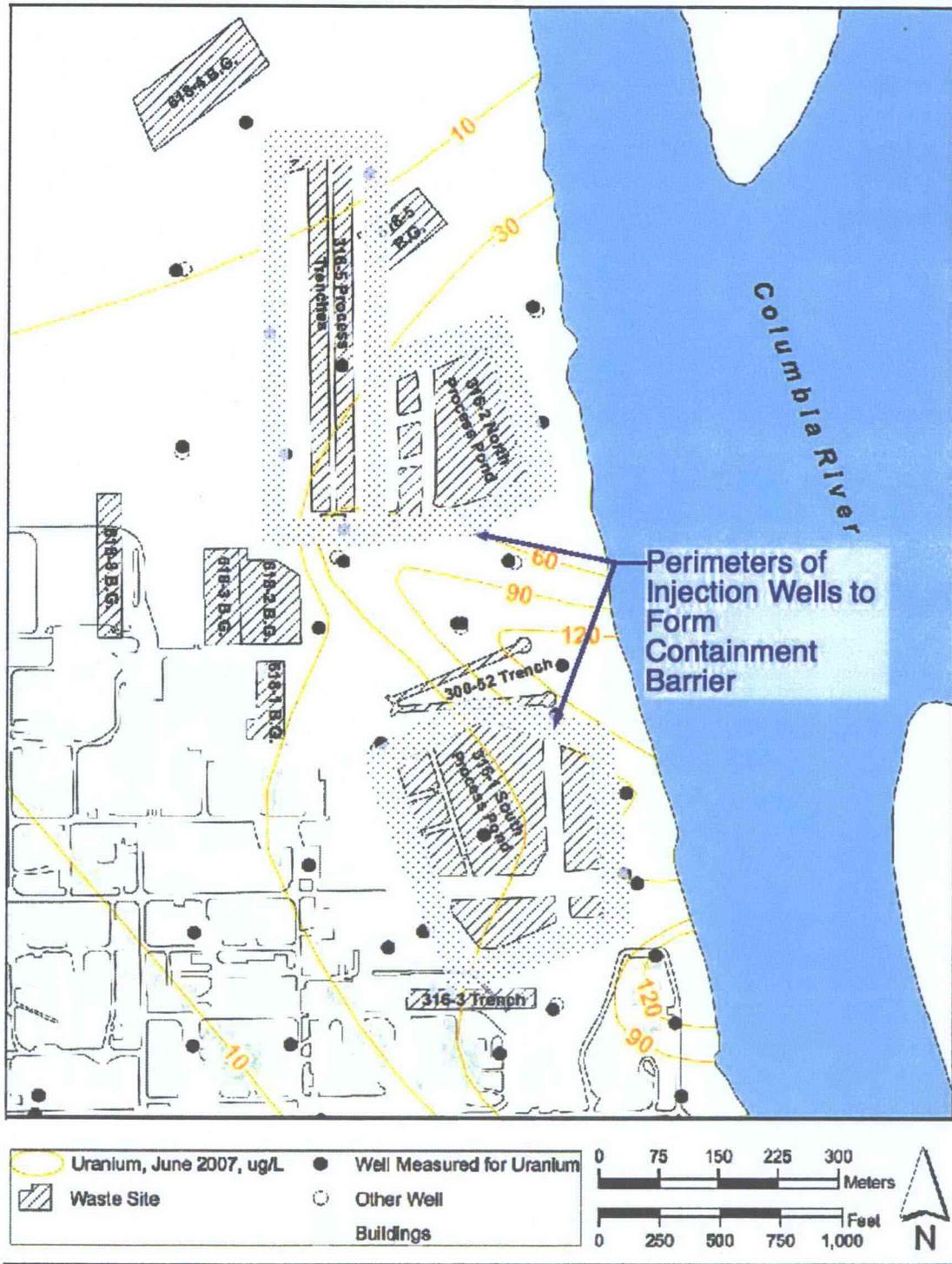
Rather than attempt to remediate all of the aquifer beneath a source area, this alternative provides the means to contain the groundwater contamination to a limited aquifer volume associated with the "footprint" of the source area. The interception scheme would minimize further contamination of the larger volume of the aquifer with fewer wells than Alternative 3A. This alternative attempts to create an in-situ reactive barrier as in Alternative 3A, but in locations for containing contamination rather than directly protecting the Columbia River and shoreline.

Technical emplacement of apatite along a reactive barrier may be difficult. The open-framework gravels and high groundwater flow velocities in the targeted zone may preclude successful emplacement of a continuous, effective reactive barrier. Repeated applications may be necessary during a variety of hydraulic gradient conditions to achieve an effective degree of containment.

##### ***Expected Performance***

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs over the duration of the uranium source.

Figure 6-3. Map of Injection Well Perimeter Lines for Phosphate Application.



#### **6.4.7 Alternative 3D: Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone**

This alternative attempts to treat the immediate source of uranium causing the persistent contamination in groundwater. Phosphate reagent solutions are applied to the ground surface to percolate through vadose zone sediments to sequester uranium above the water table, specifically focused on treating the lowermost vadose zone that is occasionally contacted by the water table. The areal extent of application will be approximately equivalent to the original disposal ponds and trenches. Tentatively, for relative cost evaluations, a modified solid-set irrigation system consisting of parallel runs of pipelines, risers, and sprinklers with reagent mixing tanks and pumps is envisioned. Make-up water would be provided from three wells on site. The sprinkler system for each waste unit would use typical agricultural irrigation equipment extensively. Figure 6-4 illustrates a conceptual design for percolation into the subsurface of phosphate reagent applied from the ground surface.

##### ***Rationale***

Form autunite within zone of fluctuating water table to provide immediate stabilization of uranium in the occasionally wetted sediment that primarily contributes to groundwater contamination.

##### ***Extent***

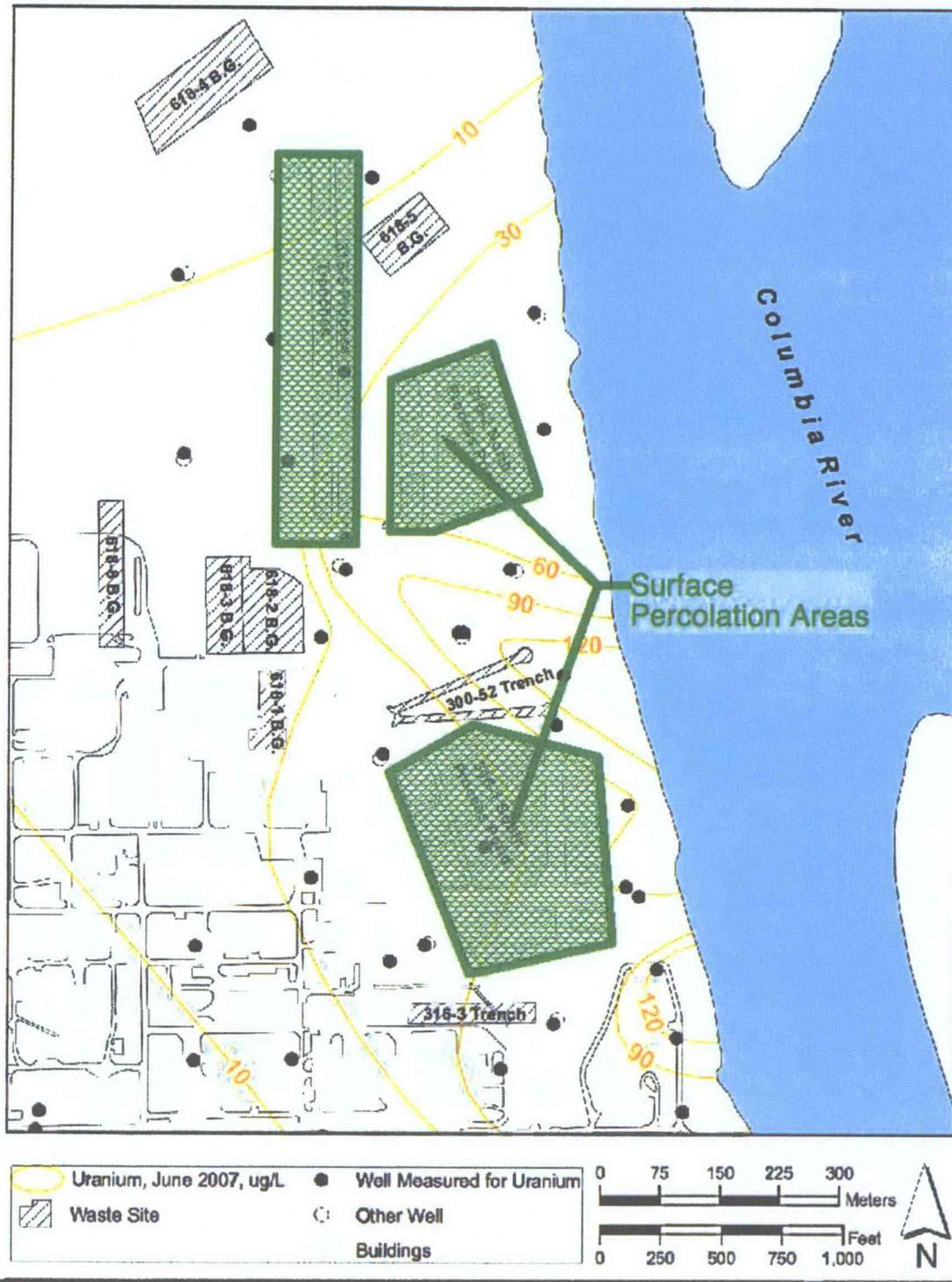
This alternative consists of a phased deployment, beginning in deep sediments near the water table beneath the North and South Process Ponds (316-2 and 316-1, respectively), and beneath the 300 Area Process Trenches (316-5). Follow-up treatment of sediments would be applied according to concentration response in groundwater. Approximately 76,000 m<sup>2</sup> (19 acres) would be treated. This area is based upon coverage of the present WIDS site boundaries for the former South Process Pond (316-1), retired filter backwash pond, North Process Pond (316-2), and the 300 Area Process Trenches (316-5).

The phosphate reagent may be formulated with polymerized compounds to delay reactions and allow depth-sequenced reaction through the percolation zone. Apatite formation with calcium is not specifically promoted. The mode of application may be ponding, furrow irrigation, or sprinkling. The timing and sequencing of the treatment is specifically focused on contacting as much of the temporarily exposed groundwater interface zone (smear zone) during the annual low of the groundwater level corresponding to reduced Columbia River levels and discharges. Particular attention to providing sufficient reagent to the smear zone will be of concern in implementing this alternative because the reagent will also be reacting in the vadose zone above the targeted smear zone.

##### ***Expected Performance***

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs by source reduction to decrease the flux of uranium into the aquifer and to shorten the duration of the groundwater plume.

Figure 6-4. Map of Application Areas for Phosphate Percolation.



#### **6.4.8 Alternative 3E: Phosphate Application by Vertical Injection Through Boreholes into Fluctuating Groundwater Interface Zone**

Phosphate reagent would be applied into vertical wells with packing or boreholes completed so as to focus reagent application into the smear zone. Apatite formation with calcium is not specifically promoted. The timing of the application would be scheduled to maximize contact with the smear zone during the seasonal groundwater fluctuation cycle. It may be possible to modify wells installed for Alternative 3A groundwater treatment within the smear zone extent with temporary vertical control packing to focus reagent into the targeted fluctuating groundwater interface zone. Figure 6-5 illustrates a conceptual design for application of phosphate reagent via wells through former disposal areas.

##### ***Rationale***

Form autunite within zone of fluctuating water table to provide immediate stabilization of uranium in the occasionally wetted sediment that primarily contributes to groundwater contamination.

##### ***Extent***

Phased deployment, beginning in deep sediments near the water table beneath the North and South Process Ponds (316-2 and 316-1, respectively) and beneath the 300 Area Process Trenches (316-5). Follow-up treatment of sediments would be applied according to concentration response in groundwater. Approximately 76,000 m<sup>2</sup> (19 acres) would be treated. This area is based upon coverage of the present WIDS site boundaries for the former South Process Pond (316-1), retired filter backwash pond, North Process Pond (316-2), and the 300 Area Process Trenches (316-5).

##### ***Expected Performance***

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs by source reduction to decrease the flux of uranium into the aquifer and to shorten the duration of the groundwater plume.

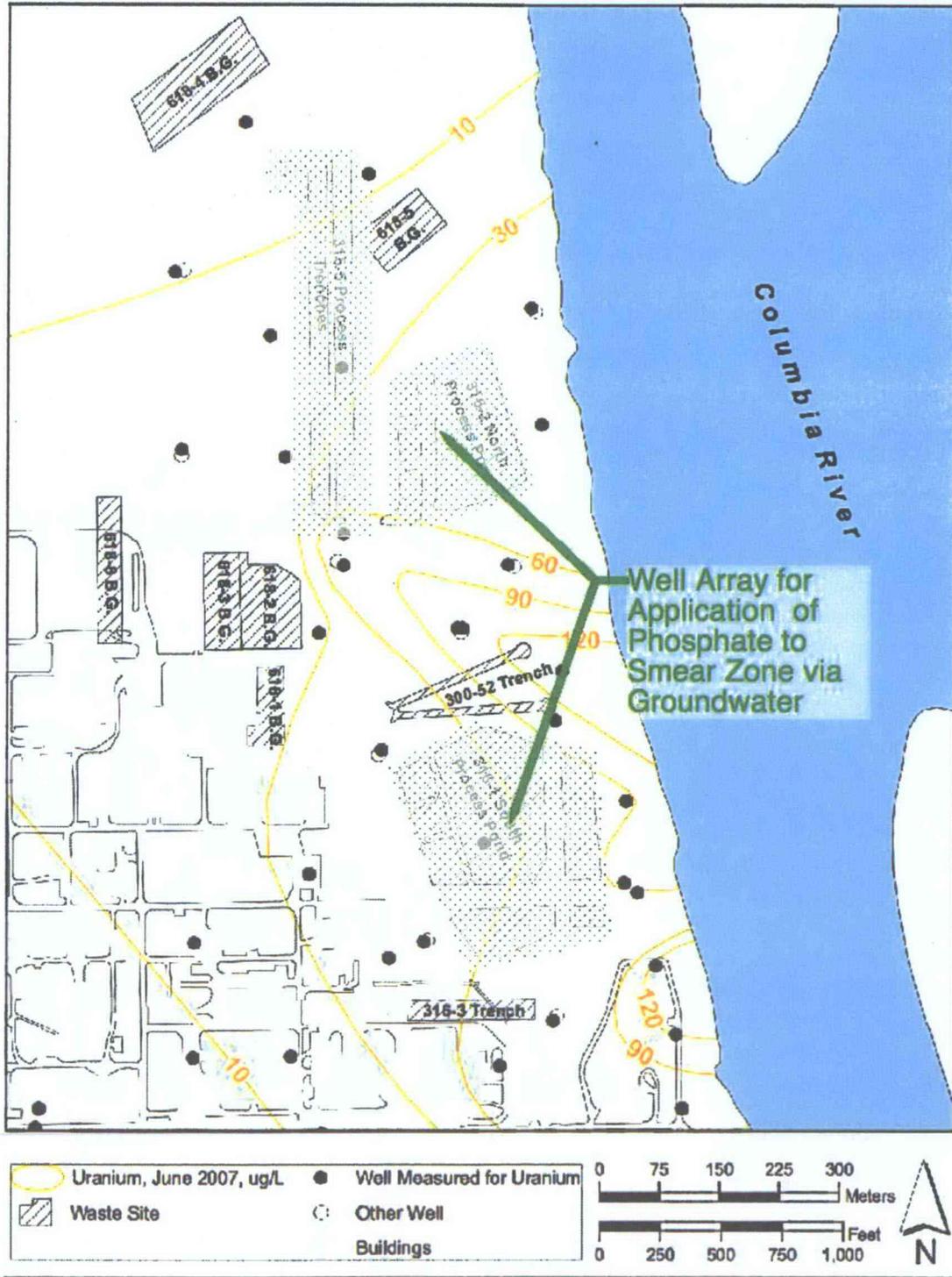
#### **6.4.9 Alternative 4: Focused Excavation and Disposal of Contaminated Sediment**

The conceptual model suggests that the greatest repository of uranium contaminating groundwater is associated with the unsaturated sediments above the water table. Approximately 80% of the uranium in the system is estimated to be stored above the groundwater in areas beneath the former uranium disposal ponds and trenches. Consequently, direct physical removal of the uranium by focused excavation of the sediment offers immediate and permanent remediation of uranium causing further groundwater contamination in the 300 Area.

Uranium is distributed primarily beneath the footprint of various multiple waste-disposal units, such as the South Process Pond (316-1), North Process Pond (316-2), and 300 Area Process Trenches (316-5). The conceptual model delineates the vadose zone uranium into two volumes. The upper zone consists of sediments that, while containing residual uranium not removed in the prior 300-FF-1 Operable Unit removal actions, are generally positioned above groundwater contact resulting from river level fluctuations. The second zone is periodically influenced by groundwater level excursion and, when wetted, is the immediate source of mobilized uranium into the aquifer. The nominal depth to groundwater in these disposal areas ranges by location between approximately 10 to 13 m (33 to 43 ft). The water

table can fluctuate as much as 2 m (6.5 ft) seasonally. Excavation to these depths is technically feasible. Excavation of sediments is somewhat challenged by the occasional presence of large rock and boulders present in the Hanford formation. Excavation in these source areas would involve conventional earthmoving equipment used in deep foundation or open-pit mining.

Figure 6-5. Map of Well Arrays for Smear Zone Treatment via Groundwater.



Such equipment includes scrapers, back hoes, drag-line shovels, and dump trucks. The upper zones of the excavation would remove uncontaminated, backfill material that was placed in previously excavated areas. This backfill was replaced when upper zones of contaminated sediments were removed as part of the 300-FF-1 Operable Unit remediation. The sidewalls of the excavations would be sloped back to prevent wall failure. Thus, the overall area of excavation will extend up to 24 to 30 m (80 to 100 ft) beyond the original surface extent of the pond or trench.

Uncontaminated overburden sediments would be sorted and stockpiled nearby. Near real-time chemical analysis of sediment would be used to control material handling. Sediment contaminated with uranium would be transported to a disposal facility, possibly the Environmental Restoration Disposal Facility (ERDF) in the 200 Area or a new disposal facility with similar containment design and permitting. Though not included within the scenario of the prototype alternative description and economic analysis, treatment of the contaminated sediment with phosphate may reduce toxicity and uranium mobility prior to disposal.

Excavation and disposal of contaminated sediments is more invasive and labor intensive than the in-situ phosphate treatment options. It does offer the greatest amount of remediation because it physically removes and with appropriate disposal, completely precludes future risk of groundwater contamination. Significant fugitive dust control measures would be required. The cost for conducting such removal activity would likely focus such work to specific, pre-delineated areas where one-time activity would be justified. Follow-up excavation would not likely be feasible as might be with in-situ treatment alternatives. If post-remediation development of the property were to correspond with the location of excavated areas, excavation costs could be partially shared with the development project.

Excavation of contaminated sediment above the unwetted groundwater interface or "smear zone" will not require special handling. The initial uncontaminated soil fill would be screened analytically and temporarily stockpiled nearby. Contaminated sediment would be transported to the ERDF or similar engineered disposal facility. Wet soil in the groundwater interface zone would require special handling, and possibly dewatering and drying in an intermediate process prior to transport and disposal. The dewatering process will incur significant expense. Because excavation and earthmoving equipment have high operating costs, rapid backfill with uncontaminated soil is desired to minimize embankment failure in excavations subject to groundwater accumulation. Dry-season climate conditions will be used to facilitate sediment dewatering.

Phosphate reagents could be selectively applied to unexcavated sediments at the bottom of excavations for the purpose of stabilizing unexcavated uranium contamination on sediments in proximity to the water table.

Implementation of this alternative would consist of selective excavation of vadose zone sediments, including removal of contaminated sediments periodically contacted by rising groundwater during high river stage. Such sediment will typically have high soil-moisture content that may require dewatering or drying prior to permanent disposal. Dry sediments would be directly transported to the disposal facility following characterization. Uncontaminated sediments would be redeposited as backfill. New, uncontaminated soil would be imported and used to fill the remaining excavation to surface grade. The backfill may be engineered to reduce future infiltration potential by clay or synthetic layer placement or phosphate addition to backfill may be implemented.

***Rationale***

Remove contaminated sediment within zone of fluctuating water table and above to prevent future mobilization of uranium into groundwater.

***Extent***

Excavate to reach wetted sediment depths during periods of low water. Excavate beneath the North and South Process Ponds (316-2 and 316-1, respectively) and beneath the 300 Area Process Trenches (316-5). Approximately 69,243 m<sup>2</sup> (17 acres) would be treated. This area is based upon coverage of the present WIDS site boundaries for the former South Process Pond (316-1), retired filter backwash pond, North Process Pond (316-2), and the southern half of the 300 Area Process Trenches (316-5).

***Expected Performance***

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs by source reduction to decrease the flux of uranium into the aquifer and shorten the duration of the groundwater plume.

**6.4.10 Alternative 5: Extensive Excavation and Disposal of Contaminated Sediment**

The conceptual model indicates the greatest repository of uranium contaminating groundwater is associated with the unsaturated sediments above the water table. Over 90% of the uranium in the system is estimated to be stored above the groundwater. Preliminary sediment characterization results suggest uranium residuals extend in sediments beyond the "footprints" of the original waste-disposal units, within a zone influenced by excursion of the water table over annual and diurnal periods. Consequently, direct physical removal of the uranium by excavation of the sediment offers increased certitude of immediate and permanent remediation of uranium causing further groundwater contamination in the 300 Area.

The nominal depth to groundwater across the 300 Area ranges by location between approximately 10 to 13 m (33 to 43 ft). The water table can fluctuate as much as 2 m (6.5 ft) seasonally. Excavation to these depths is technically feasible; however, it is very large scale. Such excavation is somewhat challenged by the occasional presence of large rock and boulders present in the Hanford formation. Excavation would involve conventional earthmoving equipment used in deep foundation or open-pit mining. This equipment includes scrapers, back hoes, drag-line shovels, and dump trucks. The upper zones of the excavation would remove uncontaminated and backfill material that was placed in previously excavated areas. Excavation would be staged to minimize impacts to the Columbia River. Contaminated sediment would be analytically identified and trucked to treatment and/or disposal facilities at the Hanford Site. Though not included within the scenario of the prototype alternative description and economic analysis, treatment of the contaminated sediment with phosphate may reduce toxicity and uranium mobility prior to disposal. Significant volumes of uncontaminated overburden sediment from areas outside of the source ponds and trenches would be generated. This material would be used as backfill. The sidewalls of the excavations would be sloped back to prevent wall failure. Thus, the overall area of excavation will extend up to hundreds of feet beyond the excavation bottom.

The focused excavations of the Alternative 4 scenario are limited to the sediments immediately below the known former uranium disposal units. Alternative 5 consists of extensive excavation of vadose zone sediments throughout the 300 Area. Excavation would involve two excavation strategies:

- Removal of sediments beneath the former disposal ponds and/or trenches that have higher concentrations or more mobile residuals of uranium and thereby pose the greater threat to contaminating groundwater
- Removal of the relatively thin zone of sediment affected by fluctuations of the water table outside the vicinity of the ponds and trenches, thereby also removing lower vadose zone sediments.

Excavation into the lower vadose zone will include removal of contaminated sediments that are periodically contacted by rising groundwater during high river stage. Such sediment will typically have high soil-moisture content that may require dewatering or drying prior to permanent disposal or treatment. Treatment may involve application of phosphate reagent to stabilize uranium.

This prototype remediation alternative is a maximum active effort and is considered to define the high end of potential scope for the remediation strategy evaluation.

#### ***Rationale***

Remove most of the contaminated vadose zone sediment above zone of fluctuating water table to reduce likelihood of future mobilization of uranium into groundwater.

#### ***Extent***

Excavate to reach wetted sediment depths during periods of low water. Excavate most of the 300 Area to remove most of the sediment contaminated with uranium. As much as approximately 500,000 m<sup>2</sup> (123 acres) would be excavated. This area is based upon the approximate lateral extent of the groundwater plume exceeding drinking water standards for uranium (Peterson et al. 2008). The extent may be modified based upon characterization or studies that may indicate attainment of clean-up criteria for alternate excavation geometries.

#### ***Expected Performance***

This alternative is expected to reduce uranium concentration in groundwater to meet the RAOs by source reduction to decrease the flux of uranium into the aquifer and to shorten the duration of the groundwater plume.

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## 7.0 PRELIMINARY SCREENING OF PROTOTYPE ALTERNATIVES

The preliminary screening evaluation of the prototype remediation alternatives was conducted based upon a conceptual design for implementing each alternative. Each conceptual design is based upon the location, extent, depth and approximated distribution of the targeted uranium contamination mapped based upon characterization conducted as of May 2008. The known extent of historical surface source areas is used to define the outer limits of vadose zone remediation units. The geometry and location of each remediation scenario assumes deployment to the presently mapped extent of the original waste-disposal areas. The assumptions of targeted treatment area/volume are presented and mapped in the description of each prototype alternative, consistent with the discussion in Section 6.0.

Utilizing these preliminary parameters, a scenario for deployment of each alternative is developed. Each scenario assumes reagent quantities that are high-end estimates based upon the present preliminary understanding of the underlying technology. Because current understanding of the in-situ treatment technologies is not well developed, the assumptions of numbers, spacing, and quantities of deployment infrastructure and reagents are preliminary and only indicative of remediation alternative descriptions that will be formulated in the future feasibility study when more information is available.

### 7.1 CRITERIA FOR PRELIMINARY SCREEN

Each prototype alternative was screened according to the preliminary screening criteria consisting of effectiveness, implementability, and relative cost. These screening categories are prescribed by the CERCLA feasibility study-screening process defined in EPA guidance (EPA 1988a). Generally, the effectiveness evaluation is related to the following:

1. estimated reliability of the process and whether it has been proven successful
2. expected ability of the method to treat the necessary volume of contaminated media
3. ability to be constructed and operated without negative human or environmental impacts.

Implementability is generally related to 1) the scale of effort and technical certainty that the method can be implemented at the site; 2) the availability of consumables, equipment, and services; and 3) the ability to obtain permits and administratively manage the method. The relative cost is generally evaluated using the preliminary conceptual design and relative cost estimates based on the relative capital and operation and maintenance required for each option. The specific evaluation criteria for each of these screening categories are listed in Table 7-1. Remediation alternatives were ranked according to the comparative assessment of implementability, effectiveness, and relative cost.

This preliminary screening is the prelude to the detailed development and screening of remediation alternatives. Within the future feasibility study when sufficient information is available to define detailed alternatives, each of the alternatives will be analyzed using nine evaluation criteria. The seven evaluation criteria are divided into three groups based upon the function of the criteria in remedy selection. The threshold criteria relate to statutory requirements that each alternative must satisfy in order to be eligible for selection and include:

- overall protection of human health and the environment
- compliance with applicable or relevant and appropriate requirements (ARARs)

The primary balancing criteria are the technical criteria upon which the detailed analysis will be primarily based and include:

- long-term effectiveness and permanence
- reduction of toxicity, mobility, or volume through treatment
- short-term effectiveness
- implementability
- cost.

The third group is made up of the modifying criteria and includes:

- state/support agency acceptance
- community acceptance.

The last two criteria are associated formally after the public comment period. Although to the extent they are known or anticipated, they will be factored into the identification of the preferred alternative of the future feasibility study.

Table 7-1. Expanded Screening Evaluation Criteria for Prototype Alternatives.

Effectiveness	Implementability	Relative Cost
<ul style="list-style-type: none"> <li>• Is the alternative able to reliably decrease the potential for uranium to further contaminate groundwater (quantity or mobility)?</li> <li>• Does the alternative offer a permanent reduction of uranium concentration in groundwater?</li> <li>• Does the alternative produce no hazardous products unless these are readily remediated or attenuated?</li> <li>• Does the alternative negatively impact the remediation of other COC to the extent that the remediation objectives could not be met for the other COC?</li> <li>• Does the alternative cause significant human risk during construction or operation?</li> <li>• Does the alternative cause significant environmental risk during construction or operation?</li> <li>• Does the alternative have a high technical certainty in estimated performance?</li> </ul>	<ul style="list-style-type: none"> <li>• Does the alternative have a high technical certainty of being reliably constructed and operated?</li> <li>• Are the engineering constraints and requirements able to be addressed using present state-of-the-art practices?</li> <li>• Is the alternative acceptable to regulators and stakeholders?</li> </ul>	<ul style="list-style-type: none"> <li>• Based on scoping calculations defining the scale of infrastructure and consumables, are the relative costs for capital and operation/maintenance expected to be grossly higher than for other alternatives with similar effectiveness and implementability?</li> </ul>
COC = Contaminant of concern.		
Reference: U.S. Environmental Protection Agency – OSWER Directive 9355.3-01FS3, November 1989		

## 7.2 METHOD OF PRELIMINARY SCREENING

Each of the prototype remediation alternatives defined in Section 6.0 are evaluated using a relative ranking protocol. This ranking protocol orders or ranks each alternative according to each of the qualities listed in Table 7-1. For each of the three preliminary screening criteria, subcategories associated with each of the criteria were used to rank the alternatives.

The ranking, except for cost, consisted of placing a numerical (ordinal) score between 1 and 5, where 5 was judged highest in fulfilling a criteria subcategory, and 1 was least compliant with a subcategory. This *ordinal* scale, or number system, is a relative estimate and not an absolute quantity. It is a qualitative judgment based on subjective analysis, and not a quantification judgment based on numerical analysis. This use of an ordinal scale allows the researcher to only distinguish one alternative from another, and to arrange them in rank or order. However, the ordinal scale can only distinguish—*not quantify*—the differences between the alternatives being ranked.

If more specific site and technological implementation information were available, a more *quantitative* scoring could be conducted on more definite, engineered designs, as typically applied in conventional feasibility studies. This remediation strategy evaluation uses the categories of a preliminary screen according to CERCLA guidance. However, because of the limited site knowledge and developmental immaturity of uranium stabilization technologies, only relative ranking using ordinal scales is used. No attempt is made to conduct detailed screening of remediation alternatives passing the preliminary screen using the seven evaluation criteria, nor explicitly identifies tradeoffs between alternatives as is done in a CERCLA feasibility study.

Table 7-2 tabulates the relative ranking of nine prototype remediation alternatives for each of the subcategories. Seven subcategories are used to rank effectiveness and three subcategories are used for implementability. Relative cost ranking was conducted in terms of estimated present value for the life cycle cost of each prototype alternative.

### 7.2.1 Cost Estimating Procedure

The present value estimation is developed using procedures proscribed by the EPA in *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 2000b), and the screening process described in the “National Oil and Hazardous Contingency Plan”(40 CFR 300.430(e)(7)(iii)).

In this remediation strategy study, the design for the remedy alternatives are pre-conceptual, without definitive and specific quantification, and the cost estimate is considered to be “order of magnitude.” Preliminary cost estimates for the deployment and operation of each remedial alternative are made but should be sufficient to compare among the alternatives. This “life cycle cost” evaluation refers to the total project cost across the life span of the project, including design, construction, operation and maintenance and closeout activities. Specific cost evaluations for each of the prototype alternatives are presented in Appendix A.

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

	1	2	3A	3B	3C	3D	3E	4	5
	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
Mean Rank- Effectiveness and Implementability ONLY	2.7	2.9	3.4	2.8	3.2	4.0	3.5	3.7	2.7
Composite of Three Criteria	2.5	2.6	2.9	2.8	2.8	3.7	3.0	2.8	2.2
Effectiveness	1.7	1.7	3.4	2.9	3.0	4.0	3.6	3.4	3.1
Reduction of Potential for U to further contaminate groundwater (quantity or mobility) [Rank is proportional to reduction]	Sub-rank - 1 No active action	Sub-rank - 1 No active action	Sub-rank - 3 Little direct treatment of source sediment. Treats groundwater as contaminated to extent that apatite is employed.	Sub-rank - 2 Little direct treatment of source sediment. Intercepts groundwater contamination.	Sub-rank - 2 Little direct treatment of source sediment. Intercepts groundwater contamination.	Sub-rank - 4 Direct treatment of source sediment, to the extent that phosphate stabilizes uranium.	Sub-rank - 3 Direct treatment of source sediment, to the extent that phosphate stabilizes uranium. Capability controlled and limited by water table excursion at time of phosphate application.	Sub-rank - 4 Direct removal of source sediment, to the extent that excavation removes uranium contributing to groundwater contamination.	Sub-rank - 5 Comprehensive removal of source sediment removes uranium contributing to groundwater contamination.

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

	1	2	3A	3B	3C	3D	3E	4	5
	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
<i>Permanent Reduction in GW Concentration [Highest rank has greatest reduction of uranium concentration.]</i>	Sub-rank - 1 No active action	Sub-rank - 1 No active action	Sub-rank - 3 Little direct treatment of source sediment. Long-term groundwater treatment remains to extent that apatite is replaced and remains in aquifer.	Sub-rank - 2 Little direct treatment of source sediment. Extended treatment limited by quantity of apatite employed. Specific location of reactive barrier does not treat larger upgradient areas of groundwater contamination.	Sub-rank - 3 Little direct treatment of source sediment. Extended treatment of groundwater limited by quantity of apatite employed.	Sub-rank - 4 Direct treatment of source sediment, to the extent that phosphate stabilizes uranium. Permanence of reduction in groundwater depends upon degree treated areas contribute to long term contamination.	Sub-rank - 3 Direct treatment of source sediment, to the extent that phosphate stabilizes uranium. Permanence controlled by efficacy of application to all of sources.	Sub-rank - 4 Direct removal of source sediment, permanently reduces concentration in ground water to the extent that ongoing uranium release is removed.	Sub-rank - 5 Direct removal of source sediment, permanently reduces concentration in groundwater.
<i>Resulting hazardous waste products [Highest rank has least waste.]</i>	Sub-rank - 1 No active action: no waste generated but existing uranium deposits continue to contaminate groundwater.	Sub-rank - 1 No active action: no waste generated but existing uranium deposits continue to contaminate groundwater.	Sub-rank - 4 Short-term risk of unreacted phosphate reagent forming a low hazard intermediate by-product. Half-life in dynamic aquifer would be very short term.	Sub-rank - 4 Short-term risk of unreacted phosphate reagent forming a low hazard intermediate by-product. Half-life in dynamic aquifer would be very short term.	Sub-rank - 4 Short-term risk of unreacted phosphate reagent forming a low hazard intermediate by-product. Half-life in dynamic aquifer would be very short term.	Sub-rank - 5 Phosphate reagent retention in sediments would be minimal with relatively rapid reaction. Minimal hazardous waste product to the extent that uranium is stabilized.	Sub-rank - 4 Short-term risk of unreacted phosphate reagent forming a low hazard intermediate by-product. Half-life in dynamic aquifer would be very short term.	Sub-rank - 2 Removal produces large volumes of uranium sediment "waste" that must be carefully disposed. Supplemental ex-situ stabilization of uranium with phosphate would reduce hazard of	Sub-rank - 1 Removal produces very large volumes of uranium sediment "waste" that must be carefully disposed. Supplemental ex-situ stabilization of uranium with phosphate would reduce hazard of

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

	1	2	3A	3B	3C	3D	3E	4	5
	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
								disposed sediment.	disposed sediment. Large quantity of non-hazardous material requires disposal.
<i>Negative impacts on remediation of other COCs [5 is least negative impact]</i>	Sub-rank - 3 No active action therefore no effect, positive or negative, on remediation of other COCs.	Sub-rank - 3 No active action therefore no effect, positive or negative, on remediation of other COCs.	Sub-rank - 4 Short term decrease in pH 7.5 to 6.0 may be caused by microbial activity that could stimulate biodegradation of VOCs.	Sub-rank - 3 Injection of phosphate along linear zone is unlikely to affect other COCs.	Sub-rank - 4 Short term decrease in pH 7.5 to 6.0 may be caused by microbial activity that could stimulate biodegradation of VOCs.	Sub-rank - 4 Any excess phosphate entering groundwater could promote short term microbial activity that could stimulate biodegradation of VOCs.	Sub-rank - 4 Any excess phosphate entering groundwater could promote short term microbial activity that could stimulate biodegradation of VOCs.	Sub-rank - 3 Excavation depth unlikely to affect other COCs.	Sub-rank - 2 Reducing proximity to river could affect other COCs.
<i>Human Risk during Implementation [Ranking is inverse to risk. 5 is least risk]</i>	Sub-rank - 3 No active action, therefore moderately low on going toxicological risk to humans from uranium persists. (See 2007 Risk Assessment)	Sub-rank - 3 No active action, therefore moderately low on-going toxicological risk to humans from uranium persists. (See 2007 Risk Assessment)	Sub-rank - 4 In-situ process minimizes health risk. Some occupational risk due to extensive well construction.	Sub-rank - 4 In-situ process minimizes health risk. Some occupational risk due to well construction.	Sub-rank - 4 In-situ process minimizes health risk. Some occupational risk due to well construction.	Sub-rank - 4 In-situ process minimizes health risk. Moderate short-term occupational risk due to surface application of reagents.	Sub-rank - 4 In-situ process minimizes health risk. Some occupational risk due to extensive well construction.	Sub-rank - 3 Moderate occupational risk during excavation and disposal. Fugitive dust hazard during excavation.	Sub-rank - 3 Moderate occupational risk during excavation and disposal. Fugitive dust hazard during excavation.

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

	1	2	3A	3B	3C	3D	3E	4	5
<i>Environmental Risk during Implementation [Highest rank has least risk.]</i>	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
	Sub-rank - 2 No active action, therefore continued low risk to river ecology from uranium flux through groundwater. (See 2007 Risk Assessment)	Sub-rank - 2 No active action, therefore continued low risk to river ecology from uranium flux through groundwater. (See 2007 Risk Assessment)	Sub-rank - 3 In-situ process minimizes environmental risk. Slight possibility of short-term eutrophication or microbial blooms at river shore.	Sub-rank - 2 In-situ process minimizes environmental risk. Slight possibility of short-term eutrophication or microbial blooms at river shore.	Sub-rank - 3 In-situ process minimizes environmental risk. Slight possibility of short-term eutrophication or microbial blooms at river shore.	Sub-rank - 3 In-situ process minimizes environmental risk. Some possibility of short-term reagent exposure to reagents to fowl.	Sub-rank - 4 In-situ process minimizes environmental risk. Minimal possibility of short-term reagent exposure at surface.	Sub-rank - 4 Some exposure and traffic risk during excavation and disposal. Fugitive dust hazard during excavation.	Sub-rank - 1 Significant acute risk of sediment and suspended solids release to river. Fugitive dust hazard during excavation.
<i>Technical Certainty in Estimated Performance [Highest rank is most certain.]</i>	Sub-rank - 1 No active action, therefore continuation of long-term natural processes that are not well understood.	Sub-rank - 1 No active action, therefore continuation of long-term natural processes that are not well understood.	Sub-rank - 3 High velocity and highly variable groundwater flows affect performance.	Sub-rank - 3 High velocity and highly variable groundwater flows adversely affect performance.	Sub-rank - 2 High velocity and highly variable groundwater flows adversely affect performance.	Sub-rank - 4 Bulk area percolation behavior is relatively predictable.	Sub-rank - 3 Wide area application via fluctuating water table subject to water table variations.	Sub-rank - 4 Excavation and removal certain but subject to unknown, unexcavated residuals.	Sub-rank - 5 Excavation and removal relatively certain.

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

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	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
<b>Implementability</b>	3.7	4.0	3.3	2.7	3.3	4.0	3.3	4.0	2.3
<i>Technical feasibility at required scale [Highest rank is most feasible].</i>	Sub-rank - 5 No active action, therefore no technical feasibility constraints.	Sub-rank - 5 No active action, therefore no technical feasibility constraints.	Sub-rank - 3 Large area of multiple injection wells feasible, but large scale application over wide area has no precedent.	Sub-rank - 3 Linear array of multiple injection wells feasible, but subsurface discontinuities may inhibit uniform reactive zone.	Sub-rank - 3 Linear array of multiple injection wells feasible, but subsurface discontinuities may inhibit uniform reactive zone.	Sub-rank - 4 Large area percolation proven and feasible. But capability to apply reagent uniformly in targeted zone constrained by subsurface heterogeneities.	Sub-rank - 3 Linear array of multiple injection wells feasible, but uniform vertical and lateral reagent spread difficult.	Sub-rank - 5 Large area excavation proven and feasible. Moisture control near water table using proven techniques.	Sub-rank - 4 Large area excavation proven and feasible. Moisture control near water table using proven techniques; however, sediment control at river is problematic.
<i>Engineering Implementation Capability Presently Available [Highest rank is most implementable.]</i>	Sub-rank - 5 No active action, therefore no engineering feasibility constraints.	Sub-rank - 5 No active action, therefore no engineering feasibility constraints.	Sub-rank - 3 Unproven engineering challenge to injection of reagent through vertical wells and chemical application not fully defined.	Sub-rank - 2 Unproven engineering challenge to injection of reagent through vertical wells and chemical application not fully defined. Proper placement of reactive barrier problematic.	Sub-rank - 3 Unproven engineering challenge to injection of reagent through vertical wells and chemical application not fully defined.	Sub-rank - 4 Minimal engineering challenge to percolation of reagent, but chemical formulation and application protocol not fully defined.	Sub-rank - 3 Moderate engineering challenge to properly locate vertical wells, also chemical formulation not fully defined.	Sub-rank - 3 Moderate engineering challenge to design dewatering and dust control systems.	Sub-rank - 2 Significant engineering challenge to design river sediment control systems.

Table 7-2. Relative Ranking of Prototype Alternatives. (6 sheets)

	1	2	3A	3B	3C	3D	3E	4	5
	No Action	Monitored Natural Attenuation	Polyphosphate Application to Groundwater Beneath Original Source Areas	Polyphosphate Application to Groundwater to Form Reactive Barrier Parallel to River	Polyphosphate Application to Groundwater along Source Area Perimeters	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone	Focused Excavation and Disposal of Contaminated Sediment	Extensive Excavation and Disposal of Contaminated Sediment
	Sub-rank - 1 No active action is not politically nor administratively acceptable.	Sub-rank - 2 Combined with appropriate active source control, natural attenuation is administratively acceptable, but will likely cause public controversy.	Sub-rank - 4 Injection of chemical to groundwater will require regulatory review. Publicly acceptable if uranium stabilization with minimal side-effects are demonstrated.	Sub-rank - 3 Injection of chemical to groundwater will require regulatory review. Protects River but does not restore groundwater. Publicly acceptable if uranium stabilization with minimal side-effects are demonstrated.	Sub-rank - 4 Injection of chemical to groundwater will require regulatory review. Publicly acceptable if uranium stabilization with minimal side-effects are demonstrated.	Sub-rank - 4 Injection of chemical to groundwater will require regulatory review. Publicly acceptable if uranium stabilization with minimal side-effects are demonstrated.	Sub-rank - 4 Injection of chemical to groundwater will require regulatory review. Publicly acceptable if uranium stabilization with minimal side-effects are demonstrated.	Sub-rank - 3 Possible regulatory and public concerns about mobilization of uranium fines to nearby river during excavation will require amelioration.	Sub-rank - 1 Significant regulatory and public concerns about impact to Columbia River.
<b>Relative Cost</b>	5	5	2	3	2	3	2	1	1
<i>Capital Cost</i>	0	\$-	\$28,500,000	\$16,000,000	\$30,400,000	\$19,200,000	\$34,400,000	\$209,000,000	\$608,000,000
<i>Operation &amp; Maintenance Cost</i>	\$	\$21,900,000	\$5,300,000	\$4,700,000	\$3,900,000	\$5,000,000	\$6,200,000	\$4,000,000	\$2,700,000
<b>Total Present Value Cost</b>	\$9,100,000	\$9,200,000	\$32,700,000	\$19,800,000	\$33,700,000	\$23,200,000	\$39,100,000	\$212,000,000	\$609,000,000
<b>PV Cost Ratio Relative to lowest-cost alternative</b>	1	1.0	3.6	2.2	3.7	2.5	4.3	23.3	66.9

Cost estimates developed during this screening analysis have an accuracy range of -50 to +300 percent. The screening level cost estimates focus on relative accuracy and consistency to make comparative estimates so that ranking between alternatives can be made. Consequently, the formulation and scope of the prototype alternatives are based on the current assumption that addressing uranium inventory associated with the "footprints" of the original uranium disposal areas will sufficiently mitigate uranium contamination to achieve cleanup criteria. The pre-conceptual designs for the prototype alternatives assume a scenario of maximum area, maximum depth, and high-end deployment difficulty given present estimates of extent of contamination.

The cost analysis has several components:

- capital cost
- annual operation and maintenance costs
- periodic costs
- present-value analysis.

#### **7.2.1.1 Capital Costs**

Capital costs are expenditures required to construct a remedial action; they are exclusive of costs required to operate or maintain the action throughout its lifetime. Capital costs were developed from multiple sources. References used include *Environmental Remediation Cost Data-Unit Price: 2005* (Means 2005), a compilation of environmental restoration cost information assembled by ECHOS and RS Means Company and vendor quotations. Cost estimates were adjusted to April 2008 prices using economic indicators published in *Chemical Engineering*.

#### **7.2.1.2 Annual Operation and Maintenance Costs**

The elements listed as operation and management (O&M) activities are incurred as part of the physical operation and maintenance activities. Contingency covers unknowns or unanticipated conditions. Cost associated with groundwater level monitoring, sampling, and chemical analysis are based upon present monitoring costs estimated by PNNL. The cost of chemicals is based upon estimated consumption rates and April 2008 market prices.

#### **7.2.1.3 Periodic Costs**

Periodic costs include expenses that occur at frequencies greater than annually. Equipment replacement or rejuvenation costs and technical costs associated with producing 5-year reports, as well as site closure and equipment dismantling costs, are listed in this category. Estimates are derived from costs provided as RS Means, as well as previous well closure costs in DOE projects.

#### **7.2.1.4 Present Value Analysis**

Remedial action projects typically involve construction costs that are expended at the beginning of the project (e.g., capital costs) and costs in subsequent years that are required to implement and maintain the remedy after the initial construction period (e.g., annual O&M, periodic costs). Present value analysis is an economic metric to evaluate expenditures over differing intervals and periods of time. This standard

methodology allows for cost comparisons on the basis of a single cost expression for each alternative. This single number, referred to as the present value, is the amount of money that needs to be reserved at the initial point in time (base year) to assure that funds will be available in the future as they are needed, assuming certain economic conditions.

The determination of present value requires three inputs:

- period of analysis
- cash outflows for each year of the project
- discount rate.

#### **7.2.1.5 Period of Analysis**

The period of analysis is the duration of the remedial action from the base year of 2008 to the final closing and dismantling of the equipment used for the alternative.

Because some alternatives have life times greater than 20 years, in accordance with *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 2000b), the analyses include a “no discounting” scenario. A non-discounted, constant-dollar cash flow over time demonstrates the impact of a discount rate on the total present value cost and the relative amounts of future annual expenditures. Non-discounted constant-dollar costs are presented for comparison purposes, but are not used in the relative ranking process.

#### **7.2.1.6 Cash Outflows**

The cash outflows for each year of the alternative is determined from an engineering assessment of capital cash outlay, annual O&M costs, and periodic costs over the operating duration of the remedial action. For feasibility study present value analysis, capital costs are assumed to occur in year 0.

#### **7.2.1.7 Discount Rate**

A discount rate was selected for the present value analysis in accordance with EPA policy (EPA 2000b). The discount rate selected for the present value analyses in this study is 2.8% for return periods 20 years or greater as specified in Appendix C (revised January 2008) of OMB Circular No. A-94 (OMB 1992).

### **7.3 RESULTS OF PRELIMINARY SCREEN**

The ranking and rationale for the ranking from best to least of the prototype alternatives considering effectiveness and implementability, but excluding relative cost, is presented on Table 7-3. When relative cost is added to the consideration, the two passive alternatives, no action and monitored natural attenuation, have very low costs relative to all of the active remedies. Consequently, although they have low ranking in terms of effectiveness and implementability, the relatively minimal cost of the passive alternatives tend to skew the combined ranking. Therefore, combined ranking of only the active prototype alternatives is considered to be useful in this study. The summary ranking from best to least for the prototype alternatives according to the combined criteria of effectiveness, implementability, and relative cost is listed in Table 7-4.

Table 7-3. Summary Ranking of All Prototype Alternatives Using Effectiveness and Implementability.  
(best at the top)

1	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone
2	Focused Excavation and Disposal of Contaminated Sediment
3	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone
4	Polyphosphate Application to Groundwater Beneath Original Source Areas
5	Polyphosphate Application to Groundwater along Source Area Perimeters
6	Monitored Natural Attenuation
7	Polyphosphate Application to Groundwater to Form Linear Reactive Barrier Parallel to River <i>Tied for Lowest Ranking</i>
8	No Action
8	Extensive Excavation and Disposal of Contaminated Sediment

Table 7-4. Summary Ranking of Active Prototype Alternatives Using Effectiveness, Implementability and Relative Cost.

1	Phosphate Application by Percolation into Fluctuating Groundwater Interface Zone
2	Phosphate Application by Vertical Bore Holes into Fluctuating Groundwater Interface Zone
3	Polyphosphate Application to Groundwater Beneath Original Source Areas <i>Next Three Rank Similarly</i>
4	Polyphosphate Application to Groundwater to Form Linear Reactive Barrier Parallel to River
4	Focused Excavation and Disposal of Contaminated Sediment
4	Polyphosphate Application to Groundwater along Source Area Perimeters <i>Significantly Lowest Rank</i>
5	Extensive Excavation and Disposal of Contaminated Sediment

## 7.4 DISCUSSION

The preceding is a preliminary screen on prototype alternatives. The relative ranking process employed is useful in assessing the ongoing process of developing a remediation strategy for addressing uranium-contaminated groundwater in the 300 Area. However, its value is constrained by the limitations of the present site characterization, and the promising but nascent state of uranium treatment technology using phosphate.

The present understanding of uranium contamination beneath the 300 Area places the preponderance of the contamination in the sediments above the groundwater. The conceptual model postulates that fluctuations in the water table provide an ongoing resupply of uranium to the aquifer. The preliminary screening indicates treatment of the uranium source area is preferred compared to groundwater treatment. Treating the source has the advantage of reducing uranium concentrations in the groundwater and shortening the remediation timeframe. Groundwater treatment does not shorten the remediation timeframe, propagating multiple disadvantages. Thus, efforts to refine the location of the source and test methods for effectively implementing remediation in the smear zone are critical for developing an effective remediation approach.

In the present conceptual model, researchers assume the groundwater interface zone directly beneath the original discharge ponds and trenches (i.e., within the "footprints") are sources of the groundwater

contamination. Consequently, the active prototype alternatives considered here generally intend to address the limited, focused control volumes associated with the "footprints." Some recent, limited characterization information suggests secondary contamination sources extend laterally beyond the "footprints." Whether such lateral spread significantly affects the groundwater is unknown. If true, the prototype treatment alternatives would only partially address the source of the groundwater contamination. Further characterization and/or possibly subsequent phased follow-up treatment of extended areas of the fluctuating groundwater interface zone will be necessary to support the detailed feasibility study.

Essentially, the set of active treatment actions consist of two strategies: chemically stabilize uranium with a form of phosphate, or physically remove the source of the uranium on sediments above the water table. Both courses of action have fundamental advantages and disadvantages.

The chemical stabilization approach has the advantages of appearing to be an order of magnitude less costly than excavation, and having the flexibility to possibly treat lateral contamination outside the contaminant source "footprint." However, the delivery technology for chemical stabilization has yet to be fully developed and proven. Effective delivery of phosphate reagent to groundwater has yet to be perfected. Furthermore, formulation and application of a phosphate reagent to the vadose zone is only in its preliminary development stage. Phosphate stabilization has the secondary advantage of immobilizing the contaminant. Additional treatability testing is needed to verify the implementability of the phosphate-based technologies for the targeted smear zone contamination.

The excavation approach has the advantage of being a mature and relatively certain technology. It has fundamental disadvantages of appearing to be more expensive than phosphate stabilization, and moving but not permanently stabilizing the uranium. As with the phosphate-based technology, to be effective, excavation must target the contamination source. Additional characterization is needed to refine the location of the source and provide the detailed information about contamination extent that will be needed for the feasibility study.

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## 8.0 DISCUSSION AND PATH FORWARD

The preliminary screening evaluation of seven active prototype remediation alternatives ranked variations of phosphate-induced uranium stabilization and focused excavation of sediments containing uranium residuals as two promising strategies to reduce concentrations of uranium in groundwater. However, the formulation of alternatives and comparative evaluation of remedies are limited by the present state of knowledge regarding 1) uranium that acts as a source to resupply the plume, and 2) implementation of a promising remediation technology. Consequently, it is premature to proceed to a feasibility study until information that clarifies key elements of these two potential remedy components is obtained. The knowledge limitations are associated with two data gaps.

The first involves uranium contamination in vadose zone sediments beneath the 300 Area. Until the recent limited field investigation (Williams et al. 2008), almost no direct information on contamination in the vadose zone beneath remedial action sites and elsewhere was available. The relationship between residual contamination at waste sites, including the underlying vadose zone, and the persistent groundwater plume has remained largely unstudied. Although many years of groundwater monitoring have provided a well-documented record for the behavior of the uranium plume in groundwater, the cause for the persistence of the plume beyond remedial investigation expectations remains enigmatic.

The second information gap involves the science and engineering associated with a promising, but not yet fully developed, remediation technology; i.e., uranium stabilization in vadose sediments using phosphate reagents. Laboratory tests have shown the potential for this technology. A remaining challenge is to develop methods to implement the technology in the dynamic, highly transmission subsurface environment at the 300 Area.

### 8.1 ADDITIONAL CHARACTERIZATION FOR URANIUM

The formulation and ranking of remediation alternatives in this remediation strategy study indicate treatment of the labile uranium residing in vadose zone sediments, and particularly in the occasionally wetted sediments near the groundwater, presents the best opportunity to reduce the uranium concentrations in the persistent groundwater plume. However, the location, lateral extent, and geochemistry of these contaminated sediments are not well characterized. Eight characterization bore holes that were drilled as part of a limited field investigation for uranium (Williams et al. 2007) and a recent investigation of VOC contamination have provided new and helpful information on uranium in lower vadose zone sediments. Additionally, recent backhoe sampling at the north and south process ponds has provided material to characterize sediments at the interface between the vadose zone and groundwater (Zachara et al. 2005).

New sediment characterization efforts presently being conducted under the DOE Integrated Field-Scale Subsurface Research Challenge program<sup>a</sup> are beginning to study the behavior and distribution of contaminating uranium beneath the former south process pond (Freshley 2008). However, very little assessment and mapping of uranium contamination in the vadose zone extending beyond the immediate "footprint" areas below the known uranium liquid waste disposal facilities has been conducted. A more comprehensive description of the extent of residual inventory of uranium remaining in the environment,

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<sup>a</sup> The Integrated Field-Scale Subsurface Research Challenge is managed by DOE's Office of Biological and Environmental Research – Remediation, Sciences Division. Its objective is to use state-of-the-science field experiments to resolve the geochemical, biophysical, and microbiological factors that control uranium migration at the Hanford Site 300 Area.

and an improved understanding of the processes that control uranium movement through environmental pathways, would be beneficial before commencing a feasibility study that will lead to an effective remedy selection process. Additional site characterization efforts that would reduce uncertainties in the conceptual model for uranium contamination are outlined in the following subsections.

### **8.1.1 Uranium in Vadose Zone Sediments**

Future drilling activities in the 300 Area provide opportunities to collect sediment samples from subsurface compartments that are key to developing an effective remedial action. Additional analytical results for sediment samples collected from beneath former liquid waste disposal sites, and from the lower vadose zone in the broader area of the plume, would help identify source(s) for resupplying the groundwater plume. Samples from the fluctuating groundwater interface zone are particularly useful. A program dedicated to solving this knowledge limitation might address the following issues.

Drilling and sampling would initially target the principal areas where effluents containing uranium were discharged to the ground; e.g., within the historical boundaries of the North and South Process Ponds and the 300 Area Process Trenches. As drilling proceeded, sediment samples would be collected throughout the vadose zone, with particular focus on sediments within the zone through which the historical and current water table fluctuates. Additional prospective drilling locations would be positioned along the apparent path that seasonally induced high concentration portions of the plume take as they migrate downgradient. The purpose for drilling at these downgradient locations is to establish whether the high concentrations away from the waste site are the result of the migrating plume, or include additional input from the vadose zone. The number of sites drilled would be sufficient to provide a statistically representative set of data to characterize the intermittently saturated sediment.

Laboratory analyses of the sediment samples would be performed to allow distinguishing between total uranium and labile uranium; other groundwater characteristics such as alkalinity, pH, Eh, major anions, and major cations would also be measured to characterize the geochemical environment. The purpose for the analytical work is to delineate the depths and area extent of uranium contamination in the vadose zone above the groundwater that should be considered for initial remediation treatment. Such delineation will be required for accurate scaling of remedies in the feasibility study, as well as for providing information regarding quantities, equipment, and infrastructure for the engineering design and timely deployment of the selected remedy.

A second phase of drilling and sampling of sediments in the lower portion of the vadose zone near the water table would be used to delineate the extent of residual uranium in sediment outside the footprints of the major ground disposal areas. Results from this drilling and sampling would be used to determine whether the groundwater contamination that developed during peak operating years has been widely distributed laterally, and has moved upward into the lower vadose zone by subsequent groundwater flow patterns. This information will help evaluate whether treatment of such extended areas would be required to attain the desired cleanup levels in the groundwater in a reasonable time frame. Prospective locations for this phase of drilling would be selected based on individual disposal facility locations and plume migration flow paths predicted by groundwater flow simulation modeling.

### **8.1.2 Hydraulic Testing of the Aquifer**

Large-scale, monitored groundwater extraction tests could be used to better understand the potential for mobilizing contaminant uranium potentially remaining in subsurface compartments. The test would use an extraction well, located inland, near a former waste-disposal unit where high uranium concentrations

are observed during high river stage. Sustained, high-flow pumping of groundwater at rates of greater than 757 L/min (> 200 gpm) would hydrologically stress the system over an extended period of time, perhaps approximately 3 months. A comprehensive network of monitoring wells would be measured and sampled. Prescribed extraction pauses would be incorporated into the test plan to evaluate rebound effects. Extracted groundwater would be analyzed, and changes in groundwater uranium geochemistry would be tracked. Such a test would provide significant information concerning mass removal of uranium and uranium plume behavior and causes.

Differences between the large-scale withdrawal test described above and the continuing large-volume extraction from water supply well 399-4-12 are as follows:

- Well 399-4-12 is on the periphery of the groundwater uranium plume where uranium concentrations are relatively low (currently ~ 20 µg/L). A large-scale test would be positioned near the high concentration portions of the uranium plume.
- Additional groundwater monitoring wells are few in the vicinity of well 399-4-12, so there is very limited baseline data to describe conditions prior to the start of pumping at that well in 1982. The large-scale withdrawal test would be located near other wells that have long-term, near-field, and downgradient monitoring data for use as baseline conditions prior to the withdrawal, so pre- and post-conditions can be compared.
- Well 399-4-12 is located in an area where the saturated Hanford formation hydrostratigraphic unit is much thicker than in areas with higher uranium concentrations. For example, characterization activities around the current polyphosphate treatability test site, where the saturated Hanford formation aquifer thickness is approximately half the thickness at well 399-4-12, were able to measure adequate drawdown for performing aquifer test analysis using a pumping rate of 200 gpm.

The substantial benefits of such a field-scale hydrogeologic test can be considered within the context of the complexity of the overall uranium contamination problem. Implementation challenges for such testing, such as water disposal, would be coordinated with other site programs. Possible disposal options include the 310 Treated Effluent Disposal Facility north of the 300 Area, re-injection to the aquifer, or direct discharge to the river, with or without treatment.

Particular questions pertinent to successful selection and implementation of future remedies for the uranium contamination that would be addressed by the proposed extraction testing include the following:

- Is the re-supply of uranium restricted to zones having relatively high concentrations at seasonal high water?
- Are December-elevated uranium concentrations observed near the Columbia River caused by migration of uranium mobilized from June groundwater elevation rises into vadose zone source areas?
- Will removal of uranium from the groundwater plume result in a temporary or permanent reduction of uranium concentrations in groundwater?

### 8.1.3 Monitoring Data to Support Simulations

Frequent measurements of groundwater hydraulic head data are used to characterize the dynamic nature of the groundwater movement, which results from fluctuations in Columbia River stage. Such data sets

are essential for calibrating groundwater flow models. Also, frequent measurements of certain water quality parameters are very useful in showing the impact of river water, which infiltrates the aquifer during periods of high river flows, on the movement of uranium contamination through the zone where the aquifer and river hydrologic systems meet. Many of these needs are being met by a recently revised groundwater monitoring plan, which will be published in the near future.

#### **8.1.4 Coordination with Research Activities and Treatability Tests**

Coordination between future feasibility study efforts and other activities focused on contaminant uranium in the subsurface beneath the 300 Area would result in efficient use of resources such as drilling and geophysical methods to achieve the desired level of knowledge. Information gained during treatability tests, and subsequent monitoring of the results of those tests, will contribute significant information for a feasibility study.

### **8.2 REMEDIATION TECHNOLOGY DEVELOPMENT**

The objective of a pilot-scale field test of applying polyphosphate to the 300 Area vadose zone would be to demonstrate applicability of the technology under 300 Area site conditions, and identify field-scale implementation challenges that cannot be addressed through the proposed bench- and intermediate-scale studies. This field test would be located within an area of deep vadose source contamination, as identified by elevated uranium concentrations in groundwater during high water-table conditions. The infiltration approach and monitoring strategy would be developed based on results from the proposed bench- and intermediate-scale testing, and an infiltration design evaluation that incorporates this laboratory-scale data into a variably saturated flow and reactive transport model.

Application approaches could range from ponded application if high infiltration rates are deemed most effective, or to a more controlled system of distributed surface application (e.g., drip emitters, sprinkler system) if lower infiltration rates are desirable. Another design consideration that would be evaluated is the advantages and disadvantages of surface application versus application at greater depth. Data from this pilot-scale field test would be used to evaluate cost and feasibility of this technology at the field scale such that cost for larger-scale applications can be effectively estimated.

### **8.3 PROGRESSION OF THE 300 NPL SITE REMEDIATION**

In accordance with the remedial investigation/feasibility study process described in EPA (1988a), the follow-up characterization outlined in the previous section is consistent with decision logic to gather further data when insufficient information is available to select a remedy. Furthermore, the need for additional data may be determined at any time and/or a number of times throughout the process according to EPA guidance, particularly in complex situations such as encountered in the 300 Area of the Hanford Site.

Previous characterization and feasibility studies to address the 300-FF-5 groundwater operable unit have largely focused on uranium contamination. Development of updated work plans to complete the CERCLA process leading to selection of final remedies is underway, and these plans will consider all contaminants of potential concern, as well as the uranium contamination. The future feasibility study for the 300 NPL Site will be inclusive of all contaminants of concern.

Previous strategies that led to current interim remedial actions (e.g., Thompson 1991, DOE-RL 2003) are being enhanced under a systematic planning process (<http://www.triadcentral.org>) that will clearly define the tasks, scope, and schedule for remediation decisions for 300 Area groundwater. This effort includes conducting a feasibility study in parallel with continued development of a phosphate-based remediation technology. A proposed plan and Record of Decision for implementation of final remedies will be based on feasibility study results having more comprehensively identified and compared the various alternatives for remedial actions associated with contaminants in the subsurface.

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**APPENDIX A**

**RELATIVE COST EVALUATIONS**

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Prototype Remediation Alternative 1		COST ESTIMATE SUMMARY	
<b>No Action (baseline for comparison)</b>			
<b>Site:</b> 300 Area	<b>Description:</b> No active remedial action.		
<b>Location:</b> Hanford, Washington	Continue interim ROD (1995) monitoring activities.		
<b>Phase:</b> Preliminary Remediation Strategy (-50% to +300%)	Continued U concentrations in groundwater >30 µg/L		
<b>Base Year:</b> 2008	Operating Duration: 75 years		
<b>Date:</b> April 30, 2008			

**Existing Facilities**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>CAPITAL COSTS</b>					
No New Capital Costs				\$ -	
<b>ANNUAL O&amp;M COSTS:</b>					
<i>O&amp;M Costs obtained from Bob Peterson, PNNL</i>					
Groundwater Monitoring	1 year		\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year		\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year		\$ 1,000	\$ 1,000	Commercial rates, includes QA R. Peterson
Analytical Costs	1 year		\$91,000	\$ 91,000	
SUBTOTAL				\$ 238,000	
Contingency	20%			\$ 47,600	
ANNUAL O&M COSTS				\$ 285,600	Based upon 2003 to 2005 with 10% inflation

**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight	5	10%		\$ 2,000	
				\$ 22,000	
Well Abandonment	76	well	\$ 4,200	\$ 210,000	Fill 50 wells with neat cement grout with waste disposal
Contingency (% of Sum)	76	25%		\$ 52,500	% of decommission activities
Project Management (% of Sum + Cont.)	76	10%		\$ 36,250	% of decommission and contingency, plus permits
SUBTOTAL for closure after 75 years of operation				\$ 298,750	

<b>Prototype Remediation Alternative 1</b> <b>No Action (baseline for comparison)</b> <b>PRESENT VALUE ANALYSIS:</b>	<b>COST ESTIMATE SUMMARY</b>
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YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ -	\$ -	1.000	\$ -	
1 to 75	Annual O&M Cost	\$ 21,420,000	\$ 285,600	31.213	\$ 8,914,368	
5	Periodic Cost	\$ 22,000	\$ 22,000	0.871	\$ 19,163	5-year report
10	Periodic Cost	\$ 22,000	\$ 22,000	0.759	\$ 16,691	5-year report
15	Periodic Cost	\$ 22,000	\$ 22,000	0.661	\$ 14,539	5-year report
20	Periodic Cost	\$ 22,000	\$ 22,000	0.576	\$ 12,664	5-year report
25	Periodic Cost	\$ 22,000	\$ 22,000	0.501	\$ 11,030	5-year report
26	Periodic Cost	\$ 22,000	\$ 22,000	0.488	\$ 10,730	5-year report
30	Periodic Cost	\$ 22,000	\$ 22,000	0.437	\$ 9,608	5-year report
35	Periodic Cost	\$ 22,000	\$ 22,000	0.380	\$ 8,369	5-year report
40	Periodic Cost	\$ 22,000	\$ 22,000	0.331	\$ 7,290	5-year report
45	Periodic Cost	\$ 22,000	\$ 22,000	0.289	\$ 6,349	5-year report
50	Periodic Cost	\$ 22,000	\$ 22,000	0.251	\$ 5,531	5-year report
55	Periodic Cost	\$ 22,000	\$ 22,000	0.219	\$ 4,817	5-year report
60	Periodic Cost	\$ 22,000	\$ 22,000	0.191	\$ 4,196	5-year report
65	Periodic Cost	\$ 22,000	\$ 22,000	0.166	\$ 3,655	5-year report
70	Periodic Cost	\$ 22,000	\$ 22,000	0.145	\$ 3,183	5-year report
75	Periodic Cost	\$ 22,000	\$ 22,000	0.126	\$ 2,773	5-year report
76	Periodic Cost	\$ 298,750	\$ 298,750	0.123	\$ 36,630	Decommission Monitoring Wells
		\$ 21,772,000			\$ 9,054,956	

TOTAL PRESENT VALUE OF ALTERNATIVE

\$ 9,054,956

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$ 21,772,000

Prototype Remediation Alternative 2		COST ESTIMATE SUMMARY	
<b>Monitored Natural Attenuation</b>			
<b>Site:</b> 300 Area	<b>Description:</b> No active remedial action.		
<b>Location:</b> Hanford, Washington	Conduct 2 yr continuous hydrology monitoring study.		
<b>Phase:</b> Preliminary Remediation Strategy (-50% to +300%)	Monitor and sample according to 2008 Monitoring Plan		
<b>Base Year:</b> 2008	Continued U concentrations in groundwater >30 µg/L		
<b>Date:</b> April 30, 2008	Operating Duration: 75 years		

**Existing Facilities**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>CAPITAL COSTS</b>					
No New Capital Costs				\$ -	
<b>ANNUAL O&amp;M COSTS:</b>					
<i>O&amp;M Costs obtained from Bob Peterson, PNNL</i>					
Groundwater Monitoring	1 year		\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year		\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year		\$ 1,000	\$ 1,000	
Analytical Costs	1 year		\$91,000	\$ 91,000	Commercial rates, includes QA R. Peterson
SUBTOTAL				\$ 238,000	
Contingency	20%			\$ 47,600	
ANNUAL O&M COSTS				\$ 285,600	Based upon 2003 to 2005 with 10% inflation

**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Repor	1, 2	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years --2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Well Abandonment	76	well	\$ 4,200	\$ 210,000	Fill 50 wells with neet cement grout with waste disposal
Contingency (% of Sum)	76	25%		\$ 52,500	% of decommission activities
Project Management (% of Sum + Cont.)	76	10%		\$ 36,250	% of decommission and contingency, plus permits
SUBTOTAL for closure after 75 years of operation				\$ 298,750	

Prototype Remediation Alternative 2  
Monitored Natural Attenuation

**COST ESTIMATE SUMMARY****PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ -	\$ -	1.000	\$ -	
1 to 75	Annual O&M Cost	\$ 21,420,000	\$ 285,600	31.213	\$ 8,914,368	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$22,000	\$22,000	0.871	\$ 19,163	5-year report
10	Periodic Cost	\$22,000	\$22,000	0.759	\$ 16,691	5-year report
15	Periodic Cost	\$22,000	\$22,000	0.661	\$ 14,539	5-year report
20	Periodic Cost	\$22,000	\$22,000	0.576	\$ 12,664	5-year report
25	Periodic Cost	\$22,000	\$22,000	0.501	\$ 11,030	5-year report
26	Periodic Cost	\$ 22,000	\$22,000	0.488	\$ 10,730	5-year report
30	Periodic Cost	\$22,000	\$22,000	0.437	\$ 9,608	5-year report
35	Periodic Cost	\$22,000	\$22,000	0.380	\$ 8,369	5-year report
40	Periodic Cost	\$22,000	\$22,000	0.331	\$ 7,290	5-year report
45	Periodic Cost	\$22,000	\$22,000	0.289	\$ 6,349	5-year report
50	Periodic Cost	\$22,000	\$22,000	0.251	\$ 5,531	5-year report
55	Periodic Cost	\$22,000	\$22,000	0.219	\$ 4,817	5-year report
60	Periodic Cost	\$22,000	\$22,000	0.191	\$ 4,196	5-year report
65	Periodic Cost	\$22,000	\$22,000	0.166	\$ 3,655	5-year report
70	Periodic Cost	\$22,000	\$22,000	0.145	\$ 3,183	5-year report
75	Periodic Cost	\$22,000	\$22,000	0.126	\$ 2,773	5-year report
76	Periodic Cost	\$298,750	\$ 298,750	0.123	\$ 36,630	Decommission Monitoring Wells
		\$ 21,892,000			\$ 9,170,098	

**TOTAL PRESENT VALUE OF ALTERNATIVE****\$9,170,098**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$21,892,000

Prototype Remediation Alternative 3A		COST ESTIMATE SUMMARY	
Phosphate Application to Groundwater Over Area			
<b>Site:</b>	300 Area	<b>Description:</b>	Multiple injection of phosphate to stabilize U in aquifer
<b>Location:</b>	Hanford, Washington		Apply through former north, south ponds, 316-5 Trend
<b>Phase:</b>	Preliminary Remediation Strategy (-50% to +300%)		Application area is ~76,000 square meters (19 acres)
<b>Base Year:</b>	2008		242 4-inch wells into Hanford aquifer, 20 meter spacing
<b>Date:</b>	April 30, 2008		Treatment Duration: 2 years; 15 years monitoring.

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					
Drill Rig Mob/Demob	4	LS	\$4,050	\$ 16,200	assumes 2.7 Hanford factor
WDOE Well Permits	242		\$ 50	\$ 12,100	
Construction Report	1	LS	\$300,000	\$ 300,000	
<b>Site Work</b>					
Install Wells	242		\$33,500	\$ 8,107,000	
Reagent (2 3-step injections, 1000 ppm, 7500 lb/well/ses)	7500	injections	\$ 2.00	\$ 7,260,000	Based upon 2007 Treatability Test Wells
Application Labor	2	sessions	\$1,000,000	\$ 2,000,000	
SUBTOTAL DIRECT CAPITAL COSTS				\$ 17,695,300	
Contingency				25%	\$ 4,423,825
TOTAL DIRECT COSTS (TDC)				\$22,119,125	
Engineering Pre-Design				10% TDC	\$2,211,913
Engineering Design				12% TDC	\$2,654,295
Permitting, Regulatory Compliance				2% TDC	\$ 442,383
Construction Quality Assurance, Management				5% TDC	\$1,105,956
TOTAL INDIRECT COSTS				\$6,414,546	
TOTAL CAPITAL COSTS:				<b>\$ 28,533,671</b>	

**ANNUAL O&M COSTS:***O&M Costs obtained from Bob Peterson, PNNL*

Groundwater Monitoring	1 year	\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team	
Aquifer Tube Monitoring	1 year	\$6,000	\$ 6,000	8 tubes, twice a year	
Spring Monitoring	1 year	\$1,000	\$ 1,000		
Analytical Costs	1 year	\$91,000	\$ 91,000	Commercial rates, includes QA R. Peterson	
SUBTOTAL				\$ 238,000	
Contingency				20%	\$ 47,600
ANNUAL O&M COSTS				<b>\$ 285,600</b>	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 3A

**COST ESTIMATE SUMMARY**

Phosphate Application to Groundwater Over Area

**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Well Abandonment	292	well	\$4,200	\$1,226,400	Fill 50+242 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 306,600	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 163,300	% of decommission and contingency, plus permits
SUBTOTAL for closure after 15 years of operation				\$1,696,300	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 28,533,671	\$ 28,533,671	1.000	\$ 28,533,671	
1 to 12	Annual O&M Cost	\$3,427,200	\$285,600	10.074	\$2,877,105	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$22,000	\$22,000	0.871	\$ 19,163	5-year report
10	Periodic Cost	\$22,000	\$22,000	0.759	\$ 16,691	5-year report
15	Periodic Cost	\$22,000	\$22,000	0.661	\$ 14,539	5-year report
16	Periodic Cost	\$1,696,300	\$ 1,696,300	0.643	\$1,090,468	Decommission Monitoring Wells
		\$ 33,843,171			\$ 32,666,779	
<b>TOTAL PRESENT VALUE OF ALTERNATIVE</b>					<b>\$32,666,779</b>	
<b>TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST</b>					<b>\$ 33,843,171</b>	

Prototype Remediation Alternative 3B		COST ESTIMATE SUMMARY	
<b>Phosphate Application to Groundwater Along Linear Reactive Barrier</b>			
<b>Site:</b>	300 Area	<b>Description:</b>	Multiple injection of phosphate to stabilize U in aquifer
<b>Location:</b>	Hanford, Washington		Apply along north-south linear intercept 3800 ft long
<b>Phase:</b>	Preliminary Remediation Strategy (-50% to +300%)		Two lines of wells 35 ft deep, parallel to River
<b>Base Year:</b>	2008		135 4-inch wells into Hanford aquifer, 20 meter spacing
<b>Date:</b>	April 30, 2008		Treatment Duration: 2 years, 15 years monitoring

## CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					
Drill Rig Mob/Demob	4	LS	\$ 4,050	\$ 16,200	assumes 2.7 Hanford factor
WDOE Well Permits	135		\$ 50	\$ 6,750	
Construction Report	1	LS	\$ 150,000	\$ 150,000	
<b>Site Work</b>					
Install Wells	135		\$ 33,500	\$ 4,522,500	
Reagent (2 3-step injections, 1000 ppm, 7500 lb/well/ses)	7500	2 sessions	\$ 2.00	\$ 4,050,000	Based upon 2007 Treatability Test Wells
Application Labor			\$ 600,000	\$ 1,200,000	

SUBTOTAL DIRECT CAPITAL COSTS	\$ 9,945,450
Contingency	25% \$ 2,486,363
TOTAL DIRECT COSTS (TDC)	\$ 12,431,813

Engineering Pre-Design	10% TDC	\$ 1,243,181
Engineering Design	12% TDC	\$ 1,491,818
Permitting, Regulatory Compliance	2% TDC	\$ 248,636
Construction Quality Assurance, Management	5% TDC	\$ 621,591
TOTAL INDIRECT COSTS		\$ 3,605,226

TOTAL CAPITAL COSTS: \$ 16,037,038

## ANNUAL O&amp;M COSTS:

*O&M Costs obtained from Bob Peterson, PNNL*

Groundwater Monitoring	1 year	\$ 140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year	\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year	\$ 1,000	\$ 1,000	
Analytical Costs	1 year	\$ 91,000	\$ 91,000	Commercial rates, includes QA R. Peterson
SUBTOTAL			\$ 238,000	
Contingency	20%		\$ 47,600	
ANNUAL O&M COSTS			<span style="border: 1px solid black; padding: 2px;">\$ 285,600</span>	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 3B Phosphate Application to Groundwater Along Linear Reactive Barrier	<b>COST ESTIMATE SUMMARY</b>
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**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Well Abandonment	185	well	\$ 4,200	\$ 777,000	Fill 50+242 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 194,250	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 107,125	% of decommission and contingency, plus permits
SUBTOTAL for closure after 15 years of operation				\$1,078,375	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 16,037,038	\$ 16,037,038	1.000	\$ 16,037,038	
1 to 12	Annual O&M Cost	\$3,427,200	\$285,600	10.074	\$2,877,105	
1	Periodic Cost	\$ 60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$ 60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$22,000	\$22,000	0.871	\$ 19,163	5-year report
10	Periodic Cost	\$22,000	\$22,000	0.759	\$ 16,691	5-year report
15	Periodic Cost	\$22,000	\$22,000	0.661	\$ 14,539	5-year report
16	Periodic Cost	\$1,078,375	\$ 1,078,375	0.643	\$ 693,234	Decommission Monitoring Wells
		\$ 20,728,613			\$ 19,772,912	

**TOTAL PRESENT VALUE OF ALTERNATIVE****\$ 19,772,912**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

**\$ 20,728,613**

Prototype Remediation Alternative 3C		COST ESTIMATE SUMMARY	
Phosphate Application to Groundwater along Source Area Perimeters			
Site:	300 Area	Description:	Multiple injection of phosphate to stabilize U in aquifer
Location:	Hanford, Washington		Apply around two perimeters (N and S ponds) and S, E sides of 316-5
Phase:	Preliminary Remediation Strategy (-50% to +300%)		Two lines of wells 35 ft deep, in staggered array
Base Year:	2008		263 4-inch wells into Hanford aquifer, 20 meter spacing
Date:	April 30, 2008		Treatment Duration: 2 years, 15 years monitoring

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					
Drill Rig Mob/Demob	4	LS	\$ 4,050	\$ 16,200	assumes 2.7 Hanford factor
WDOE Well Permits	135		\$ 50	\$ 6,750	
Construction Report	1	LS	\$150,000	\$ 150,000	
<b>Site Work</b>					
Install Wells	263		\$33,500	\$8,810,500	Based upon 2007 Treatability Test Wells
Reagent (2 3-step injections, 1000 ppm, 7500 lb/well/see)	7500	lb/well/see	\$ 2.00	\$7,890,000	
Application Labor	2	sessions	\$1,000,000	\$2,000,000	

SUBTOTAL DIRECT CAPITAL COSTS		\$ 18,873,450
Contingency	25%	\$4,718,363
<b>TOTAL DIRECT COSTS (TDC)</b>		<b>\$23,591,813</b>

Engineering Pre-Design	10% TDC	\$2,359,181
Engineering Design	12% TDC	\$2,831,018
Permitting, Regulatory Compliance	2% TDC	\$ 471,836
Construction Quality Assurance, Management	5% TDC	\$1,179,591
<b>TOTAL INDIRECT COSTS</b>		<b>\$6,841,626</b>

<b>TOTAL CAPITAL COSTS:</b>		<b>\$30,433,438</b>
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**ANNUAL O&M COSTS:***O&M Costs obtained from Bob Peterson, PNNL*

Groundwater Monitoring	1 year	\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year	\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year	\$ 1,000	\$ 1,000	
Analytical Costs	1 year	\$91,000	\$ 91,000	Commercial rates, includes QA R. Peterson
SUBTOTAL			\$ 238,000	
Contingency	20%		\$ 47,600	
<b>ANNUAL O&amp;M COSTS</b>			<b>\$ 285,600</b>	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 3C Phosphate Application to Groundwater along Source Area Perimeters	<b>COST ESTIMATE SUMMARY</b>
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**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<u>Short Term Hydrogeologic Monitoring and Analysis</u>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$ 50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$ 20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Well Abandonment	313	well	\$ 4,200	\$ 210,000	Fill 50+242 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 52,500	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 36,250	% of decommission and contingency, plus permits
SUBTOTAL for closure after 15 years of operation				\$ 298,750	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$30,433,438	\$30,433,438	1.000	\$30,433,438	
1 to 12	Annual O&M Cost	\$3,427,200	\$285,600	10.074	\$2,877,105	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$22,000	\$22,000	0.871	\$ 19,163	5-year report
10	Periodic Cost	\$22,000	\$22,000	0.759	\$ 16,691	5-year report
15	Periodic Cost	\$22,000	\$22,000	0.661	\$ 14,539	5-year report
16	Periodic Cost	\$298,750	\$298,750	0.643	\$ 192,052	Decommission Monitoring Wells
		\$34,345,388			\$33,668,130	

TOTAL PRESENT VALUE OF ALTERNATIVE

\$33,668,130

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$34,345,388

Prototype Remediation Alternative 3D		COST ESTIMATE SUMMARY	
<b>Phosphate Application into "Smear Zone" by Percolation</b>			
Site:	300 Area	Description:	Percolate Phosphate Reagent by Solid Set Irrigation System
Location:	Hanford, Washington		Solid Set Irrigation System: series of pipelines, risers, sprinklers
Phase:	Preliminary Remediation Strategy (-50% to +300%)		3 water wells, mixing tank, pumps, reagent tanks
Base Year:	2008		Application system for each waste unit.
Date:	April 30, 2008		Treatment Duration: 3 to 6 months, 15 years monitoring

## CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					
Equipmet Mob/Demob	5		\$ 1,350	\$ 6,750	assumes 2.7 Hanford factor
Support Equipment Mob/Demob	1	LS	\$ 3,000	\$ 3,000	
Construction Report	1	LS	\$150,000	\$ 150,000	
<b>Site Work</b>					
Solid Set Irrigation System	19	acre	\$ 2,336	\$ 44,388	BC Irrigation Cost (March 2003) High End**
Submersible Pumps, 6", 500 gpm, 125' head w controls	3		\$10,359	\$ 31,076	33 23 0581* 20 hp
Reagent Supply Tanks, 20,000 gal sgl wall w leak detecti	6		\$30,222	\$ 181,334	33 10 9748, 33 10 9713 *
Mixing Tanks, 5000 gal double wall fiberglass	3		\$21,740	\$ 65,219	33 10 9744 *
Water Supply Well Pumps, 500 gpm, 20HP	3		\$ 8,937	\$ 26,811	33 29 0111*
Process Control, Infrastructure	1	LS	\$214,000	\$ 214,000	Estimated 3 times tanks and pumps
<b>Treatment</b>					
Application Labor	3	w-yr	\$190,000	\$ 570,000	
Phosphate Reagent	5,300,000	lb	\$ 2.00	\$10,600,000	Assumed 3 times GW rate
SUBTOTAL DIRECT CAPITAL COSTS				\$ 11,892,578	
Contingency				25%	\$2,973,145
TOTAL DIRECT COSTS (TDC)					\$14,865,723
Engineering Pre-Design				10% TDC	\$1,486,572
Engineering Design				12% TDC	\$1,783,887
Permitting, Regulatory Compliance				2% TDC	\$ 297,314
Construction Quality Assurance, Management				5% TDC	\$ 743,286
TOTAL INDIRECT COSTS					\$4,311,060
TOTAL CAPITAL COSTS:					<b>\$19,176,783</b>

## ANNUAL O&amp;M COSTS:

O&amp;M Costs obtained from Bob Peterson, PNNL

Groundwater Monitoring	1	year	\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1	year	\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1	year	\$ 1,000	\$ 1,000	
Analytical Costs	1	year	\$91,000	\$ 91,000	Commercial rates, includes QA R. Peterson
SUBTOTAL				\$ 238,000	
Contingency				20%	\$ 47,600
ANNUAL O&M COSTS					<b>\$ 285,600</b>

Based upon 2003 to 2005 with 10% inflation

## Prototype Remediation Alternative 3D

## COST ESTIMATE SUMMARY

## Phosphate Application into "Smear Zone" by Percolation

## PERIODIC COSTS:

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Decommission Monitoring Wells	50	wells	\$ 4,200	\$ 210,000	Fill 50 wells with neat cement grout with waste disposal
Decommission Application System	1	LS	\$113,000	\$ 113,000	20% of original equipment cost
Contingency (% of Sum)		25%		\$ 80,750	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 40,375	% of decommission and contingency, plus permits
SUBTOTAL for closure after 15 years of operation				\$ 444,125	

## PRESENT VALUE ANALYSIS:

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$19,176,783	\$19,176,783	1.000	\$19,176,783	
1 to 15	Annual O&M Cost	\$4,284,000	\$285,600	12.112	\$3,459,324	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$50,000	\$50,000	0.871	\$ 43,552	5-year report
10	Periodic Cost	\$50,000	\$50,000	0.759	\$ 37,935	5-year report
15	Periodic Cost	\$50,000	\$50,000	0.661	\$ 33,043	5-year report
16	Periodic Cost	\$444,125	\$444,125	0.643	\$ 285,506	Decommission Wells & Equipment
		\$24,174,908			\$23,151,284	

TOTAL PRESENT VALUE OF ALTERNATIVE

**\$23,151,284**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$24,174,908

Prototype Remediation Alternative 3E		<b>COST ESTIMATE SUMMARY</b>	
<b>Phosphate Application into "Smear Zone" by Injection through Vertical Wells during Rising Groundwater</b>			
<b>Site:</b> 300 Area	<b>Description:</b> Inject Phosphate Reagent through Vertical Wells		
<b>Location:</b> Hanford, Washington	Well array corresponds with original disposal areas.		
<b>Phase:</b> Preliminary Remediation Strategy (-50% to +300%)	Reagent application coordinated with spring water table rise.		
<b>Base Year:</b> 2008	20 meter well centers		
<b>Date:</b> April 30, 2008	Treatment Duration: 2 years (2 high water table cycles)		

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					
Drill Rig Mob/Demob	4	LS	\$4,050	\$ 16,200	assumes 2.7 Hanford factor
WDOE Well Permits	325		\$ 50	\$ 16,250	assumes 2.7 Hanford factor
Construction Report	1	LS	\$300,000	\$ 300,000	
<b>Site Work</b>					
Install Wells	242		\$33,500	\$ 8,107,000	Based upon 2007 Treatability Test Wells
<b>Treatment</b>					
Reagent (2 injections, 1500 ppm, 11250 lb/well/session)	11250	lb/well/session	\$ 2.00	\$ 10,890,000	phosphate attempting to contact only smear zone
Application Labor	2	sessions	\$1,000,000	\$ 2,000,000	
SUBTOTAL DIRECT CAPITAL COSTS				\$ 21,329,450	
Contingency				25%	\$5,332,363
TOTAL DIRECT COSTS (TDC)				\$ 26,661,813	
Engineering Pre-Design				10% TDC	\$2,666,181
Engineering Design				12% TDC	\$3,199,418
Permitting, Regulatory Compliance				2% TDC	\$ 533,236
Construction Quality Assurance, Management				5% TDC	\$1,333,091
TOTAL INDIRECT COSTS				\$7,731,926	
TOTAL CAPITAL COSTS:				<b>\$ 34,393,738</b>	

**ANNUAL O&M COSTS:***O&M Costs obtained from Bob Peterson, PNNL*

Groundwater Monitoring	1 year	\$140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year	\$6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year	\$1,000	\$ 1,000	
Analytical Costs	1 year	\$91,000	\$ 91,000	Commercial rates, includes QA R. Peterson
SUBTOTAL			\$ 238,000	
Contingency			20%	\$ 47,600
ANNUAL O&M COSTS			<b>\$ 285,600</b>	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 3E

**COST ESTIMATE SUMMARY**

Phosphate Application into "Smear Zone" by Injection through Vertical Wells during Rising Groundwater

**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Decommission Wells	292	well	\$ 4,200	\$1,226,400	Fill 50+242 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 306,600	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 163,300	% of decommission and contingency, plus permits
SUBTOTAL for closure after 15 years of operation				\$1,696,300	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 34,393,738	\$ 34,393,738	1.000	\$ 34,393,738	
1 to 15	Annual O&M Cost	\$4,284,000	\$285,600	12.112	\$3,459,324	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$20,000	\$20,000	0.871	\$ 17,421	5-year report
10	Periodic Cost	\$20,000	\$20,000	0.759	\$ 15,174	5-year report
15	Periodic Cost	\$20,000	\$20,000	0.661	\$ 13,217	5-year report
16	Periodic Cost	\$1,696,300	\$ 1,696,300	0.643	\$1,090,468	Decommissioning
		\$ 40,554,038			\$ 39,104,483	

**TOTAL PRESENT VALUE OF ALTERNATIVE****\$39,104,483**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$ 40,554,038

Prototype Remediation Alternative 4		COST ESTIMATE SUMMARY	
Selective Excavation and Disposal of Contaminated Sediment into GW Interface.			
<b>Site:</b> 300 Area	<b>Description:</b> Focused Excavation of Ponds and Trenches ("foot prints")		
<b>Location:</b> Hanford, Washington	Stockpile uncontaminated sediment with analytical screening.		
<b>Phase:</b> Preliminary Remediation Strategy (-50% to +300%)	Excavate and dispose contaminated sediment		
<b>Base Year:</b> 2008	Excavate, dewater, dispose contaminated sediment within boundaries		
<b>Date:</b> April 30, 2008	Treatment Duration: 4 years (3 low water table cycles)		

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
<b>Mobilization/Demobilization</b>					assumes 2.7 Hanford factor
Equipment Mobilization	1	LS	\$ 150,000	\$ 150,000	
Environmental, Grading Permit	1	LS	\$ 350,000	\$ 350,000	
Construction Report	1	LS	\$ 150,000	\$ 150,000	
<b>Site Work</b>					
Excavate Overburden	298000	CY	\$ 8.84	\$ 2,633,054	17 03 0250 with 4 draglines
Excavate, Dispose (to Smear)	911000	CY	\$ 53.22	\$ 48,481,671	17 03 0282, 02225 3301
Excavate, Dewater Smear Zone	183000	CY	\$ 145.48	\$ 26,622,108	see Excavation Backup
Dispose Smear Sediment	183000	CY	\$ 53.22	\$ 9,738,909	17 03 0282, 02225 3301
Replace Overburden	298000	CY	\$ 3.27	\$ 975,205	no Hanford factor
Import Replacement	1093000	CY	\$ 33.31	\$ 36,412,202	no Hanford factor
Back fill Replacement	1093000	CY	\$ 3.71	\$ 4,055,030	17 03 0415 no Hanford factor
<b>SUBTOTAL DIRECT CAPITAL COSTS</b>				\$ 129,568,178	
Contingency			25%	\$ 32,392,045	
<b>TOTAL DIRECT COSTS (TDC)</b>				\$ 161,960,223	
Engineering Pre-Design	10%	TDC		\$ 16,196,022	
Engineering Design	12%	TDC		\$ 19,435,227	
Permitting, Regulatory Compliance	2%	TDC		\$ 3,239,204	
Construction Quality Assurance, Management	5%	TDC		\$ 8,098,011	
<b>TOTAL INDIRECT COSTS</b>				\$ 46,968,465	
<b>TOTAL CAPITAL COSTS:</b>				\$ 208,928,687	

**ANNUAL O&M COSTS:***O&M Costs obtained from Bob Peterson, PNNL*

Groundwater Monitoring	1 year	\$ 140,000	\$ 140,000	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year	\$ 6,000	\$ 6,000	8 tubes, twice a year
Spring Monitoring	1 year	\$ 1,000	\$ 1,000	Commercial rates, includes QA R.
Analytical Costs	1 year	\$ 91,000	\$ 91,000	Peterson
<b>SUBTOTAL</b>			\$ 238,000	
Contingency	20%		\$ 47,600	
<b>ANNUAL O&amp;M COSTS</b>			\$ 285,600	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 4

**COST ESTIMATE SUMMARY**

Selective Excavation and Disposal of Contaminated Sediment into GW Interface.

**PERIODIC COSTS:**

DESCRIPTION	Frequency (years)	UNIT	UNIT COST	TOTAL	NOTES
<b>Short Term Hydrogeologic Monitoring and Analysis</b>					
Hydrogeologic Monitoring, Logging, Report	2, 3	year	\$50,000	\$ 50,000	Required to better establish hydrogeology. M. Williams
SUBTOTAL				\$ 50,000	
Contingency	20%			\$ 10,000	
Hydro Monitoring Study Total				\$ 60,000	Limited for 2 years ~2010
Five Year Review Report	5	EA	\$20,000	\$ 20,000	1 report at end of every 5th year
Administrative Management & Oversight		10%		\$ 2,000	
	5			\$ 22,000	
Well Abandonment	40	well	\$ 4,200	\$ 168,000	Fill 40 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 42,000	% of decommission activities
Project Management (% of Sum + Cont.)		10%		\$ 31,000	% of decommission and contingency, plus permits
SUBTOTAL for closure after 20 years of operation				\$ 241,000	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$208,928,687	\$208,928,687	1.000	\$208,928,687	
1 to 12	Annual O&M Cost	\$3,427,200	\$285,600	10.074	\$2,877,105	
1	Periodic Cost	\$60,000	\$60,000	0.973	\$ 58,366	Short-Term hydrologic study
2	Periodic Cost	\$60,000	\$60,000	0.946	\$ 56,776	Short-Term hydrologic study
5	Periodic Cost	\$60,000	\$60,000	0.871	\$ 52,262	5-year report
10	Periodic Cost	\$60,000	\$60,000	0.759	\$ 45,522	5-year report
15	Periodic Cost	\$60,000	\$60,000	0.661	\$ 39,651	5-year report
20	Periodic Cost	\$60,000	\$60,000	0.576	\$ 34,537	5-year report
21	Periodic Cost	\$241,000	\$241,000	0.560	\$ 134,947	Decommission Monitoring Wells
		\$212,956,887			\$212,227,853	

TOTAL PRESENT VALUE OF ALTERNATIVE

**\$212,227,853**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$212,956,887

Prototype Remediation Alternative 5		COST ESTIMATE SUMMARY	
<b>Selective Excavation and Disposal of Contaminated Sediment into GW Interface.</b>			
<b>Site:</b> 300 Area	<b>Description:</b> Complete Excavation of 300 Area		
<b>Location:</b> Hanford, Washington	Stockpile uncontaminated sediment with analytical screening.		
<b>Phase:</b> Preliminary Remediation Strategy (-50% to +300%)	Excavate and dispose contaminated sediment		
<b>Base Year:</b> 2008	Excavate, dewater, dispose contaminated sediment within boundaries		
<b>Date:</b> April 30, 2008	Treatment Duration: 5 years (4 low water table cycles)		

## CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
					based on Alternative 4B using ratio of areas assumes 2.7 Hanford factor
<b>Mobilization/Demobilization</b>					
Equipment Mobilization	1	LS	\$ 705,000	\$ 705,000	
Environmental, Grading Permit	1	LS	\$ 350,000	\$ 350,000	
Construction Report	1	LS	\$ 705,000	\$ 705,000	
<b>Site Work</b>					
Excavate Overburden	1400600	CY	\$ 8.84	\$ 12,375,351	17 03 0250 with multiple draglines
Excavate, Dispose (to Smear)	4281700	CY	\$ 53.22	\$ 227,863,853	17 03 0282, 02225 3301
Excavate, Dewater Smear Zone	860100	CY	\$ 145.48	\$ 125,123,908	see Excavation Backup
Dispose Smear Sediment	183000	CY	\$ 53.22	\$ 9,738,909	17 03 0282, 02225 3301
Replace Overburden	0	CY	\$ 3.27	\$ -	no Hanford factor
Import Replacement	0	CY	\$ 33.31	\$ -	no Hanford factor
Back fill Replacement	0	CY	\$ 3.71	\$ -	17 03 0415 no Hanford factor
SUBTOTAL DIRECT CAPITAL COSTS				\$ 376,862,021	
Contingency			25%	\$ 94,215,505	
TOTAL DIRECT COSTS (TDC)				\$ 471,077,526	
Engineering Pre-Design			10% TDC	\$ 47,107,753	
Engineering Design			12% TDC	\$ 56,529,303	
Permitting, Regulatory Compliance			2% TDC	\$ 9,421,551	
Construction Quality Assurance, Management			5% TDC	\$ 23,553,876	
TOTAL INDIRECT COSTS				\$ 136,612,483	
TOTAL CAPITAL COSTS:				\$ 607,690,009	

## ANNUAL O&amp;M COSTS:

O&amp;M Costs obtained from Bob Peterson, PNNL

Groundwater Monitoring	1 year	\$ -	\$ -	50 monitoring wells, varied frequency, facility monitoring team
Aquifer Tube Monitoring	1 year	\$ -	\$ -	8 tubes, twice a year
Spring Monitoring modified for construction	1 year	\$ 5,000	\$ 5,000	
Analytical Costs	1 year	\$ 182,000	\$ 182,000	Commercial rates, includes QA modified for Construction Impact
SUBTOTAL			\$ 187,000	
Contingency			20%	\$ 37,400
ANNUAL O&M COSTS			\$ 224,400	Based upon 2003 to 2005 with 10% inflation

Prototype Remediation Alternative 5 Selective Excavation and Disposal of Contaminated Sediment Into GW Interface.	<b>COST ESTIMATE SUMMARY</b>
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**PERIODIC COSTS:**

No repetitive periodic costs

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST PER YEAR	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.8%)	PRESENT VALUE	NOTES
0	Capital Cost	\$607,690,009	\$607,690,009	1.000	\$607,690,009	
1 to 5	Annual O&M Cost	\$2,692,800	\$224,400	4.606	\$1,033,581	
		\$610,382,809			\$608,723,590	

TOTAL PRESENT VALUE OF ALTERNATIVE

**\$608,723,590**

TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$610,382,809

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