PNNL-11958
UC-502

1999 Vadose Zone Monitoring Plan and Guidance for Subsequent Years

D. G. Horton
S. P. Reidel
G. V. Last

August 1998

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

MASTER

Pacific Northwest National Laboratory
Richland, Washington 99352

DISCLAIMER

Summary

The U.S. Department of Energy's Hanford Site has the most diverse and largest amounts of radioactive waste in the United States. The majority of the liquid waste was disposed to the soil column where much of it remains today. This document provides the rationale and general framework for vadose zone monitoring at cribs, ditches, trenches and other disposal facilities to detect new sources of contamination and track the movement of existing contamination in the vadose zone for the protection of groundwater.

The document provides guidance for subsequent site-specific vadose zone monitoring plans and includes a brief description of past vadose zone monitoring activities (Chapter 3); the results of the Data Quality Objective process used for this plan (Chapter 4); a prioritization of liquid waste disposal sites for vadose monitoring (Chapter 5 and Appendix B); a general Monitoring and Analysis Plan (Chapter 6); a general Quality Assurance Project Plan (Appendix A), and a description of vadose monitoring activities planned for FY 1999 (Appendix C).

Appendix C of this document is to be amended in FY 1999 to include site-specific maps, waste inventories, constituents of concern, results of previous monitoring, existing subsurface access, existing contamination, applicable regulatory limits, and monitoring frequencies for liquid waste disposal facilities requiring vadose monitoring. That information, along with much of the information in the general Monitoring and Analysis plan and in the QAPjP in this document, can serve as part of subsequent site-specific vadose zone monitoring plans.

Contents

Figure

Tables

Acknowledgments

This document benefited from the participation of K. R. Fecht, G. W. Gee, V. G. Johnson, A. J. Knepp, F. M. Mann, C. J. Murrey, R. J. Serne, R. M. Smith, M. D. Sweeney, A. L. Ward, and G. Whelen in the Data Quality Objective process. Their comments, thoughts, and ideas contributed much to the author's conceptual implementation of vadose zone monitoring.

1.0 Introduction

The U.S. Department of Energy's (DOE) Hanford Site has the most diverse and largest amounts of radioactive waste in the United States. These radioactive wastes came from various sources: 1) plutonium and uranium recovery processing of approximately 100,000 Mtu of irradiated fuel, 2) tank waste processing for radionuclide recovery, and 3) miscellaneous sources (e.g., laboratories and reactor decontamination solutions). The neutralized wastes contained sodium nitrate, sodium hydroxide, sodium aluminate, sodium phosphate, large amounts of organic materials, and approximately 260 MCi of radioactivity.

Much of the radioactive waste was stored in 149 single-shell tanks (SST) and 28 double-shell tanks (DST). However, the majority of the effluent volume was disposed to the soil column either to absorb the liquid and its hazardous or radioactive material (specific retention facilities) or to chemically react (adsorption/precipitation) with the materials (cribs, french drains, ponds, etc.).

DOE Order 5400.1, *General Environmental Protection Program*, specifies that environmental surveillance shall be conducted to monitor the effects of DOE activities on on-site and offsite environmental and natural resources. The environmental surveillance, in part, is to 1) verify compliance with applicable environmental laws and regulations and with commitments in Environmental Impact Statements and Environmental Assessments; 2) characterize and define trends in the physical and chemical condition of environmental media; 3) establish a baseline of environmental quality; and 4) identify and quantify new or existing environmental quality problems. The *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office* (DOE 1997a) defines the requirements for effluent monitoring and near-facility, surface and groundwater monitoring necessary to accomplish to goals of DOE Order 5400.1.

The Hanford Groundwater Project was started in 1997 to integrate the groundwater and vadose zone monitoring activities at Hanford in fulfilling the goals and objectives of the *Resource Conservation and Recovery Act of 1976* (RCRA), the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), U.S. Department of Energy (DOE) Orders, and the Washington Administrative Code. Groundwater monitoring at that time was well established partly because of the emphasis placed on groundwater by environmental regulations. Vadose zone monitoring, which lacks a similar emphasis, was limited to geophysical monitoring at dry wells within single shell tank farms and dry wells and groundwater wells at a few liquid effluent disposal facilities. No strategy for sitewide and source-specific vadose zone monitoring existed.

The purpose of this plan is to provide the rationale and general framework for vadose zone monitoring to detect new sources of contamination and track the movement of existing contamination for the protection of groundwater. A similar document with guidance for designing a Data Quality Objective based RCRA groundwater monitoring plan is in preparation (Chou and Johnson in prep.). This monitoring plan addresses some of the elements of a source-specific vadose zone monitoring strategy. This plan describes the technical and administrative controls on vadose zone monitoring in support of the Hanford Groundwater Monitoring Project. Information obtained from implementing this and subsequent site-specific vadose zone monitoring plans will be integrated with other monitoring and technical activities within the Hanford Groundwater Monitoring Project as well as support to all programs and projects at Hanford.

The dominant mission at Hanford is environmental remediation. One important connection between the Hanford Groundwater Project vadose zone monitoring and Hanford remediation activities is through the process identified in the 200 Area soil remediation strategy (DOE 1996). As the vadose zone monitoring project discovers needs for baseline data against which to monitor or needs based on existing borehole surveys, those needs can be passed to the 200 Areas soil investigations for inclusion in appropriate limited field investigations (LFI). Any new characterization facility (e.g., boreholes) may then become additional monitoring points for the vadose project.

This document is not intended to delineate all the specific details of monitoring any particular site. That scope belongs to the site-specific monitoring plans that will be developed for each vadose monitoring task. Instead, this vadose monitoring plan is intended to provide a framework and general criteria directing site-specific monitoring plans and a path to achieve site-specific vadose zone monitoring.

A modified data quality objective (DQO) process was used as a major source of information to produce this plan. The results of the DQO process and subsequent reviews of this plan resulted in a road map leading from the general guidance of this plan to the details necessary in a site-specific monitoring plan. Those results are presented in the DQO chapter of this plan (Chapter 4.0).

It is recognized that vadose zone strategies at Hanford are evolving and that this document will need revision to reflect new priorities and new information.

1.1 Scope

The scope of this plan covers all liquid and solid waste disposal facilities and unplanned releases with two exceptions. First, vadose zone monitoring that is part of the TWRS Program is not considered by this plan. Second, facilities and unplanned releases that currently are undergoing remediation and remediated sites that do not require post-closure vadose zone monitoring are not considered by this plan.

The basic purpose of the monitoring described in this plan is protection of groundwater. This is accomplished by monitoring contaminants in the vadose zone for changes in the subsurface distribution of those contaminants or for changes in soil characteristics that could lead to changes in contaminant distribution. Any changes in subsurface contamination are to be evaluated for impacts on groundwater. Characterization activities are not part of the scope covered by this plan although the vadose monitoring project may recommend site-specific characterization activities to establish a baseline against which to monitor. Where needed, the vadose zone monitoring project may make recommendations for types, sizes and depths of monitoring points and monitoring networks to be protective of groundwater.

1.2 Document Organization

This document consists of four parts. The main part provides guidance for subsequent site-specific vadose zone monitoring plans and includes 1) background information consisting of a brief description of the Hanford Site vadose zone geology and existing monitoring data, 2) a description of the results of the DQO process used for this plan, 3) a prioritization of waste sites that need vadose monitoring, and 4) a general Monitoring and Analysis Plan.

In addition, this document contains three appendices. The first is a general Quality Assurance Project Plan (QAPjP) (Appendix A). That appendix and portions of the main document can serve as part of site-specific monitoring plans. The second appendix (Appendix B) is a detailed description of the prioritization process used to rank liquid waste disposal facilities for vadose monitoring. That appendix will be updated as new information is available. The third appendix (Appendix C) will contain site-specific information for those sites to be monitored during the upcoming fiscal year. The appendix will contain site-specific maps, inventories, constituents of concern, results of previous monitoring, existing subsurface access, existing contamination, applicable regulatory limits, and monitoring frequencies. Appendix C will be updated as necessary to support annual vadose zone monitoring activities.

2.0 Vadose Zone Geology

The stratigraphy of the Hanford site consists of the Columbia River Basalt Group overlain by the Ringold Formation, the Hanford formation and Holocene fluvial and eolian deposits (Figure 2.1). The vadose zone consists of the upper portion of the Ringold Formation, the Hanford formation, local units such as the Plio-Pleistocene unit, and Holocene deposits.

2.1 Ringold Formation

The Ringold Formation is a heterogeneous mix of variably cemented and compacted gravel, sand, silt, and clay. These strata record a history of alluvial and lacustrine sedimentation and pedogenic activity associated with the ancestral Columbia River system between 8.5 and 3.4 million years ago (Fecht et al. 1987). Braided streams and lacustrine settings dominated the depositional environment. Ringold Formation deposits on the Hanford Site represent an eastward shift of the Columbia River from the west side of the Site to the east side.

Lindsey (1996) described the Ringold Formation in terms of five facies consisting of fluvial gravels, fluvial sands, overbank-paleosol deposits, lacustrine deposits and basaltic alluvium. Using these facies, Lindsey (1996) then divided the Ringold Formation into three informal members: the member of Wooded Island, containing five separate intervals designated units A, B, C, D, and E, the member of Taylor Flat, and the member of Savage Island (Figure 2.1).

The Ringold Formation is up to 185 m thick in the deepest part of the Cold Creek syncline south of the 200 West Area. The vadose portion of the Ringold Formation thins from east to west (approximately 16 m (50 ft) to about 13 m (40 ft)) and consists primarily of a slightly silty coarse- to medium-grained sandy gravel (Ringold unit E).

2.2 Intervening Plio-Pleistocene Unit, Pre-Missoula Gravels, and Early "Palouse" Soil

Locally the Ringold Formation and overlying Hanford formation are separated by an informally defined, discontinuous late Pliocene to early Pleistocene deposits.

The Plio-Pleistocene unit unconformably overlies the Ringold Formation in the western Cold Creek syncline near 200 West Area. The unit is up to 25 m (82 ft) thick and consists of basaltic gravels and pedogenic calcrete (Delaney et al. 1991). The eastern edge of the gravel facies occurs along the southwest boundary of 200 West Area. The Plio-Pleistocene unit appears to be correlative to other sidestream alluvial and pedogenic deposits found near the base of the ridges bounding the Pasco Basin on the north, west, and south.

The pre-Missoula gravels consist of quartose to gneissic clast-supported pebble to cobble gravel with a quartzo-feldspathic sand matrix (Delaney et al. 1991). These deposits underlie the Hanford formation near

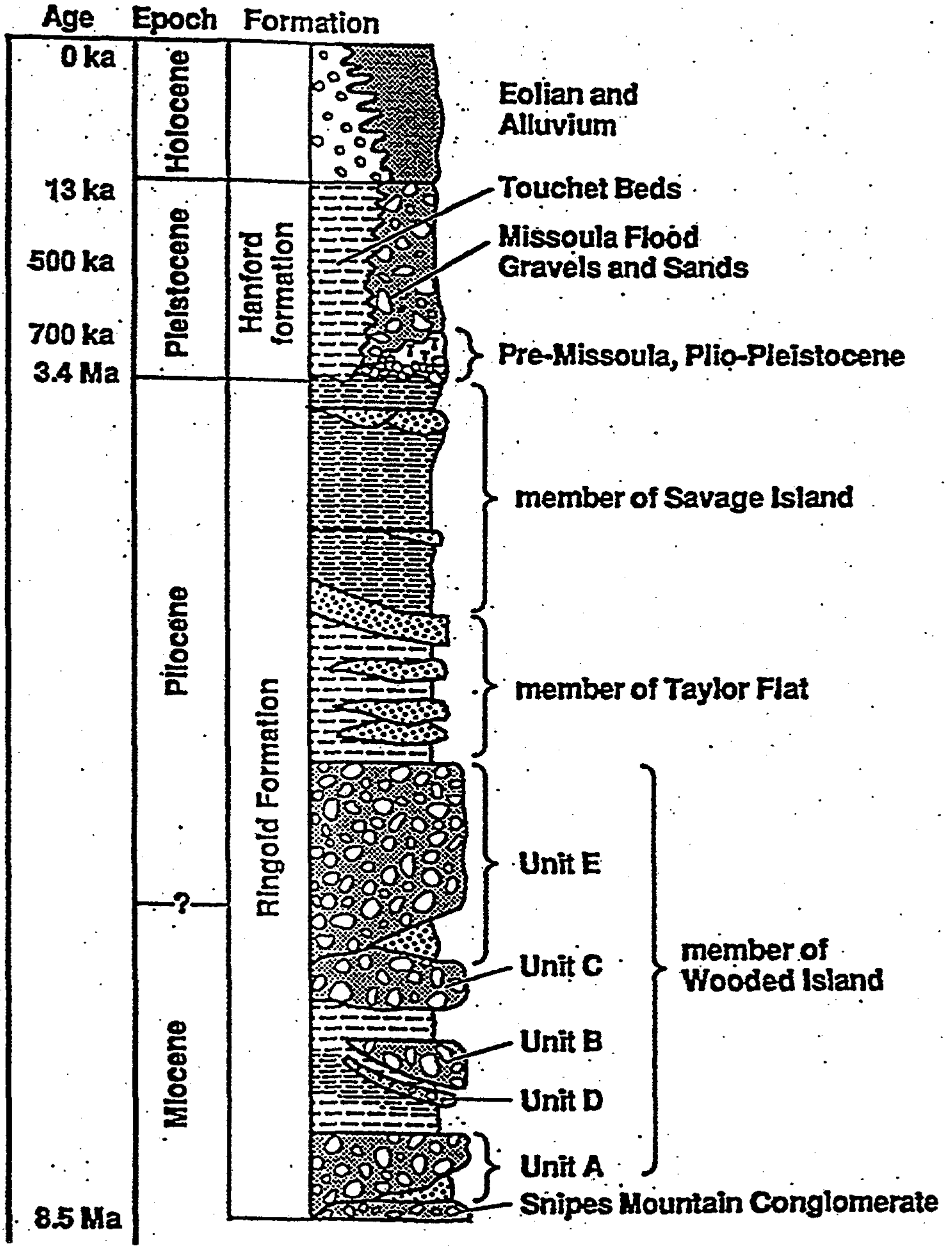

Figure 2.1. Suprabasalt Stratigraphy at the Hanford Site

the 200 East Area. They are up to 25 m (82 ft) thick and are distinguished from the underlying Ringold deposits in that they contain less basalt and have a distinctive bleached color. The nature of the contact between the pre-Missoula gravels and the Hanford formation is not well determined (Delaney et al. 1991).

The early "Palouse" soil consists of up to 20 m (65 ft) of massive and compact silt and fine-grained sand that overlies the Plio-Pleistocene unit in the western Cold Creek syncline around the 200 West Area (DOE 1988). The unit is differentiated from overlying Hanford deposits by greater calcium carbonate content, massive structure, and high natural gamma response in geophysical logs (DOE 1988).

2.3 Hanford Formation

The Hanford formation is an informally named unit that represents all the deposits of the cataclysmic floods of the Pleistocene epoch (2 Ma to 13 ka). The floods came from glacial Lake Missoula, Lake Bonneville, and other ice margin lakes associated with continental glaciers that spread south as far as the present Columbia Plateau. Glaciers damming the lakes may have given way as many as 40 times during late Wisconsin time, allowing impounded water to spread across eastern Washington and form the Channeled Scablands. These flood waters collected in the Pasco Basin and formed Lake Lewis, which slowly drained through the small water gap in the Horse Heaven Hills called Wallula Gap.

Three principal types of deposits were left behind by the Lake Missoula floods: (1) high-energy deposits consisting of gravel; (2) low-energy, slackwater deposits consisting of rhythmically bedded silt and sand, known as the Touchet Beds; and (3) coarse to fine sand deposits representing an energy transition environment. The Hanford formation typically has been divided into a variety of sediment types, facies, or lithologic packages. Recent reports dealing with the Hanford formation (e.g., Delaney et al. 1991; Reidel et al. 1992), have recognized three basic lithofacies: (1) gravel-dominated, (2) sand-dominated, and (3) silt-dominated. These facies generally correspond to the high energy, coarse gravels, the transitional laminated sands, and the lower energy, graded rhythmites respectively (DOE 1988; Baker et al. 1991; and Delaney et al. 1991).

Gravel-dominated strata consist of coarse-grained sand and granule to boulder size gravel that display massive bedding, plane to low-angle bedding, and large-scale cross-bedding in outcrop. Matrix commonly is lacking from the gravels, giving them an open-framework texture. The sand-dominated facies consists of fine-to coarse-grained sand and granules that display plane lamination and bedding and, less commonly, ripple lamination and plane and trough cross-bedding. Small pebbles and pebbly interbeds (<20 cm thick) may be encountered in the sand-dominated facies. The silt content of these sands varies, although where it is low, an open-framework texture may occur. The silt-dominated facies consists of silt and fine- to coarse-grained sand forming normally graded rhythmites. Plane lamination and ripple cross-lamination is common in outcrop.

2.4 Holocene Deposits

Holocene surficial deposits consisting of silt, sand, and gravel form a thin (<5 m) veneer across much of the Hanford Site. These deposits resulted from recent fluvial processes along the Columbia River and sidestream channels and from eolian processes in the central part of the Hanford Site.

2.5 Discontinuities

Discontinuities in the vadose zone sediments can serve as preferential pathways or as barriers to liquids reaching groundwater. The major discontinuities are clastic dikes, faults, fractures and joints.

Clastic dikes are a common geologic feature in the suprabasalt sediments at Hanford. Clastic dikes are generally vertical to subvertical sedimentary structures that cut across normal sedimentary layering. They are most common in the Hanford formation but also have been identified in the Ringold Formation, the Ellensburg Formation, and the Columbia River basalts. Clastic dikes exhibit a wide variation in their dimensions, internal structure, infilling material, and relationships with one another. The most important feature of clastic dikes is their potential to either enhance or inhibit (depending on textural relationships) vertical and lateral movement of contaminants in the subsurface. Black (1979) and Fecht et al. (1998) have compiled most of the information known about clastic dikes in the Pasco Basin.

Faults, fractures and joints are structural discontinuities that can provide potential vertical pathways to groundwater. These features are most common in competent rock near anticlinal ridges but are not confined to only those areas. Faults have been observed throughout the Pasco Basin but are typically sparse away from the major anticlines. Joints and fractures differ from faults in that there is little to no relative movement on either side of the fractures. They are very common wherever competent, brittle deforming rock has undergone folding as in the Pasco Basin. Fractures and joints typically break the cemented rock of the Ringold Formation and caliche layers of the Plio-Pleistocene unit. The uncemented Hanford formation and ductile clay-rich beds of the Plio-Pleistocene unit are probably less susceptible to joints and fractures. However, shrinkage of clay-rich beds as they dry out will produce abundant joints and fractures.

3.0 Past Vadose Zone Monitoring at Hanford

Traditionally, at Hanford, vadose zone monitoring has consisted primarily of borehole geophysical logging using a gamma-ray sonde. The earliest logging was gross gamma-ray logging. Spectral gamma-ray logging has been used at the Site since the late 1970's. Other, but less often used tools included neutron probes for moisture content, temperature probes for tracking the heat of radionuclide decay, and copper foils for alpha tracking. This chapter describes the historical monitoring that has been done at Hanford with particular emphasis on results that have been published and are available to serve as a baseline for future vadose zone monitoring.

3.1 Gross Gamma-Ray Logging

Scintillation well logging started at Hanford in the late 1940's to assess the performance of waste disposal facilities. The earliest, published scintillation probe studies were conducted in 1964 and 1969 to evaluate the distribution, redistribution and decay of radionuclides discharged to the ground from crib facilities. The studies were based on scintillation probe profiles developed from crib monitoring, well-logging operations between 1954 and 1968. The 1964 study (Raymond and McGhan 1964) discusses the disposition of radionuclides beneath most of the crib facilities in use up to 1963, whereas the later study (Tillson and McGhan 1969) discusses only those crib facilities where changes or lack of changes in the scintillation profiles through 1968 were considered significant (Fecht et al. 1977).

Fecht et al. (1977) report gross gamma-ray monitoring results from about 300 wells adjacent to approximately 100 crib facilities. Their purpose was to qualitatively measure the distribution of radionuclides beneath the facilities. They published the resulting scintillation profiles and compared those profiles to previous measurements. Additon et al. (1978a, 1978b) produced an updated catalogue of available scintillation profiles but included no interpretation of the data.

Most of the scintillation logs collected for the above studies were collected with the "third generation" logging system. The system sonde consisted of a 7 cm diameter stainless steel container housing a preamplifier and a 5.1 cm by 5.1 cm NaI(Tl) crystal coupled to a photomultiplier tube. The equipment was not calibrated to today's standards but some calibration was done. Fecht et al. (1977) report that the system had a low detection limit of about 3 pCi (^{106}Ru-^{106}Rh)/ml in water and about 3 x 10^4 millirems (^{226}Ra)/hr in air. The maximum meter count rate in air was 1,000,000 counts/min in a field of about 150 mr/hr. Maximum meter count rate in water occurred at a ^{106}Ru-^{106}Rh concentration of about 5000 pCi/ml (Fecht et al. 1977).

3.2 Spectral Gamma-Ray Logging

Since about 1990 approximately 450 Hanford boreholes have been logged with the Radionuclide Logging System (RLS). The RLS was based on, but highly modified from, its predecessors the Mobile Radiation Analytical Laboratory (MRAL) II and Devan II which had been used at tank T-106 and other sites. The RLS uses logging tools with sodium iodide and intrinsic germanium gamma-ray detectors.

This system, its associated software for quantitative analysis, and calibration facilities brought a degree of quantitativeness not found in the earlier logs.

Many, but not all of the results of spectral gamma logging with the RLS have been reported in topical publications, characterization studies, and unpublished letter reports. All spectral gamma log data collected since 1990 have been cataloged into a database that is available through the Hanford Groundwater Monitoring Project on the PNNL server at \\pnlatlas\geodata.

3.3 Neutron Logging

A neutron soil moisture logging system was designed and fabricated in 1963 to delineate subsurface wetted zones adjacent to liquid waste disposal sites and for use in stratigraphic studies (Sheen et al. 1964). A well (699-11-45A) was drilled and cored specifically for calibration of the neutron probe. Core samples were analyzed for water content, and the well was logged with the neutron probe to relate probe response to water content of the subsurface geologic media. The neutron logging system was extremely sensitive and easily detected a fraction of a percent change in moisture content. Use of the neutron probe was discontinued when more stringent radiation protection measures were implemented that made it difficult to shield operating personnel from the Pu-Be source radiation (Raymond and McGhan 1992). Much of the early neutron logs exist in files, but they have not been collected into a database or a comprehensive catalogue. No interpretation or compilation of early neutron logs has been published.

In 1995, Westinghouse Hanford Company adapted a commercially available moisture tool for use in vadose zone logging at Hanford. Since that time, nearly 50 wells have been logged but most of the data have not been published. Moisture calibration models were constructed in 1994 under a Cooperative Research and Development Agreement (Engelman et al. 1995) and the models currently are available for use.

3.4 Compilations of Logging Data

Several compilations of borehole geophysical logs have been published over the years. These reports did not produce any new data nor accumulate existing data but did enumerate what data exist and referenced sources for its retrieval.

The first such report was by Blair et al. (1981). They cataloged the existing borehole geophysical data collected from about 800 wells between 1954 and 1980. Their report associates the type of log (gamma-gamma, neutron-gamma, neutron epithermal neutron, natural gamma, caliper, and sonic) with the date collected and source well.

Lewis and Pearson (1992) compiled a listing of over 1000 geophysical logs obtained from over 250 monitoring wells in the 100 Areas and adjacent 600 Area. They list, among other things, the type of log, the date collected, the well logged, and the physical location of the log.

Eight similar compilations were made in 1991 and 1992 as part of geologic data packages in support of the Aggregate Area Management Studies. One compilation was made for each of B Plant (Teel et al. 1992), C Plant (Chamness et al. 1992a), PUREX (Chamness et al. 1992b), S Plant (Teel 1992), T Plant (Chamness et al. 1991a), U Plant (Chamness et al. 1991b), Z Plant (Chamness et al. 1991c) and 200 N Area (Chamness et al. 1992c).

3.5 Other Characterization and Monitoring Data Sources

Several special studies have been done over the years at Hanford that produced data and information that may be a suitable baseline for certain types of vadose monitoring.

Over 2,900 wells were constructed on the Hanford Site by 1985 (McGhan et al. 1985). Nearly all of these wells were installed to provide a means for monitoring the waste disposal sites both within the vadose zone and within the upper most aquifer. Under Waste Management Programs at Hanford, numerous waste disposal facilities (including cribs, trenches, french drains, reverse wells, ponds, ditches, and burial grounds) were characterized beginning in the 1950s. Most of these characterizations were primarily limited to the measurement of radionuclide distributions in the sediments around the facilities. Documentation of these studies exist primarily in topical reports and letter reports by Hanford contractors. It is beyond the scope of this document to compile and annotate each of those characterization efforts. As monitoring tasks are implemented, site-specific monitoring plans will be written and those plans will describe existing characterization data appropriate to compare with newly acquired monitoring data.

3.6 Uses of Historical Data for Current and Future Monitoring

The major use of historical information for vadose zone monitoring is as baseline information against which to compare new information. It is recognized that the pedigree of some older data is unknown and that some older data were not collected in a manner that could meet today's QC standards. Nevertheless, much of the older data, when properly qualified, is useful for comparisons with new information to determine changes in subsurface contaminant distribution.

4.0 Data Quality Objectives Process

4.1 Introduction

Chapter 4.0 addresses the relevant components of the general data quality objectives (DQO) process as they apply to vadose zone monitoring at the Hanford Site. This chapter describes the outcome of the DQO process as it was applied to vadose zone monitoring. The authors of this plan met with key individuals who have been involved with vadose zone activities across the Hanford Site. These individuals were asked to discuss the vadose zone and their perspective on what should or should not be done, why it should or should not be done, and how it should be done. The individuals included geoscientists from Bechtel Hanford Inc., the Prime Hanford Management Contractor, and Pacific Northwest National Laboratory representing a wide variety of projects including the Integrated Groundwater-Vadose Zone Project and the Tank Waste Remediation Systems (TWRS), in order to obtain a wide range of perspectives. Each participant had an opportunity to review this plan during its preparation.

4.2 Description of Data Quality Objective Process and Limitations

Data Quality Objectives ensure that the type, quantity, and quality of environmental data used in the decision making process are appropriate for their intended applications. The process for developing DQOs involves seven steps:

- statement of problem (Chapter 4.4)
- decision and expected action (Chapter 4.5)
- decision inputs (Chapter 4.6)
- study boundaries (Chapter 4.7)
- decision rule (Chapter 4.8)
- limits on decision errors (Chapter 4.9)
- optimize sampling design (Chapter 4.10)

The DQO process has both a quantitative and a qualitative aspect. The quantitative aspect seeks to use statistics to design the most efficient field investigation that minimizes the possibility of making an incorrect decision. The qualitative aspect seeks to encourage good planning for field investigations and complements the statistical design. The DQO process is designed to be both flexible and iterative.

This vadose zone monitoring plan specifies the type, quantity, and quality of data needed to support decisions related to monitoring the vadose zone at hazardous waste sites.

4.3 Data Requirements and Regulatory Drivers

The principal driver for monitoring the vadose zone is protection of groundwater. Although there are no regulations requiring vadose zone monitoring, such monitoring is being considered as an alternative or an extension of groundwater monitoring for at least one RCRA regulated facility, the Liquid Effluent

Retention Facility (LERF). Declining water levels beneath the LERF will soon render the current groundwater monitoring network non-compliant with established groundwater protection standards (40 CFR 265, WAC 173-303-645). Although neither the Environmental Protection Agency (EPA) nor the Washington State Department of Ecology (Ecology) has promulgated regulations relative to RCRA vadose zone monitoring, the DOE and Ecology have proposed vadose monitoring activities for the Hanford Site. An alternative monitoring strategy is necessary to maintain RCRA compliance at LERF and vadose zone monitoring is considered to be one component of the strategy.

DOE Order 5400.1 specifies an environmental surveillance program designed to monitor the effects of DOE activities on on-site and offsite environmental and natural resources. At Hanford, effluent monitoring and near-facility, surface and groundwater monitoring have been established to accomplish the goals of DOE Order 5400.1. Vadose zone monitoring is one of the approaches to augment near-facility and groundwater monitoring.

The DQO process participants concluded that in spite of the absence of any regulatory driver for monitoring the vadose zone such monitoring is in the best interests of the DOE and the public because it represented the *best management practice* for the Hanford Site. Most of the waste disposed to the vadose zone remains in the vadose zone and most groundwater plumes originated from waste in the vadose zone. Once waste has reached the groundwater, the difficulty and expense of cleaning it up greatly increases. Thus, monitoring the vadose zone contributes to an early warning system that can head off potentially expensive groundwater remediation.

4.4 Statement of Problem

The overall goal of vadose zone monitoring is protection of groundwater through monitoring changes in subsurface contaminants. Vadose zone monitoring provides an early warning system with respect to hazardous material moving through the vadose zone to the groundwater. Early detection can save money on expensive corrective actions and protect natural resources. Periodic measurement of the concentration and distribution of vadose zone contaminants accomplish this goal.

To develop the DQOs that adequately address vadose zone monitoring data needs, the overall performance objective or goal must be identified. One objective of monitoring is to support the Hanford Groundwater Project by providing information on contaminant movement in the vadose zone before it reaches the water table. A second objective is to collect data that can be used to demonstrate that radiological and hazardous contaminants will or will not exceed applicable groundwater standards (e.g., WAC 246-290, WAC 173-200, 40 CFR 141, 40 CFR 143 and DOE Order 5400.5) or that contaminants will or will not cause unacceptable health risks (e.g., $>10^{-4}$). The first objective is the primary objective of this plan. The second objective requires an assessment of the amount and rate of movement of contaminants through the vadose zone and their impact on the groundwater. This assessment is beyond the scope of this plan but vadose zone monitoring as described in this plan is designed to collect data that can support both of these objectives.

As discussed above, there are no applicable regulatory standards for vadose zone monitoring. Therefore, the problem that vadose monitoring should address is:

Will contamination in the vadose zone migrate to the groundwater and result in the exceedance of applicable groundwater standards or pose an unacceptable risk to human health or the environment?

4.4.1 Conceptual Model Considerations

Part of the first step in the DQO process is the development of a conceptual model of the processes to ensure that the type, quantity, and quality of monitoring data to be collected are appropriate for the intended use.

The principal element of a vadose zone model of the Hanford Site is the stratigraphy (see Chapter 2.0). The stratigraphic units of the vadose zone form a series of nearly horizontal layers across the site. The horizontal layering is locally cut by clastic dikes and by joints in the more competent units. Clastic dikes are vertical to subvertical sedimentary structures that cut across normal sedimentary layering. Both of these features have the potential to provide preferential pathways to the water table. In addition, poor borehole construction from past installations also may provide conduits to the water table. Finally, and although not directly related to the vadose zone stratigraphy, the high salt content of some disposed waste can also lead to preferential flow, or fingering, through the vadose zone.

Because of the limited information available for the subsurface, there is a great uncertainty associated with the conceptual model. Boreholes are the main source of information followed by limited geophysical data. Some sites have just a few boreholes while others have higher degrees of characterization. Thus the uncertainty will vary from site to site and can not be generalized for the Hanford vadose zone.

In the past, contaminants were directly discharged to the vadose zone with the intent that they would be immobilized due to the sorption properties of the soil. The capacity of the discharge areas varied and some sites received more waste than could be captured by the soil column. In sites that exceeded their capacity the more mobile constituents reached the water table producing the present groundwater plumes. At the low volume sites, where much less effluent was discharged, the mobile constituents have been retained in the soil column and are only slowly draining to the water table under either natural or artificial recharge conditions.

The important factors in this conceptual model were brought out during the DQO process and include: 1) the constituents disposed to the soil column, 2) the migration or exposure pathways, and 3) the driving force. Any combination of unfavorable factors could result in contaminants migrating to the water table and producing or adding to a groundwater plume. Therefore, the conceptual model that this DQO process addresses is one where the mobile and hazardous contaminants that were disposed to the vadose zone are migrating to the water table. The driving force is either natural or artificial recharge.

4.4.2 Resource Constraints

At this time, the principal resource constraints are 1) the lack of proven technologies to detect some of the constituents of interest in the soil or to detect them at the required level of detection, 2) budget constraints, and 3) the lack of a baseline for some sites.

4.5 Decision and Expected Action

The second step in the DQO process is to identify the key decisions that will be made with the monitoring data and any alternative actions that may be taken based on the findings of the monitoring program. The first decision to be made is:

Is there a need to monitor the vadose zone at a specific site?

The relevant decision that will be made using the vadose zone monitoring data is:

Are contaminants migrating through the vadose zone and likely to reach the water table and exceed applicable drinking water standards, other applicable environmental standards, or pose unacceptable environmental risks?

The actions that may be taken depend on the answer to this question. If there is no impact then no action is required. If there is an impact then the action to be taken at a site depends on the level of the impact and the status of the site.

4.6 Decision Inputs

There are three main factors that need to be evaluated for each site in order to arrive at the correct answers to these questions:

1. What are the constituents of concern?

The constituents of concern that were disposed at a waste site is the most important factor to be considered for vadose zone monitoring. The vadose zone monitoring DQO process established the specific constituents of concern for Hanford waste sites and categorized them into three groups: mobile constituents, long-lived radionuclides, and moisture (driving force).

Mobile constituents are those compounds or ions that can readily move through the soil column without being sorbed or reacting with the soil and being significantly delayed as they move downward through the vadose zone. Mobile constituents can be essentially non-reactive, complexes or move by colloidal transport. Long-lived nuclides are those that will not decay before reaching groundwater. A working definition of a long-lived nuclide is one that would take 20 half-life (10^6 reduction) to reach groundwater at the Darcy velocity.

Not all hazardous constituents disposed to the vadose zone are mobile or long-lived or even present in significant abundance. Under the right conditions, a relatively immobile radionuclide (such as ^{239}Pu) could reach the water table before it has decayed and thus significantly affect the groundwater. A hazardous and mobile but low abundant constituent of concern, even if it is long lived, might not significantly affect groundwater if it does not reach the water table in high enough concentrations. Therefore, the abundance and mobility of a radio-contaminant must also be considered along with its half-life.

The DQO effort enumerated the important constituents of concern as the mobile contaminants technetium-99, iodine-129, nitrate, uranium, chromium, carbon tetrachloride, cyanide, and soluble aluminum and the immobile and/or moderate or long-lived radionuclides of plutonium, americium, and cesium.

The DQO process brought out that some of the constituents of concern are not readily detectable using standard monitoring techniques so surrogates may need to be used. Moisture was considered a constituent of interest because moisture may serve as a surrogate for mobile contaminants and also because moisture is the driver for contaminant movement in the subsurface. Therefore, moisture was included as a constituent of interest.

2. What is the recharge rate?

Artificial or natural recharge is the driving force for migration of contaminants in the vadose zone and the next most important factor after constituents of concern. The amount of recharge is site dependent. Natural infiltration affects all waste sites but the infiltration rates are greater where vegetation is lacking, no cover is present, or the overlying material is coarse grained. Artificial recharge historically has been the greatest source of recharge and can come from a variety of sources including other waste sites, broken water lines, and runoff from natural precipitation that has been channeled or otherwise concentrated in a smaller area by surface features. Localized variations in recharge can have significant effects on the potential for constituent transport. Some sites have had many pore volumes of liquid added to the site, effectively flushing the mobile constituents down to the water table.

3. What are the flow paths through the vadose zone?

The dominant flow path through the vadose zone is the most difficult factor to quantify. The conceptual model for the vadose zone is one of horizontal layering with features such as clastic dikes or poorly constructed boreholes that might provide conduits to the water table. Horizontal layering will cause lateral spreading as it impedes downward movement of moisture; perched water is not uncommon at Hanford. If these layers become saturated then horizontal layering can have little effect on slowing downward migration. The principal flow path for a site will be dependent on a combination of these factors and thus will be difficult to predict without detailed characterization.

4.7 Study Boundaries

This section identifies the spatial and temporal domain boundaries needed to address the decision rules. This step in the DQO process defines the set of boundaries covered by the decision(s) being put forth.

- *Spatial Boundaries*. The spatial boundaries for vadose zone monitoring should include the actual disposal site plus the area that could be impacted by migration from the disposal site. The area impacted is that area where lateral spreading could occur. At present there are established regulatory compliance boundaries only for RCRA regulated sites. Most past liquid waste disposal sites are not covered under RCRA and, therefore, have no established regulatory boundaries.

The disposal site boundaries are well defined but it is difficult to estimate the extent of lateral spreading. Characterization activities should define the extent of lateral spreading but the characteristics of each waste site will need to be considered in establishing the specific spatial limits of a site.

- *Temporal Boundaries*. The temporal boundary includes how often is it necessary to monitor and how long monitoring should be done. Infiltration rates are probably the dominant factor controlling the rate of contaminant migration. Unless a waste disposal site is an active site or near a site that is receiving effluent (e.g., B-Pond), downward migration could be assumed to be slow because natural recharge is low. Thus, infiltration rates can be used as a method for estimating the relative frequency needed for monitoring. The presence of long-lived constituents will be the controlling factor for how long it will be necessary to monitor a site.

  The current status of a waste site is also a factor in defining temporal boundaries. All else being equal, inactive waste sites require less frequent monitoring than do active waste sites. Finally, sites with signs of recent contaminant movement should require more frequent monitoring than sites with a history of no contaminant movement.

4.8 Decision Rule

As described in the DQO guidance manuals, this step integrates previous steps into a statement that describes the logical basis for choosing among alternate actions. This involves specifying 1) the constituents of interest, 2) need for monitoring at a site and the site's priority level, and 3) the monitoring methods that could be employed. These elements are then combined into **"if-then"** statements that can be used for developing the decision rules that can then be applied for determining if a site needs to be monitored, its priority, and the appropriate monitoring techniques.

1. Is there a current impact to groundwater at a site? Is there a known groundwater contamination plume emanating from the site and is it above some applicable standard? If there is a current impact on groundwater at the site, then contaminants at the site are migrating into the groundwater and vadose zone monitoring can not be used as an early warning system for groundwater contamination. However, vadose zone monitoring still can provide information on the rate of migration and how long the site may continue to impact the environment. If the site has already affected groundwater, then monitoring the site should receive a lower priority.

2. Are there vadose zone plumes associated with the sites? Has past monitoring or baseline characterization shown that there is a known vadose zone plume at the site? If there is a known vadose zone plume at the site and if the magnitude of contamination could cause groundwater to exceed regulatory limits, then the vadose zone at the site should receive a higher priority for monitoring.

3. Is there a potential for future impact to groundwater? Are their known conditions such as high recharge that would lead one to suspect that the site could impact groundwater in the future? If there are conditions that would likely exceed a groundwater limit, then the site should receive a higher priority for monitoring.

4. Are there mobile contaminants at the site? If there are mobile contaminants at the site, then the site should receive a higher priority for monitoring.

5. Are there driving forces external to the site? Is the site in an area where some conditions such as a nearby waste site that could result in driving mobile contaminants to the water table? If there are external driving forces, then the site should be given a higher priority for monitoring.

6. Are there long-lived contaminants associated with the site? Are there constituents at the site that, even in small quantities, are so long lived that they could provide hazardous conditions in the future? If there are long-lived radionuclides, then the site should be given a higher priority for (but perhaps less frequent) monitoring.

7. Are characterization and/or baseline data available? Has the site been adequately characterized so that potential pathways and soil conditions are known? Has a baseline survey been done at the site so that future monitoring can be compared to it? If a baseline exists then the site should be given a higher priority. If no baseline or characterization data are available but, if a baseline can be established using monitoring tools then the site should be given a higher priority. The baseline for these latter sites will consist of the first in a temporal line of monitoring events. If no baseline or characterization data are available and available monitoring methods can not establish a baseline, then the site should be given a lower priority for monitoring and recommendations should be made to complete a baseline survey and site characterization.

8. Is there a current threat imposed by site conditions on the environment? Are there known or suspected factors or conditions that would lead one to believe that the site is or could impact groundwater? If there is a current threat to the environment by the site, then the site should be given a higher priority for vadose zone monitoring.

9. Is there a regulatory reason to monitor? Are there applicable laws or regulations that require a site to be monitored? If there is no regulatory reason to monitor, then the site should be given a lower priority for monitoring.

10. Is the site in an area that is currently receiving liquid effluent? Are facilities currently discharging hazardous or radioactive waste to the soil at the site? If the site is currently receiving liquid effluent, then the site should receive a higher priority for monitoring.

11. Have mobile constituents been "flushed" from the vadose zone? Has the site received so much liquid that mobile constituents could have been completely removed from the soil column and flushed into the groundwater? Did past practice activities dispose high volumes of liquid that could have remobilized the hazardous or radioactive waste and removed it from the soil column? If the site has had several pore volumes of liquid put through it that contained no hazardous, mobile or long-lived compounds, then mobile constituents may have been flushed from the site and there may be no reason to monitor the vadose zone. If, however, immobile and long-lived contaminants were disposed to the site, they may not have been flushed and vadose monitoring may be appropriate. If the site has been flushed of contaminants, then the site should be given a lower priority for monitoring.

4.8.1 Statistical Parameters of Interest

The statistical term "population" refers to the total collection of objects or media to be studied and from which a sample is to be drawn. For the vadose zone the population is the contaminant plume in the vadose zone. The principal parameter to be measured is the change in concentration of constituents of concern at any point in the vadose zone. The principal problem is how to obtain a measurement of that parameter in the subsurface in an efficient and cost-effective manner, and is that measurement appropriate for statistical analysis?

For groundwater monitoring, appropriate statistical analysis is prescribed in the regulations. For vadose zone monitoring, analogous regulations do not exist so that the appropriate statistical analysis for vadose monitoring is that which adds to answering the question "Will contaminants in the vadose zone adversely impact groundwater?" Table 4.1 lists the principal conceptual model elements and the statistical parameters of interest which are used to evaluate whether contaminants in the vadose zone will adversely impact groundwater.

There are several ways to obtain information from the subsurface. Boreholes are a common method of taking subsurface measurements. Either new boreholes can be drilled and samples collected and analyzed or existing boreholes can be used and estimates of constituents of concern measured using some appropriate techniques. In addition, non-borehole techniques, such as lysimeters, excitation of mass, or surface geophysical methods can be used to locate moisture zones in the soil. Each technique has its own requirements and constraints, and each method has different ways of obtaining the principal parameter. In addition each has its own cost associated with obtaining data using that method and the DQO process is designed to take into account the cost of obtaining information.

Table 4.1. Parameters of Interest

Conceptual Model Element	Property or Parameter	Constituents of Interest	Sampled Population	Statistical Parameters
Constituents Disposed to Soil Column	Half-life, Mobility	^{99}Tc, ^{129}I, NO_3^-, U, Cr, CCl_4, CN^-, Al, ^{241}Am, ^{137}Cs, ^{239,240}Pu	Boreholes	Central tendency
Driving Force	Long-term Recharge Rate	Water (moisture)	Lysimeters Tensiometers, Environmental tracers, Other	Central tendency
	Contemporary Recharge Rate	Water (moisture)	Lysimeters Tensiometers, Environmental tracers, Other	Central tendency
Pathways	Site Characterization	NA	NA	NA

4.8.2 Action Level or Measurement Threshold

This element is generally taken as a cleanup standard or other regulatory standard. Because there is no regulatory standard, the action level will be taken as the point where it can be conclusively demonstrated that contaminants from the vadose zone will impact the groundwater in such a way that an applicable groundwater standard may be exceeded.

4.8.3 Alternative Actions

Exceedance of the performance standard may require that some action be taken. The action may be remediation of the site, an alternative to remediation such as construction of a barrier over the site to decrease recharge, repair or maintenance of a leaking source that is impacting the site, maintenance of the site, or no action. The choice and implementation of alternative actions involving remediation are beyond the scope of this plan but the decisions fall out of the "If-then" statements at the beginning of this section. A tentative "If-then" statement for alternative actions, is:

> **If waste from the vadose zone beneath a site is impacting, or will impact the groundwater, then monitoring should continue pending use of some engineering methodology to decrease or stop the driving force for the contamination or remove the source of contamination.**

4.9 Limits on Decision Errors

This step of the DQO process specifies the limits on decision errors that are deemed tolerable. Errors related to input data acquisition consist of both sampling and measurement components. The combination of these errors is the **total study error**, which is directly related to the decision error.

A decision error occurs when the data lead the decision maker(s) to believe 1) the null hypothesis is false when it is actually true (a false positive) or 2) the null hypothesis is true when it is actually false (a false negative). To reduce such errors, an adequate estimate of key population parameters is needed. Reducing such error generally involves greater cost for sample collection and analysis. However, reducing decision error at an increased cost may or may not be the most desirable approach to take.

For site vadose zone monitoring, the statistical parameter of concern is the change in subsurface contamination as either an increase in concentration or a change in depth distribution. The main factors needing evaluation are the constituents of concern and recharge (see Table 4.1). (Flow paths are a third factor needing evaluation but that is part of characterization instead of monitoring.) Obtaining values for change in constituents of concern and recharge is dependent on the method of collecting the data. Direct drilling and sampling is one approach, utilization of existing boreholes is another approach, and surface surveys are a third approach.

As stated above, the statistical parameter of concern is change. Any change in concentration of a constituent of concern at a specific point in the subsurface is determined by comparing most recent monitoring data with previously collected data. A change in concentration at sites with sufficient past monitoring to establish a baseline is considered to be an increase in concentration of 2 sigma from the baseline value.

For sites without sufficient baseline data, a change in concentration is considered to exist if the most recent monitoring value differs from the previous value by more than 2 sigma error on the measurement. For geophysical logging this is determined from counting statistics.

Calibration issues are dependent on the specific monitoring technology used for data collection. Likewise, measurement errors are dependent on the specific monitoring technology. These errors can be considered in site-specific monitoring plans after a monitoring method is chosen for an individual site.

Errors associated with sample acquisition are dependent on the method of collecting the sample and the variation in the environment being sampled. As mentioned above, direct drilling and sampling, using existing boreholes, and surface measurements are three possible ways to obtain data. Different monitoring methods can use each of these accesses to samples. Errors associated with sampling are to be discussed in site-specific monitoring plans where specific methodologies are delineated.

4.10 Optimizing Sampling Design

This final step in the DQO process is intended to develop alternative environmental sampling designs and evaluate their efficiency at providing the data for meeting the overall performance objective. The purpose is to identify the most resource-effective sampling design. Application or implementation of the DQO process described in this and previous sections and additional operational details are described in Chapter 6.0 and in the respective site-specific sampling and analysis plans (SAPs).

As indicated, the primary focus of the DQO process has been on obtaining measurements to determine if the constituents of concern have migrated in the subsurface. The most resource efficient sampling design is the use of existing and readily available methodologies, that require a minimum of resources for data collection and data interpretation, and utilize available access to subsurface contamination (see Chapter 6.1.4 for a discussion of potential limitation on the use of existing boreholes).

4.11 Site-Specific Vadose Zone Monitoring Strategy

Table 4.2 summarizes the major elements of the strategy behind the development of site-specific vadose zone monitoring. This plan recognizes that the strategy for vadose monitoring at Hanford is evolving and elements in this plan will need to follow that evolution. However, Table 4.2 provides the overall process that is necessary to develop site-specific monitoring. The following chapters elaborate on the elements in the table and provide the rationale for prioritizing waste sites, selecting the constituents of concern and selecting monitoring methods.

Table 4.2. Elements of Vadose Zone Monitoring

Vadose Zone Monitoring Component	Element	Requirement or Procedure	Documentation
Assessment of Liquid Effluent Disposal Facilities	List of Prioritized Facilities	DQO Process	This Plan
	Define Data Needs		
Site-Specific Vadose Zone Monitoring Plans	Conceptual Model.		Site-Specific Plan
	Identify Site-specific Data Needs		
	Evaluate Site-specific Data		
	Develop Vadose Zone Monitoring Network		
Site-Specific Monitoring	Sampling and Analysis Plan	Best Management Practice	
	Procure Data Collection Services	Groundwater Project QAPP	Laboratory Contract, Logging Contracts, SOWs
	Coordinate with Team Members and Supporting Services		
	Field Inspection of Facilities and Boreholes	Best Management Practice	Field Inspection Forms, Borehole Completion Reports
	Data Collection	Vendor-specific QAPP, Vendor-specific Procedures, SW 846	Chain-of-Custody, Sample Field Records, Borehole Survey Data Sheets, Calibration Certificates, Laboratory Analytical Records, Analytical Data Sheets
	Quality Control	Vendor-specific Procedures, Vendor-specific QAPP, Groundwater Project QAPP,	Chain-of-Custody, Sample Field Records, Borehole Survey Data Sheets, Calibration Certificates, Laboratory Analytical Records, Analytical Data Sheets
Data Analysis and Interpretation	Comparison with Past Monitoring Data.		
Data Management	Maintenance of Data Bases	Groundwater Project QAPP	HEIS Database, PNNL geophysics database
Reporting			Hanford Site Groundwater Monitoring Reports, Hanford Site Environmental Reports

5.0 Site Prioritization

This chapter briefly describes the process used to prioritize liquid and solid waste disposal sites to determine the needs for vadose monitoring. A more complete description of the prioritization process is given in Appendix B.

5.1 Prioritization Process

The DQO process led to the following criteria to be applied to determining the need for vadose zone monitoring at each waste site (see Chapter 4.8).

1. Is there a current threat imposed by site conditions on the environment?
2. Is there a regulatory reason to monitor?
3. Are there mobile contaminants associated with the site?
4. Are there long lived constituents associated with the site?
5. Have mobile constituents been "flushed" from the vadose zone?
6. Is there a potential for future impact to groundwater?
7. Are there vadose plumes associated with the site?
8. Is there a current impact to groundwater at the site?
9. Is the site in an area that is currently receiving liquid effluent?
10. Are there driving forces external to the site?
11. Are characterization and/or baseline data available?

These criteria were applied to each waste site in the 200 Areas. The *Waste Site Grouping for 200 Areas Soil Investigations* (DOE 1997b) was used as a pre-prioritized list of sites. Positive responses to the criteria included the site on the highest priority list; negative responses relegated the site to a lower priority list. Decision rules were combined when possible. Sites remaining on the lists after all eleven criteria were applied were further prioritized according to the type of facility (e.g., specific retention, crib) and how recently the site had been monitored.

The criteria "Are there mobile contaminants associated with the site?" considered technetium-99, iodine-129, nitrate, uranium, chromium, carbon tetrachloride, cyanide, and soluble aluminum as the mobile contaminants of concern. There were no data for aluminum available in the right format to include in this prioritization effort. Some data about aluminum inventories exist in some of the source aggregate area management study reports and that data can be included in subsequent efforts.

5.2 Prioritization Results

The results of the prioritization effort are given in Appendix B. Table B.1, in the appendix shows the highest priority sites. Sixty two sites are on the high priority list. These are the LERF, the 100-KE Basin, and sites 1) with associated constituents of concern, 2) that have not had the mobile constituents "flushed" from the soil column (sites at which 10 or less pore volumes of effluent were disposed - see Appendix B for rationale for 10 pore volumes), and 3) that have data available to serve as baseline for monitoring.

Also in Appendix B are Table B.2 and Table B.3. Table B.2 lists the priority sites that have associated constituents of concern, less than or equal to ten pore volumes but no associated baseline information for monitoring. Table B.3 shows the intermediate priority sites that have long-lived, relatively immobile constituents of concern but received greater than ten pore volumes.

Within each of the tables in the appendix sites are further prioritized as follows. First, the relative ranking of waste site groups has been retained from *the Waste Site Grouping for 200 Area Soil Investigations* (DOE 1997b). Then, within each waste site group, individual sites are ranked first by waste site type, second by amount of natural recharge, and third by the date that the site was last monitoring. When ranking by waste site type, specific retention facilities were placed higher on the list than other sites. This essentially ranked the sites according to decreasing pore volume because effluent discharged to specific retention facilities was usually limited to 10 percent or less of the available pore volume between the facility and the groundwater.

6.0 Monitoring and Analysis

This document is a general plan that describes the rationale and general procedures for data collection and data analyses to be used during vadose zone monitoring. Subsequent revisions to this plan will include an appendix with site-specific maps, available subsurface access, constituents of concern, past monitoring results, and any applicable regulatory limits for each site to be monitored. Based on that information, site-specific monitoring plans will be prepared annually for those sites to be monitored during that year. Monitoring methods and monitoring frequencies will be included in the site-specific monitoring plans.

6.1 Vadose Monitoring

The tasks involved in vadose monitoring include:

- Determination of facilities to be monitored
- Selection of constituents of interest
- Selection of monitoring techniques
- Designation of the monitoring network
- Pre-monitoring activities
- Acquisition of monitoring data
- Data handling
- Data analysis
- Data interpretation
- Documentation
- Data Management
- Reporting

6.1.1 Facilities To Be Monitored

Chapter 5.0 described the process and results of an initial prioritization of sites for vadose zone monitoring. Revisions to the prioritization will be required as new information becomes available, as new Site priorities develop, and as remediation efforts progress.

Monitoring for carbon tetrachloride is deferred at active carbon tetrachloride remediation sites in the 200 West Area. Two remediation activities for the carbon tetrachloride expedited response action are 1) the CCl_4 pump and treat at 200-ZP-1 Operable Unit and 2) the Soil Vapor Extraction at 200-ZP-2 Operable Unit. Monitoring for CCl_4 at these sites may be implemented after remediation to support post remediation evaluation and long term monitoring.

6.1.2 Selection of Constituents of Concern

The constituents of concern were determined during the DQO process. They include the mobile species ^{99}Tc, ^{129}I, nitrate, chromium, carbon tetrachloride, cyanide, aluminum, and uranium and the immobile and/or long-lived radionuclides of plutonium, americium, and ^{137}Cs. In addition, moisture was repeatedly mentioned during the DQO process and is included as a constituent of interest.

Moisture is included as a constituent of interest because it is a primary driving force for movement of contaminants in the subsurface. Also, no readily available method to monitor some of the mobile constituents of interest currently exists (^{99}Tc, nitrate and ^{129}I, for examples) thus, moisture movement may provide an indication of movement of the more mobile constituents.

6.1.3 Selection of Monitoring Methods

Selection of a monitoring method depends on technical, implementation, environmental and regulatory, and economic considerations. The most important technical consideration is "Can the method detect the constituents of concern/interest at the required levels?". The availability of the method, its level of development, its complexity and reliability are also important technical considerations.

The effort to implement the monitoring method depends on the availability of the method, appropriate access to the subsurface, level of maintenance, calibration considerations, and the time involved in actual monitoring.

Environmental and regulatory considerations include whether permits are required to use the method, health and safety risks during installation, monitoring, maintenance, and calibration, generation of secondary wastes during monitoring, and any environmental effects remaining after monitoring is completed.

Economic considerations include the costs of installation, maintenance, and calibration as well as costs of monitoring and data analysis and interpretation.

Table 6.1 lists some technically, environmentally, and economically viable monitoring methods for the constituents of interest. The information listed in Table 6.1 is abstracted from Lewis and Teel (1994), from Wilson et al. (1995), and from input received during the review process of this document. Lewis and Teel (1994) evaluated 32 technologies for use in leak detection at Hanford. Some of the technologies they evaluated may also be applicable to vadose zone monitoring. Table 6.1 is not an exhaustive list of potential vadose monitoring technologies nor are all technologies listed equally feasible. Selection of a specific technology for monitoring will be a function of specific site characteristics and will be documented in site-specific monitoring plans. Regardless of the method selected, it must provide reasonable coverage, be cost effective, provide early warning of contamination or contaminant migration, and be implementable at Hanford.

6.1.4 Determine the Monitoring Network

6.1.4.1 Monitoring Points

Gilbert (1987), in discussing the important considerations in designing a monitoring network, states that the crucial point is defining the target population to achieve the study objectives. The statistical parameter of concern (i.e., the study objective) for vadose zone monitoring is change in contaminant

Table 6.1. Monitoring Methods Applicable to the Constituents of Interest

Constituent of Interest	Method	Comments
In-situ Measurement of Constituents of Interest		
Uranium, Cs-137, Plutonium, Americium	Gross Gamma-ray Logging	Reliable, easy and quick to operate; ease in data analysis; limited depth of investigation (about 8 in. radial distance from well); detection limit between 2 and 500 pCi/g (^{137}Cs); long history of use at Hanford; can use existing drywells; can not distinguish among radionuclides.
	Spectral Gamma-ray Logging	Commercially available; more complex than gross gamma-ray logging; can resolve specific radionuclides (^{60}Co, ^{137}Cs, ^{152,154} Eu, ^{235,238}U, ^{239,241}Pu, ^{233}Pa, ^{241}Am, and others) ; limited depth of investigation (about 8 in. radial distance from well); detection limit between about 0.2 and 1000+ pCi/g (^{137}Cs) for solid state detector; some detectors saturate at high count rates; can use existing drywells;
Uranium, Plutonium, Americium	Prompt Fission Neutron Logging	Commercially available; limit depth of investigation (about 8 in. radial distance from well); lower detection limit about 1 nCi/g (^{239}Pu); can use existing drywells; system cannot distinguish fissionable nuclides (U-233, U-235, Pu-239)
CCl$_4$, Aluminum	Pulsed-neutron Logging	Commercially available with either scintillation or solid state detectors; more difficult to operate and to process and analyze data than other methods. System can detect H, Cl, C, O, Al, Si, Ca, S, and Fe.
CCl$_4$	Various Mass, Optical, and Electrochemical Sensors	Emerging technologies
Water Content	Neutron-neutron Logging	Commercially available; limit of investigation about 4 ft^3, detection limits between about 1% and 40% H$_2$O; can use existing steel-cased drywells.
	Electrical Induction Logging	Commercially available; can see up to 6 feet into formation; detection limit about 5% to 100% fresh H$_2$O; can not operate in steel-cased boreholes.
	Pulsed-neutron Spectroscopy	Commercially available with either scintillation or solid state detectors; more difficult to operate and to process and analyze data than other methods; limit of investigation between 1% and 40% H$_2$O.
	Electrical Resistivity Tomography	Not commercially available; detection limit unknown (requires change in moisture content); can not use existing boreholes.
	Ground Penetrating Radar (Including Borehole)	Commercially available; surface antennae can scan large areas; detection limits are dependent on site specific calibration, independent local measurements may be required.
	Shear-Wave Seismic Tomography	Recently commercially available; labor intensive; detection limit is 10% to 15% change in water saturation; can use existing boreholes.
	Time Domain Reflectometry	Recently commercially available; point measurement; detection limit 1% to 40% H$_2$O; can use existing boreholes with modifications.
	Capacitance Probes	Commercially available; detection limit dependent on site-specific calibrations and access borehole configuration; small zone of influence; repeatability better than 0.005 volumetric water content; large sensitivity to small changes in water content in dry soils; can not use existing dry wells.
	Electromagnetic Induction	Commercially available; quick and easy to operate; can provide estimates over large areas; does not require boreholes; can detect small variations in soil conductivity but calibration to water content is difficult

Table 6.1. (contd)

Constituent of Interest	Method	Comments
	Resistivity Blocks	Commercially available; work poorly in coarse-grained soils; point measurement; detection limit about –1 bar to –0.1 bar; can use existing boreholes with modifications.
Direct Sampling and Ex-situ Analysis		
All those above plus technetium-99, iodine-129, nitrate, chromium, and cyanide	Lysimeters (suction samplers)	Various samplers are commercially available; most samplers can not be used with existing boreholes; difficulties in dry soils (effective range 0-60 bars of suction); requires analytical laboratory facilities.
	Membrane/Filter Samplers (e.g., SEAMIST)	Commercially available; labor intensive; point measurements; difficulties in dry soils, can use existing boreholes with modifications; requires analytical laboratory facilities
	Core Sampling	Various samplers are commercially available; labor intensive and expensive; point measurement; can not resample same point; requires analytical laboratory facilities
CCl_4	Active Soil Gas Sampling	Commercially available; labor intensive; requires laboratory facilities; can use existing boreholes with modifications.
	Passive Soil Gas Sampling	See above
Measurement of Transport Parameters		
Matric Potential	Tensiometers (including deep/borehole tensiometers)	Commercially available; site must be fairly moist (i.e., tension <0.85 Bar) ; can use existing boreholes with modifications.
	Thermocouple Psychrometers	Commercially available; applicable in very dry soils (with tensions up to 80 bars) ; must be individually calibrated and needs correction for diurnal temperature changes; can use existing boreholes with modifications.
	Heat Dissipation Sensors	Commercially available; work poorly in coarse-grained soils (effective range is 0-10 bars soil suction); must be individually calibrated and are susceptible to hysteresis; point measurement; can use existing boreholes with modifications.
	Fiber Optic Sensors	
	Osmotic Sensors	Commercially available
Water Flux	Water Balance (Drainage) Lysimeters	Facilities exist throughout Hanford Site; must be properly designed to avoid edge and evapotranspiration effects; provides an integrated measurement at a particular location
	Composite In Situ Measurements	In use at Hanford; flux calculated from standard measurements of water content and matric potential; requires biweekly to monthly measurements.
	Flux Meter	Not commercially available.

concentration and distribution. Thus the target population is defined as the vadose zone containing contamination. Monitoring, then, becomes collecting representative samples such that the suite of samples gives an accurate picture of the contaminant plume. The problem now becomes choosing a sampling scheme to collect representative samples in a space-time framework.

The U.S. ACOE (1994) discusses by Gilbert (1987) and in guidance several sampling strategies. The choice of a sampling plan depends on the study objectives (change in concentration), variability in the target population (contaminant concentration and geometry), cost-effectiveness, the type of measurements to be made, and convenience (Gilbert 1987). Two situations exist for vadose zone monitoring: 1) a facility is to be monitored to detect discharges that will impact the environment and 2) a facility with specific and known contamination is being monitored to determine change. A different sampling scheme is required for each of the two situations. A statistical sampling strategy probably will be most appropriate for monitoring a facility's impact on the environment. A biased or non-statistical sampling scheme probably will be most appropriate for monitoring changes in previously defined plumes.

The rationale for a specific sampling network is site dependent but monitoring points (e.g., well locations) should be located consistent with DQOs in the areas most vulnerable to contamination or contaminant migration. Site-specific sampling plans will describe the sampling scheme most appropriate for the specific situation given a set of constraints defined by 1) the objective of monitoring (i.e., surveillance versus plume tracking), 2) the facility design (including soil column storage properties), 3) the contaminants of concern, 4) the monitoring technique, and 5) the level of detection (uncertainty) that is acceptable.

6.1.4.1.1 The Use of Existing Boreholes. Most liquid disposal facilities at Hanford have associated wells and boreholes. Use of existing boreholes should be strongly considered, if appropriate for the objectives of the site-specific monitoring, because they are existing access to subsurface contamination and because their use can be a substantial cost savings over emplacement of new monitoring points.

If existing boreholes are to be used for monitoring, a fitness for use evaluation that includes the following considerations are pertinent:

- **The location of the borehole with respect to the facility and to existing contamination.** Most existing boreholes were located to intercept known contamination. A review of historical data will indicate which boreholes have encountered contamination in the past. Existing plume maps should be checked and the location of boreholes relative to the plumes noted.

- **The construction and configuration of the existing boreholes.** Existing boreholes have been constructed using a variety of materials, methods, and specifications, which may or may not conform with the objectives of site-specific monitoring. If existing boreholes are to be used, well casing impacts, well seal impacts, and screen impacts must be evaluated to assure usability of the borehole and that project required tolerances can be met. Unknowns in the casing thickness and material and in well seal construction and material may mean large errors in monitoring results. Borehole configuration and construction information is available through the ERC Home page (http://www.erc.rl.gov), in databases maintained by Waste Management Northwest Inc., and PNNL, and in data compilations such as *Hanford Wells* (Chamness and Merz 1993).

6.1.4.2 Monitoring Frequency

A second aspect of the sampling design is frequency of sampling. As with the selection of monitoring points, the selection of sampling frequency will depend on the objective of monitoring, the contaminants of concern, the monitoring technique, and the acceptable level of uncertainty. For example, a surveillance objective will require a relatively high sampling frequency; a trend monitoring objective will require less frequent but long sequences of sampling (Gilbert 1987). Mobile contaminants will require more frequent monitoring than less mobile, long-lived contaminants. The site-specific DQOs will dictate the sampling frequency described in the site-specific monitoring plans and the examination of prior data should be factored into determining the frequency.

6.1.5 Pre-Monitoring Activities

Preparation activities necessary to begin a vadose monitoring project include the following:

- a site-specific monitoring plan providing a strong technical basis for the site-specific monitoring
- planning
- coordinate with team members
- coordinate with support services as addressed in the Quality Assurance Project Plan (QAPjP) portion of this plan (Appendix A).
- obtain monitoring services and equipment.

Activities in preparation for field operations are to be accomplished prior to monitoring. Activities to be considered include Radiation Control Technologist (RCT) support for generation of Radiation Work Permits, access to radiation zones, swabbing of wells, removal of pumps and packers from wells, surveys of instrumentation as it is removed from wells or the site, and any special requirements. If existing boreholes are to be used, the boreholes must be evaluated to assure they meet project specification. Also, if existing boreholes are to be used, coordination also must be made with projects, such as soil vapor extraction, that are already using the boreholes scheduled for monitoring. Also, boreholes that have not been entered recently may need a field inspection and be swabbed for internal contamination. Finally, coordination with the facility owner or operator should occur to avoid conflicts with facility operations.

6.1.5.1 Acquisition Of Monitoring Services

A detailed Statement of Work should be prepared prior to selection of an organization to perform monitoring. The Statement of Work will delineate

- the monitoring method to be used
- the constituents of interest including detection limits
- QC parameters including precision, accuracy, and frequency of QC samples
- calibration requirements

- document control requirements
- deliverables
- quality assurance requirements
- cost and schedule constraints
- administrative contacts and controls.

PNNL will maintain access to organizations capable of supplying required vadose zone monitoring services for the Hanford Groundwater Monitoring Project. Potential sources of services include Hanford contractors and subcontractors, subcontractors designated as pre-qualified by Hanford contractors, and evaluated, independent private industry.

The PNNL Hanford Groundwater Monitoring Project maintains contract analytical laboratory services for use. Those services will be used as needed.

6.1.5.1.1 Monitoring Procedures. All vadose zone monitoring will be conducted according to approved procedures. Specific technical procedures required will be designated in the Statement of Work but will include procedures for

- data acquisition
- calibration practices and standards
- quality control and acceptance criteria
- equipment maintenance and calibration
- data reduction, verification, and reporting
- data storage and security
- document control
- administrative procedures including personnel training, health and safety documentation, QA/QC program, change control, and control and disposition of secondary waste.

Only proven techniques with procedures adequate to control the quality of the data will be used. All software used in the acquisition of data, the reduction and analysis of data, and data interpretation will be reviewed to confirm that the software performs as expected and correctly.

6.1.6 Data Reduction, Data Analysis, and Data Interpretation

6.1.6.1 Data Reduction

The specifics of reducing monitoring data from initially obtained raw information (electrical pulses counted at a multichannel analyzer, for example) are highly dependent on the specific monitoring technique and on the specific methods used by the service organization collecting the data. Most of the details concerning data reduction are not of interest since it is the resulting concentrations or activities that are the data to be used by the end user. It is important, however, that any algorithms and software used during data reduction be verified and tested to assure that the results are accurate.

6.1.6.2 Data Analysis and Interpretation

The ultimate use of vadose monitoring data is comparison with past monitoring data to delineate any changes in the subsurface distribution or concentration of contaminants. This is achieved through time series analyses; that is, comparing data for a specific contaminant at a specific location with past data for that contaminant at the same location. Past data should be adjusted to the same scale and same units as newly collected data prior to making comparisons. Detection limits and analytical errors are available for more recently acquired monitoring data. Where this information is available for past data, quantitative or semi-quantitative comparisons may be possible. For much of the older data, however, quantitative comparisons probably will not be possible because associated errors, calibration information, and detection limits are generally not available. In such cases, qualitative or relative comparisons can be done.

Presentation of the results can be as graphs of depth versus concentration, maps of location versus concentration, tables of concentration values, or any other similar and applicable presentation. Where applicable, cross-sections and maps should be prepared showing changes in subsurface contamination. To the extent that "good" prior data exist, the format for data presentation should complement comparing new data to old data.

Available information that may be related to contaminant concentrations such as local geology, effluent discharge history, and chemical properties of contaminants, co-contaminants and host soils should be used to help understand contaminant distribution and changes in contaminant distribution.

6.1.7 Data Management

The data resulting from vadose monitoring should be assimilated in one of two ways depending on the specific monitoring effort. First, if hard copy data packages are available they should contain all pertinent header sheets, work sheets, control charts, monitoring results, QC results, data summaries, calibration information, and narratives. Hard copy data packages should be assembled and made available to all potential data users.

Second, electronic files of all raw data, processed data, QC data and any other information should be collected and made available to users where electronic data are available. Hard copy data and/or electronic data should be placed in appropriate databases and libraries for use. The original data or copies of the data will be managed according to PNNL data management procedures (see QAPjP, Appendix A).

6.1.8 Reporting

The results of vadose zone monitoring should be made available for Hanford Site use. Mechanisms include publication in topical reports and in the annual Hanford Site Groundwater Monitoring reports. All reporting will be peer reviewed. Topical reports will be issued according to PNNL procedures for Information Release which ensure technical review. The annual groundwater report also utilizes the PNNL Information Release system and undergoes extensive technical, peer review.

7.0 References

40 CFR 141, Code of Federal Regulations, Title 40, Part 141. *National Primary Drinking Water Regulations.*

40 CFR 143, Code of Federal Regulations, Title 40, Part 143. *National Secondary Drinking Water Regulations.*

40 CFR 265, Code of Federal Regulations, Title 40 Part 265. *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*

Additon, M. K., K. R. Fecht, T. L. Jones, and G. V. Last. 1978a. *Scintillation Probe Profiles 200 East Area Crib Monitoring Wells.* RHO-LD-28, Rockwell Hanford Company, Richland, Washington.

Additon, M. K., K. R. Fecht, T. L. Jones, and G. V. Last. 1978b. *Scintillation Probe Profiles 200 West Area Crib Monitoring Wells.* RHO-LD-29, Rockwell Hanford Company, Richland, Washington.

Baker, V. R., B. N. Bjornstad, A. J. Busacca, K. R. Fecht, E. P. Kiver, U. L. Moody, J. G. Rigby, D. F. Stradling, and A. M. Tallman. 1991. "Quaternary Geology of the Columbia Plateau." *The Geology of North America,* Vol. K-2, *Quaternary Nonglacial Geology*, Conterminous U.S.

Black, R. F. 1979. *Clastic Dikes of the Pasco Basin, Southeastern Washington,* RHO-BWI-C-64, Rockwell Hanford Operations, Richland, Washington.

Blair, S. C., L. S. Law, and J. W. Lindberg. 1981. *A Catalog of Borehole Geophysics on the Hanford Site, 1958 to 1980.* PNL-3504. Pacific Northwest Laboratory, Richland, Washington.

Chamness, M. A., R. E. Lewis, S. S. Teel, and A. W. Pearson. 1991a. *T Plant Geologic and Geophysics Data Package for the 200 Aggregate Area Management Study.* WHC -SD-EN-DP-022, Westinghouse Hanford Company, Richland Washington.

Chamness, M. A., S. S. Teel, D. L. McAlister, A. W. Pearson, K. R. O. Barton, R. W. Fruland, and R. E. Lewis. 1991b. *U-Plant Aggregate Area Management Study Geologic Data Package.* WHC-SD-EN-DP-019, Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., S. S. Teel, D. L. McAlister, A. W. Pearson, K. R. O. Barton, R. W. Fruland, and R. E. Lewis. 1991c. *Z-Plant Aggregate Area Management Study Geologic Data Package.* WHC-SD-EN-DP-020, Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., S. M. Goodwin, S. S. Teel, and R. E. Lewis. 1992a. *Semi-Works (C-Plant) Aggregate Area Management Study Geologic Data Package.* WHC-SD-EN-DP-027, Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., R. E. Lewis, S. S. Teel, R. J. Brockman, D. C. Lanigan, and A. W. Pearson. 1992b. *PUREX Aggregate Area Management Study Geologic Data Package*. WHC-SD-EN-DP-025, Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., D. L. McAlister, J. P. McDonald, A. W. Pearson, and R. E. Lewis. 1992c. *200 North Aggregate Area Management Study Geologic Data Package*. Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., and J. K. Merz. 1993. *Hanford Wells*. PNL-8800, Pacific Northwest Laboratory, Richland, Washington.

Chou, C. J., and V. G. Johnson, in preparation, *Guidance for Designing a DQO-Based RCRA Groundwater Monitoring Plan*. Pacific Northwest National Laboratory, Richland, Washington.

Delaney, C. D., K. A. Lindsey, and S. P. Reidel. 1991. *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*. WHC-SD-ER-TI-003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

DOE Order 5400.1, *General Environmental Protection Program*. U.S. Department of Energy, Washington, D.C.

DOE Order 5400.5, *Radiation Protection of the Public and Environment*. U.S. Department of Energy, Washington, D.C.

DOE. 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*. DOE/RW-0164, Vols. 1-9, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, Washington, D.C.

DOE. 1996. *200 Areas Soil Remediation Strategy - Environmental Restoration Program*. DOE/RL-96-67, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 1997a. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. DOE/RL-91-50, Rev.2, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 1997b. *Waste Site Grouping for 200 Areas Soil Investigations*. DOE/RL-96-81, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Engelman, R. E., R. E. Lewis, D. C. Stromswold, and J. R. Hearst. 1995. *Calibration Models for Measuring Moisture in Unsaturated Formations by Neutron Logging*. PNL-10801, Pacific Northwest Laboratory, Richland, Washington.

Fecht, K. R., G. V. Last, and K. R. Price. 1977. *Evaluation of Scintillation Probe Profiles From 200 Area Crib Monitoring Wells*. ARH-ST.156, Atlantic Richfield Hanford Co., Richland, Washington.

Fecht, K. R., S. P. Reidel, and A. M. Tallman. 1987. *Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State - A Summary*. In, Schuster, J. G., ed., Selected Papers on the Geology of Washington. Division of Geology and Earth Resources Bulletin 77, Department of Natural Resources, Olympia, Washington, p. 219-248.

Fecht, K. R., K. A. Lindsey, B. N. Bjornstad, D. G. Horton, G. V. Last, and S. P. Reidel. 1998. *An Atlas of Clastic Injection Dikes of the Pasco Basin and Vicinity.* BHI-01103, Bechtel Hanford, Inc., Richland, Washington.

Gilbert, R. O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold Company Inc., New York.

Lewis, R. E., and A. W. Pearson. 1992. *A Catalog of Borehole Geophysics for the 100 Areas and Adjacent 600 Area, Hanford Site, 1962 to May 1992*. PNL 8230, Pacific Northwest Laboratory, Richland, Washington.

Lewis, R. E., and S. S. Teel. 1994. *A Survey of Existing and Emerging Technologies for External Detection of Liquid Leaks at the Hanford Site*, PNL-10176, Pacific Northwest Laboratory, Richland, Washington.

Lindsey, K. A. 1996. *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon.* Open File Report 96-8, Washington State Department of Natural Resources, Olympia, Washington.

McGhan, V. L., P. J. Mitchell, and R. S. Argo. 1985. *Hanford Wells*, PNL-5397, Pacific Northwest Laboratory, Richland, Washington.

Raymond, J. R., and V. L. McGhan. 1964. *Scintillation Probe Results - 200 Area Waste Disposal Site Monitoring Wells*. HW-a4577, General Electric Co., Richland, Washington.

Raymond, J. R., and V. L. McGhan. 1992. *History of Geophysical Well Logging on the Hanford Site*, unpublished letter report, Pacific Northwest Laboratory, Richland, Washington.

Reidel, S. P., K. A. Lindsey, and K. R. Fecht. 1992. *Field Trip Guide to the Hanford Site.* WHC-MR-0391, Westinghouse Hanford Company, Richland, Washington.

Sheen, E. M., W. L. Bunch, and M. R. Wood. 1964. *Neutron Soil Moisture Monitor*. HW.82009, General Electric Co., Richland, Washington.

Teel, S. S. 1992. *S-Plant Aggregate Area Management Study Geologic Data Package*, WHC-SD-EN-DP-021, Westinghouse Hanford Company, Richland, Washington.

Teel, S. S, R. E. Lewis, M. A. Chamness, D. C. Lanigan, V. L. McGhan, and R. J. Brockman. 1992. *B-Plant Aggregate Area Management Study Geologic Data Package*. WHC-SD-EN-DP-026, Westinghouse Hanford Company, Richland, Washington.

Tillson, D. D., and V. L. McGhan. 1969. *Changes in Scintillation Probe Findings - 1963 to 1968, 200 Area Waste Disposal Site Monitoring Wells*. BNWL-CC-2255, Pacific Northwest Laboratory, Richland, Washington.

U.S. ACOE. 1994. *Environmental Quality Requirements for the Preparation of Sampling and Analysis Plans,* U.S. Army Corps of Engineers Manual EM-200-1-3.

WAC 173-200, Washington Administrative Code. *Water Quality Standards for Ground Waters of the State of Washington.* Olympia, Washington.

WAC 173-303, Washington Administrative Code. *Dangerous Waste Regulations.* Olympia, Washington.

WAC 246-290, Washington Administrative Code. *Public Water Supplies.* Olympia, Washington.

Wilson, L. G., L. G. Everett, and S. J. Cullen, eds. 1995. *Handbook of Vadose Zone Characterization & Monitoring*. Lewis Publishers, Boca Raton, Florida.

Appendix A

Quality Assurance Project Plan

Appendix A

Quality Assurance Project Plan

A.1 Background Information

Vadose zone monitoring activities are part of the overall objectives in support of the Integrated Groundwater Project. Thus, the quality control/quality assurance (QC/QA) procedures for vadose zone monitoring shall be consistent with those of the Integrated Groundwater Project. This Quality Assurance Project Plan (QAPjP) is intended to be used in all aspects of vadose zone monitoring. Implementation of the QA/QC requirements in this section will insure that the vadose monitoring activities are carried out to achieve the specified data quality goals, and that the quality of data gathered can be monitored and documented.

A.1.1 Quality Assurance Project Plan Applicability and Relationship to the Integrated Groundwater Project Quality Assurance Program

This QAPjP applies specifically to various activities performed for vadose monitoring in support of the Integrated Groundwater Project. The QAPjP is an element of the Vadose Zone Monitoring Plan prepared specifically for vadose zone monitoring support to the Integrated Groundwater Project and is consistent with other environmental work and the overall quality program requirements at Hanford. Distribution and revision control of this monitoring plan including this QAPjP will comply with standard procedures in *The Hanford Ground-Water Monitoring Project Quality Assurance Project Plan* (PNNL 1997).

A.2 Project Organization and Responsibilities

A.2.1 Technical Lead Responsibilities

The Applied Geology and Geochemistry Group of PNNL has primary responsibility for overseeing vadose zone monitoring aspects of the Hanford Integrated Groundwater Project. The primary responsibility for the Hanford Integrated Ground Water Project lies in the Field Hydrology and Chemistry Group of PNNL.

A.2.2 Analytical Data Acquisition Systems

Data acquisition and analysis will be subcontracted to support organizations as described in Chapter 6.0 of the main plan. All data collection, data reduction, and data analyses activities shall be performed in compliance with PNNL reviewed and/or approved QA plans and analytical procedures.

A.2.3 Health Physics

Because the nature of many of the sites to be monitored render them contamination zones, Radiation Work Permits and Health Physics support may be necessary.

A.2.4 Support Contractors

Procurement of any contracted activities shall be in compliance with the PNNL Standards Based Management System. Statements of Work are to be reviewed and signed by the project Quality Engineer prior to submittal to contractors. All work shall be performed in compliance with PNNL approved QA plans and/or procedures and shall be subject to assessment activities. Applicable quality requirements shall be invoked as part of the approved procurement documentation or work order.

A.3 Objectives for Measurements

This project is a monitoring activity to obtain data that will be used to determine the subsurface configuration of contaminants. The overall data quality requirements to meet the intent of this plan were determined as described in Chapter 4.0 of the main plan. Detailed and specific data quality requirements for individual waste sites will be documented in the site-specific monitoring plans. The general requirements are discussed in the following sections.

A.3.1 General Precision and Accuracy Objectives

As an outcome of the Data Quality Objective (DQO) process, the general requirement for precision and accuracy is intended to be such that changes in subsurface contaminant distribution or concentration can be documented. However, the individual site-specific monitoring plans take precedence in setting the specific specifications for precision and accuracy of the monitoring to be performed. The general guidance or objective may be accomplished differently for different monitoring methodologies. For example, geophysical logging may require relogging of specific repeat sections whereas moisture or vapor extraction techniques may require duplicate samples to meet the monitoring objective and/or to satisfy regulatory requirements or DOE Orders.

A.3.2 Monitoring Measurements

Representative analyses are necessary for accurate determination of subsurface contaminant distribution. Accurate interpretations of the subsurface data form the framework for subsequent decisions concerning remediation, and for subsequent modeling of the subsurface. Monitoring measurements provide a means by which cleanup decisions and modeling can be accomplished.

A.3.2.1 Monitoring Points

Specific monitoring points are to meet site-specific DQOs and will be delineated in the site-specific monitoring plans.

A.3.2.2 Constituents to be Measured

The DQO process specified the constituents of concern/interest for vadose zone monitoring. Site-specific contaminants of concern are to be developed from the overall contaminants of concern and from site-specific inventories and delineated in the site-specific monitoring plans.

A.4 Measurement Procedures

A.4.1 Procedure Approvals and Control

All procedures required for vadose monitoring activities shall be approved and shall comply with the requirements of the project. Where PNL-MA-568 (PNL 1994) procedures are referenced, equivalent procedures shall be used by subcontractors.

A.4.2 Measurement Procedures

This section describes procedures related to collecting monitoring data from boreholes and soil and pore fluid samples for the constituents of interest. Alternative measurement methods and procedures may be used but must be controlled and documented in accordance with the requirements in this QAPjP.

A.4.2.1 ^{233,235,238}U, ^{137}Cs, ^{239,241}Pu, and ^{241}Am

Two borehole geophysical logging techniques can be used to measure the activity of the gamma emitting isotopes of uranium, cesium, plutonium, and americium: gross gamma-ray logging and spectral gamma-ray logging. Gross gamma-ray logging gives a sum of the activities of all gamma emitting radionuclides whereas spectral gamma-ray logging gives activities for each individual radionuclide. These parameters are obtained by inserting gamma detectors into wells and boreholes. Borehole configuration specifics about casing type and seals must be known for quantitative corrections to gamma measurements. Also, accurate determinations of reference point, usually the top of casing, must be known. Most well casing elevations are surveyed to within ±0.01 ft (±0.3 cm) and this accuracy is well within the requirements for vadose monitoring. Wells without accurate surveys must have a survey completed prior to monitoring. Procedures for borehole gamma-ray logging are vendor specific but must conform to the requirements of this QAPjP.

Fissionable nuclides (^{233}U, ^{235}U, and ^{239}Pu) can be measured by prompt fission neutron logging in boreholes. These systems are commercially available and measurement procedures are vendor specific. The system can not distinguish among the fissionable nuclides.

Gamma emitting radionuclides can also be quantified by gamma spectrometry in a laboratory. Discrete samples of pore fluid are necessary. Laboratory specific methods are used that are recognized as acceptable within the technical radiochemical industry (Gillespie, in Hartman and Dresel 1998). Specific procedures are available through the PNNL technical contract administrator for the radiochemistry laboratory. The method involves direct counting using an intrinsic germanium or lithium-drifted germanium detector. Isotopes with gamma-ray energies from 60 to 2,000 KeV are detected.

In addition to gamma spectrometry, activities of alpha emitting isotopes of uranium, plutonium and americium can be measured in pore fluid samples by alpha spectrometry after isotopic separation by exchange resins. This method requires samples of pore fluid. Procedures are laboratory specific and recognized as acceptable within the technical radiochemical industry (Gillespie, in Hartman and Dresel 1998).

A.4.2.2 ^{99}Tc and ^{129}I

There are no readily available procedures for measurement of ^{99}Tc and ^{129}I in boreholes.

Laboratory procedures exist for the measurement of ^{99}Tc and ^{129}I activities in discrete samples of pore fluid. The procedures are laboratory specific and must conform to industry recognized practice. Technetium and or iodine are chemically separated from the sample and technetium-99 is measured by liquid-scintillation beta counting and iodine-129 by a low-energy photon detector (Gillespie, in Hartman and Dresel 1998).

A.4.2.3 Chromium, Aluminum, Nitrate, Cyanide, and Carbon Tetrachloride

Various laboratory procedures are available for analysis of these constituents of concern in samples of pore fluid. Laboratory procedures for the analysis of chromium and aluminum include flame atomic absorption according to EPA Method 218.2 (EPA 1982), graphite furnace atomic absorption according to SW-846 Method 7191 (EPA 1986) and ICP-MS by SW-846 Method 6020 (EPA 1986).

Field methods are available for measurement of chromium as described in SW-846 Method 7196 (EPA 1986). However, there are no readily available procedures for measurement of chromium in the vadose zone in boreholes.

Aluminum can be measured in boreholes by pulsed-neutron logging. Procedural methods are vendor specific. The use of pulsed-neutron logging for measurement of soluble aluminum is not practical at Hanford because the technique will measure all aluminum around the borehole including that in alumino-silicate minerals.

Cyanide in pore fluid can be measured by SW-846 Methods 1910 and 1912 (EPA 1986). There is no readily available procedure for measurement of cyanide in the vadose zone in boreholes.

Carbon tetrachloride is measured in the laboratory by gas chromatography per SW-846 Method 8260 (EPA 1986). There are also several available methods for measurement of carbon tetrachloride in the field. The method currently used by the soil vapor extraction project is infrared photoacoustic spectrometry following the manufacturers recommended procedure. Carbon tetrachloride can also be measured by pulsed-neutron logging using vendor specific procedures. The actual measurement is Cl and C so that other compounds with these elements will be included as part of the measured result.

The laboratory procedure for the analysis of nitrate in pore fluid is ion chromatography by SW-846 Method 9056 (EPA 1986) or EPA Method 300.0 (EPA 1984). Field methods are available for measurement of nitrate in water samples but there are no readily available procedures for measurement of nitrate in the vadose zone in boreholes.

A.4.2.4 Water Content, Matric Potential, and Water Flux

There are numerous methods for the measurement of these parameters (see Table 6.1 in the main plan). Lewis and Teel (1994) evaluated the following methods as having potential at Hanford. Borehole methods include neutron-neutron logging, pulsed-neutron spectroscopy logging, and electrical induction logging. Cross borehole methods include electrical resistivity tomography and shear-wave seismic tomography. In situ, soil moisture instrumentation methods include time-domain reflectometry and resistivity blocks. Lysimeters and membrane/filter samplers can collect pore fluid samples for either measurement of the soil moisture content or dissolved constituents. Analytical laboratory measurement of moisture is usually gravimetric.

EPA approved procedures do not exist for many of the techniques listed in Table 6.1 of the main plan. Vendor specific procedures or manufacturers recommended procedures are available for most commercially available methods. ASTM, EPA or other standards exist for neutron-neutron logging (ASTM D5220-92, Standard Test Method for Water Content of Soil and Rock In-Place by the Neutron Depth Probe Method; ASTM D3017-96e1, Standard Test Method for Water Content of Soil and Rock In-Place by Nuclear Methods (Shallow Depth); and ASTM D6031-96, Standard Test Method for Logging In-situ Moisture Content and Density of Soil and Rock by the Nuclear Method in Horizontal, Slanted and Vertical Access Tubes), for direct sampling and ex-situ analysis (ASTM D 4696, Standard Guide for Pore-Liquid Sampling from the Vadose Zone; ASTM D2216, Percent Moisture Analysis) and for field measurement of water content or hydrologic properties (ASTM D5126-90, Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone; ASTM D3152-72(1994)e1, Standard Test Method for Capillary Moisture Relationships for Fine-textured soils by Pressure Membrane Apparatus; ASTM D2325-68(1981)e1, Standard Test Method for Capillary Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-plate Apparatus; ASTM, Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper; and ASTM D5093-90, Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed Inner Ring).

A.4.2.5 Other Procedures

If it is determined that other procedures are required that are not already identified in this QAPjP, they will be identified in the appropriate site-specific monitoring plan. Documentation requirements shall be addressed within individual procedures.

A.4.3 Procedure Changes

Should deviations from established procedures be required to accommodate unforeseen field situations, they may be authorized by the project lead for the site-specific monitoring concerned in accordance with the requirements in the applicable Statements of Work, site-specific requirements, and the applicable vendor-specific procedures. Deviations from established procedures must be documented in the project files.

A.5 Sample Handling

All data obtained during the course of vadose monitoring activities shall be controlled as required by this QAPjP and the *Hanford Groundwater Monitoring Project Quality Assurance Project Plan* (PNNL 1997). Chain-of-custody procedures shall be used that maintain sample integrity and identification throughout the analytical process. Chain-of-custody forms shall be initiated for returned residual samples. Results of analyses shall be traceable to original samples through unique code or identifier specified in the site-specific monitoring plan. In general, chain of custody is not required for borehole measurement techniques. However, header sheets containing location, dates, techniques and other information are required to be a permanent attachment to each geophysical log data set. All results of data analyses shall be controlled as permanent project quality records as required by standard PNNL procedures.

A.6 Calibration Procedures

All measuring and test equipment shall be calibrated in compliance with the requirements of applicable procedures. Equipment that requires user calibration or field adjustment shall be calibrated as required by standard procedures.

Borehole logging equipment will be calibrated according to industry standard procedures maintained by the vendors conducting the logging. Two calibrations are applicable to borehole logging: a depth calibration of the cable and cable hoist system and a calibration of the detector and associated electronics.

All calibration of laboratory measuring and test equipment shall meet the minimum requirements of the *Hanford Ground-Water Monitoring Project Quality Assurance Project Plan* (PNNL 1997). Such requirements shall be invoked through PNNL procurement control procedures. All subcontractor QA plans shall address equipment to be calibrated and the calibration schedules.

A.7 Analytical Procedures

Analytical methods are identified and discussed above and in appropriate site-specific monitoring plans. All analytical procedures used to support this monitoring plan shall comply with SW-846 where possible. All analytical procedures approved for use in vadose monitoring shall require the use of standard reporting techniques and units wherever possible to facilitate the comparability of data sets in terms of precision and accuracy. All approved procedures shall be retained in the project QA records and shall be available for review upon request.

A.8 Data Reduction, Validation, and Reporting

Data from monitoring activities will be used primarily to determine the presence and amounts of contaminants of interest in specified locations and intervals. The support organization responsible for acquiring the monitoring data shall be responsible for the examination and verification of results to the extent appropriate. The requirements discussed in this section shall be invoked, as appropriate, in procurement documentation prepared in compliance with standard PNNL procedures. Results from all monitoring measurements shall be summarized in required reports and supported by QC checks, equipment calibration data, spectra, or other verification data as appropriate.

Project records shall be managed according to the PNNL Records Management System. All reports and supporting data may be subjected to a detailed technical review by a qualified reviewer. All reports, technical reviews, and supporting data shall be retained as permanent project QA records in compliance with referenced procedures.

A.9 Internal Quality Control

The quality of vadose monitoring data shall be subject to in-process QC checks in the field, during data reduction, or in the laboratory as appropriate. Minimum requirements are defined as follows.

Specific field checks shall be appropriate to the specific monitoring method and be documented in site-specific monitoring plans. Unless otherwise specified in a site-specific monitoring plan, minimum field QC checks for borehole logging activities shall include the following.

- Pre and post-monitoring detector verification using a known and documented source. Acceptance criteria are to be documented in applicable procedures.

- A minimum of 10 feet in each borehole is to be relogged as a QC sample. The portion of the borehole to be relogged can be at the discretion of the log operator.

Internal QC checks performed by the analytical laboratories shall be in compliance with approved analytical procedure requirements.

A.10 Performance and System Assessments

Acceptable performance for vadose monitoring is defined as compliance with the requirements of this QAPjP, its implementing procedures, the associated site-specific monitoring plans, and other applicable PNNL QA program plans. All activities addressed by this QAPjP are subject to assessments of project performance and systems adequacy. Assessments shall be conducted in accordance with appropriate PNNL procedures and shall be scheduled at the discretion of the cognizant quality engineer or technical lead.

A.11 Preventive Maintenance

All measurement and testing equipment used in the field and in laboratories that directly affects the quality of the monitoring data shall be subject to preventive maintenance measures. These measures are designed to ensure the availability of instrumentation and the reliability of operation to prevent delays or loss of data. Subcontractors shall be responsible for performing or managing the maintenance of their equipment; maintenance requirements, spare parts lists, and instructions shall be included in individual methods or in subcontractor QA plans. All QA plans shall be subject to PNNL review and approval.

A.12 Corrective Action

Corrective action requests required as a result of assessment reports shall be documented and dispositioned as required by standard PNNL corrective action procedures. Primary responsibilities for corrective action resolution are assigned to the project technical lead and the Quality Engineer.

Other measurement systems, procedures, or plan corrections that may be required as a result of routine review processes shall be resolved as required by governing procedures or shall be referred to the technical lead for resolution. Copies of all assessment documentation shall be routed to the project QA records upon completion or closure.

A.13 Quality Assurance Reports

Project performance shall be evaluated by the assessment process. Assessment documentation shall be routed to the project records upon completion or closure of the activity. A report summarizing assessment activity, as well as any associated corrective actions, shall be prepared by the QA coordinator at the completion of the project.

A.14 References

Environmental Protection Agency (EPA). 1982. *Methods for Chemical Analysis of Water and Waste.* EPA-600/4-82-055, U.S. Environmental Protection Agency, Washington, D.C.

Environmental Protection Agency (EPA). 1984. *Test Method: The Determination of Inorganic Anions in Waster by Ion Chromatography - Method 300.0.* EPA-600/4-84-17, U.S. Environmental Protection Agency, Washington, D.C.

Environmental Protection Agency (EPA). 1986. *Test Methods for Evaluating Solid Waste - Physical/ Chemical Methods*. SW-846 (3rd. Edition), Office of Solid Waste and Energy Response, U.S. Environmental Protection Agency, Washington, D.C.

Gillespie, B. M., Appendix C, Analytical Methods, in, Hartman, M. J. and P. E. Dresel. 1998. *Hanford Site Groundwater Monitoring for Fiscal Year 1997.* PNNL-11973, Pacific Northwest National Laboratory, Richland, Washington.

Lewis, R. E., and S. S Teel. 1994. *A Survey of Existing and Emerging Technologies for External Detection of Liquid Leaks at the Hanford Site.* PNL-10176, Pacific Northwest Laboratory, Richland, Washington.

Pacific Northwest Laboratory (PNL). 1994. *Procedures for Groundwater Investigations*. PNL-MA-567, Pacific Northwest Laboratory, Richland, Washington.

Pacific Northwest National Laboratory (PNNL). 1997. *The Hanford Ground-Water Monitoring Project Quality Assurance Project Plan*. QA Plan ETD-012, Pacific Northwest National Laboratory, Richland, Washington.

Appendix B

Site Prioritization

Appendix B

Site Prioritization

B.1 Introduction

This Appendix describes the process used to prioritize liquid waste disposal sites for the vadose zone monitoring plan.

Eleven criteria resulted from the DQO process (see Chapter 4.8). Each criterion was applied to each waste site to help determine potential need for vadose zone monitoring. The criteria are

1. Is there a current threat imposed by site conditions on the environment?
2. Is there a regulatory reason to monitor?
3. Are there mobile contaminants associated with the site?
4. Are there long lived contaminants associated with the site?
5. Have mobile constituents been "flushed from the vadose zone?
6. Is there a potential for future impact to groundwater?
7. Are there vadose plumes associated with the site?
8. Is there a current impact to groundwater at the site?
9. Is the site in an area that is currently receiving liquid effluent?
10. Are there driving forces external to the site?
11. Are characterization and/or baseline data available?

The waste sites evaluated for this monitoring plan were all the waste sites in the 200 Areas as reported in the *Waste Site Grouping for 200 Areas Soil Investigations* (Table A.1 in DOE 1997). The *Waste Site Grouping for 200 Areas Soil Investigations* placed each of 662 waste sites into one of 23 waste site groups that were previously developed by the *200 Areas Soil Remediation Strategy - Environmental Restoration Program* (DOE 1996). The placement primarily was based on the chemical processes generating the waste streams disposed to the facilities. The waste site groups were then prioritized (as groups) on the basis of past, current, and potential future impacts to groundwater, contaminant types and contaminant chemistry, geographic location, and other parameters (DOE 1997). Many of the decision rules developed during the DQO process for this vadose zone monitoring plan are similar to the criteria used by the *Waste Site Grouping for 200 Area Soil Investigations* to prioritize waste site groups.

B.2 Prioritization Process

The first criterion is "Is there a current threat imposed by site conditions on the environment?" No sites from Table A.1 in the *Waste Site Grouping for 200 Areas Soil Investigations* received a positive response to this question. However, one site in the 100 K Area, the 100 KE Basin, received a positive response to this question because it contributes potentially significant inventories of fission products and TRUs to the soil column (Johnson et al. 1995) and because of its proximity to the Columbia River. Thus, the 100 KE Basin is included on the priority list.

The second criterion is "Is there a regulatory reason to monitor?" Although there are no EPA or Ecology regulations requiring vadose zone monitoring at any of the facilities included in the *Waste Site Grouping for 200 Areas Soil Investigations*, vadose monitoring is being considered as an alternative or an extension of groundwater monitoring at the Liquid Effluent Retention Facility (LERF) because changes in the ground water system beneath that facility will soon make the LERF non-compliant with established ground water protection standards (40 CFR 265, WAC 173-303-645). For this reason, the LERF is included on the priority list. All the sites in the *Waste Site Grouping for 200 Areas Soil Investigations* are covered by DOE Order 5400.1.

The next two criteria determine whether there are constituents of concern associated with the sites. The constituents of concern are the mobile contaminants ^{99}Tc, ^{129}I, nitrate, uranium, chromium, carbon tetrachloride, cyanide, and soluble aluminum; the immobile and/or long-lived contaminants plutonium, americium and ^{137}Cs; and the parameter moisture (see Decision Inputs, Chapter 4.6). The *Waste Site Grouping for 200 Areas Soil Investigations* included inventories for all these constituents except ^{99}Tc, ^{129}I, aluminum and moisture. Data for ^{99}Tc and ^{129}I were obtained from the Cumulative Decayed Inventory Reports maintained by Waste Management Northwest Inc., (L. P. Diediker, personnel communication 1998) and were included with the other data. It should be noted that in searching for this information, differences were found in reported quantities for ^{99}Tc and ^{129}I depending on the source examined. No data for aluminum was found in an electronic format to include in this evaluation. Some inventory data on aluminum in effluent do exist for some sites and will be compiled for inclusion in subsequent evaluations for potential vadose zone monitoring. Moisture is considered later where driving forces are evaluated.

Application of the two criteria dealing with constituents of concern yielded 214 sites that have associated constituents of concern. The vast majority of the sites without inventoried constituents of concern were unplanned releases, landfills and dumps, and septic tanks and drain fields.

The next step in the evaluation considered the three criteria "Have mobile constituents been 'flushed' from the vadose zone?," "Is there a potential for future impact to groundwater?", and "Are there vadose zone plumes associated with the site?". It was assumed that sites where mobile contaminants have been flushed from the vadose zone have already impacted groundwater.

The number of pore volumes disposed to each facility was determined by dividing the effluent volumes by the pore volumes. The volume data used was that reported in DOE (1997). Less than or equal to 10 pore volumes was the delimiting volume for this evaluation. This was based on the fact that anything over one pore volume would have introduced mobile constituents to the groundwater. In such cases, vadose monitoring as an early detection system for protection of groundwater is "after the fact". Ten pore volumes were chosen as a conservative measure.

Forty-one sites did not have the volume information to calculate the number of pore volumes, 61 sites had more than 10 pore volumes disposed, and 114 had less then or equal to 10 pore volumes disposed to them. Data for the 41 sites with no volume information will be sought and, if available, included in subsequent evaluations. About half of the 41 sites are radioactive landfills and dumps.

All except 7 of the 61 sites with greater than 10 pore volumes have associated long-lived, relatively immobile constituents of concern. Because the long-lived constituents of concern can remain in the soil column even after 10 pore volumes, those sites are retained as intermediate priority sites.

The next criteria are "Is the site in an area that is currently receiving liquid effluent?" and "Are there driving forces external to the site?". Basically, three potential sources for a driving force were considered: 1) is the site actively receiving effluent, 2) is the site influenced by a known source of water recharge from man-made systems, and 3) natural recharge.

Except for LERF, none of the sites that received less than or equal to ten pore volumes is an active site. Whether a site is influenced by a known source of water recharge from a man-made system is more difficult to answer. The *Waste Site Grouping for 200 Areas Soil Investigation* considered this aspect and concluded that none of the sites was within 30 meters of a known source of water recharge from man-made systems (DOE 1997, p. 5-6). An effort currently is underway to identify facilities that may be impacted by leaking or broken water lines, storm runoff systems, or other man-made facilities. Results of that effort will be incorporated in subsequent evaluations once they are available but until that time the conclusion of the *Waste Site Grouping* is used.

The last aspect, natural recharge, was evaluated by plotting each of the 114 sites with constituents of concern and less than or equal to ten pore volumes on an updated version of the Hanford Site recharge map produced by Fayer et al. (1996). For sites within disturbed areas, Fayer et al. (1996) estimated recharge assuming there was no plants and the soil type was what it was prior to Hanford. For sites outside of disturbed areas, they used the pre-Hanford soil type with the vegetative cover defined by the vegetation map of Downs et al. (1993). It is recognized that these assumptions may not represent actual cover on the waste sites. The application of natural recharge to the site prioritization can be updated as newer information becomes available. Also, any enhancement of infiltration due to local topographic features will be accounted for during evaluation of specific sites.

Most waste sites fell into the 50 to 100 mm/year areas on the recharge map because they lie in disturbed areas and Fayer et al. (1996) treated these areas as bare soil. All other facilities fell into the 0.5 to 5 mm/yr, 5 to 10 mm/yr or the 10 to 20 mm/yr recharge zones. Sites in higher recharge zones receive higher priority for vadose monitoring than do sites in lower recharge zones.

The final criterion is "Are characterization and/or baseline data available?" for comparison with new monitoring data. Several sources of past monitoring and characterization information were checked to see whether data were available and published. Most sources of historical monitoring data were gross gamma-ray and spectral gamma-ray log data. A cut off date of 1977 was made for consideration of such data because data collected before that time are considered to have too many associated unknowns for comparison with current data. The major sources of baseline data are Fecht et al. (1977), Additon et al. (1978a, 1979b), Brodeur et al. (1993), and part of a very recently completed database of spectral gamma-ray logs that have been collected since about 1991 (see the database at PNNL server site \\pnlatlas\geodata).

Numerous published characterization studies that report laboratory and field testing results can be found. Many of these reports probably contain data suitable for use as baseline for vadose zone monitoring. A thorough search for these reports was not made, however, because of the monumental effort that would be involved. Site-specific monitoring plans must consider this source of information.

Sixty-two sites with less than or equal to 10 pore volumes and have associated contaminants of concern also have identified baseline data (Table B.1). The 54 sites without baseline data (Table B.2) are recommended to the Integrated Groundwater/Vadose Project as sites for which some sort of characterization information is needed if future monitoring is to be done at those sites. These sites are retained as intermediate priority sites. In some instances, initial characterization data may also serve as initial monitoring data.

B.3 Prioritization Results

The results of this evaluation are shown in Tables B.1, B.2, and B.3. Table B.1 shows the 62 high priority sites. These are the sites with associated constituents of concern, less than or equal to ten pore volumes, and have associated baseline information for monitoring.

Table B.2 shows the intermediate priority sites that have associated constituents of concern, less than ten pore volumes but no associated baseline information for monitoring. Table B.3 shows the intermediate priority sites that have long-lived, relatively immobile constituents of concern but received greater than ten pore volumes of effluent.

All sites have been further prioritized within each of Tables B.1, B.2, and B.3. First, the relative ranking of waste site groups has been retained from *the Waste Site Grouping for 200 Area Soil Investigations* (DOE 1997). Then, within each waste site group, sites are ranked first by waste site type, second by amount of natural recharge, and third by the date that the site was last monitored.

Table B.1. Liquid Disposal Sites With Constituents of Concern, Less Than 11 Pore Volumes, and Baseline Information

Site	Site Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline Information
Potential Environmental Impact						
KE Basin	Fuel Storage Basin				10 - 20	
RCRA Regulated Facilities						
LERF	RCRA TSD				0.5 - 5	
Uranium Rich Process Condensate/Process Waste Group						
216-A-1	Specific Retention Crib	U Tc NO3	Pu Cs	0.0	50 - 100	1977, 1978
216-A-18	Specific Retention Crib	U Tc NO3	Pu Cs	0.0	50 - 100	1978
Plutonium/Organic-Rich Process Condensate/Process Waste Group						
216-Z-1A	Tile Field	Tc CCl4 NO3	Pu Am Cs	0.1	50 - 100	1977, 1978, 1993
216-Z-9	Enclosed Trench	U Tc CCl4 NO3	Pu Am Cs	1.6	50 - 100	1977, 1978, 1993
216-Z-18	Crib	CCl4 NO3	Pu	0.3	50 - 100	1977, 1978, 1993
Organic-Rich Process Condensate/Process Waste Group						
216-S-13	Specific Retention Crib	U Tc NO3 Cr	Pu Cs	1.9	50 - 100	1977, 1978, 1993
216-A-2	Specific Retention Crib	U Tc	Pu Cs	0.2	0.5 - 5	1977, 1978
216-A-31	Specific Retention Crib	U Tc	Pu Cs	0.0	0.5 - 5	1977, 1978
216-A-7	Crib	U Tc	Pu Cs	1.5	50 - 100	1978
Fission Product-Rich Process Condensate/Process Waste Group						
216-B-50	Crib	U Tc NO3	Pu Cs	5.5	10 - 20	1977
216-S-9	Crib	U Tc NO3	Pu Cs	3.3	50 - 100	1977, 1978
General Process Condensate and Process Waste Group						
216-C-5	Specific Retention Crib	U Tc	Pu Cs	0.1	50 - 100	1977
216-S-22	Crib	U Tc NO3	Pu Cs	0.2	50 - 100	1977, 1978
216-S-23	Crib	U Tc NO3	Pu Cs	5.7	50 - 100	1977, 1978
Tank Waste Group						
216-T-5	Specific Retention Trench	U Tc NO3	Pu Cs	2.7	50 - 100	1977, 1978
216-B-41	Specific Retention Trench	U Tc NO3	Pu Cs	0.3	10 - 20	1977, 1978
216-B-38	Specific Retention Crib	U Tc NO3	Pu Cs	0.3	10 - 20	1993
216-B-36	Specific Retention Trench	U Tc NO3	Pu Cs	0.4	10 - 20	1977, 1978, 1993, 1998b
216-T-14	Specific Retention Trench	U Tc NO3	Pu Cs	0.2	0.5 - 5	1977, 1978
216-T-15	Specific Retention Trench	U Tc NO3	Pu Cs	0.2	0.5 - 5	1977, 1978
216-T-21	Trench	U Tc NO3	Pu Cs	0.1	50 - 100	1978
216-T-22	Trench	U Tc NO3	Pu Cs	0.4	50 - 100	1978
216-T-23	Trench	U Tc NO3	Pu Cs	0.4	50 - 100	1993
216-B-9	Crib and Tile Field	U Tc NO3	Pu Cs	1.4	50 - 100	1977, 1978, 1993
216-B-8	Crib and Tile Field	U Tc NO3	Pu Cs	0.5	10 - 20	1977, 1978, 1998b
216-T-17	Trench	U Tc NO3	Pu Cs	0.2	0.5 - 5	1993
Scavenged Waste Group						
216-B-20	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.3	50 - 100	1977, 1978
216-B-21	Specific Retention Trench	U Tc	Pu Cs	0.3	50 - 100	1977, 1978
216-B-22	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.3	50 - 100	1977, 1978
216-B-24	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.3	50 - 100	1977, 1978
216-B-26	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978
216-B-28	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978
216-B-29	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978

Table B.1. (contd)

Site	Site Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline Information
216-B-31	Specific Retention Trench	U Tc CN NO3		0.4	50 - 100	1977, 1978
216-B-34	Specific Retention Trench	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978
216-T-18	Specific Retention Crib	U Tc NO3	Pu Cs	1.4	50 - 100	1977, 1978, 1993
216-B-42	Specific Retention	U Tc CN NO3	Pu Cs	0.3	10 - 20	1978
216-B-15	Crib	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978
216-B-17	Crib	U Tc CN NO3	Pu Cs	0.2	50 - 100	1977, 1978
216-B-19	Crib	U Tc CN NO3	Pu Cs	0.4	50 - 100	1977, 1978
216-B-14	Crib	U Tc CN NO3	Pu Cs	0.5	50 - 100	1977, 1978, 1993
216-B-16	Crib	U Tc CN NO3	Pu Cs	0.3	50 - 100	1977, 1978, 1993
216-B-18	Crib	U Tc CN NO3	Pu Cs	0.5	50 - 100	1977, 1978, 1993
216-B-43	Crib	U Tc CN NO3	Pu Cs	0.2	10 - 20	1977, 1978
216-B-44	Crib	U Tc CN NO3	Pu Cs	0.6	10 - 20	1977, 1978
216-B-45	Crib	U Tc CN NO3	Pu Cs	0.5	10 - 20	1977, 1978
216-B-46	Crib	U Tc CN NO3	Pu Cs	0.7	10 - 20	1977, 1978, 1998b
216-B-47	Crib	U Tc CN NO3	Pu Cs	0.4	10 - 20	1977, 1978, 1998b
216-B-48	Crib	U Tc CN NO3	Pu Cs	0.4	10 - 20	1977, 1978
216-B-51	French Drain	NO3		0.0	10 - 20	1977, 1993
Steam Condensate Group						
216-T-36	Crib	U Tc	Pu Cs	0.1	50 - 100	1977, 1978
Gable Mtn/B Pond & Ditch Cooling Water Group						
216-A-40	Specific Retention Trench	NO3		0.1	50 - 100	1978
200 Areas Chemical Laboratory Waste Group						
216-B-10B	Crib	Tc	Cs	0.1	50 - 100	1977, 1978
216-T-8	Crib	U Tc Cr	Pu Cs	0.4	50 - 100	1978
216-Z-7	Crib	U Tc NO3	Pu Cs	2.6	50 - 100	1977, 1978, 1993
300 Areas Chemical Laboratory Waste Group						
216-T-34	Crib	U Tc NO3	Pu Cs	2.8	0.5 - 5	1977, 1978
216-T-35	Crib	U Tc NO3	Pu Cs	0.4	0.5 - 5	1977, 1978, 1993
Miscellaneous Waste Group						
216-A-4	Specific Retention Crib	U Tc NO3 Cr	Pu Cs	6.6	0.5 - 5	1977, 1978
216-T-33	Crib	U Tc	Pu Cs	2.8	0.5 - 5	1977, 1978
216-A-27	Crib	U Tc Cr	Pu Cs	4.6	0.5 - 5	1977, 1978, 1993

Sources of Baseline Information
Fecht et al. 1977.
Additon et al. 1978a and 1978b.
Brodeur et al. 1993.
All other information is from database at \\pnlatlas\geodata.

Specific retention facilities were designed to use the moisture retention capability of the soils to retain contaminants. Ideally, liquid disposed to specific retention facilities was to be limited to 6 to 10 percent of the soil volume between the facility and the groundwater so that the groundwater would not be impacted (Waite 1991). Specific retention facilities were used at Hanford between 1951 and 1958 for tank waste. Because of their history and intended use, specific retention facilities are considered higher

Table B.2. Liquid Disposal Sites With Constituents of Concern, Less Than 11 Pore Volumes, and No Baseline Information

Site	Facility Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline
Uranium Rich Process Condensate/Process Waste Group						
216-A-19	Specific Retention Trench	U Tc NO3	Pu Cs	0.9	50 - 100	
216-A-20	Specific Retention Trench	U Tc NO3	Pu Cs	0.8	50 - 100	
216-B-60	Specific Retention Crib	U Tc		0.0	50 - 100	
216-A-28	Crib	U Tc NO3		0.2		
216-S-8	Trench	U Tc NO3	Pu Cs	1.0	50 - 100	
216-U-5	Trench	U Tc NO3		1.4	50 - 100	
216-U-6	Trench	U Tc NO3		1.4	50 - 100	
216-A-3	Crib	U Tc	Pu Cs	3.2	50 - 100	
Plutonium-Rich Process Condensate/Process Waste Group						
216-Z-4	Crib	U Tc	Pu Cs	0.1	50 - 100	
216-Z-6	Crib	U Tc NO3	Pu Cs	0.2	50 - 100	
216-Z-8	French Drain		Pu Am	0.9	50 - 100	
Organic-Rich Process Condensate/Process Waste Group						
216-U-15	Trench	U Tc	Pu Cs	0.1	50 - 100	
216-C-4	Crib	U Tc	Pu Cs	0.4	50 - 100	
Fission Product-Rich Process Condensate/Process Waste Group						
216-C-6	Crib	U Tc	Pu Cs	1.1	50 - 100	
General Process Condensate and Process Waste Group						
216-C-7	Crib	U Tc	Pu Cs	0.1	50 - 100	
216-T-20	Trench	U Tc NO3	Cs	0.3	50 - 100	
216-U-17	Crib	U	Am	1.0	50 - 100	
216-A-45	Crib	U Tc I	Am Cs	1.8	50 - 100	
216-C-10	Crib	U Tc	Pu Cs	2.3	50 - 100	
216-C-3	Crib	U Tc I	Pu Cs	4.1	50 - 100	
216-S-4	Trench	NO3		6.7		
Tank Waste Group						
216-B-35	Specific Retention Trench	U Tc NO3	Pu Cs	0.2	10 - 20	
216-B-39	Specific Retention Trench	U Tc NO3	Pu Cs	0.3	10 - 20	
216-B-40	Specific Retention Trench	U Tc NO3	Pu Cs	0.3	10 - 20	
216-B-37	Specific Retention Trench	U Tc NO3	Pu Cs	0.8	10 - 20	
216-T-16	Trench	U Tc NO3	Pu Cs	0.2	0.5 - 5	
216-T-24	Trench	U Tc NO3	Pu Cs	0.4	50 - 100	
216-T-25	Trench	U Tc NO3	Pu Cs	1.1	50 - 100	
Scavenged Waste Group						
216-B-25	Specific Retention	U Tc CN NO3	Pu Cs	0.3	50 - 100	
216-B-27	Specific Retention	U Tc CN NO3	Pu Cs	0.3	50 - 100	
216-B-23	Specific Retention	U Tc CN NO3	Pu Cs	0.3	50 - 100	
216-B-30	Specific Retention	U Tc CN NO3	Pu Cs	0.4	50 - 100	
216-B-32	Specific Retention	U Tc CN NO3	Pu Cs	0.4	50 - 100	
216-B-33	Specific retention	U Tc CN NO3	Pu Cs	0.4	50 - 100	
216-B-52	Specific Retention Crib	U Tc CN NO3	Pu Cs	0.5		
216-B-49	Crib	U Tc CN NO3	Pu Cs	0.7	10 - 20	

Table B.2. (contd)

Site	Facility Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline
Gable Mtn/B Pond & Ditch Cooling Water Group						
216-B-2-2	Ditch		Pu Cs	0.7	50 - 100	
216-C-9	Pond		Pu Cs	5.3	50 - 100	
200 North Pond Cooling Water Group						
216-N-5	Crib	Tc	Cs	4.4	0.5 - 5	
216-N-7	Crib	Tc	Cs	4.9	0.5 - 5	
216-N-3	Crib	Tc	Cs	5.1	0.5 - 5	
216-N-4	Pond	U	Pu Cs	7.3	0.5 - 5	
216-N-6	Pond	U	Pu Cs	9.7	0.5 - 5	
S Ponds/Ditches Cooling Water Group						
216-S-17	Pond	U NO3	Pu Cs	4.2	50 - 100(?)	
T Ponds/Ditches Cooling Water Group						
216-T-1	Ditch	U	Pu Cs	4.7	0.5 - 5	
200 Areas Chemical Laboratory Waste Group						
216-S-19	Pond	U	Pu Cs	5.2	10 - 20(?)	
216-U-4	Dry Well	NO3		0.0	50 - 100	
216-U-4B	French Drain	Tc NO3	Pu Cs	3.0	50 - 100	
300 Areas Chemical Laboratory Waste Group						
216-B-53B	Specific Retention Trench	U Tc NO3	Pu Cs	0.0	50 - 100	
216-B-58	Specific Retention Crib	U Tc NO3	Pu Cs	0.1	50 - 100	
216-B-54	Specific Retention Crib	U Tc NO3	Pu Cs	0.2	50 - 100	
216-B-53A	Specific Retention Trench	U Tc NO3	Pu Cs	0.3	50 - 100	
Miscellaneous Waste Group						
216-U-13	Trench	U Tc	Pu Cs	0.0	50 - 100	
216-S-12	Trench	U Tc	Pu Cs	0.0	50 - 100	

priority than the other facility types on the tables (except for LERF and KE Basin). (There is discrepancy among sources as to the name and type of many of the liquid waste disposal facilities at Hanford.) By placing specific retention facilities higher on the list than other sites, most sites with fewer than 1 pore volume is at the top of the lists.

B.4 Monitoring Recommendation

Two recommendations are made concerning sites for potential vadose zone monitoring. First, the priority sites listed on Table B.1 should be considered first for future monitoring. Particular emphasis is placed on LERF, 100 KE Basins, and specific retention facilities. Second, because of their use and history, specific retention facilities included on Table B.2 should receive second priority despite there being no baseline data.

Table B.3. Liquid Disposal Sites With Long-Lived Radionuclides and Greater Than 10 Pore Volumes

Site	Facility Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline Information
Uranium-Rich Process Condensate/Process Waste Group						
216-A-5	Crib	U Tc NO3	Pu Cs	557.3	0.5 - 5	1977, 1978
216-A-36A/B	Cribs	U Tc Cr	Pu Am Cs	19.5	0.5 - 5	1977, 1978, 1993
216-A-10	Crib	U Tc I	Pu Am Cs	114.4	0.5 - 5	1977, 1978, 1993
216-C-1	Crib	U Tc	Pu Cs	29.8	50 - 100	
216-S-1&2	Cribs	U Tc NO3	Pu Cs	26.6	50 - 100	1977, 1978
216-B-12	Crib	U Tc	Pu Cs	28.4	50 - 100	1977, 1978, 1993
216-U-8	Crib	U Tc	Pu Cs	34.1	50 - 100	1977, 1978
216-S-7	Crib	U Tc NO3	Pu Cs	46.6	50 - 100	1977, 1978, 1993
216-U-12	Crib	U Tc	Pu Am Cs	107.1	50 - 100	1977, 1978, 1993
216-U-1&2	Cribs	U Tc NO3	Pu Cs	115.5	50 - 100	1977, 1978, 1993
Plutonium-Rich Process Condensate/Process Waste Group						
216-Z-5	Crib	U Tc NO3	Pu Cs	64.6	50 - 100	1977, 1978
216-Z-10	Reverse Well	NO3	Pu Am	1000.0	50 - 100	
Plutonium/Organic-Rich Process Condensate/Process Waste Group						
216-Z-3	Crib	U Tc NO3	Pu Cs	409.2	50 - 100	1977, 1978
216-T-19	Tile Field/Crib	Tc CCl4 NO3	Pu Am Cs	36.4	50 - 100	1977, 1978, 1993
216-Z-12	Crib	U Tc CCl4 NO3	Pu Cs	187.3	50 - 100	1977, 1978, 1993
Organic-Rich Process Condensate/Process Waste Group						
216-A-8	Crib	U Tc	Pu Cs	32.6	50 - 100	1977, 1978
216-A-24	Crib	U Tc	Pu Cs	15.2	50 - 100	1977, 1978, 1993
Fission Product-rich Process Condensate/Process Waste Group						
216-S-3	Crib	U Tc NO3 Cr	Pu Cs	12.6	50 - 100	
216-B-62	Crib	U Tc	Pu Am Cs	24.4	50 - 100	1977, 1978, 1993
216-B-57	Crib	U Tc	Pu Cs	14.6	10 - 20	1977, 1978, 1993
216-B-11A&B	Reverse Wells	U Tc	Pu Cs	174.9	10 - 20	1977, 1978, 1993
General Process Condensate and Process Waste Group						
216-A-37-1	Crib	U Tc NO3	Pu Am Cs	23.7	50 - 100	
Tank Waste Group						
216-T-32	Crib	U Tc NO3	Pu Cs	11.0	50 - 100	1977, 1978
216-T-7	Crib	U Tc NO3	Pu Cs	12.4	50 - 100	1977, 1978
216-T-6	Crib	U Tc NO3	Pu Cs	34.5	50 - 100	1977, 1978, 1993
216-B-7A&B	Cribs	U Tc NO3	Pu Cs	78.1	10 - 20	1977, 1978, 1993
Scavenged Waste Group						
216-T-26	Crib	U Tc CN NO3	Pu Cs	17.6		1977, 1978, 1993
Steam Condensate Group						
216-A-37-2	Crib	U Tc	Am Cs	35.7	50 - 100	
216-S-25	Crib	U Tc NO3	Pu Cs	30.0	10 - 20	1977, 1978
216-B-55	Crib	U Tc	Pu Am Cs	67.5	50 - 100	1977, 1978
216-A-6	Crib	U Tc NO3	Pu Cs	147.7	50 - 100	1977, 1978
216-S-5	Crib	U Tc NO3	Pu Cs	55.6	50 - 100	1977, 1978, 1993
216-S-6	Crib	U Tc NO3	Pu Cs	127.3	50 - 100	1977, 1978, 1993
216-A-30	Crib	U Tc NO3	Pu Am Cs	223.9	50 - 100	1977, 1978, 1993

Table B.3. (contd)

Site	Facility Type	Mobile Constituents	Immobile or Long Lived Constituents	Number of Pore Volumes	Natural Recharge (mm/yr)	Baseline Information
Chemical Sewer Group						
216-S-11	Pond	U	Pu Cs	20.4	50 - 100	
216-S-10D	Ditch	U	Pu Am Cs	192.2	50 - 100	
216-B-63	Trench	U	Pu Am Cs	658.1	50 - 100	
U Pond/Z Ditches Cooling Water Group						
216-U-10	Pond	U	Pu Am Cs	91.7	50 - 100	
216-Z-20	Crib	Tc NO3	Pu Am Cs	172.7	50 - 100	
Gable Mtn/B Pond & Ditch Cooling Water Group						
216-A-25	Pond	U	Pu Am Cs	445.2		
216-A-9	Crib	U Tc NO3	Pu Cs	48.9	50 - 100	1977, 1978
216-B-3	Pond and Ditches	U	Pu Am Cs	105.1	50 - 100	
216-B-2-1	Ditch		Pu Am Cs	1338.0	50 - 100	
200 North Pond Cooling Water Group						
216-N-2	Crib	Tc	Cs	10.3	0.5 - 5	
T Ponds/Ditches Cooling Water Group						
216-T-12	Trench	U Tc	Pu Cs	23.4	0.5 - 5	
200 Areas Chemical Laboratory Waste Group						
216-S-26	Crib	NO3	Am Cs	23.4	50 - 100	
216-U-4A	French Drain	U Tc NO3	Pu Cs	27.3	50 - 100	
216-Z-17	Trench	U Tc	Pu	11.1	50 - 100	
216-B-10A	Crib	U Tc NO3 Cr	Pu Cs	21.5	50 - 100	1977, 1978
216-Z-16	Crib	Tc	Pu	44.4	50 - 100	1977, 1978
216-S-20	Crib	U Tc NO3	Pu Cs	22.4	50 - 100	1977, 1978, 1993
216-B-6	Reverse Well	Cr		4285.7	50 - 100	
300 Areas Chemical Laboratory Waste Group						
216-T-27	Crib	U Tc NO3	Pu Cs	10.6	50 - 100	1977, 1978, 1993
216-T-28	Crib	U Tc NO3	Pu Cs	62.2	50 - 100	1977, 1978, 1993
Miscellaneous Waste Group						
216-U-3	French Drain	U Tc	Pu Cs	20.3	50 - 100	
216-A-21	Crib	U Tc NO3 Cr	Pu Cs	32.8	0.5 - 5	1977, 1978

Sources of Baseline Information

Fecht et al. 1977.

Additon et al. 1978a and 1978b.

Brodeur et al. 1993.

B.5 References

40 CFR 265, Code of Federal Regulations, Title 40, Part 265. *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*

Additon, M, K., K. R. Fecht, T. L. Jones, and G. V. Last. 1978a. *Scintillation Probe Profiles 200 East Area Crib Monitoring Wells.* RHO-LD-28, Rockwell Hanford Company, Richland, Washington.

Additon, M, K., K. R. Fecht, T. L. Jones, and G. V. Last. 1978b. *Scintillation Probe Profiles 200 West Area Crib Monitoring Wells.* RHO-LD-29, Rockwell Hanford Company, Richland, Washington.

Brodeur, J. R., R. K. Price, R. D. Wilson, and C. J. Koizumi. 1993. *Results of Spectral Gamma-Ray Logging of Select Boreholes for the 200 Aggregate Area Management Study.* WHC-SC-EN-TI-021, Westinghouse Hanford, Co., Richland, Washington.

Diediker, L. P. 1998. *Cumulative Decayed Inventory Reports.* Unpublished database, Waste Management Northwest Inc., Richland, Washington.

Downs, J. L., W. H. Rickard, C. A. Brandt, L. L. Cadwell, C. E. Cushing, D. R. Geist, R. M. Mazaika, D. A. Neitzel, L. E. Rogers, M. R. Sackschewsky, and J. J. Nugent. 1993. *Habitat Types on the Hanford Site: Wildlife and Plant Species of Concern.* PNL-8942, Pacific Northwest Laboratory, Richland Washington.

Fayer, M. J., G. W. Gee, M. L. Rockhold, M. D. Freshley, and T. B. Walters. 1996. *Estimating Recharge Rates for a Groundwater Model Using a GIS.* Jour. Of Environmental Quality, v. 25, pp. 510-518.

Fecht, K. R., G. V. Last, and K. R. Price. 1977. *Evaluation of Scintillation Probe Profiles From 200 Area Crib Monitoring Wells.* ARH-ST.156, Atlantic Richfield Hanford Co., Richland, Washington.

Johnson, V. G., C. J. Chou, and J. W. Lindberg. 1995. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins.* WHC-SD-EN-AP-174, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy (DOE). 1996. *200 Areas Soil Remediation Strategy - Environmental Restoration Program.* DOE/RL-96-67, Department of Energy, Richland Washington.

U.S. Department of Energy (DOE). 1997. *Waste Site Grouping for 200 Areas Soil Investigations.* DOE/RL-96-81. Department of Energy, Richland Operations Office, Richland, Washington.

WAC 173-303, Washington Administrative Code. *Dangerous Waste Regulations.* Olympia, Washington.

Waite, J. L. 1991. *Tank Wastes Discharged Directly to the Soil at the Hanford Site.* WHC-MR-0227, Westinghouse Hanford company, Richland, Washington.

Appendix C

1999 Vadose Zone Monitoring Plan

Appendix C

1999 Vadose Zone Monitoring Plan

Current schedule for vadose monitoring in FY 1999 includes the following tasks.

Prepare the detailed site-specific information including site-specific maps, inventories, constituents of concern, results of previous monitoring, existing subsurface access, existing contamination, applicable regulatory limits, and monitoring frequencies for sites to be monitored in FY 1999.

Monitor vadose zone contamination beneath about 20 specific retention facilities using geophysical spectral gamma-ray techniques at specific retention trenches. Report results of the logging effort.

Complete a feasibility/cost analysis of preferred alternatives for vadose zone monitoring to supplement existing groundwater monitoring at LERF.