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Vadose Zone Characterization Project
at the Hanford Tank Farms

Modeling-Needs Assessment for Hanford Tank Farm Operations

April 1996

MASTER

U.S. Department of Energy
Grand Junction Projects Office

Work Performed Under DOE Contract No. DE-AC04-94AL96907 for the U.S. Department of Energy

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Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Projects Office

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Executive Summary

A modeling-needs assessment was completed for Hanford Tank Farm Operations. The goal of the project was to integrate site characterization and previous modeling efforts into a decision-based framework that guides Tank Farm Operations in implementing future modeling studies. The technical approach to this study was (1) to review the regulatory framework that governs Tank Farm Operations, (2) to solicit participation from stakeholder and Native American groups through a written survey, (3) to review previous subsurface modeling work, interview personnel with previous experience modeling the single-shell tank (SST) sites, and evaluate site characterization efforts to assess how modeling can be used to meet regulatory, programmatic, stakeholder, and Native American needs.

Operations at the SSTs are regulated under 40 Code of Federal Regulations (CFR) 265 Subpart J - Tank Systems. Tank operators are required to comply with four general sections in the regulations: (1) integrity testing, (2) containment and detection of releases, (3) inspections, and (4) response to leaks or spills. Tanks more than 15 years old must normally have secondary containment structures in place to collect potential releases from the storage tanks. SSTs more than 15 years old are permitted under a variance if the owner can demonstrate that favorable geohydrologic conditions combined with favorable management practices would control risks to human health and the environment. Transport modeling can be used to support variance applications.

Tank Farm Operations must also report tank releases, if they occur, to the Environmental Protection Agency (EPA) and the Washington State Department of Ecology. These reports must contain information such as the likely route of migration of the release, characteristics of the surrounding soils, results of any monitoring or sampling in connection with the release, proximity to downgradient water supplies, and any proposed actions. Modeling can also be used to support these reporting requirements.

The existence of known leaks, together with the gathering of new characterization data under the spectral-gamma logging program, compelled Tank Farm Operations to transform its mission statement into the following set of mission-critical questions that support the immediate regulatory requirements:

- Are the tanks stable and sound?
- Has a leak occurred?
- What is the volume of the leak?
- Where is the source of the leak?
- What is the extent of the contamination?
- What are the transport mechanisms?
- Is the existing contamination stable?
- Where will the contamination migrate?
- When will it get there?
- What parameters affect the transport?
- What are the future implications?

A written survey was prepared and distributed to a broad cross section of interested stakeholders and Native Americans to solicit input on these Tank Farm Operations issues. Of the 82 stakeholders surveyed, 21 responded to this survey. Respondents to the survey consisted mainly of organizations with direct involvement in the Federal Facilities Agreement and Consent Order (Tri-Party Agreement). Except for a few cases, the respondents agreed with the importance of addressing these questions. Responses to this survey are discussed within the body of this document.

A review of previous modeling studies was completed to evaluate if these Tank Farm Operations issues were being addressed by the previous modeling. Four modeling studies associated with the SSTs were reviewed as part of this project. The first study was a simulation of Ru-106 transport following a documented leak from tank T–106. The second study simulated plume migration that might occur during hydraulic sluicing of Tank 241–C–106. The third study evaluated the extent of groundwater contamination that would result from injection of salt water at the 105A mockup tank. The fourth study, which is still in progress, simulated contaminant transport from each tank farm to estimate the travel time for peak concentrations to migrate to groundwater and calculated the human health risks resulting from drinking water at a point 100 meters from a tank farm. The main conclusion drawn from these reviews is that the previous models are potentially useful to address some of the Tank Farm Operations issues. However, shortages of site-specific data on soil moisture, geochemical properties, and hydraulic parameters make it difficult to calibrate the models.

A review of the spectral-gamma logging program indicates that delineating the extent of Cs-137 contamination in the subsurface is useful primarily as a means of obtaining a first-approximation of the gamma-emitting contaminant distribution. The spectral-gamma logging provides gamma-emitting constituent concentrations in the subsurface, but in some cases the contamination appears to extend below the depth of the boreholes. Transport modeling may be used in these cases to help estimate the potential contaminant distributions; however, additional physical sampling would be necessary to calibrate such modeling results.

A sampling program was completed by Freeman-Pollard and others (1994) for the leak at Tank T-106. In addition to providing potential calibration data, this study showed a strong correlation between concentrations of mobile chemical species and soil moisture. This correlation suggests that collection of soil moisture data with geophysical logging would be helpful for any future transport modeling. This additional data collection could be further enhanced with recharge and moisture redistribution measurements at the tank farms, combined with modeling various surface-cover alternatives to control recharge.

1.0 Introduction

This report presents the results of a modeling-needs assessment conducted for Tank Farm Operations at the Hanford Site. The goal of this project is to integrate geophysical logging and subsurface transport modeling into a broader decision-based framework that will be made available to guide Tank Farm Operations in implementing future modeling studies. In support of this goal, previous subsurface transport modeling studies were reviewed, and stakeholder surveys and interviews were completed (1) to identify regulatory, stakeholder, and Native American concerns and the impacts of these concerns on Tank Farm Operations, (2) to identify technical constraints that impact site characterization and modeling efforts, and (3) to assess how subsurface transport modeling can best be used to support regulatory, stakeholder, Native American, and Tank Farm Operations needs.

This report is organized into six sections. Following this introduction, Section 2.0 discusses background issues that relate to Tank Farm Operations. Section 3.0 summarizes the technical approach used to appraise the status of modeling and supporting characterization. Section 4.0 presents a detailed description of how the technical approach was implemented. Section 5.0 identifies findings and observations that relate to implementation of numerical modeling, and Section 6.0 presents recommendations for future activities.

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2.0 Background

Remediation of the high-level underground waste-storage tanks at Hanford is one of the most critical environmental issues being addressed by the U.S. Department of Energy (DOE). Some of the tanks have been used since the 1940s to store high-level waste generated from reprocessing spent fuel. There are approximately 56 million gallons of high-level waste stored in 177 underground tanks at the Hanford Site. Of these tanks, 149 are older SSTs without secondary containment; 67 of these SSTs are known to have leaked high-level waste into the surrounding soil. Most of the SSTs have been interim stabilized by pumping fluids out of the SSTs into double-wall tanks, while others have been interim stabilized by removing piping to prevent additional fluids from being inadvertently added. Salt cake, sludge, and some interstitial fluids remain in the SSTs. A Resource Conservation and Recovery Act (RCRA) Part A (interim status) permit application and Closure/Work Plan have been submitted to the Washington State Department of Ecology for the SSTs at Hanford. The SSTs are not expected to receive any additional hazardous substances.

According to DOE (1995), "...if high-level waste is inadequately managed, it can pose serious immediate as well as long-term risks." The tank farms have been described as "...a major source of risk to workers and the public..." (Blush and Heitman 1995). Therefore, it is critical that the extent of the contamination and the preferred migration pathways be thoroughly understood to better manage the potential risks.

DOE's Tank Farm Operations group at the Hanford Site is responsible for managing the SSTs. The mission of Tank Farm Operations is to "...cost effectively manage tank wastes in a manner that limits risks to human health and the environment by minimizing the generation of new wastes; and maintaining safe and environmentally sound treatment, storage, and disposal of existing and newly generated radioactive, hazardous chemical, and mixed wastes to ensure continued safe storage of tank wastes without uncontrolled release to the environment." Figure 2–1 illustrates how this modeling needs assessment is tasked with making recommendations to meet these goals.

One strategy for accomplishing the goals outlined in the mission statement for Tank Farm Operations is to use site characterization in combination with subsurface transport modeling, when appropriate, to address regulatory commitments. In this assessment the term "transport modeling" implicitly includes surface and subsurface processes.

The SSTs and the vadose zone are monitored by Tank Farm Operations to address a number of questions that can be derived from the Tank Farm Operations Mission Statement. These mission-critical questions were identified as part of this project. They include the following: "Are the tanks stable and sound?", "Has a leak occurred?", "What is the volume of the leak?", and "What is the source of the leak". Data collection using baseline geophysical logging of the vadose zone can help answer the question "What is the extent of contamination?" The extent of contamination may be addressed more completely through transport modeling after a site conceptual model is developed to support the question "What are the transport mechanisms?"

When combined with future geophysical logging of migrating contamination plumes in the vadose zone, future transport modeling may be used to answer the questions "Where will the contamination migrate?", "When will it get there?", and "What are the parameters affecting the transport?".

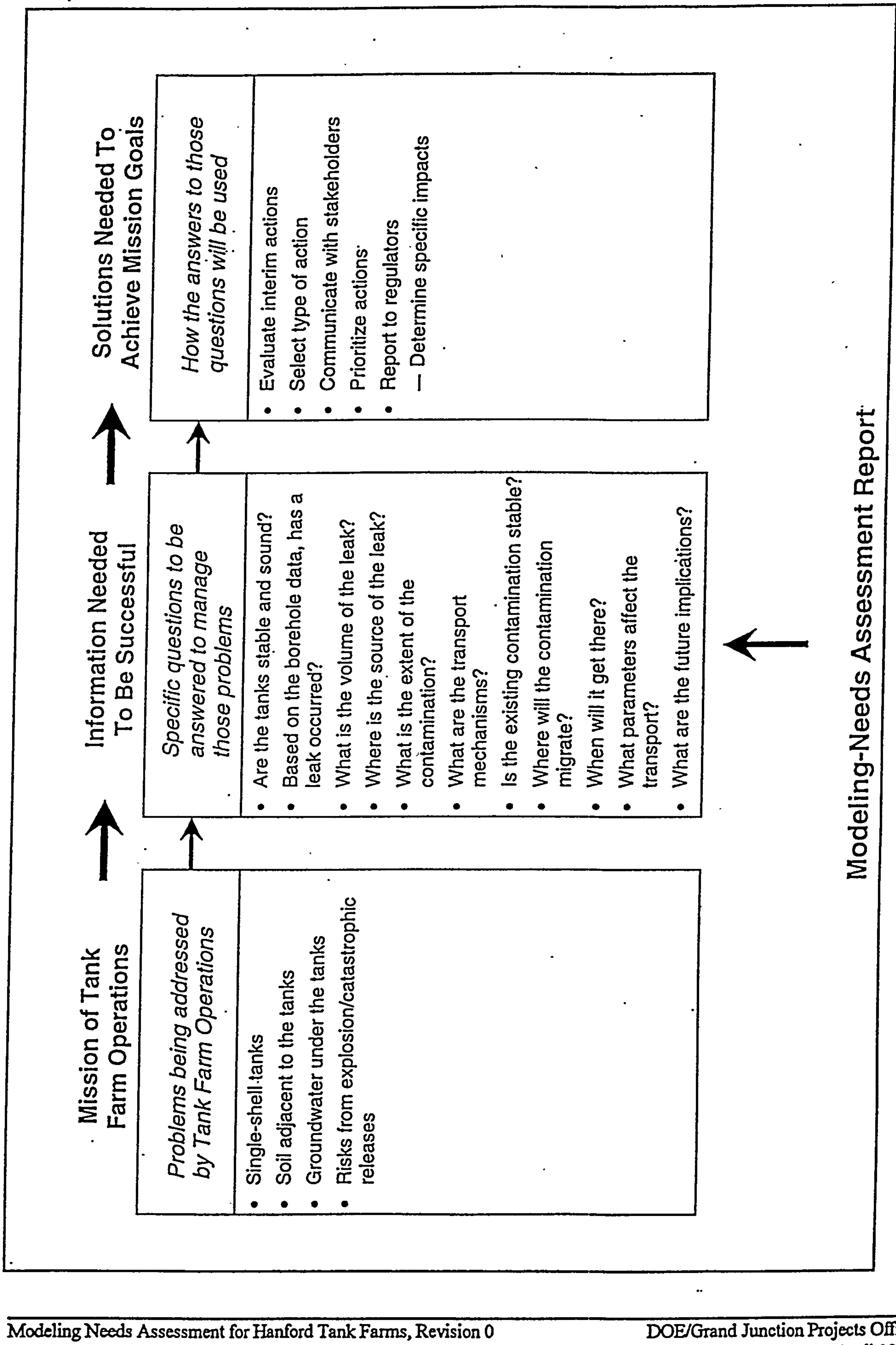

Figure 2–1. How the Modeling-Needs Assessment Supports Tank Operation Activities

3.0 Technical Approach

A three-staged approach was used to consider transport modeling and its relationship to the Tank Farm Operations program. First, the regulatory framework was reviewed to identify what actions are required for Tank Farms Operations to comply with State regulations. Second, stakeholder and Native American groups were given a written survey to solicit their input on important operational decisions. Third, previous work and work in progress were reviewed, including the high-resolution spectral-gamma logging program, transport modeling efforts, and interviews with personnel responsible for transport modeling. Each of these three aspects of the technical approach is described below.

3.1 Review of Regulatory Framework

In general, the Washington Administrative Code (WAC) sets forth the final status regulations that govern the SSTs. However, since the SSTs are presently being operated under interim status, they are regulated under 40 CFR 265 Subpart J - Tank Systems. These regulations are practically identical to the final status regulations that appear in Section 173-303-640 of the WAC.

Tank operators are required to comply with four general sections of regulations specified in 40 CFR 265: (1) integrity testing, (2) containment and detection of releases, (3) inspections, and (4) response to leaks or spills. Provisions in each of these sections were reviewed to establish whether transport modeling could be used to support the reporting required by these regulations. Closure and postclosure care requirements are being implemented by others; therefore, closure and postclosure care requirements are not reviewed in this document.

3.2 Stakeholder and Native American Surveys

A written survey was prepared for distribution to stakeholder and Native American groups on November 1, 1995. The survey was prepared by individuals with many years of programmatic and technical experience pertinent to the SSTs, as well as others with technical and regulatory expertise. Responses to the questionnaire identified and validated the major issues and generated stakeholder input regarding additional issues that need to be addressed. Figure 3–1 presents a copy of the survey and lists the questions that were identified as important to Tank Farm Operations.

The list of stakeholder and Native American groups, including the names and addresses of the contact persons, was obtained from the Hanford Site Home Page on the Internet World Wide Web (http://www.hanford.gov). A total of 82 surveys were mailed out.

A list of stakeholder and Native American groups that received the surveys is presented in Appendix A. Results of the survey are discussed in Section 4.2.

Name ______________________; Affiliation ______________________________;
Position Held__________________; Telephone _______________; Date _________

In addressing the contaminant releases from the single-shell tank site at Hanford, please indicate whether you perceive the following to be important issues. Please check yes, no, or unsure in the space provided.

Where is the contamination presently distributed ?
Yes ( ) No ( ) Unsure ( )
What are the transport mechanisms responsible for movement of the contamination in the subsurface soil ?
Yes ( ) No ( ) Unsure ( )
What is the volume of leaks responsible for the existing contaminant distribution ?
Yes ( ) No ( ) Unsure ( )
What is the source of (which tank(s) is responsible for) the leaking material ?
Yes ( ) No ( ) Unsure ( )
Has a leak occurred ?
Yes ( ) No ( ) Unsure ( )
Where is the contamination migrating to ?
Yes ( ) No ( ) Unsure ( )
When will the contamination get there ?
Yes ( ) No ( ) Unsure ( )
What is uncertainty with regard to our data ?
Yes ( ) No ( ) Unsure ( )
What is the uncertainty with regard to our predictions ?
Yes ( ) No ( ) Unsure ( )

Please indicate in the space provided whether there are any other environmental questions you feel are important with regard to the SSTs at the Hanford Facility (please use additional paper if required).

____
____
____
____

Figure 3–1. Survey Distributed to Stakeholders and Native American Groups

3.3 Review of Previous Work and Work in Progress

Technical evaluations of subsurface transport-modeling work already performed or still in progress were completed by assembling all known subsurface modeling documents for the SST sites. It is acknowledged that a considerable body of subsurface and surface modeling documents exists for other portions of the Hanford Site, namely the cribs, ponds, and trenches. These other areas were excluded from this study to focus efforts specifically on the SST sites where the high-resolution spectral-gamma logging project is being conducted, and because the SSTs are unique in that they contributed much lower volumes of fluid to the subsurface in comparison to these other sources.

The modeling documents that were reviewed included Smoot and Sagar (1990), Smoot and others (1989), Arnett and others (1977), Lowe and others (1993), Piepho (1995), and Piepho (1994). This list of documents represents the extent of published work on subsurface transport modeling at the SST sites. In addition, Freeman-Pollard and others (1994), which is not a modeling document, was reviewed during this project because it presents new information regarding the Tank T–106 leak.

The document review was completed to evaluate the degree to which transport modeling supports management decisions at Tank Farm Operations. These management decisions are based on the following questions:

- Are the tanks stable and sound?
- Has a leak occurred?
- What is the volume of the leak?
- Where is the source of the leak?
- What is the extent of the contamination?
- What are the transport mechanisms?
- Is the existing contamination stable?
- Where will the contamination migrate?
- When will it get there?
- What parameters affect the transport?
- What are the future implications?

A systematic approach was used during the document review to evaluate if the modelers (1) defined their objectives (i.e., what questions were being addressed?), (2) developed a conceptual model, (3) developed a water budget, (4) stated their calibration criteria, (5) identified potential errors in the data, (6) achieved calibration, (7) achieved the modeling objectives, (8) stated how the conceptual model could be refined in the future, and (9) archived the input files for future modeling efforts.

The modeling review also involved interviewing onsite contractors who were directly engaged in the modeling studies. Interviews were scheduled with representatives from Pacific Northwest National Laboratory (PNNL) and from the Westinghouse Hanford Company. In attendance from PNNL were Glendon Gee and Mark Freshley. John Smoot from PNNL completed a questionnaire designed to address the model-evaluation criteria; however, he did not participate in an interview. Westinghouse Hanford Company was represented by Niall Kline, Jack Sonnichsen, Allen Lu, Frank Schmittroth, Fred Mann, and Raz Khaleel. The interviews were conducted by Stan Morrison and Mark Kautsky, both of Rust Geotech, and Jerry Cammann of Daniel B. Stephens Associates, Inc.

A limited review of the high-resolution spectral-gamma logging program was also conducted. The evaluation of this program consisted of reviewing reports completed by the geophysical logging program to document which gamma-emitting constituents are presently being logged and what additional value would be provided if transport modeling was used in combination with the logging. John Brodeur, Rust Geotech's technical lead for the spectral gamma logging project, was interviewed to help address any unresolved issues.

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4.0 Summary of Program Reviews

This section presents details of what was learned during the program review. It includes a discussion of the regulatory framework, the written survey, previous work and work in progress, and includes a discussion of the geophysical logging program.

4.1 Review of Regulatory Framework

The SSTs at the Hanford Site are regulated as RCRA treatment, storage, and disposal units and are subject to the operating standards and permit requirements of RCRA Sections 3004 and 3005, respectively. The USEPA implements these requirements using the rules in 40 CFR 265.

The specific rules that regulate Tank Farm Operations at the Hanford Site are found in 40 CFR 265 Subpart J - Tank Systems. These rules apply to owners and operators of facilities that use tank systems to treat or store dangerous waste. Tank operators are required to comply with four general sections of the regulations: (1) integrity testing, (2) containment and detection of releases, (3) inspections, and (4) response to leaks or spills. (Although tank operators must also comply with closure and postclosure care regulations, these issues are being addressed by others and were purposely left out of this presentation).

40 CFR 265.193 "Containment and Detection of Releases" requires a secondary containment system for tanks more than 15 years old to prevent releases of dangerous waste into the subsurface. However, this section allows the owner (in this case, DOE) to obtain a variance from the secondary-containment requirement if the owner can demonstrate that "...alternative design and operating practices, together with location characteristics, will prevent the migration of hazardous waste or hazardous constituents into the groundwater, or surface water at least as effectively as secondary containment during the active life of the tank system or that in the event of a release that does migrate to groundwater or surface water, no substantial present or potential hazard will be posed to human health or the environment." Transport modeling would be a useful tool in support of variance applications if they were deemed necessary by Tank Farm Operations. The way in which transport modeling could be applied to address these regulatory requirements is discussed in Section 6.0.

40 CFR 265.196 "Response to Leaks or Spills and Disposition of Leaking or Unfit-for-Use Tank Systems" requires that tanks systems that have leaked must be immediately removed from service, wastes must be removed from the tank systems, and sampling and monitoring data relating to the release must be submitted to the EPA as soon as they are available. Section 265.196 requires the owner (DOE) to identify (1) the "...likely route of migration of the release.", (2) the "...characteristics of the surrounding soil (soil composition, geology, hydrogeology, climate)," and (3) the "...results of any monitoring or sampling conducted in connection with the release (if available). If sampling or monitoring data relating to the release are not available within thirty days, these data must be submitted to the EPA Regional Administrator as soon as they become available.", (4) the "...proximity to down gradient drinking water, surface water, and population

areas.", and (5) the "...description of response actions taken or planned." Geophysical logging in conjunction with transport modeling can be used to support reporting on these issues as well. The way in which transport modeling could be applied to address these regulatory requirements is discussed in Section 6.0.

4.2 Results of Stakeholder and Native American Surveys

Of the 82 surveys sent to stakeholder and Native American groups, 21 responses were received. Most of the respondents agreed with the importance of the questions identified in Figure 3–1.

The bulk of the responses were received from stakeholders directly linked to the Tri-Party Agreement. This group consists of four respondents from DOE, five respondents from Westinghouse Hanford Company contractor personnel, and three respondents from the Washington State Department of Ecology. Surveys were sent to each of the Native American nations; however, only one nation responded—the Nez Perce Nation. Dozens of surveys were sent to public interest groups; only two of these groups responded. The remaining responses came from stakeholders with other State agencies.

DOE–Richland agreed unanimously with the entire list of questions on the survey. Only one additional concern was raised in regard to the environmental impacts of waste contained in the SSTs. Responses from Westinghouse Hanford Company stakeholders were generally in agreement with the survey; however, two of the respondents were either unsure about or disagreed with the importance of identifying the transport mechanisms for movement of contamination in the subsurface soil, the volume of leaks responsible for the existing contamination, and the source of the leaking material. Similarly, a respondent from the EPA disagreed with the importance of identifying the volume of leaks responsible for the existing contamination and the source of the leaking material.

The Washington State Department of Ecology was generally in agreement with the entire survey; however, one stakeholder was concerned that focusing characterization efforts on spectral-gamma logging would make it impossible to identify all of the contaminants of concern and to adequately characterize and model plume movement. This stakeholder felt that a more thorough vadose zone characterization program is necessary.

A stakeholder from the Washington State Department of Health, and another from the Washington State Department of Ecology were unsure of the importance of questions having to do with uncertainty estimates. An Idaho State Bureau of Environmental Health and Safety stakeholder expressed reservations with the methods used previously by DOE to assess uncertainty and thought that the way in which uncertainty is calculated was important.

Another stakeholder supported the importance of ascertaining the contaminant inventory. Numerous documents are available that identify the nature of contaminants that leaked from the SSTs (e.g., Rockwell Hanford Operations (RHO) 1984). Another stakeholder pointed out that contamination in the vadose zone is chemical specific (i.e., Cs moves slowly, while Tc moves quickly). This disparity in transport rates between the various chemicals is a valid concern; it is discussed more completely in Section 4.3 of this document. A related comment was received from the Nez Perce stakeholder, who inquired about the physical (porosity and permeability) and chemical properties of the vadose zone near both the SSTs and double-shell tanks; these issues are discussed in Section 4.3.

Stakeholders from the public interest groups were concerned that the list of questions did not specifically address calculating the environmental impacts and health risks stemming from the SST sites. It should be emphasized that the questions presented in Figure 3–1 are limited in scope, and that they only pertain to the environmental impacts affecting the vadose zone and the groundwater. Tank Farm Operations intends to address environmental impacts and health risks associated with potential leaks of tank waste and their transport in the vadose zone. The broader health risks (e.g., worker exposure during retrieval, safety risks that are due to explosions resulting from increasing hydrogen gas concentrations, etc.) will be addressed by others in the *Single-Shell Tank Closure Work Plan* (DOE–RL 1995).

Several respondents were concerned that technological issues were not addressed in the questionnaire. They specifically mentioned various contaminant-stabilization technologies including in situ fixation with polymer injections, cryogenic techniques to contain and recover contaminants, and in situ vitrification. These respondents also questioned whether the technologies required to manage the spread of contamination are fully developed. In response to these issues, it should be stated that available technologies are being studied by others, and selection of these remedies will be done in accordance with milestones presented in the Tri-Party Agreement. Tank Farm Operations is actively engaged in addressing these issues.

4.3 Review of Modeling Studies

4.3.1 Summary of Documented Models

On the basis of interviews with Hanford groundwater modelers, four studies were identified that are directly applicable to the scope of this study: (1) a two-part PNNL study of Tank 241–T–106 performed by Smoot and Sagar (1990) and Smoot and others (1989), (2) a two-part Westinghouse Hanford Company study of Tank 241–C–106 by Lowe and others (1993) and Kline and Khaleel (1994), (3) a study of the effects of a proposed salt-tracer injection at mock-up tank 105A by Piepho (1994), and (4) an in progress risk-based assessment (RA) supporting closure of the Hanford Site SSTs as landfills. These four investigations are referenced in the remainder of this document as the PNNL, WHC, Piepho, and RA studies, respectively. Although the RA study is preliminary, the critical aspects of the work have been defined. In all four studies, moisture-dependent hydraulic conductivities were estimated from data collected on the Hanford Site but not in immediate proximity to the study areas. The consensus of these studies is that site-specific data are needed to improve the simulation results.

The PNNL study simulates plume migration from a leak at Tank 241–T–106 using the transport code PORFLOW (Runchal and Sagar 1989). The three-dimensional PORFLOW model uses temporally varied infiltration rates based on measured precipitation from 1947 to 1988 (and projected out to the year 2020) and one-dimensional UNSAT–H (Fayer and Jones 1990) simulations of the upper 2 meters of soil. The average infiltration calculated in this manner is 13 centimeters per year (cm/yr). Flow rates were enhanced around the tank perimeter (simulated by impermeable nodes) to simulate water flowing off the top of the tank (the "umbrella effect"). These simulations overestimate the observed migration of the Ru-106 plume for data collected by gross-gamma logging during 1973 and 1978. In contrast to the Ru-106 plume, the modeled Cs-137 plume closely approximates the observed data. Chemical retardation is included for Cs-137 but not for Ru-106. The UNSAT–H simulations showed that a 15-cm-thick silt layer placed at ground level over the tanks would greatly reduce infiltration, leading PNNL to conclude that surface barriers of silt would be effective to limit plume migration.

The purpose of the WHC study was to predict plume migration of a leak that might occur during hydraulic sluicing of Tank 241–C–106. The model domain is a two-dimensional vertical slice through the center of 241–C–106 and two adjacent tanks (241–C–104, 241–C–105) that extends to the water table. Infiltration rates computed by a three-dimensional model were entered into the two-dimensional model to simulate the enhanced infiltration that is due to the "umbrella effect". Both two- and three-dimensional simulations were performed with PORFLOW. The leak volumes used in the models were consistent with estimates derived from a statistical analysis of leaks from SSTs. Unlike previous models, WHC considered the effects of moisture-dependent anisotropy.

The objective of the Piepho study was to evaluate the extent of groundwater contamination that would result from injecting 2,000 (or 4,000) gallons of salt water (7,000 milligrams per liter [mg/L] sodium chloride) at the mock-up tank 105A. The results of the model simulations were used for a risk-based decision to determine if the injection is environmentally acceptable. The planned injection experiment was designed to observe the migration of a conservative tracer through the subsurface using electrical-resistance tomography (ERT) methods. The resulting database is intended for use in model calibration. Piepho examined the sensitivity of the salt-plume migration to infiltration rate, dispersion, quantity of salt, and position of the leak. Piepho concludes that the 7,000-mg/L salt concentrations would reduce to less than 10 mg/L in approximately 300 years for most of the simulations. The simulations were performed with PORFLOW using hydraulic properties estimated from data collected on the Hanford Site.

The RA study uses the RADCON module of the Multimedia Environmental Pollutant Assessment System (MEPAS) (Buck and others 1989) to simulate contaminant transport. RADCON simulates transport through the unsaturated zone in one dimension with a semianalytical solution for steady-state flow. Transport in the saturated zone is simulated in two dimensions. The SSTs on the Hanford Site are grouped into six tank farms and simulations are performed for each farm. Each tank farm is assigned a stratigraphic sequence and hydraulic parameters for each geologic unit in the section. The release rate of the contamination is calculated from the recharge rate and the contaminant's solubility. Each contaminant is assigned a specific distribution coefficient and decay-rate constant. Maximum concentrations and peak arrival times for each contaminant are then calculated at a point 100 meters from the tank farm in the groundwater. Potential health effects of consuming drinking water with these concentrations of contaminant are then determined. A preliminary conclusion from the RA study is that more than 99 percent of the tank-waste inventory may have to be removed to prevent unacceptable human health risks.

4.3.2 Choice of Modeling Codes

PORFLOW has been the code of choice for most of the previous subsurface-transport modeling studies at the Hanford Site. PORFLOW is capable of modeling unsaturated-saturated groundwater flow using state-of-the-art algorithms and, as such, is a reasonable choice; it would also be useful for simulations with the objectives of addressing Tank Farm Operations issues.

Initial conditions, boundary conditions, node spacings, time steps, hydraulic/geochemical parameter values, and other variables can greatly affect the model results. There is no standardized format that can be applied to model formulation. Thus, modeling results are influenced by the choices the modeler makes. Processes that may be important to contaminant transport rates but were not considered include chemical speciation and kinetics, coupling of hydraulic conductivity to mineral precipitation/dissolution, microbiological effects on chemical transport, and the effects of mineral aging on contaminant transfer from solid to liquid phases.

Although all these processes are important to plume migration, the capability to model each of these processes explicitly is limited. Considering the inherent uncertainties in model formulation and the added complexities (and cost of computational time) of extending the models to larger domains, it may be unnecessary to add more hydrodynamic processes to the model to address the needs of Tank Farm Operations.

4.3.3 Boundary Conditions, Initial Conditions, and Material Properties

4.3.3.1 PNNL, WHC, and Piepho Studies

The PNNL, WHC, and Piepho studies are similar in their requirements for boundary conditions, initial conditions, and material properties. The approach for each study was to define a domain that has a relatively small lateral range (about 30 meters from the center of the leaking tank) but extends vertically to (or in some cases a few meters below) the groundwater saturated zone.

No flow is allowed across the vertical side boundaries. Water is either permitted to leave through the lower horizontal boundary at a rate equal to the recharge or through the aquifer where it intersects the side boundary (a small gradient is assigned to the aquifer in this case). Infiltration occurs along the upper horizontal boundary. These boundary conditions force the flow to be directed nearly vertically downward; however, some lateral spreading occurs where the flow encounters a lower permeability horizon. The tanks have been modeled as either low permeability elements (PNNL) or as enhanced recharge nodes (WHC). In either case, the flow is enhanced around the tank to simulate the "umbrella effect" of water running over the top of the tank and down the sides. Infiltration at the ground surface was varied between 5 and 13 cm/yr on the basis of precipitation records and UNSAT–H modeling for a gravelly backfill that lacks vegetation (the tank farms have been kept free of vegetation). Tank leaks are modeled by allowing recharge of contaminated water at the assumed leak location. The volume and concentration of leaks are based on either historical information (for Tank T–106) or a statistical analysis of tank leaks (for sluicing scenarios at Tank 241–C–106).

In most of the models, the initial moisture conditions are set by running the model for a period before tank emplacement. Contaminant concentrations are set to zero throughout the domain before the leaks.

On the basis of stratigraphy observed in boreholes at the tank farm, a greatly simplified stratigraphic sequence is defined for the models. The lithology for each borehole is depicted as homogenous horizontal layers (up to seven layers were used with thicknesses of 5 to 50 meters). Material properties (van Genuchten parameters, dispersivities, diffusion constants, and chemical retardation factors) are assigned to each layer on the basis of the lithology. Parameters that define the rate of water movement through the unsaturated zone (van Genuchten parameters) have not been measured on any samples collected from the 200 West Area where the T Tank Farm is located. Therefore, both the PNNL and the WHC studies applied parameters measured in the 200 East Area at the 241–AP tank farm. The van Genuchten parameters measured at the 200 East Area should be validated at the low moisture content, typical of Hanford Site sediment. The authors of both studies note their concern in using parameters that may not adequately represent the conditions at the modeled site. Similarly, the Piepho study uses parameters that were measured on samples from a nearby site. Geophysical logging of moisture and density in the tank farms would also yield formation porosity in the vadose zone and, therefore, contribute to the site-specific inputs to the van Genuchten parameters..

Dispersivities and molecular diffusion constants are assumed and are not based on measurements made at the Hanford Site. Although chemical retardation studies have been performed at Hanford, the PNNL and WHC studies use undocumented values. All models treat retardation as an equilibrium process in which the ratio of contaminant in the solid fraction to contaminant in the groundwater remains constant throughout a given simulation.

4.3.3.2 RA Study

The unsaturated zone in the RA study is modeled in one dimension. The upper boundary is assigned a constant infiltration rate (usually 0.1 cm/yr). The flux of each contaminant is governed by its solubility and the infiltration rate. As with the other studies, each tank farm in the RA study is assigned a stratigraphy on the basis of the lithology in the area. Material parameters, including moisture-dependent hydraulic conductivities and porosities, are assigned to each layer. Retardation coefficients are assigned for each contaminant on the basis of the laboratory studies conducted by PNNL on Hanford sediments.

4.3.4 Model Calibration

For this report, model calibration is defined as the process in which model outputs are compared to known data to test the model's predictive ability. Model calibration alone does not guarantee model accuracy because model outputs are seldom unique. However, at a minimum, a model must be able to simulate known conditions. The level of confidence in using models for decision making increases as successful calibrations are performed.

Models can be calibrated to chemical concentrations or moisture data. Highly constrained data sets are more valuable for model calibration than data sets with one or more important unknown parameters. Constrained data sets can be collected if a leak occurs in a well-monitored tank or if a planned injection experiment is performed. Preliminary calculations in the RA study indicate that Np-237, U-238, Tc-99, and I-129 are the radionuclides that are most likely to pose a health risk at the tank farms, while the nonradioactive risk drivers are NO_3, As, Cr, and Sb. Measurement techniques that could provide a subsurface map of these constituents would be useful for model calibration. Plumes of other dissolved chemicals could also be used to calibrate models.

Calibrations in the four modeling studies are limited. The PNNL study attempted to match its model output to the Ru-106 concentrations in a plume that had leaked from Tank T–106 in 1973. This plume was measured using gross-gamma logging in 1973 and again in 1978. However, the gross-gamma logging upon which the modeling was based did not provide validated data; consequently, the model calibration was debatable. In addition, the model output for the Ru-106 plume significantly overestimated the rate of plume migration as measured by the invalidated gross-gamma logging results. The WHC report raised the question of whether the picocuries per liter (pCi/L) units on the Ru-106 plume map are expressed as per liter of water or per liter of bulk soil. The unit conversions could significantly modify the concentration contours. There was also concern that interpretation of the gross-gamma logs is complicated by rusting casings that preferentially adsorb some radionuclides.

The presence of Cs-137 was also mapped at Tank T–106 using the gross-gamma logging results. The PNNL study successfully matched the Cs-137 results for 1973 but did not document any attempt to model Cs-137 for the 1978 data. Cs-137 is highly retarded by the Hanford sediments, thereby limiting plume migration. The model simulations will be more sensitive to the distribution coefficient used and less sensitive to the hydraulic parameters. However, in one study the mobility of Cs-137 increased in the presence of complexing agents such as ethylenediaminetetraacetic acid (EDTA) (Means and Crerar 1978). It is unknown if EDTA is present in sufficient quantities at the tank farms to enhance the migration of Cs-137.

Knowledge of the moisture distribution in the subsurface is useful in calibrating the transport models. The WHC study cites field observations by Caggiano and Goodwin (1991) and Brodeur (1993) of approximately 5 percent moisture by weight in the subsurface under the 241–C tank. These data were used to lend support to the use of moisture-dependent anisotropy. Methods to obtain additional moisture data from downhole geophysical logs should be explored to support model calibration efforts.

Results of successful field injection experiments could also be used for model calibration. The Piepho study involved a simulation of a planned salt-water injection test that was to be monitored using ERT. The ERT data, converted into concentration data, can be used to calibrate models for chemically conserved species. Unfortunately, the plume observed during the actual salt-water injection was only monitored down to a depth of approximately 30 feet because of limited borehole depths.

Although they are of limited use in calibrating hydraulic parameters, results of laboratory column experiments can be used to test the chemical retardation algorithms for transport models. Because the hydraulic and transport parameters are known in a laboratory column, any deviation of the measured concentration breakthrough profile from that of a mobile contaminant can be attributed to interactions between the aqueous and solid phases. Models should be able to adequately predict the concentration profiles for both contaminant retardation and release. In a retardation experiment, water with dissolved chemicals is passed through columns containing solids mineralogically similar to sediments at the site. In a release study, uncontaminated water is passed through columns containing contaminated sediments from the site. Effects of pH, Eh, solution composition, and (in the case of release studies) aging, may need to be considered to accurately predict contaminant breakthrough profiles. Calibration with laboratory columns can be used to determine the validity of models that impose an equilibrium chemical condition such as a distribution coefficient.

4.4 Review of Geophysical Logging Program

Geophysical logging is one of the only ways to obtain subsurface data in the tank farms because the areas are congested with tanks and considerable buried piping that restrict safe access with mobile drilling equipment. Furthermore, because the tanks have virtually exceeded their design lives, the tank domes themselves are potentially unstable. Lastly, the safety concerns associated with exposure to the potentially high levels of radioactivity make it difficult to collect soil samples directly.

These difficulties may be overcome with geophysical logging of existing boreholes in the tank farms. However, the information that borehole logging provides is limited by the steel casings that are required to maintain hole stability. In some instances, the casing thicknesses are unknown. In rare instances, such as in the T Tank Farm, dual-steel casings are used in the same borehole and the annular space between the two casings is filled with grout. These factors increase the uncertainty in the geophysical measurements, because they influence instrument calibration and hinder correct interpretation of the geophysical logs.

The nuclide Cs-137 emits beta and high-energy gamma radiation en route to its stable daughter Ba-137. Radionuclide inventories for the SST sites suggest that the original activities of Cs-137 are on the order of 1×10^6 Curies[1] (RHO 1984). Because of its abundance, Cs-137 is the primary constituent that is detected in gamma logging of the tank farm boreholes. The half life of Cs-137 is 30.17 years (Walker and others 1989). Knowledge regarding where Cs-137 is distributed in the subsurface is important to know because it will strongly affect any proposed retrieval actions.

However, because of a relatively short half life, most of the Cs-137 will be gone after 300 years. Consequently, its importance as a "risk driver" will subside with time. As a general rule, Cs-137 is not very mobile because of its strong affinity for the solid phase. However, in one study the mobility of Cs-137 increased in the presence of complexing agents such as EDTA (Means and Crerar 1978). It is unknown if EDTA is present in sufficient quantities at the tank farms for the

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[1]Curie represents the quantity of radioactive material in which the number of disintegrations per second is 3.7×10^{10}. It is acknowledged that the inventory represents estimates of the actual quantities present and is subject to estimation errors.

Cs-137 to be mobilized in response to a complexation reaction. Therefore, knowledge of the baseline distribution of the Cs-137 is equally important as changes in its distribution over time. In some cases, the logging results indicate that Cs-137 contamination may be present beyond the maximum depth of some of the boreholes. In these cases, the logging results can be used in combination with transport modeling to estimate the potential vertical depth and lateral extents of contamination from past releases. Modeling has not been used previously in this way to estimate contaminant distributions at the SST sites.

Sr-90 is another abundant radionuclide in the tank farms. Radionuclide inventories suggest that the original activities of Sr-90 are on the order of 1×10^6 to 1×10^7 Curies for each SST site (RHO 1984). Sr-90 only emits beta radiation en route to becoming stable Zr-90, but it can be detected indirectly from its bremsstrahlung signal in gamma-ray spectra. This capability is being developed as part of the geophysical logging program for Tank Farm Operations. Sr is relatively more mobile than Cs; therefore, it may be possible to detect temporal changes in its subsurface distribution. Logging these temporal changes in the Sr distribution over time would be useful for model calibration. In cases where the Sr extends to a depth exceeding the borehole depth, the logging results can be used in combination with transport modeling to estimate the extent of Sr contamination.

The radionuclide inventory indicates that other radionuclides are also present in the tank farms, namely C-14, Tc-99, I-129, Cs-135, U-234, U-235, U-238, Np-237, Pu-238, Pu-239, Pu-240, and Am-241. Of the radionuclides listed, only C-14, Tc-99, I-129, and the uranium isotopes are transported with the same velocity as groundwater. From this perspective, they are considered "conservative radioisotopes". Both U-235 and U-238 can be measured in the subsurface if required, and a determination can be made regarding whether these constituents result from chemical processing at the Hanford Site by evaluating their relative abundance. The U-235 concentrations are detectable directly by measuring the 185.7- kiloelectronvolt (keV) gamma ray. There is an interference from the 185.9-keV gamma ray of Ra-226, but a correction for this radium interference can be calculated and applied during processing of the logging data. The U-238 can be assayed without relying on the postradium gamma-emitting progenies by using the 1001-keV gamma ray of Pa-234m, as long as the intensity is strong enough to be useful. Therefore, if U-235 and U-238 are present at detectable levels in the vadose zone, transport modeling could be used in combination with spectral-gamma logging to forecast the arrival of these radionuclides at the groundwater. A well-documented plume of Eu-154 or Co-60 would be another useful model calibration tool.

Another option for geophysical logging is to locate soil moisture distributions, because one of the outputs from transport models is the moisture content. Moisture logging would enhance the logging program because changes in subsurface moisture could be monitored with geophysical methods and simulated with transport models.

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5.0 Findings and Observations

This section presents the significant findings and observations associated with this project. These findings and observations are based on the previous and current understanding of the subsurface conditions at the SST sites, as described in Section 4.0.

Because management decisions must be addressed as data collection proceeds, and each tank farm is at a different stage of characterization, it follows that decision making and reporting to the regulatory agencies will progress at different rates for each tank farm. Characterization at each tank farm will probably evolve through the following three successive periods: (1) Establish Present Conditions, (2) Evaluate Changing Source Conditions, and (3) Predict Future Conditions. A minimum set of management decisions must be made during each of these periods.

Figure 5–1 is a decision-making logic diagram that illustrates (1) the minimum activities and management decisions required for each period, and (2) that data collection and careful interpretation are fundamentally linked to establishing present conditions and evaluating changed source conditions. Fate and transport modeling is an activity that best supports the prediction of future conditions. However, it may also be used to estimate the present vertical and lateral extents of contamination when the contamination is believed to extend beyond the existing monitoring devices. The value of these predictions is directly proportional to the quality of the input data. In other words, as the parameter uncertainty decreases, the value of the predictive modeling increases.

Survey responses from stakeholder and Native American groups were rather limited. From a total of 82 surveys issued, only 21 completed surveys were returned (approximately 26 percent). Many of the responses were obtained from stakeholders closely associated with the Tri-Party Agreement. The main finding of the survey was that most of the respondents agreed with the importance of the questions listed. However, there was some disagreement regarding the importance and relevance of a few issues, such as, "What is the volume of a leak?", and "What is the source of a leak?". One stakeholder was concerned that focusing characterization efforts on spectral-gamma logging alone would make it impossible to identify all of the contaminants of concern and to adequately characterize and model plume movement. This stakeholder felt that a more thorough vadose zone program is necessary.

The main conclusion drawn from reviewing the previous modeling efforts is that the models are potentially useful to Tank Farm Operations. The PNNL modeling study laid a foundation for developing surface management activities that could be used in combination with geologic parameters to control the rate of plume migration, in lieu of secondary containment. The WHC, Piepho, and RA studies present travel times to the water table. These studies form a basis for addressing the regulatory issue of "...the likely route of migration of the release..." and the "...proximity to down gradient drinking water, surface water and populated areas." These estimates are directly dependent upon the infiltration rates and, therefore, can be controlled with effective surface management activities.

However, shortages of site-specific data on soil moisture, geochemical properties, and hydraulic parameters make it difficult to calibrate the modeling. To resolve these issues, geophysical methods should be used to collect moisture and density data to the extent practicable at each tank farm. Geochemical and hydraulic parameters should also be collected at the tank farms to address the lack of subsurface data regarding modeling parameters. Also, because the transport modeling codes provide soil moisture as an output, geophysical moisture logging should be performed to bridge this data need. Porosity data obtained through moisture and density logging would provide location-specific inputs to the van Genuchten parameters and improve the data quality used by subsurface transport models.

Freeman-Pollard and others (1994) have demonstrated that mobile constituents such as total nitrate, nitrite, sodium, Tc-99, total uranium, gross beta, and gross alpha did not fully penetrate the vadose zone after the largest tank leak on record, the Tank T–106 leak. In the event that no additional large leaks of this magnitude occur in the SSTs and recharge is controlled with surface covers, the likelihood of contaminants leaking to the groundwater from any of the other tanks would be low. Therefore, an additional use of modeling and characterization results would be to demonstrate the effectiveness of geologic units, in combination with alternative design and operating practices, to serve as barriers to the transport of contaminants to groundwater.

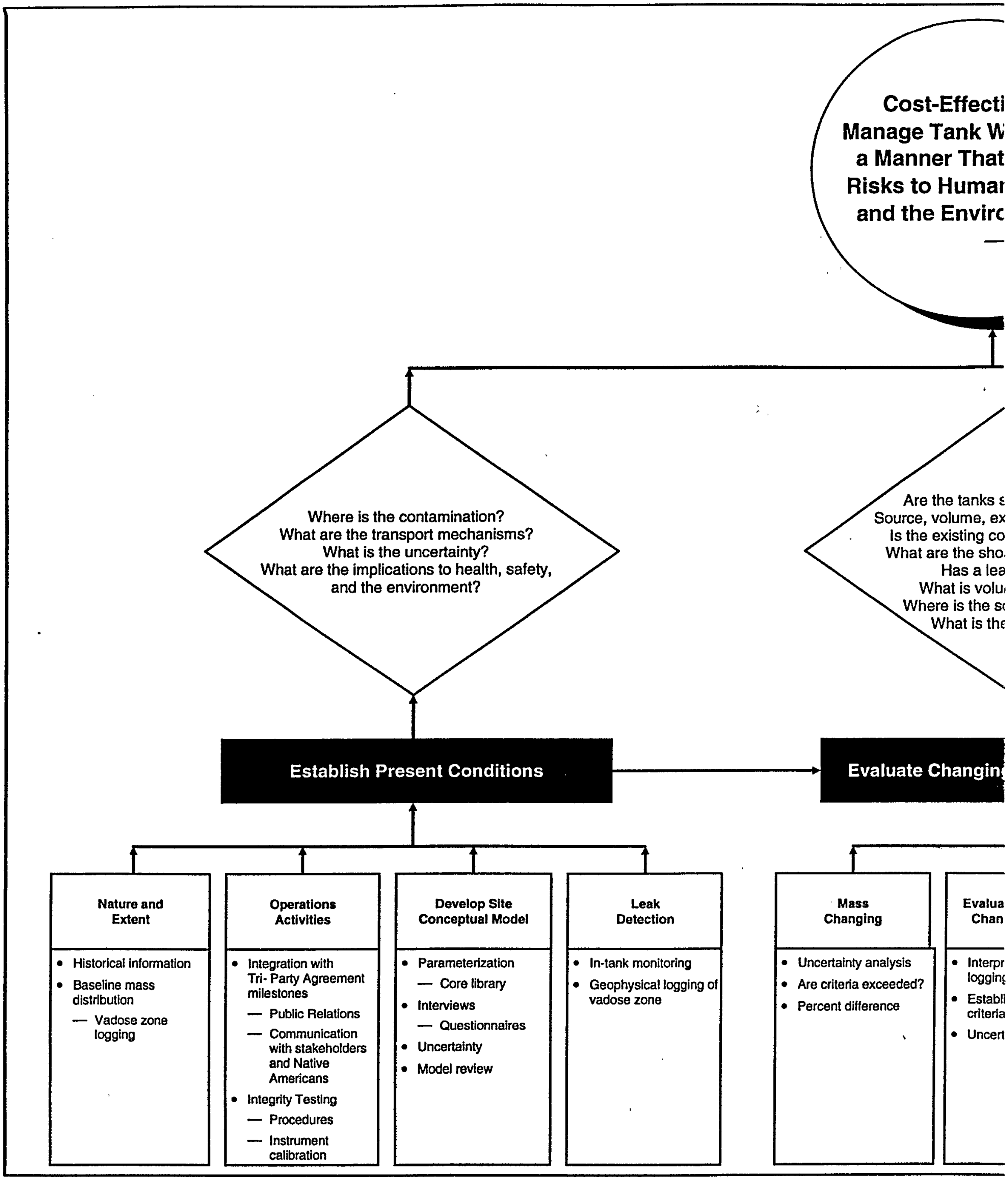
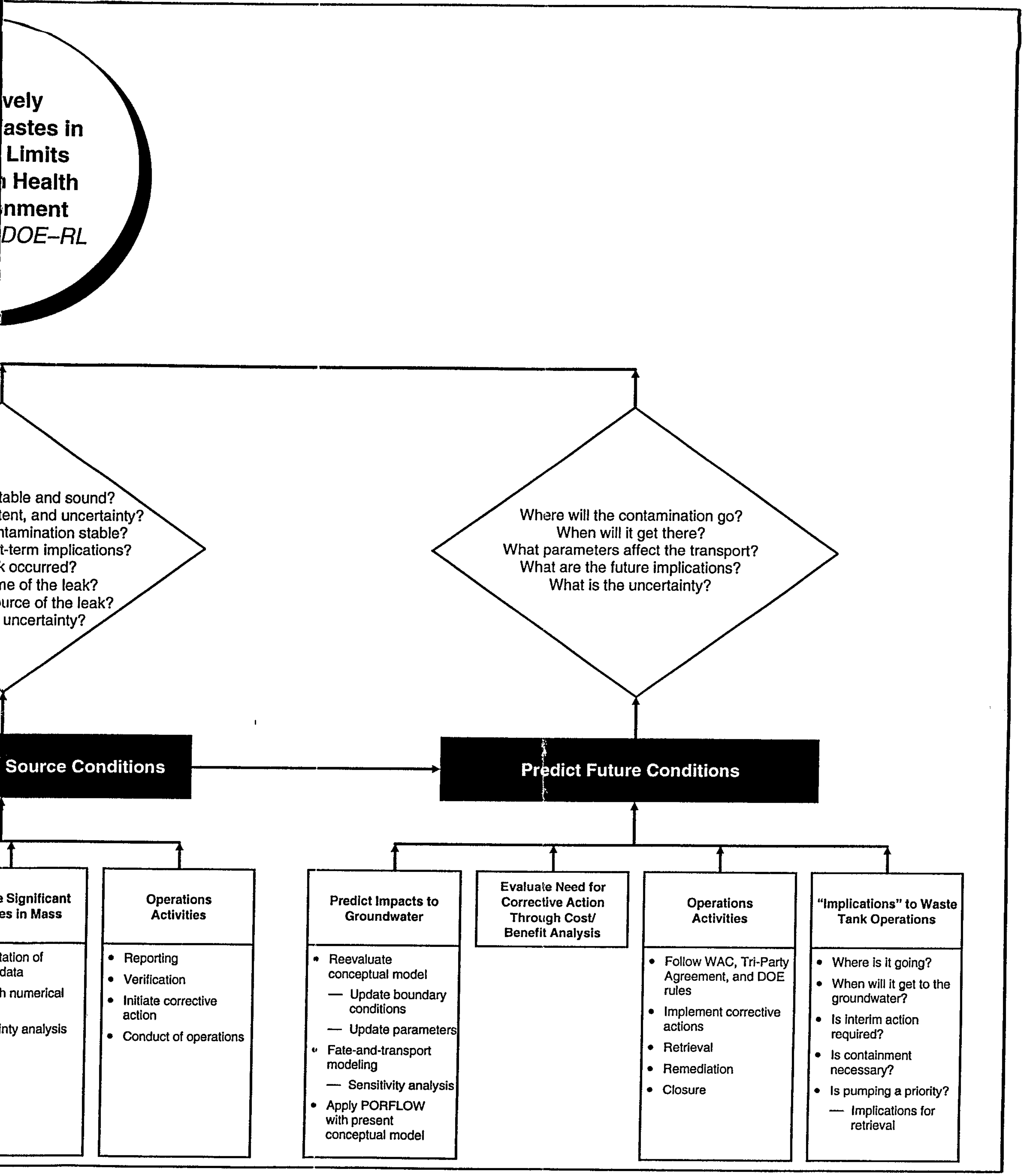


Figure 5–1. Decisio



-Making Logic Diagram

6.0 Recommendations

6.1 Modeling Applications

The existence of known leaks, together with the gathering of new vadose-zone characterization data under the spectral-gamma logging program, have compelled Hanford Tank Farm Operations to identify a set of mission-critical questions that concern the movement of radioactive constituents and moisture in the vadose zone near the SST sites. The water table represents the lower boundary of concern with regard to these recommendations. Since the interim-status regulations in 40 CFR 265 apply directly to SST operations, the recommendations in this section are developed to address each question from a regulatory perspective, one at a time.

- ***Are the Tanks Stable and Sound?***

This is an issue addressed specifically in 40 CFR 265.191 "Assessment of Existing Tank System's Integrity". Provisions are made in these regulations requiring "...leak test that is capable of taking into account the effects of temperature variations, tank end deflection, vapor pockets and high water table effects." Integrity testing is also required "...that addresses cracks, leaks, corrosion and erosion." If, as a result of these assessments, the tank is found to be leaking, the owner/operator must comply with the requirements of 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Tank Systems". Under this section, the owner must file reports with the EPA Regional Administrator concerning (1) the likely route of migration of the release, (2) the characteristics of the soils and hydrologic conditions, and (3) the response actions that have either been taken or are planned. Tank Farm Operations can use geophysical logging results in combination with modeling to support reporting on these issues.

- ***Has a Leak Occurred?***

Evaluations of whether a tank leak has occurred are discussed in 40 CFR 265.193, "Containment and Detection of Releases". A secondary containment system is required for tanks more than 15 years old to prevent releases of dangerous waste into the subsurface. However, this section of the WAC allows the owner (in this case, DOE) to obtain a variance from the double-wall tank requirement if it can be demonstrated that "...alternative design and operating practices, together with location characteristics, will prevent the migration of any hazardous waste or hazardous constituents into the groundwater, or surface water at least as effectively as secondary containment during the active life of the tank system or that in the event of a release that does migrate to groundwater or surface water, no substantial present or potential hazard will be posed to human health or the environment."

Transport modeling would be a useful tool in support of applications submitted to the EPA Regional Administrator for such variances because surface management plans can be developed to demonstrate the beneficial effects of surface covers to control (minimize or totally eliminate) recharge (infiltration of meteoric water below the root zone). These modeling studies, performed in combination with simulations of the vadose zone profile to account for the geochemical and hydrodynamic processes across the entire profile, can illustrate the effectiveness of engineered and natural barriers on the transport of contaminants to groundwater. If deemed necessary by Tank Farm Operations, these studies could be used to petition the EPA Regional Administrator for a variance from secondary containment during the interim-operation life cycle of the SSTs.

- ***What Is the Volume of the Leak?***

Evaluations of the volume of a leak are required in 40 CFR 265.196, " Response to Leaks or Spills and Disposition of Unfit-for-Use Systems. Under this section, the "...results of any monitoring or sampling conducted in connection with the release..." must be submitted to the EPA Regional Administrator "...as soon as they become available". Generally, the information for this requirement would be generated through the in-tank monitoring program being conducted by Tank Farm Operations. This information is important for reconstructing the history of past leaks and is an important input parameter to be used in transport models to estimate the vertical and lateral extent of contamination when the contamination extends beyond the limits of the vadose-zone monitoring network.

- ***Where Is the Source of the Leak?***

Evaluations of the source of a leak are required in 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the "...results of any monitoring or sampling conducted in connection with the release..." must be submitted to the EPA Regional Administrator "...as soon as they become available." The baseline information for this requirement would be generated through both the in-tank monitoring program and the spectral-gamma logging project being conducted for Tank Farm Operations. This information is important for reconstructing the history of past leaks and can be used in transport models to estimate the vertical and lateral extents of contamination when the contamination extends beyond the boundaries of the monitoring network.

- ***What Is the Extent of the Contamination?***

Evaluations of the source of a leak are required in 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the "...results of any monitoring or sampling conducted in connection with the release..." must be submitted in a report to the EPA Regional Administrator "...as soon as they become available." The baseline information for this requirement would be generated through the vadose-zone monitoring program being conducted by Tank Farm Operations. This information is important for developing a baseline for the extent of contamination and can be used in transport models to estimate the vertical and lateral extent of contamination when the contamination extends beyond the limits of the vadose zone monitoring network.

- ***What Are the Transport Mechanisms?***

Knowledge of the transport mechanisms is required under 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the owner/operator must prepare a report to the EPA Regional Administrator that discusses the "...(I) likely route of migration of the release; (ii) characteristics of the surrounding soil (soil composition, geology, hydrogeology and climate)...." These issues have a direct bearing on the transport mechanisms at the SST sites and are important input parameters to transport models. The authors of previous modeling studies expressed concern when using data that may not adequately represent the conditions at the modeled site. Obtaining site-specific data on the soil-water balance and flow parameters is considered critical to improving upon past modeling studies.

- ***Is the Existing Contamination Stable?***

The stability of existing contamination is best addressed through obtaining "snapshots" of the contaminant distribution over time. If the temporal variations in contaminant distributions and moisture are stable through time, then the existing contamination profile is probably stable. However, in some cases geophysical logging alone cannot measure the contaminant distributions with enough precision to detect significant changes. To resolve these difficulties, contaminant stability may need to be evaluated with other methods. For example, moisture-weighing lysimeters installed in the vicinity of the tank farms can be used to assess the amount of moisture that actually enters the vadose zone. These data, in combination with geophysical moisture log data, could be used in transport models to estimate the mobility of constituents that migrate with the groundwater recharge. However, caution is advised with this approach because such estimates cannot be verified without calibration data over the range of the simulation domain.

- ***Where Will the Contamination Migrate?***

Knowledge of where the contamination will migrate is required under 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the owner/operator must prepare a report to the EPA Regional Administrator that discusses "...the likely route of migration of the release...." Obtaining an answer to this question requires transport modeling. Systematic steps to complete such modeling are described in Section 6.2 "Modeling Implementation Plan".

- ***When Will it Get There?***

Knowledge of when the contamination arrives at its destination (i.e., the water table) is required under 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the owner/operator must prepare a report to the EPA Regional Administrator that discusses "...the likely route of migration of the release...", and the "...proximity to down gradient drinking water, surface water and population areas." This question is best resolved with transport modeling. The various constituents in the tank inventory should be studied to address this question because the travel time may exceed the radioactive lifetime of some constituents. The RA study discussed in Section 4.0 of this document addressed the travel time issue for each tank farm using a one-dimensional model. Tank Farm Operations should consider awaiting the release of the RA study before to initiating new modeling studies to address this question.

- *What Parameters Affect the Transport?*

Knowledge of what parameters affect the transport is required under 40 CFR 265.196, "Response to Leaks or Spills and Disposition of Unfit-for-Use Systems". Under this section, the owner/ operator must prepare a report to the EPA Regional Administrator that discusses "...characteristics of the surrounding soil (soil composition, geology, hydrology, climate)." These characteristics of the porous medium have a direct bearing on the parameters responsible for transport at the SST sites. They are also important input parameters to transport models. The authors of previous modeling studies expressed concern when using data that may not adequately represent the conditions at the modeled site. Obtaining site-specific data on the flow parameters (i.e., effective porosity, moisture characteristics, unsaturated hydraulic conductivity) is considered critical to improving on past work. Even if the exact flow parameters are not known, they can be approximated and sensitivity analyses can be used to estimate the impacts of these parameters on the important management decisions. Using moisture and density logging to collect porosity data would improve the quality of the data inputs used in transport models since they would constitute site-specific van Genuchten parameters.

The amount of moisture that actually enters the vadose zone should also be studied by quantifying recharge, by identifying the effects of tank domes on concentrating recharge and redistribution (possibly by simulating tank-farm surface conditions in weighing lysimeters), by quantifying the influence of surface conditions on recharge (i.e., evapotranspiration, water storage capacity, and water retention characteristics), by accounting for other sources of fluids that could influence transport, and investigate if there are any preferential pathways, either natural or anthropogenic, that could affect the route and rate of infiltration and contaminant migration. These data, in combination with geophysical moisture log data, could be used in transport models to estimate the mobility of constituents that migrate with the groundwater recharge. However, caution is advised with this approach because such estimates cannot be verified without calibration data over the range of the simulation domain.

- *What Are the Future Implications?*

Future implications consist of environmental, and safety and health concerns that pose risks to human health and the environment. For example, these issues would involve comparative studies of transport time versus the radioactive life of each constituent in the inventory, identification of constituents that pose significant health risks, etc. Resolution of these issues while the SSTs still contain waste, rather than during closure, would identify critical issues at the earliest possible stage and feed into future tank closure activities.

6.2 Modeling Implementation Plan

Modeling of subsurface transport at the SST sites is recommended at each tank farm upon completion of the spectral-gamma logging for that tank farm. Because the geophysical characterization report for each tank farm would discuss localities where data interpretation is problematic (e.g., in areas where the geophysical logging data show contamination extending beyond the limits of data collection), it would be appropriate to use transport modeling to estimate the extent of contamination, forecast its migration rate, and predict the travel time to the water table. In summary, the objectives of the modeling must support mission-critical questions that stem from regulatory requirements to be addressed by Tank Farm Operations.

On the basis of its applicability and relevance to the Hanford Site, as well as its acceptance by the regulatory community, the PORFLOW modeling code (Runchal and Sagar 1989) is recommended for subsurface transport modeling. The infiltration of meteoric water at the SSTs is important because it provides the main driving force for subsurface transport. Therefore, the approach used in the PNNL study (Smoot and others 1989) to address infiltration, or an equivalent method, is recommended for any new modeling.

Modeling at the SSTs should be conducted on a performance-based basis that would be used to measure progress. New modeling efforts should provide a concise written and graphical description of the conceptual model; calibration targets should be identified; a water budget should be developed; sources of error associated with the data, calibration targets, and water budget should be documented; method(s) for calibration should be presented; methods for how sensitivity analyses should be used to support the calibration should be developed; and a data-archival system should be created and maintained for any future modeling efforts. Deviations from these goals should be justified and clearly documented. Progress meetings should be held with a DOE Richland Operations Office review team to discuss work in progress toward achieving these goals.

The modeling report should document every item listed in the *Modeling Work Plan*. The report should discuss if the calibration targets were met; define where the model is sensitive; identify the cells that are most difficult to calibrate and explain why; evaluate the reliability of the modeling predictions; identify where nonunique solutions may exist; discuss how the conceptual model could be improved for future work; provide recommendations for future, postmortem modeling studies; and include input files in the report pocket on diskette for future use by the DOE review team, the regulatory community, stakeholders, and Native Americans (it will be responsibility of each group to obtain its own copyrighted version of the simulation code).

Calibration data sets should be evaluated and compiled in a single document or a data-archival system with shared, read-only access available to other modelers. Consequently, it is recommended that a clearinghouse be established for modeling data. Calibration data sets should include annotated references to the original work, present the analytical results of field moisture and contaminant concentration data, identify applicable laboratory column data, and summarize results of field tests.

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