An Integrated Site-Wide Assessment of Nuclear Wastes to Remain at the Hanford Site, Washington

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ABSTRACT

Since its creation in 1943 until 1988, the Hanford Site, a facility in the U.S. Department of Energy (DOE) nuclear weapons complex was dedicated to the production of weapons grade plutonium and other special nuclear materials. The Hanford Site is located in eastern Washington State and is bordered on the north and east by the Columbia River. Decades of creating fuel, irradiating it in reactors, and processing it to recover nuclear material left numerous waste sites that involved the discharge of contaminated liquids and the disposal of contaminated solid waste. Today, the primary mission of the Hanford Site is to safely cleanup and manage the site's legacy waste. A site-wide risk assessment methodology has been developed to assist the DOE, as well as state and federal regulatory agencies, in making decisions regarding needed remedial actions at past waste sites, and safe disposal of future wastes. The methodology, referred to as the System Assessment Capability (SAC), utilizes an integrated set of models that track potential contaminants from inventory through vadose zone, groundwater, Columbia River and air pathways to human and ecological receptors.

Monitoring programs at the Hanford Site indicate that the Columbia River is a Class A river, with excellent water quality that is suitable for all uses. Further, monitoring shows that contaminants that originate at the Hanford Site are not adversely impacting either the Columbia River or groundwater that is withdrawn for water supplies adjacent to the Site. It is important to all parties (e.g., DOE, regulatory agencies, public) that decisions made today regarding the cleanup of past waste disposals and the continued disposal of waste associated with stabilizing and solidifying tank waste will not lead to adverse impacts to off-site groundwater and the Columbia River. Analyses conducted using the SAC compliment waste-site and waste-form specific analyses conducted under DOE Order 435.1, RCRA, and CERCLA, to provide decision makers with the information needed to assess far-field and off-site safety of multiple releases.

A current application of the SAC involves simulation of the potential risk and impact associated with the DOE baseline plan for cleanup and waste disposal at the Site. Past analyses has demonstrated a continuing decline in Hanford impacts on both the unconfined aquifer and the Columbia River. However, the current work is the first analysis involving a holistic look at past releases and their remediation, and the products of treatment processes for all tank wastes including the primary waste forms to be generated (e.g., glass) and the secondary waste streams to be disposed at Hanford. These results will provide insight on the relative role of past disposals compared to future (tank waste) disposals on water resources of the region.

1.0 INTRODUCTION

One of the primary drivers for development of the SAC for conducting integrated site-wide assessments is the requirement in DOE Order 435.1 to ensure public safety through the management of active and planned low-level radioactive waste disposal facilities associated with the Hanford Site (DOE/HQ-Order M435.1-1). A Composite Analysis (integrated site-wide assessment) is defined as "a reasonably conservative assessment of the cumulative impact from active and planned low-level waste disposal facilities, and all other sources from radioactive contamination that could interact with the low-level waste disposal facility to affect the dose to future members of the public." At the Hanford Site, a composite analysis is required for continued disposal authorization for the immobilized low-activity waste, tank waste vitrification plant melters, low-level waste in the 200 East and 200 West Solid Waste Burial Grounds, and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste in the Environmental Restoration Disposal Facility.

The Composite Analysis being conducted in 2004 and 2005 will be a site-wide analysis, considering final remedial actions for the Columbia River corridor and the Central Plateau. The river corridor includes waste sites and facilities in each of the 100 Areas as well as the 300, 400, and 600 Areas. The remedial actions for the river corridor are being conducted to meet residential land use standards with the vision of the river corridor being devoted to a combination of recreation and preservation. The "Central Plateau" describes the region associated with operations and waste sites of the 200 Areas. DOE is developing a strategy for closure of the Central Plateau by 2035. At the time of closure, waste management activities will shrink to a Core Zone within the Central Plateau. The Core Zone will contain the majority of Hanford's permanently disposed waste. Figure 1 shows the Core Zone, Central Plateau and Hanford Reach National Monument.

The Composite Analysis will be a companion site-wide assessment to waste-specific and site-specific assessments. The Composite Analysis also will provide supporting information on a regional or site-wide basis for use in important Hanford assessments and decisions such as the CERCLA 5-year review in 2005, tank closure decisions, decisions on final groundwater remedies for the 200 Areas, decisions on final groundwater remedies for the 100 Areas, and the Columbia River corridor final record of decision.

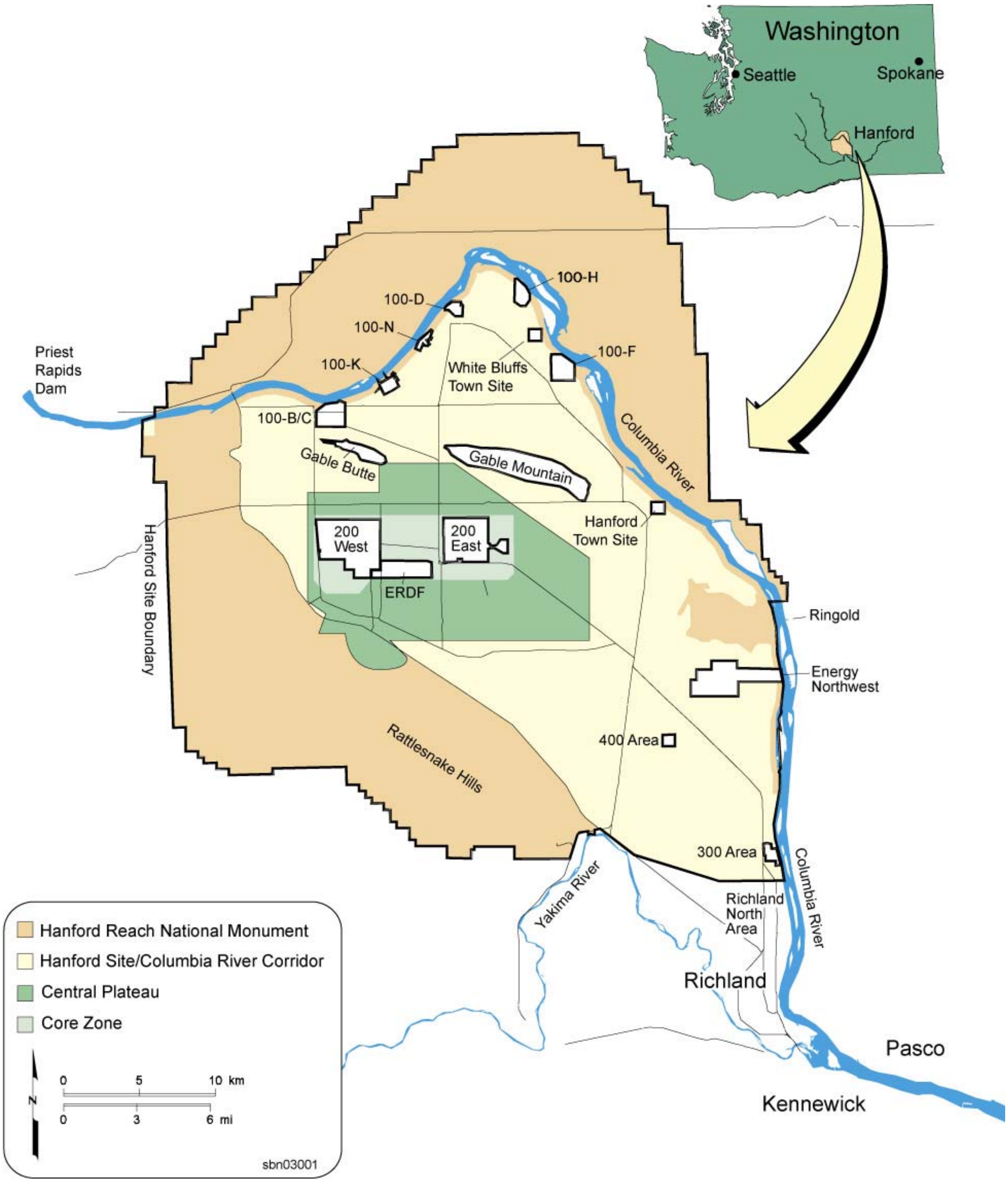

Figure 0.1. Major Remediation Areas at the Hanford Site

Regional Setting

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Basin in southeastern Washington State (see Figure 1). The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern site boundary. The Yakima River flows near a portion of the southern boundary and joins the Columbia River downstream of the city of Richland.

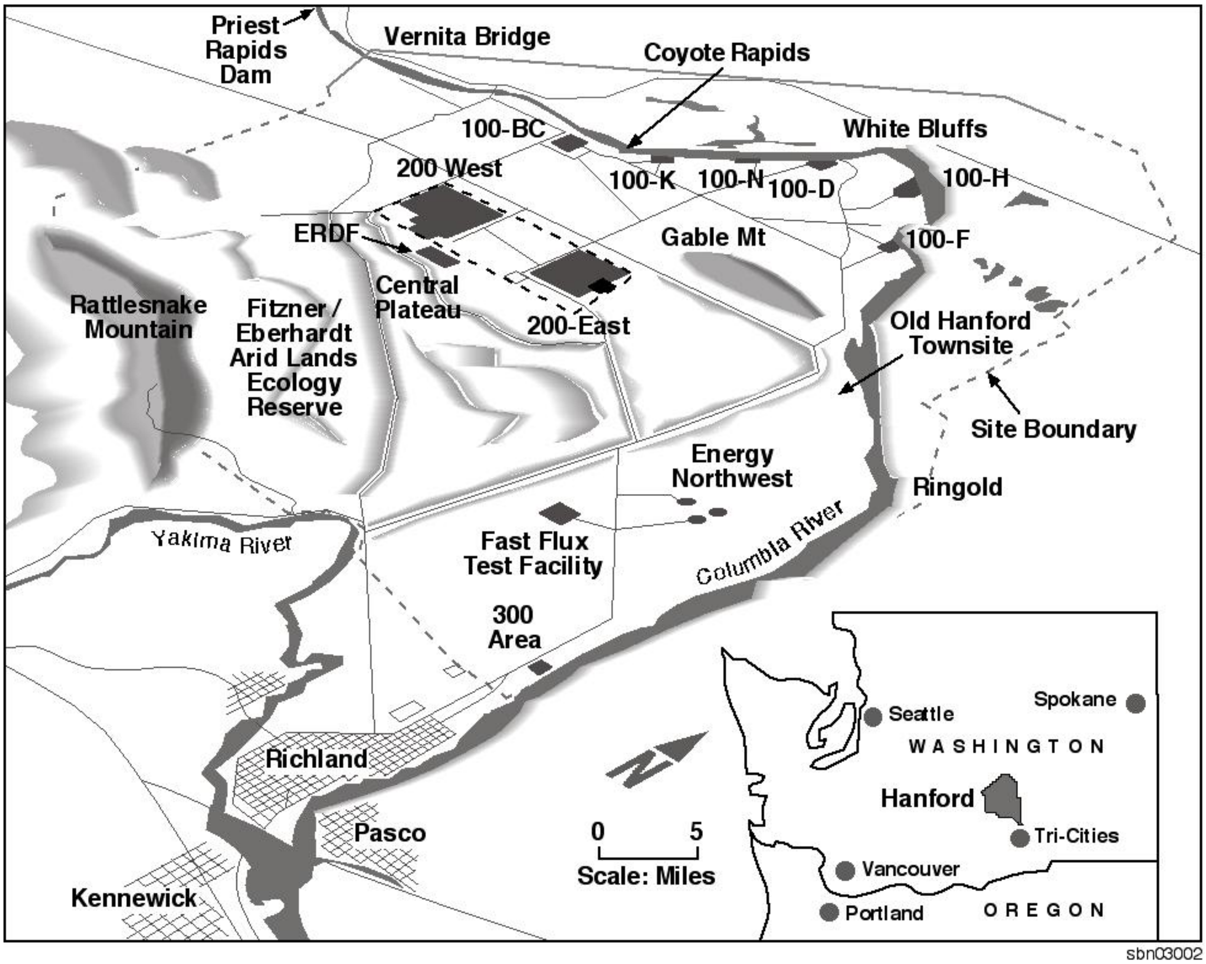

Figure 0. Map of the Hanford Site

The Hanford Site occupies an area of approximately 1517 square kilometers (approximately 586 square miles) located north of the city of Richland, Washington, and the confluence of the Yakima and Columbia Rivers.

Historical Site Operations

From its creation in 1943 until recently, Hanford Site facilities were dedicated primarily to the production of weapons-grade plutonium for national defense (Gephart and Lundgren 1998, DOE/EM-0319). The current missions of the Hanford Site are to safely clean up and manage the Hanford Site legacy waste and to develop and deploy science and technology (DOE/RL-96-92). During its nearly 40-year mission to produce special nuclear materials, the Hanford Site has:

- Fabricated reactor fuel (300 Area)
- Performed research and development (300 Area)
- Operated nine production reactors (100 Areas)
- Operated five chemical separation facilities (200 Areas)
- Fabricated plutonium components for nuclear weapons (200 West Area).

Performance Objectives

The performance objectives of the Composite Analysis are to

- Estimate the combined radionuclide releases to groundwater, surface water, and air from multiple sources, and, based on those estimates,
- Estimate the potential cumulative dose to a hypothetical future member of the public from radionuclides associated with waste disposal sites at the Hanford Site.

DOE Order 5400.5 (DOE/HQ-Order 5400.5) identifies actions to be taken at two trigger points; 100 millirem and 30 millirem.

If the projected total dose to a member of the public from all pathways is over 100 millirem in a year, DOE will alter its waste disposal plan to reduce this dose. If the projected dose is over 30 millirem in a year, DOE will determine whether a different economically viable approach to waste disposal will lead to substantially lower doses. In both cases, DOE will use an options analysis and ALARA (As Low As Reasonably Achievable) assessment to evaluate possible alternate remedial actions to reduce the estimated dose.

2.0 COMPOSITE ANALYSIS SCOPE

Geographic boundaries of the Composite Analysis for the surface and subsurface water pathways extend across the Hanford Site from Rattlesnake Mountain to the Columbia River and include the Columbia River from Vernita Bridge to the City of Richland. Where the boundary of the Hanford Site coincides with the Columbia River, the boundary is the high water mark of the river. Future Hanford Site boundaries are expected to retract to the Core Zone where facilities are expected to remain for some time to manage the remaining waste at the Hanford Site. It is also anticipated that groundwater in this area will be precluded from use.

Geographic boundaries of the Composite Analysis for the air pathway includes a rectangle that extends 5 kilometers north,, 30 kilometers east, 40 kilometers south and 10 kilometers west of the Hanford Site boundaries.

Waste Sites and Facilities

Within the spatial boundaries of the assessment, it is necessary to clearly define the population of disposal waste sites. The Waste Information Data System (WIDS) database showed 2730 waste sites at the Hanford Site in January 2003. Of these 2730 waste sites, 974 sites were identified for consideration in the Composite Analysis. Several screens were applied to the WIDS list of waste sites to identify those to be included in the Composite Analysis. Waste sites were screened out that were 1) initially misclassified as waste sites, 2) not representing releases to the environment, 3) receiving waste streams categorized as "non" radioactive or "non" hazardous chemical waste streams, 4) not including key waste contaminants, and 5) duplicate sites.

The bulk of the 974 waste sites are located within the 100, 200, and 300 areas. However, some waste was discharged or disposed outside of these operational areas (for example, the Gable Mountain Pond, the waste disposal caissons located adjacent to the Energy Northwest property, the 300 North burial grounds, and the Environmental Restoration Disposal Facility—ERDF--located between 200 West and 200 East Areas). The Hanford Site also includes a commercial low-level waste disposal site operated by US Ecology Inc. that is located southwest of the 200 East Area.

List of Contaminants of Concern for Groundwater, Surface Water, and Air Exposure Pathways to Be Included in the Composite Analysis

Groundwater/Surface Water	Groundwater/Surface Water	Air
Tritium	Europium-152	
Carbon-14	Radium-226[e]	Carbon-14
Chlorine-36	Protactinium-231	
Selenium-79	Uranium-233	
Strontium-90	Uranium-234	
Technetium-99	Uranium-235	
Iodine-129	Neptunium-237	Iodine-129
Cesium-137	Uranium-238	

Temporal and Spatial Resolution

The time period of the assessment will extend from 1944 through 3035 inclusive to include the 1000 years following the assumed Hanford Site closure date of 2035 as required by DOE Order 435.1. Two potential exceptions to the 2035 closure date are final closure of commercial low-level waste site and the final movement and burial of the graphite cores of the production reactors. Releases to the environment from 1944 to the present will be treated as annual releases to ensure temporal realism and to support history matching efforts based on estimates of mass in the aquifer indicated by monitoring data. During the period from present day until site closure, the temporal resolution of releases will be the same to ensure a realistic representation of disposal and facility decontamination and decommissioning. Thereafter, the temporal resolution will be sufficient to support the risk and impact assessment. Use of annual average or coarser values of time from a groundwater or river simulation will be supplemented with empirical data to estimate seasonal variations in water quality.

3.0 SYSTEM ASSESSMENT CAPABILITY

The System Assessment Capability (SAC) is a set of models and data that have been assembled since the previous 1998 Composite Analysis was performed to allow the collective impact of all the waste that will remain at the Hanford Site to be estimated. Computer codes that have been well tested at the Hanford Site have been used when possible and new software has been written when necessary to simulate the features and processes that affect the release of contaminants into the environment, transport of contaminants through the environment, and the impact those contaminants have on living systems, cultures and the local economy. The components have been organized to simulate the transport and fate of contaminants from their presence in Hanford waste sites, through their release into the vadose zone, to their movement in the groundwater, and into the Columbia River. Components of SAC such as the groundwater model, the ecological impact component, and the human health component were originally developed and tested for previous Hanford assessments.

The elements of the SAC computational tool include:

- Inventory Module – develops an inventory of specific waste disposal and storage locations for the period 1944 to Hanford Site closure based on disposal records, process knowledge, and the results of tank and field samples. The year 2035 is used as the Hanford Site closure date for the Composite Analysis because it has been identified as the time of site closure for major facilities (such as, tanks, solid waste burial grounds, chemical separations plants). Future runs will use the closure date predicted at the time of the run. This module also identifies the material scheduled for disposal in offsite repositories, including high-level waste, transuranic waste, and spent fuel.

- Release Module - simulates the annual release of contaminants to the vadose zone from the variety of waste types in the modeled waste sites. This module also simulates future remediation actions that move waste to ERDF.

- Air Transport Module – simulates the transport of contaminants through the air from release points to points of deposition.

- Vadose Zone Transport Module - simulates fluid flow and contaminant transport in the vadose zone, which is the unsaturated sediment between the land surface and the unconfined aquifer.

- Groundwater Transport Module - simulates the fluid flow and contaminant transport in the unconfined aquifer that underlies the Hanford Site using the transient inverse calibrated three-dimensional site-wide groundwater model.

- Soil Module - simulates the buildup of contaminants in the plant root-zone soil layer due to air deposition and irrigation. Solutions are available for the cases of no irrigation, irrigation with groundwater, and irrigation with river water.

- River Module - simulates river flow and contaminant/sediment transport in the Hanford Reach from Vernita Bridge downstream to McNary Dam. This module simulates background concentrations and background plus the Hanford Site concentrations to enable an assessment of the Hanford Site incremental impact to the Columbia River and its ecosystem.

- Riparian Zone Module – uses river and groundwater information to simulate the concentration of contaminants in seep or spring water and in the wet soil near the edge of the river.

- Risk/Impact Modules - perform risk/impact analysis in four topical areas: human health, ecological health, economic impact, and cultural impact with the latter two being new impact metrics for Hanford assessments. The human health risk module will be applied in the Composite Analysis. Other modules of risk/impact will be applied to inform the public and regulators regarding issues related to the Composite Analysis (for example, chemical hazards and ecological impact).

Each module was assembled so that it could be tested and evaluated independently of the other modules. The inventory, release, environmental pathways, and risk/impact were then linked to test the overall performance of the system.

The conceptual illustration of SAC (Figure 3) portrays a linear flow of information. In general, inventory feeds to release to the atmospheric, vadose zone, groundwater, and Columbia River pathways. At times, release occurs directly to the groundwater through reverse wells and to the Columbia River from the single-pass reactors. During chemical separation plant operation, release occurred to the atmosphere. The atmosphere, groundwater, Columbia River and riparian zone technical elements provide media-specific concentration estimates used in the risk and impact assessment.

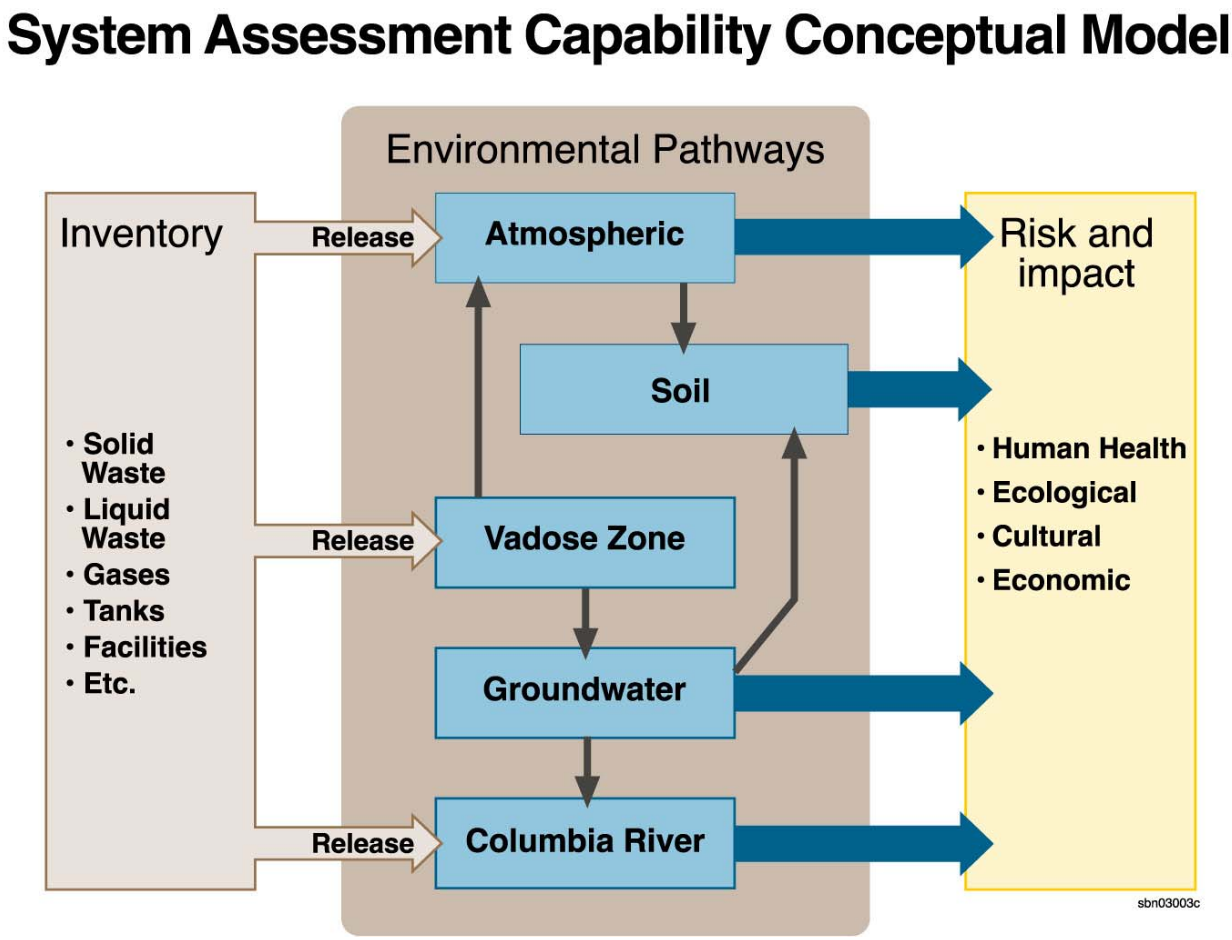

Figure 3. Conceptual Model of the System Assessment Capability

One of the challenges associated with performing an assessment is appropriately presenting how well the results predict what might actually occur. This is because the attributes of the site that effect transport of contaminants, the impact of contaminants on living systems, and the future conditions used in the assessment, as well as many other factors upon which the predictions depend, are not completely understood. SAC was developed to allow the performance of a probabilistic risk assessment so an indication of the effect of parameter uncertainty on results could be examined. In general, other sources of uncertainty, such as conceptual model uncertainty, will not be handled within the calculations but will be discussed in the interpretation of the results of this analysis.

For the Composite Analysis, SAC will be modified to enable the import of results from detailed assessments of individual waste sites by other programs. Such results come from the Hanford Immobilized Low-Activity Waste Site Performance Assessment (DOE/ORP-2000-24 Rev 0) and single-shell tank closure risk assessments (RPP-13774 2004). Information on 1) release to vadose zone or 2) release to water table will be imported into the SAC deterministic analysis. The Composite Analysis will treat best estimate simulations by other programs as "median" simulations and incorporate them into an overall "median-input" deterministic simulation.

To perform a stochastic analysis, best-estimate data (geologic profile, hydraulic properties, geochemical properties, recharge sequence, etc.) used by other programs to perform assessments will be interpreted as “median” values for distributions where the data range is defined by the Hanford wide data set previously compiled for SAC. A simplified model (such as, release and one-dimensional vadose zone or release and two-dimensional vadose zone) will be calibrated to reproduce key aspects of the median simulation provided by the detailed assessment. This simplified but calibrated model will be used to generate the stochastic realizations. Where available, comparison will be made between the range of SAC stochastic responses and the range of deterministic sensitivity cases provided by the program.

Significant differences may exist between the SAC representation of uncertainty and the representation of sensitivity used by other assessments. This is especially true when the site specific assessment is using sensitivity analyses to explore alternate conceptual models of waste form release (for example, tank residuals modeled with a solubility model, diffusion model, advection-desorption model, linear release—time--model) or barrier performance (for example, alternate surface barriers and engineered containment systems surrounding a glass waste form).

Background information for the development of the initial SAC is presented in *Groundwater/Vadose Zone Integration Project: Preliminary System Assessment Capability Concepts for Architecture, Platform and Data Management* (Bechtel 1999), which can be found at http://www.hanford.gov/cp/gpp/modeling/sacarchive.cfm. This document includes a description of alternate architectures for SAC as well as conceptual models for each technical element of the capability. Design of the initial SAC tool is summarized in Kincaid et al. (BHI-01365). Results of an initial assessment performed with the SAC are provided in Bryce et al. (PNNL-14027), and a description of the software is provided in Eslinger et al. (PNNL-13932 Vols 1 and 2).

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