# Appendix K

# Nonoperational Area

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# K1 Introduction

This appendix presents information that supports the CERCLA Remedial Investigation/Feasibility Study (RI/FS) conducted for 100-K (DOE/RL-2010-97). Most of the waste sites in the 100 Area (including those in the 100-K Operable Unit) are located close to decommissioned reactors. There are large land areas (beyond the reactors and their associated facilities and waste sites) which have little or no subsurface infrastructure or indication of past or present releases of hazardous constituents. This land is referred to as nonoperational property. This appendix presents an evaluation of the nonoperational property (NPE) specific to 100-K.

## K1.1 Scope of the Nonoperational Property Evaluation

This NPE is not directly part of the CERCLA RI/FS process, in that it has no role in determining the basis for remedial action or in evaluating remedial alternatives for contaminated soils or groundwater. The National Contingency Plan requires that the nature and extent of contamination is evaluated and that appropriate remedial actions are taken. Two important outputs from the NPE are evidence that effort has been taken to identify where waste may be present outside of operational areas and, where appropriate, the inclusion of NPE waste sites that may warrant further consideration as part of the RI/FS. The NPE also documents nonoperational conditions for use in risk communication and for informing stakeholders.

There are fate and transport mechanisms that could potentially distribute contaminants to nonoperational areas. The most credible are human disposal, wind-blown dust dispersion, air emissions from stacks during active operations, overland flow, and biological vectors (intrusion by plants and animals). Multiple lines of evidence have been developed to assess these fate and transport mechanisms and the potential for contamination to exist outside known operational areas. Areas of focus in developing the lines of evidence include:

- **Review of existing programs, data, and information with a nonoperational area focus:** Decades of environmental monitoring and surveillance have been conducted and reported at the Hanford Site. In addition to general (routine) monitoring that has included nonoperational areas, special studies have been commissioned and conducted that assess broad-area evidence of emissions and releases from facilities and waste sites.

- **Results of Orphan Sites Evaluations:** The Orphan Sites Evaluation (OSE) is a program, which has been designed primarily to support cleanup and long-term stewardship activities in the River Corridor. It provides a detailed understanding of disturbed areas (contaminated or not). Review of historical records and imagery, combined with on-the-ground walk-downs and field investigations; provide a comprehensive evaluation of current conditions in nonoperational areas.

- **Statistical analyses:** Two statistical analyses were conducted as adjuncts to environmental monitoring, data review, and field investigations. The first was developed and applied to enhance efforts to systematically and rigorously locate potential waste disposal sites. The second evaluated radionuclide distribution (based on available soil concentration data and aerial radiological surveys) in order to quantify and understand relationships with known waste sites and examine the potential for unidentified sites to exist outside operational areas.

## K1.2 100-K Description

100-K covers an area of approximately 9.0 $km^2$ (3.5 $mi^2$) and includes the 100-KR-1 and 100-KR-2 Source OUs, the 100-KR-4 groundwater OU and nonoperational area. It is situated on relatively flat and level ground, except near the Columbia River where the land surface changes to gentle, low-relief slopes.

A perimeter fence surrounds a 1.2 $mi^2$ (3.1 $km^2$) area where the majority of active operations took place. Within the perimeter fence the ground surface and upper vadose zone has been highly disturbed and reworked by human activities that include pre-WWII agriculture activities followed by intense reactor construction and operations and, eventually, waste site and ground water remedial activities that extend to the present (DOE/RL-2008-46, ADD2; PNNL-SA-41467). A significant additional area of disturbance extends about 1.5 km outside of the northeast corner of the perimeter fence where a large cooling water disposal trench was operated (116-K-2). The trench has excavated, contaminated soil and debris removed, the excavation backfilled, and the site revegetated with native plants. Otherwise, the area outside of the perimeter fence is relatively undisturbed.

Spatial data provided by the Ecological Monitoring and Compliance program show three primary types of vegetation to the east, south, and west of the perimeter fence: Sandberg's bluegrass-cheatgrass, gray rabbitbrush/Sandberg's bluegrass-cheatgrass, and small patches of big sagebrush/Sandberg's bluegrass-cheatgrass. Wildlife species observed in this area also are described in PNNL data summary for the reactor areas along the River Corridor. The riparian environment adjacent to 100-K extends in a strip along the Columbia River to the north and slightly west of the facility. The strip varies in width from a narrow zone (50 to 75 m) lying north of the eastern end of 100-K to a wider zone (150 to 200 m) at the westernmost portion of the facility near the river. (PNNL-SA-41467).

## K2 Nonoperational Property Evaluation Approach

River Corridor cleanup efforts have focused on known waste sites located within operational areas (often within perimeter fences) and on a limited number of known sites outside these boundaries. Where surveillance monitoring or focused investigative activities have identified previously unknown sites, they have been identified and evaluated for inclusion within the scope of the cleanup efforts. Operational areas comprise a small fraction of the total land surface in the River Corridor. Outside of the operational areas is the Nonoperational Property area. For purposes of this appendix, the Nonoperational Property area in the River Corridor is defined as that area beyond the boundaries of waste sites listed in the Waste Information Data System (WIDS) database. The Nonoperational area is considered not to be directly associated with a Hanford Site process or operational activity known or suspected to contribute CERCLA hazardous constituents to the environment.

The approach to the NPE for the River Corridor is to develop a conceptual model of the fate and transport mechanisms that could distribute contaminants from Hanford operations that would warrant further evaluation in the nonoperational areas, and then apply multiple lines of evidence to examine the likelihood that such contamination is present. The lines of evidence include: results from long-term surveillance and monitoring programs and other studies; results from a spatial model for predicting the location of man-made features (including waste sites) based on proximity to man-made and topographic features; a spatial model for predicting where elevated radionuclide concentrations (specifically Cs-137) are present in soil based on aerial radiological survey results; and, results from the OSE program.

Section K2.1 presents a brief description of potentially significant contaminant fate and transport pathways. Summary descriptions of the key surveillance and monitoring programs and other studies for the nonoperational area in the 100-K OU are presented in Section K2.2. Brief descriptions of the statistical analyses are presented in Section K2.3. A brief description of the OSE program is presented in Section K2.4.

## K2.1 Nonoperational Contaminant Transport Pathways

The Nonoperational Property area, having no history of releases of hazardous or radioactive substances, is presumed to have a low likelihood of contamination that would require a response action under CERCLA. The principal objective of this evaluation is to examine multiple lines of evidence to confirm that hazardous or radioactive substance releases are not present in the Nonoperational Property area. An outcome of this evaluation could be the identification of areas where releases, or contaminant transport, may have occurred.

There is a select set of contaminant release pathways that apply when evaluating the potential for contaminant transport into Nonoperational areas. They include:

- **Anthropogenic contaminant sources.** Contaminants from facilities or known waste sites may have been physically transported by human actions to shallow soils outside of waste site boundaries. Several activities and programs at the Hanford Site identify waste sites that have resulted from these types of activities. Section K2.2 presents an overview of these activities and programs.

- **Transport via wind-blown dust.** Hazardous and radioactive substances in surface soils and materials can become suspended into the air, dispersed to downwind locations, and subsequently deposited onto the ground. Approximately 6 percent of the 1,518 $km^2$ (586 $mi^2$) Hanford Site (about 83 $km^2$ [32 $mi^2$], or 8,909 ha [20,000 ac]) has been actively disturbed or used. Potential fugitive dust emission sources are located in the five operations areas within this actively disturbed area: the 100, 200 East, 200 West, 300 Area, and 400 Area. The potential for fugitive dust emissions from these sources is generally conceived to occur subsequent to disturbance, erosion, or removal of soil covers over waste sites or through plant or animal biointrusion. These events can expose erodible material that contains contamination. Engineering controls (e.g., surface soil stabilization, dust suppression water, work cessation due to wind conditions) can be, and are, applied to mitigate or eliminate this transport pathway. However, there are contaminated areas posted as Radiologically Controlled Areas or Soil Contamination Areas that could contain erodible material that could produce fugitive emissions from resuspension of windblown dust (DOE/RL-2010-17). Figure K-1 depicts a conceptual model of wind-blown dust transport.

- **Emissions from facility stacks.** Hazardous and radioactive substances emitted into the air from former and currently operating facility stacks and vents can be dispersed to downwind locations and subsequently deposited onto the ground. Three groups of sources of Hanford Site stack air emissions had the potential to impact the River Corridor by air deposition. Two of the groups, which represent by far the greatest potential contributors, are stack emissions that occurred during active operations between 1944 and 1972. The two groups are examined separately based on their physical location and type of contamination. Group one is stack emissions from 200 Area operations that separated plutonium and uranium from irradiated reactor fuel. The second group is stacks in the 100 Area that exhausted ventilation air from the working areas of the nine production reactor facilities. The 100 Area sources were minor emissions compared with those from 200 Area facilities. The third group is nonradionuclide emissions resulting from coal-fired power plants used to generate steam for heating and process operations. There were large two power plants in the 200 Area that operated until the mid-1990s: 284-E Power Plant in the 200 East Area and 284-W Power Plant in the 200 West Area (WHC-EP-0472). Nonradionuclide toxic air pollutants that could be emitted from coal-fired power plants are principally trace metals, but also include traces of volatile organic compounds such as formaldehyde, and polycyclic organic matter. The polycyclic aromatic organic matter and certain trace metals, in particular arsenic, cadmium, lead and antimony, adhere to the fine particulate matter

emitted from a power plant stack. Figure K-2 presents the conceptual model of transport from stack emissions.

- **Overland transport.** Hazardous and radioactive substances in surface materials can be transported away from facilities or known waste sites by surface runoff (overland flow). This could conceivably occur following precipitation events or, as has been documented, from releases (or "spillage") of process liquid waste that had been discharged to liquid waste disposal sites. Overland flow potentially results in the transport of contaminated sediments or water away from a waste site. Factors that affect overland flow include slope of the ground surface, soil texture, and vegetative cover, and frequency of precipitation.

  The Hanford Site is in a semiarid region and precipitation is more than balanced by evaporation and transpiration such that substantial overland flow from precipitation is an unlikely occurrence. A more likely source for overland flow is spills or releases from liquid waste disposal facilities during historical active operations. In general, these leaks were infrequent and documented through written and photographic records. Most resulted in localized contamination in and around the disposal sites. A number of these sites have been remediated under the Interim Action RODs.

- **Biointrusion.** Hazardous and radioactive substances in shallow soil can be transported to plants at ground surface through their roots or, disturbed and transported to the soil surface by burrowing animals or insects. Plants extend roots into the soil to extract nutrients and water. Most of the mass of plant roots is concentrated within the shallow soil; however, some deep-rooted plant species are found at the Hanford Site. Unless actively managed and controlled, deep-rooted vegetation (e.g., tumbleweeds, sagebrush) growing over underground sources of contamination may selectively uptake contaminants, particularly radionuclides, into their tissues. When radionuclides are transported from roots to aerial portions of the plant, surface contamination may result. Desert animals and insects burrow for shelter from the heat, cold, or predators; reproduction; feeding; and water conservation. Most wildlife burrow no more than a few feet in depth; however, some macroinvertebrates (harvester ants) have been reported to burrow to depths of up to 2.4 m (8 ft) in soil at the Hanford Site. Animals that burrow into contaminated soils could unearth contaminants and disperse them on the soil surface. The conceptual model of biointrusion is depicted in Figures K-3 and K-4

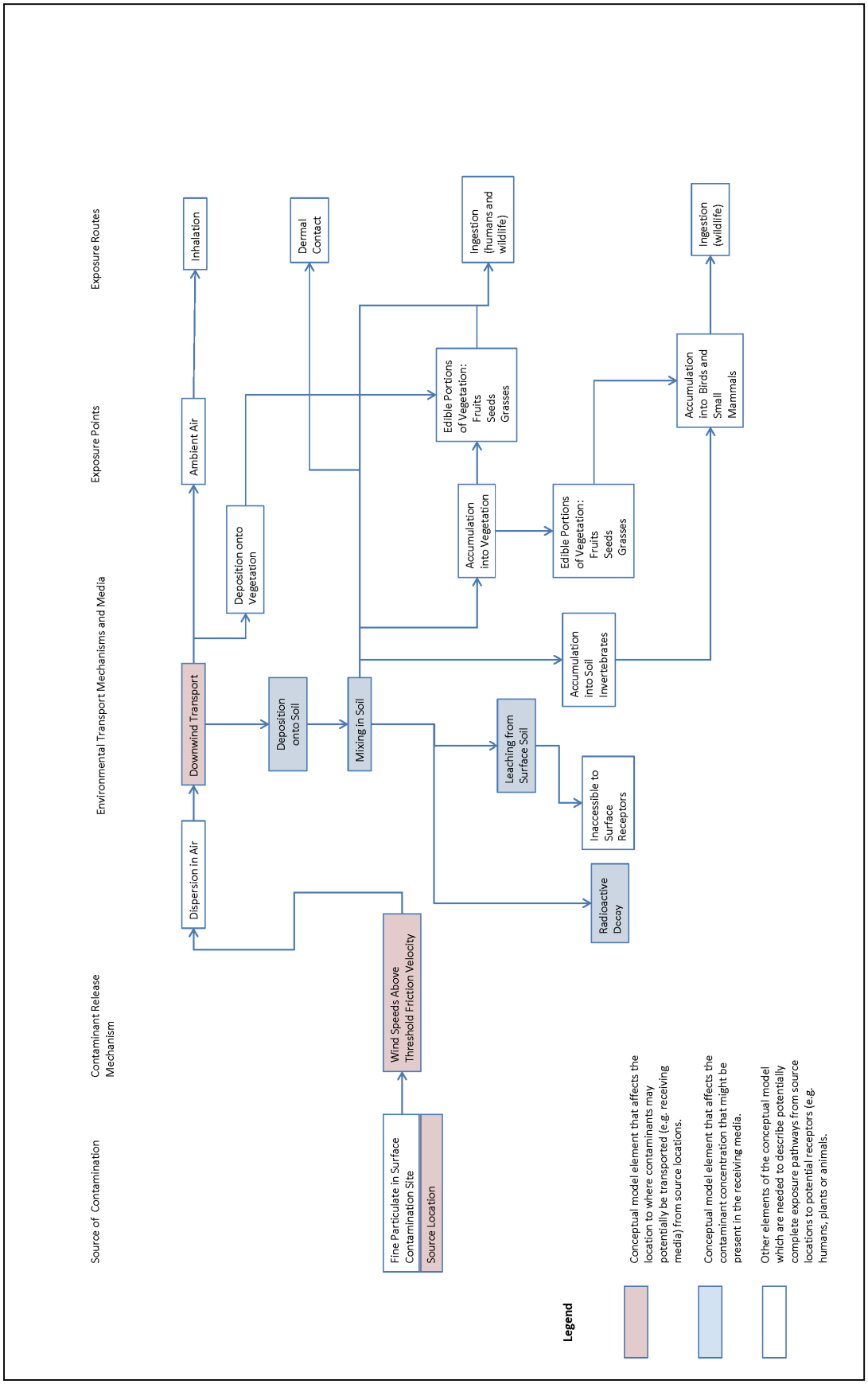


**Figure K-1. Nonoperational Area Conceptual Model of Contaminant Fate and Transport Pathways—Transport of Windblown Dust**

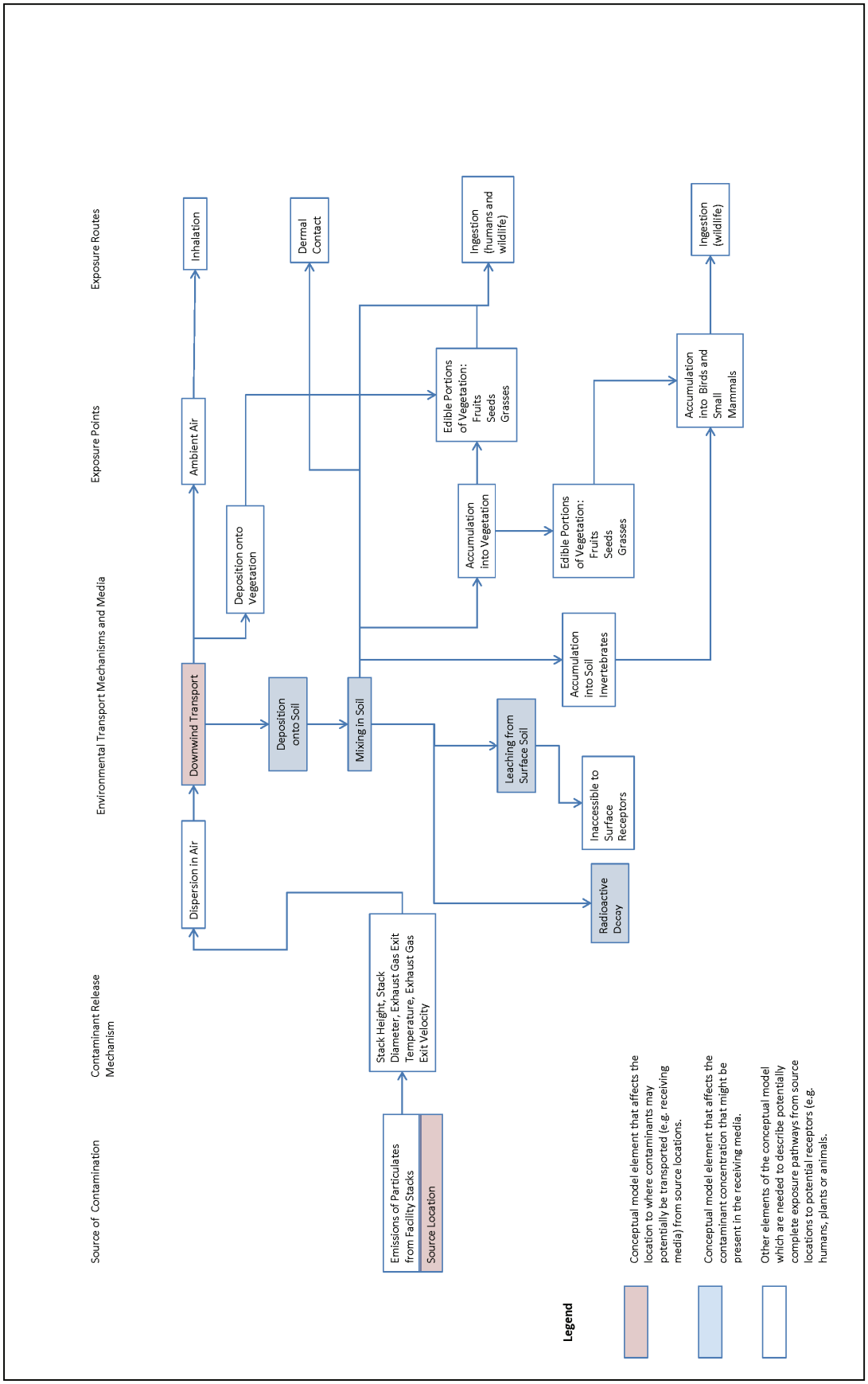


**Figure K-2. Nonoperational Area Conceptual Model of Contaminant Fate and Transport Pathways—Transport via Emissions from Facility Stacks**

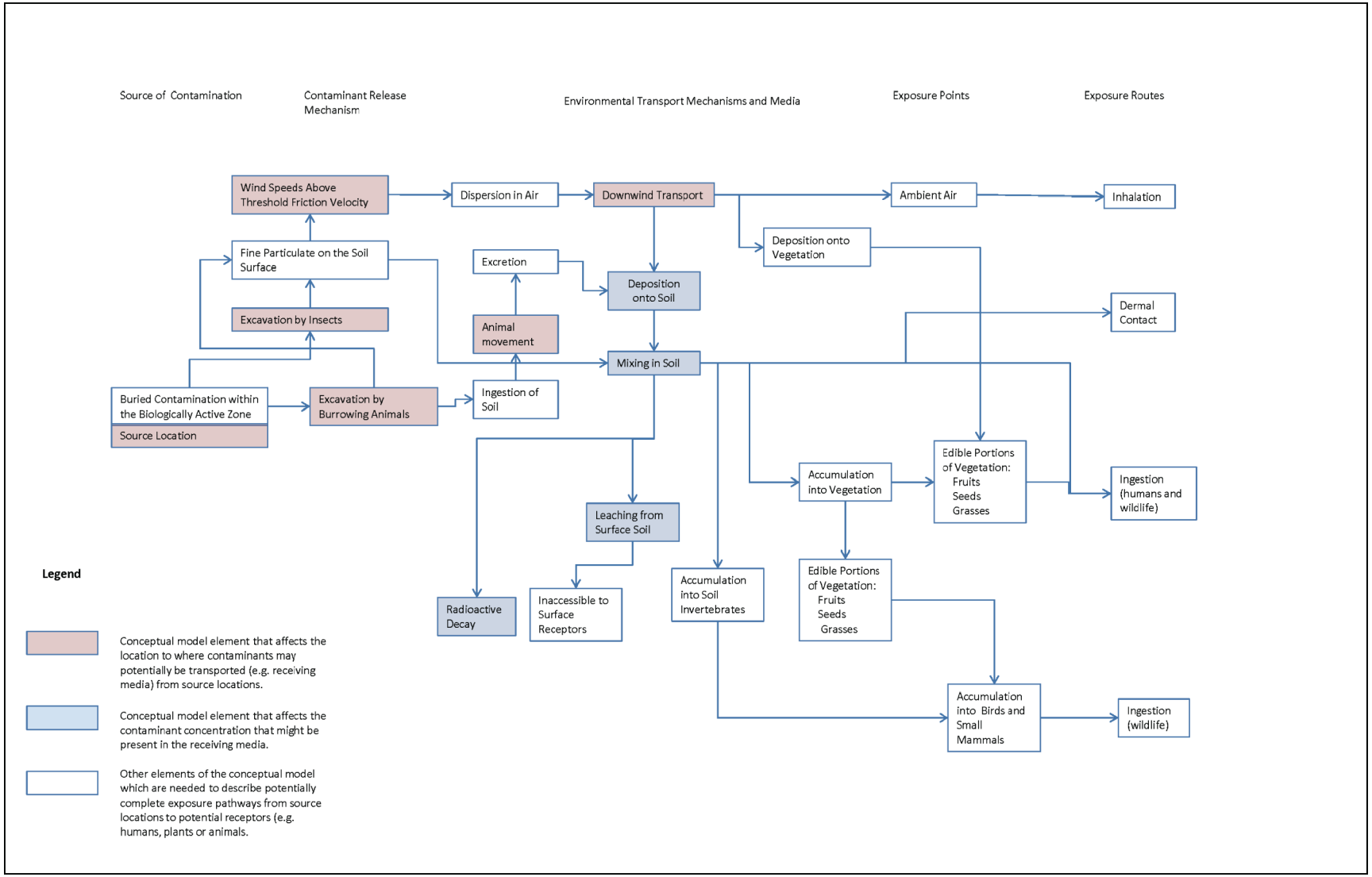


**Figure K-3. Nonoperational Area Conceptual Model of Contaminant Fate and Transport Pathways—Transport via Animal Intrusion of Buried Contaminants**

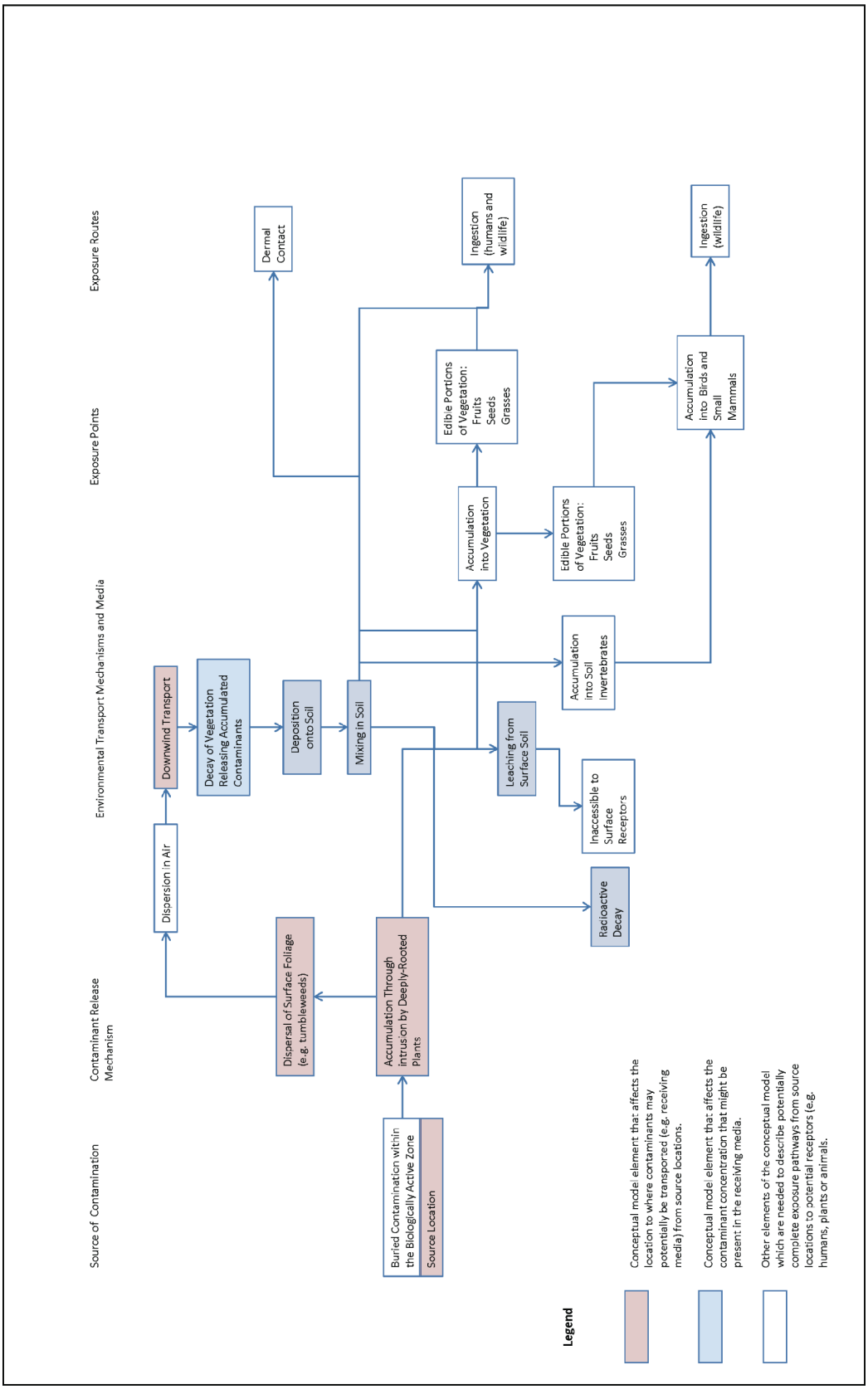


**Figure K-4. Nonoperational Area Conceptual Model of Contaminant Fate and Transport Pathways—Transport via Intrusion of Deep-Rooted Plants**

## K2.2 Surveillance and Monitoring Programs

Several programs at the Hanford Site collect environmental surveillance and monitoring data. Many of these programs collect data to address regulatory requirements for emissions, effluent discharges, or DOE Orders regarding radiological control. Other programs perform environmental monitoring of soil, water, air, or vegetation. Most of these programs are summarized in the Annual Environmental Report for the Hanford Site (see PNNL-19455 for an example of an environmental report).

Fifteen Hanford Site programs that identify waste sites and/or collect environmental monitoring and surveillance data are listed in Table K-1. In addition, Table K-1 identifies five other sources of information and data applicable to a nonoperational area evaluation. Information and data from these programs were evaluated to identify trends in how hazardous substances or radionuclides may have been transported from operational areas or waste sites to nonoperational areas within the River Corridor. Information from the programs involved with soil, air, or vegetation monitoring, or with radiological control, were of most use in the NPE. The evaluation of the results from these programs as they pertain to the 100-K OU is summarized in Section K3.1.

**Table K-1. Existing Hanford Site Programs Related to Environmental Data and Monitoring**

| **Ongoing Hanford Site Programs** | |
|---|---|
| Air Emissions Monitoring | Liquid Effluent Monitoring |
| Ambient Air Monitoring Near Hanford Site Facilities and Operations | Sitewide and Offsite Ambient Air Monitoring |
| Soil Monitoring Near Hanford Site Facilities and Operations | Sitewide and Offsite Soil Monitoring |
| Vegetation Monitoring Near Hanford Site Facilities and Operations | Sitewide and Offsite Vegetation Monitoring |
| Radiological Dose Measurement Near Hanford Site Facilities and Operations | Radiological Surface Surveys Near Hanford Site Facilities and Operations |
| Groundwater Monitoring | Radiation Area Remedial Action Project |
| Waste Information Data System | Spill and Release Reporting |
| Vegetation Control Activities | |
| **Additional Information and Data Sources** | |
| Aerial Radiological Surveys | *River Corridor Baseline Risk Assessment* (DOE/RL-2007-21) |
| Aerial Photography (includes LiDAR [Light Detection and Ranging]) | Emissions estimation and dose assessments conducted as part of the Hanford Environmental Dose Reconstruction (HEDR) Project. |
| Hanford Site background studies | |

## K2.3 Statistical Analyses

The statistical analyses focused on:

- Developing and applying a predictive model for waste site locations
- Establishing association between Cs-137 measured directly in soil and high resolution aerial survey results
- Developing a sitewide model of soil Cs-137 using lower resolution sitewide aerial surveys

The results of these analyses were used to model the likelihood of finding previously undiscovered waste sites in the nonoperational areas as a function of man-made and topographic features, and model the potential for radionuclide concentrations (specifically Cs-137) in surface soil to be higher than selected threshold concentrations.

These lines of investigation are described below. Section K3.2 discusses the results from these analyses.

### K2.3.1 Predictive Modeling of Waste Site Locations

The predictive model is based on the conceptual model that waste sites are located in proximity to anthropogenic features such as roads or existing operational areas, or flat or low-lying topography. The distributions of these geographic variables, measured at WIDS sites, were compared with the distribution of the same variables calculated at an unbiased set of locations systematically distributed across the Hanford Site. A quantitative model was developed to show the probability of a waste site being located at any unsampled location within the Hanford Site as a function of these geographic measures. Factors considered in developing geographic variables for known waste sites and sources included distance to operational areas; distance to roads, railroad grades, utility rights of way (e.g., power lines) and roads; and topography, including slope aspect elevation, and curvature. These models were used to rank areas based on the relative probability that a previously undiscovered waste site might exist.

### K2.3.2 Aerial Surveys and Soil Radionuclides

Measurements of the presence of radionuclides were available from direct soil measurements, as well as from laterally extensive aerial radiological surveys. Soil measurements were expressed as activities per unit mass (pCi/g), suitable for estimation of exposure for risk assessment, whereas data obtained from aerial surveys were expressed as gross counts for gamma emitting radionuclides. Aerial survey data could be used to estimate exposure if it could be calibrated with soil Cs-137 activity data. Predictive models and maps of the probability that Cs-137 levels would be expected to exceed screening levels could be prepared based on the statistical relationship between soil activity measurements and aerial survey gross counts.

A detailed investigation in the BC Control Area which included collecting high-resolution aerial survey data and relatively high density soil sampling provided data to perform a detailed geostatistical analysis. The analysis of the BCCA data supported development of a sitewide model based on less resolved, but more laterally extensive, aerial surveys of all of the Hanford Site. The results of the site wide model were used to draw conclusions specific to River Corridor. The results of both analyses support the utility of aerial radiological surveys for estimating concentrations in soil for unsampled areas.

## K2.4 Orphan Sites Evaluation

The OSE is a systematic approach to evaluate land parcels in the River Corridor to ensure that all waste sites or releases requiring characterization and cleanup have been identified. Information collected

through these evaluations also supports elements of the CERCLA Section 120(h)(4), Federal Property Real Disposal Process, requirements for review and identification of uncontaminated property at federal facilities. The OSE supplemented past systematic efforts that identified source waste sites, including the TPA MP-14 discovery process for identifying known and potential waste sites and the CERCLA hazard ranking conducted in 1985 and 1986 to place the Hanford Site on the National Priorities List (NPL).

Two of the key elements of an OSE include a historical review and a field investigation. Review of historical information was conducted to identify potential orphan sites and to target areas for further evaluation during the course of conducting the associated field investigation. Historical research focused on identifying specific items or features typically associated with a waste site. The most common features associated with a waste site in reactor areas include drains, cribs, drywells/French drains, burial grounds, pipelines, aboveground and belowground storage tanks, septic systems, drain fields, burn pits, trenches, ditches, pits, spills, sumps, vaults, ash pits, disposal areas, pumps, and buildings and facilities that contain chemicals and radiological contaminants. Information obtained and used in the historical review included the following resource types:

- Maps
- Construction and operations drawings
- Technical and operations documents
- Construction and operations photographs
- Aerial photographs
- Geophysical survey results
- Cleanup verification packages
- Sampling logbooks
- Personnel interviews

Field investigation activities were used to provide another level of assurance by conducting systematic walking surveys to document potential orphan sites and to follow up on potential orphan sites identified from historical review. Three primary tools provided the media to record the information observed in the field including hand-held Trimble GeoXT™ GPS units, digital cameras, and field logbooks. Geophysical survey instrumentation was used to supplement these tools in selected areas of suspect subsurface features identified during the historical review or field investigation.

To ensure a systematic approach for area coverage, standardized 30 × 30 m conceptual grids were established over the investigation areas. The grid and existing known features in the areas were loaded onto the GeoXT GPS units, which were used in the field to monitor progress and record information. Walking surveys were typically performed in pairs with approximately 15 m spacing between individuals. Features encountered during this investigation were recorded using the GPS unit, digital camera, and field logbook.

The field investigation for regions of the River Corridor used a graded approach. High resolution, four-band (red, green, blue, and near-infrared) orthophotography imagery and Light Detection and Ranging (LiDAR) topography data were collected for approximately 57,468 ha (142,000 ac) of the River Corridor in April 2008. The data were collected in the early spring when foliage and undergrowth obscuring the ground surface was at a minimum. The orthophotography and LiDAR data were used to conduct “virtual walkdowns” of the areas. Based on results of these “virtual walkdowns,” areas were

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™Trimble GeoXT is a trademarked product of Trimble Navigation Limited, Sunnyvale, California.

selected to conduct walking surveys ( 30 × 30 m reference grid system). Vehicle surveys along accessible roads and utility easements were also part of the field investigation. In addition, standard walking surveys were conducted throughout the River Corridor along the Columbia River, based on the level of interest in the shoreline area and its inclusion as part of the Hanford Reach National Monument (65 FR 37253).

100-K was addressed by a combination of three separate OSE reports including the 100-K OSE, *100-K Area Orphan Sites Evaluation Report* (OSR-2008-0003), parts of Segment 1 OSE, *100-F/IU-2/IU-6 Area – Segment 1 Orphan Sites Evaluation Report* (OSR-2009-0002), and Segment 4 OSE, *100-F/IU-2/IU-6 Area – Segment 4 Orphan Sites Evaluation Report* (OSR-2011-0001). Within 100-K, 22 orphan sites (new discovery sites) that were identified through the OSEs are addressed in the 100-K RI/FS report. The results from this evaluation are discussed in Section K3.3.

# K3 Evaluation Results

This section summarizes the results of the NPE in the 100-K OU of the River Corridor based on the approach presented in Section K2. The NPE is based on multiple lines of evidence, including the results from surveillance and monitoring programs, and other studies conducted in the River Corridor; the results from statistical analyses performed to identify the potential presence of waste sites and to evaluate the spatial distribution of selected radionuclides in soil; and the results from the OSE.

## K3.1 Results from Surveillance and Monitoring Programs

Hanford Site programs, which provided information characterizing conditions in the nonoperational areas in and around the 100-K OU, included the soil, air, and vegetation sampling conducted as part of the Near Facility Monitoring program and the Surface Environmental Surveillance Program (SESP). The radiological control program with emphasis on radiological surveys and activities for identifying and controlling biological vectors (biointrusion from plants and animals), and external radiation monitoring conducted as part of the SESP.

Other activities that contribute to characterizing conditions in the nonoperational areas include the waste site discovery process under TPA-MP-14, which results in identified waste sites being inventoried in WIDS and, as discussed in Section K3.3, the OSE. Historically, interim actions conducted under the Radiation Area Remedial Action (RARA) project contributed to stabilizing and controlling releases from waste sites. The results from these programs have been discussed using the framework of the conceptual model described in Section K2.1.

### K3.1.1 Anthropogenic Disposal Activities

Past and present investigation activities provide confidence that waste site locations within the River Corridor are known. Waste site identification activities in the River Corridor fall into two categories: systematic and observational. Various systematic programs have been conducted at different times since the beginning of Hanford Site transition from production to cleanup in the 1980s, with the most recent being the OSE program that was initiated in 2004 (Section K3.3). An inventory of known and potential waste sites has been maintained in the WIDS database since the early 1980s, and is continually maintained through the TPA-MP-14 discovery process. Between 1985 and 1988, preliminary assessment/site inspection activities were completed to identify waste sites and prioritize the relative hazards. Waste disposal information was collected through exhaustive reviews of literature and maps, employee interviews, and visual inspection of all sites and unplanned releases. Results were organized and sites were ranked with respect to potential environmental impacts in accordance with a slightly modified version of the CERCLA hazard ranking system. The results from this process provided

information to support addition of the 100 and 300 Areas to the NPL and subsequent listing of waste sites in Appendix C of the Tri-Party Agreement (Ecology, et al., 1989).

A variety of characterization activities conducted as part of the RI/FS process has further characterized potential release and disposal activities in the 100 Area. These historical activities are summarized in the RI/FS Work Plan for the 100 Area (DOE/RL-2008-46).

### K3.1.2 Windblown Dust Emissions

Emission sources, which could release contaminants through wind-blown dust, are described variously as "fugitive," "diffuse," or "nonpoint" emissions sources (DOE/RL-2010-17). The Hanford Site consists of 1,518 $km^2$ (586 $mi^2$) of semiarid shrub-steppe land, of which approximately 6 percent (about 83 $km^2$ [32 $mi^2$], or 8,909 ha [20,000 ac]) has been actively disturbed or actively used. This 6 percent of land is distributed into large operational and support areas where almost all fugitive emissions sources are located: the 100, 200 (which include 200 East and 200 West), 300, and 400 Areas.

The potential for fugitive dust emissions from waste sites (prior to their cleanup) is generally characterized as occurring subsequent to erosion of soil covers or plant or animal biointrusion, which may expose erodible material containing concentrations of radionuclides. Contaminated areas posted as Radiologically Controlled Areas or Soil Contamination Areas also could contain erodible material that is radiologically contaminated, and that could produce fugitive emissions from resuspension of windblown dust (DOE/RL-2010-17).

The RARA program is responsible for the interim stabilization, surveillance, and maintenance of the inactive waste sites at the Hanford Site. Interim stabilization measures to control fugitive dust have historically been performed on inactive waste sites prior to their cleanup. Stabilization measures included consolidation of surface contamination within the waste site from which it originated, then covering the waste with a layer of soil or other material (such as cobbles). Waste sites were then revegetated or treated as needed with a nonselective herbicide. Quarterly surveillance, annual radiological surveys, annual herbicide applications, removal of deep-rooted vegetation, and occasional corrective action for small areas of surface contamination that appear continued following stabilization. Interim stabilization reduced sources of windblown dust potentially originating from contaminated soils.

The potential magnitude of windblown dust transport can be evaluated from the frequency of restrictions to visibility and ambient air monitoring for particulate matter and radionuclides in air. Dust, blowing dust, and smoke from field burning are described as phenomena causing restrictions to visibility (i.e., visibility less than or equal to 9.6 kg [6 mi]. Reportedly, there are few such days at Hanford (PNNL-6145). Particulate air monitoring shows that annual average $PM_{10}$ (particulate matter finer than 10 cm in diameter) concentrations at the Hanford Meteorological Station are similar to $PM_{10}$ concentrations at the Benton Clean Air Authority station located in Kennewick.

### K3.1.3 Stack Emissions

Radionuclide emissions formerly from stacks in the 200 Area and the 100 Area had the potential to impact the River Corridor through deposition from the air. Based on studies conducted as part of the Hanford Environmental Dose Reconstruction (HEDR) project, most of the emissions occurred between 1944 and 1972 from facilities in the 200 Area that separated plutonium and uranium from irradiated reactor fuel (WDOH, 2004; Heeb, 1994). The largest releases from these facilities occurred in 1945, before effective collection devices were installed ahead of the stacks to prevent the discharge of volatile and particulate radionuclides. Most of the inventory emitted consisted of gaseous and/or short-lived radionuclides, which would be unlikely to result in measurable concentrations in soil in Hanford Site nonoperational areas. The nine production nuclear reactors in the 100 Area had stacks to exhaust

ventilation air from the working areas of the reactor facilities. These were minor sources of emissions compared to the 200 Area facilities. No significant stack releases from 300 Area operations were reported in the documents that evaluated soil sampling and monitoring. The 300 Area primarily supported fuel fabrication processes and research activities that were not expected to have contributed to radioactive airborne emissions released on the Hanford Site (DOE/RL-2005-49).

Releases of long-lived radionuclides, including Am-241, Cs-137, I-129, Sr-90, Pu-238, Pu-239/240, and Pu-241, from the 200 East and the 200 West Area major stacks, were a very small fraction of the total inventory emitted into the air. A review of dose reconstruction information indicates that most of the total releases of long-lived radionuclides consist of Cs-137 and Sr-90 with a minor contribution of the other radionuclides.

Potential long-term impacts from these emissions within the Hanford Site have been assessed through air and soil sampling conducted as part of the Near Facility Monitoring and SESP programs (PNNL-19455). Air sampling at the 100-K is performed at a sampling station located south of the fence line of the operational area. Particulate sampling for gross alpha and beta radiation, conducted at this station since 1991, shows either a flat or a declining trend in concentrations. Direct measurements of gamma dose made at this station with a thermoluminscent detector since 1970 have shown background levels of radioactivity, with the exception of an elevated level measured in 2005. The Annual Environmental Reports describe the general trends in radionuclide concentrations measured in soil. While concentrations at some near-facility sampling locations are higher than offsite locations, average concentrations are low and show no changes in trends over several years (PNNL-19455). In general, concentrations of sampled radionuclides, including Cs-137, Sr-90, Pu-239/240, U-235, and U-238, resemble Hanford Site background concentrations in soil.

### K3.1.4 Overland Flow

The Hanford Site is in a semiarid region and thus experiences many dry periods. January, March, and December are the only months that have always received measurable precipitation, reported from 1946 through 2004. Normal annual precipitation at the Hanford Site is 17.7 cm (6.98 in.) (PNNL-15160). In the Hanford semiarid climate, precipitation is balanced by evaporation, transpiration, and vegetative uptake such that substantial overland flow from precipitation is an unlikely occurrence.

A more likely source for overland flow is historical spills or releases from liquid waste disposal facilities during active operational periods. Liquid effluents generated as a direct result of reactor operations consisted primarily of reactor cooling water, fuel storage basin water, and decontamination solutions.

Cooling water was transferred from the reactor buildings through effluent lines to the retention basins for cooling and decay of short-lived radionuclides. From the retention basins, the water was transferred through large pipes to the outfall structures, then into pipes that discharged to the Columbia River. Overflow from the outfall structures also could discharge directly to the shore of the river through nearby spillways (WHC-SD-EN-TI-239). During 1975, sampling was performed of all the retired radioactive liquid waste disposal sites, retention basin systems, and associated diversion trenches in the 100 Area. Sampling was performed of the contaminated fill inside the basins and along and in effluent lines and junction boxes, and through the basin floors; most importantly for understanding overland flow, samples were taken along the outside of the retention basin walls (UNI-946).

Leaks from the liquid waste disposal sites in the 100 Area that resulted in overland flow are described in the report of the 1975 sampling event (UNI-946). In general, these leaks were infrequent, well-cocumented, and resulted in localized contamination around the periphery of the disposal sites. The leaks have been characterized historically or as part of the current RI/FS process. The majority have been cleaned up and

interim closed out in accordance with the interim action RODs. The identification of leaks or spills from waste sites also is incorporated into the procedure for maintaining WIDS in accordance with the Tri-Party Agreement Procedure TPA-MP-14 (RL-TPA-90-0001). Based on the available information, overland flows from liquid waste disposal facilities are limited in lateral extent, and unplanned liquid release sites are identified through existing programs such as WIDS. The factors considered in this evaluation indicate that contamination in nonoperational areas through overland transport is unlikely to occur.

### K3.1.5 Biointrusion

The Quarterly Environmental Radiological Survey Summary (HNF-SP-0665, Rev 79) identifies mud dauber wasp nests as a potential animal intrusion concern in 100-K. Radiological surveillance monitoring or vegetation sampling conducted as part of the Near-Facility Monitoring Program (PNNL-19455) has not identified contaminated vegetation episodes around the 100-K OU.

## K3.2 Statistical Evaluations

The statistical evaluations provide estimates of the likelihood of finding previously undiscovered waste sites in the nonoperational property areas and the potential for exposure to Cs 137 exceeding selected threshold concentrations in surface soils.

### K3.2.1 Relative Probability of Missing an Existing Waste Site

Known waste sites have largely been located in proximity to anthropogenic features and relatively particular topographic conditions. For example, most waste sites found to date are close to roads, in low lying areas such as ditches or ponds, or proximate to operational areas. The distributions of these geographic variables, measured at known WIDS sites, were compared with the distribution of the same variables calculated at an unbiased set of locations systematically distributed across the Hanford Site.

Logistic regression was used to test the hypothesis that waste sites are predictably located across the Central Plateau and River Corridor. To test this hypothesis, the geographic variables measured at waste site locations were compared with the same variables measured at a series of regularly spaced locations across the Hanford Site. The method builds the predictive model of the binary variable (presence or absence of a waste site) against the explanatory variables of interest (Hosmer and Lemeshow 1989, *Applied Logistic Regression*).

Factors considered in developing predictor variables for known waste sites and sources included distance to operational areas; distance to roads, railroad grades, lakes, streams, utility rights of way (e.g., power lines); and topography.

Predictive models of waste site locations were developed with logistic regression. Separate working models were selected for predicting waste site locations in general (Model A, n = 2,148 sites) and for predicting 100 200 300 Series waste sites (Model B, n=510 sites). Model A consists of five predictors, which are all distance measures to geographic features: local road, railroad, power line, Hanford Road, 200 Area Ponds (216 S 16P). The same five predictors were selected for Model B. All regression coefficients in Models A and B were highly significant ($p < 0.001$). In Model A, distance to local roads was the strongest predictor of waste sites (largest regression coefficient in magnitude); the odds ratio associated with being 1,000 m (3,280 ft) from a local road was .019 (CI = 0.014 to 0.029). Inversely, the odds of finding a waste site along a local road were 53 times (CI = 34 to 72) the odds of finding a waste site 1,000 m (3,280 ft) from a local road. In Model B, distance to local road was also the strongest predictor with the odds of finding 100 200 300 Series waste site along a local road being 333 times (CI = 10 to 1,000) the odds of finding a 100 200 300 Series waste site 1,000 m (3,280 ft) from a local road.

### K3.2.2 Spatial Analysis of Soil Radionuclides and Aerial Surveys

Measurements of the presence of radionuclides were available from direct soil measurements, as well as from laterally extensive radiological aerial surveys. Soil measurements were expressed as activities per unit mass (pCi/g) suitable for estimation of exposure for risk assessment, whereas data obtained from aerial surveys were expressed as gross counts for gamma emitting radionuclides. The aerial survey data were not directly applicable to estimation of potential exposure without calibration to soil Cs-137 activity data. A preliminary analysis using geostatistical methods was used to develop a spatially explicit relationship between soil activity measurements and aerial survey gross counts within the BCCA. Detailed geostatistical analysis was conducted within the BCCA because high-resolution aerial survey data and relatively high-density soil sampling were available for this area. The preliminary analysis of the BCCA data was used as a pilot study to support determination to proceed with development of a more extensive sitewide model based on less resolved, but more laterally extensive aerial surveys of all the Hanford Site. An approach based on logistic regression was used to develop a relationship between the probability that Cs-137 levels exceed selected threshold values and gross counts from radiological aerial surveys. Linking soil and aerial survey measurements will provide a basis for inference to Cs-137 levels at broad spatial scales, not possible with soil samples alone.

The two most recent aerial surveys were conducted in 1996 (DOE-0335, 2007, *An Aerial Radiological Survey of the Hanford Reservation Richland Washington, Date of Survey: February 29 to March 21, 1996*) and 2009 (SGW-45563, 2010, *An Aerial Radiological Survey of the Hanford BC Controlled Area and West Lake Area*). The 1996 survey provides sitewide coverage whereas the 2009 survey is restricted to the BCCA, but is also a higher resolution survey. In addition to the higher resolution survey in 2009, there were also a large number of ground radiological surveys conducted in the BCCA to establish a relationship to the aerial survey results. This high-resolution survey is generally understood to provide reliable estimates of soil gamma emitting radionuclides in soils, while the reliability of the broader sitewide survey for prediction of radionuclide levels in soil was not known. It was hypothesized that quantifying soil radionuclide levels in specific areas of the NP could be greatly improved by taking advantage of the much greater spatial coverage of the 1996 aerial surveys, provided that reliable predictions of soil radionuclides could be justified.

A statistical model of the probability that soil Cs-137 levels exceed selected threshold levels (1.05, 1.5, 3.1, and 6.2 pCi/g) was developed as a function of gross counts of gamma emitting radionuclides using sitewide aerial survey results. The threshold levels overlap the range of preliminary remediation goals and remedial action goals for a residential scenario for Cs-137 in the River Corridor. Each soil sample was coded as either a zero or a one, indicating whether the soil measurement exceeded each threshold level. The logistic regression approach described previously was also applied to the soil Cs-137 samples. This binary (i.e., yes or no) variable was modeled as a logistic function of the gross counts from the aerial surveys. The results of the model are estimates of the probability that soils Cs-137 levels at a particular location (where gross counts are known) exceed the corresponding threshold levels. The logistic regression model provides a mathematical function that summarizes variation in the proportion of soil samples exceeding threshold levels as this proportion varies with radiological gross counts. Supporting this model development, there were 632 surface soil Cs-137 measurements within the Hanford Site that were paired with aerial survey gross counts for statistical analysis. Of these 632 samples, 435 (68 percent) were collected within the BCCA, which represents a much smaller percentage of the outer area. Because the BCCA is represented disproportionately to its size, summaries were developed both with and without the BCCA data.

Table K-2 shows that for all threshold levels (1.05, 1.5, 3.1, and 6.2 pCi/g) the percentage of samples exceeding all four threshold levels increases with gross counts. Figures K-5 and K-6 summarize the same data graphically as bar charts. Where gross counts are less than 5,000, the percentage exceeding threshold

levels was 4 percent for the 1.05 pCi/g threshold level and just 1 percent for the 6.2 pCi/g threshold level. When gross counts exceed 8,000, much higher than the majority of the NP, 77, 73, 64, and 64 percent for soil samples exceeded the 1.05, 1.5, 3.1, and 6.2 pCi/g threshold levels, respectively. In general, gross counts rarely exceed 6,000 in the NP.

When the BC control samples are removed from the analysis, the percentage exceeding threshold levels in areas where the gross counts are less than 5,000 approximately doubled from a range of 1 to 4 percent to a range of 2.5 to 10 percent. For areas with higher gross counts, the estimated percentage exceeding threshold levels was insensitive to inclusion or exclusion of the BCCA data. This can be seen by comparing rows 3 and 4 to rows 4 and 9, respectively, in Table K-3. The greatest sensitivity to inclusion or exclusion of the BCCA samples is in areas where aerial radiological survey gross counts are between 5,000 and 8,000.

The probability of exceeding threshold levels was strongly associated with gross counts for all four threshold levels ($p<0.0001$) for both data subsets—including or excluding BCCA. Four logistic regression models were developed to describe the probability of exceeding 1.05, 1.5, 3.1, and 6.2 pCi/g threshold levels as a function of gross counts from sitewide radiological aerial survey. Each of the four models was fit to the full set of Cs-137 samples as well as to a reduced set that excluded samples from the BCCA. Regression summaries for each of the eight analyses are listed in Table K-4, including coefficient (parameter) estimates, standard errors, significance levels for the test of no association, and finally odds ratios describing the increase in odds associated with a change of 1,000 in gross counts.

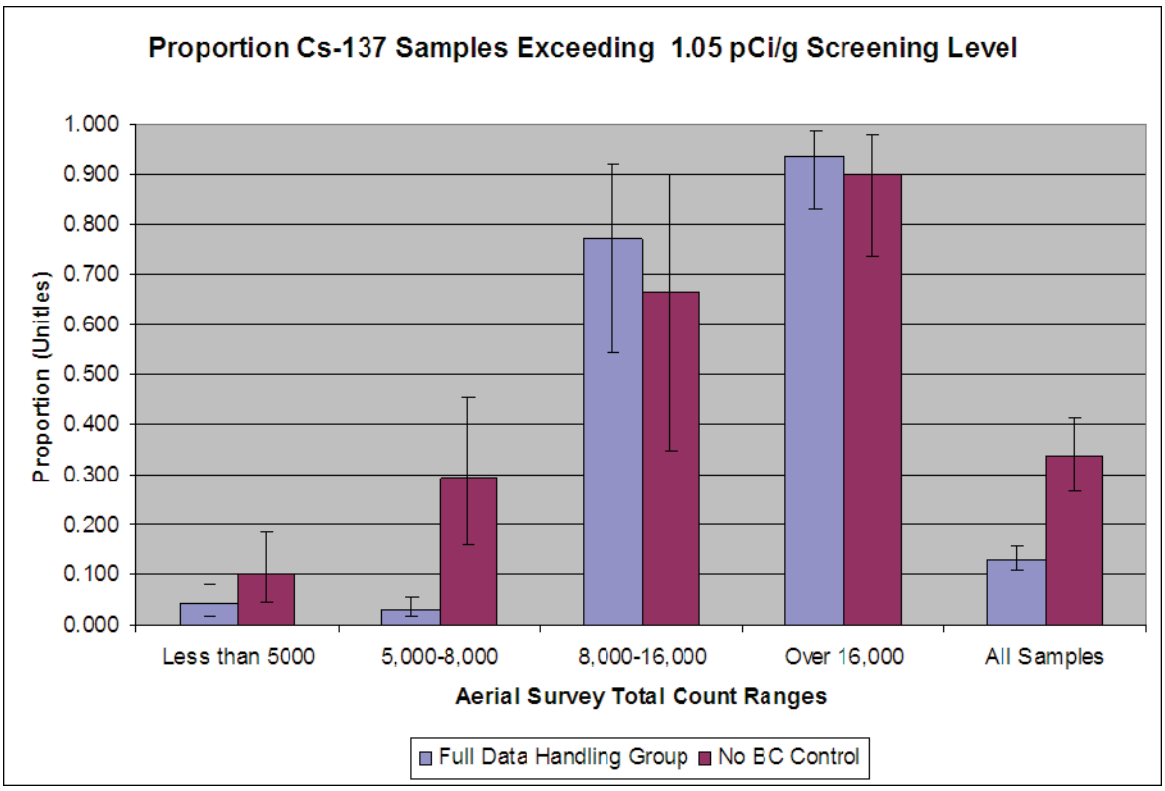
The logistic regression models provide estimates of the probability of exceeding threshold levels, which can be interpreted as estimates of the proportion of an area that would be expected to exceed those levels if one were to sample them. Figures K-7 and K-8 provide a map corresponding to the fitted probability model for the 1.05 pCi/g threshold level for the entire Hanford Site and for the 100-K Operable Unit, respectively. It can be seen that probabilities reflect the gross patterns of variation seen in aerial survey gross counts. The highest probabilities are clearly in proximity to known radiological sources. Figure K-9 shows the spatial distribution of the probability of exceeding 6.2 pCi/g threshold level, with the same color scale as that used for the 1.05 pCi/g threshold level, and it can be seen that nearly all of the nonoperational area have less than 2.5 percent probability of exceeding the 6.2 pCi/g threshold level. The nearly uniformly dark color of the map shows the much lower probability that surface soil samples are expected to exceed 6.2 pCi/g as compared to the probability of exceeding 1.05 pCi/g shown in Figure K-7. This illustrates the high degree of sensitivity to the selection of threshold levels regarding the area of the site that might be expected to exceed them.

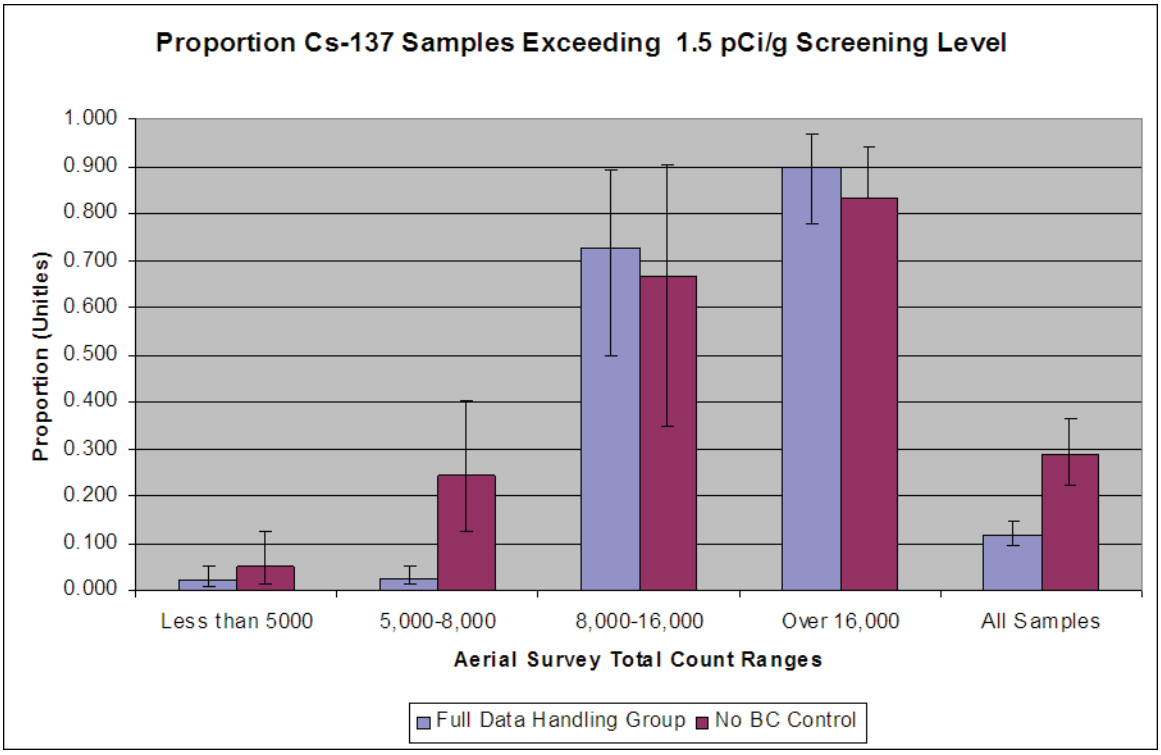
**Table K-2. Logistic Regression Models Predicting Probability that a Location is a Waste Site**

| Model | Endpoint | Predictor | Estimate | Std Error | Wald Chi-Square | P | OR* | 95% Confidence Intervals | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | OR LCL | OR UCL |
| A | All Waste Sites (n = 2148) | (Intercept) | -0.36030 | 0.06500 | 30.7 | <0001 | NA | NA | NA |
| | | Distance to Local Road | -0.00394 | 0.00017 | 570.4 | <0001 | 0.019 | 0.014 | 0.027 |
| | | Distance to Railroad | -0.00058 | 0.00004 | 258.8 | <0001 | 0.560 | 0.522 | 0.601 |
| | | Distance to Power line | -0.00046 | 0.00003 | 188.2 | <0001 | 0.631 | 0.591 | 0.675 |
| | | Distance to Hanford Road | 0.00042 | 0.00003 | 216.3 | <0001 | 1.516 | 1.435 | 1.601 |
| | | Distance to 200 Area Ponds (216-s-16P) | -0.00001 | 3.409E-06 | 19.1 | <0001 | 0.990 | 0.983 | 0.997 |
| B | 100-200-300 Series Waste Sites (n = 510) | (Intercept) | -0.72570 | 0.14930 | 23.6 | <0001 | NA | NA | NA |
| | | Distance to Local Road | -0.00596 | 0.00070 | 72.9 | <0001 | 0.003 | 0.001 | 0.010 |
| | | Distance to Railroad | -0.00237 | 0.00020 | 137.1 | <0001 | 0.093 | 0.063 | 0.139 |
| | | Distance to Power line | -0.00539 | 0.00046 | 135.1 | <0001 | 0.005 | 0.002 | 0.011 |
| | | Distance to Hanford Road | 0.00054 | 0.00007 | 60.2 | <0001 | 1.718 | 1.498 | 1.970 |
| | | Distance to 200 Area Ponds (216-S-16P) | 0.00004 | 6.13E-06 | 40.4 | <0001 | 1.040 | 1.027 | 1.052 |

* Odds ratio (OR) associated with being an additional 1,000 m (3,280 ft) distant from a given geographic feature.

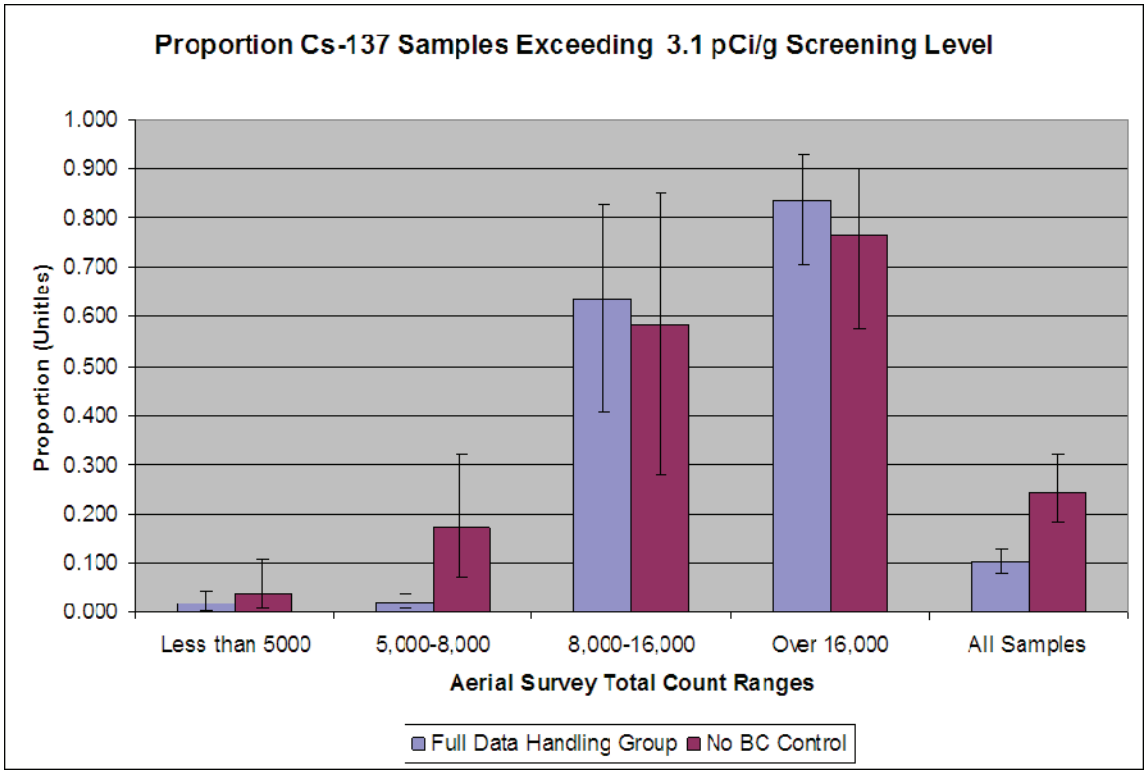
NA = not applicable
Std = standard
LCL = lower confidence limit
UCL = upper confidence limit

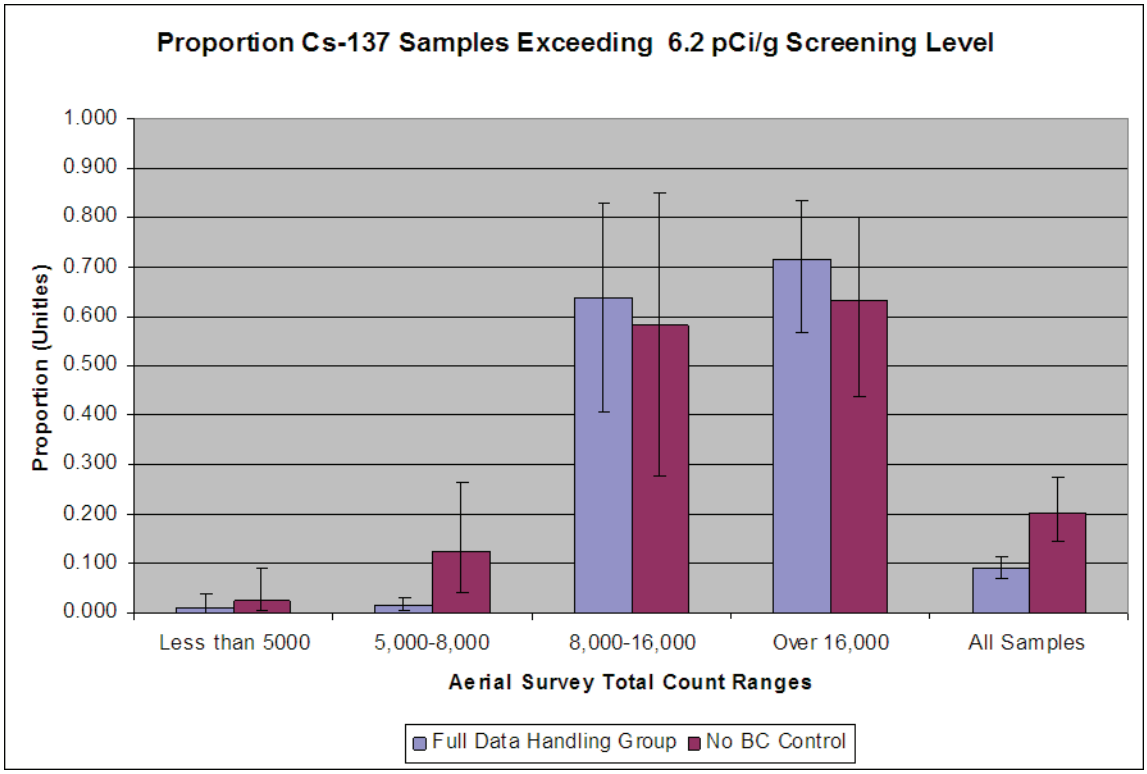



Note: Error Bars Represent 95 percent Exact Binomial Confidence Limits.

**Figure K-5. Proportion of Cs-137 Samples Exceeding the 1.05 pCi/g (Panel A) and the 1.50 pCi/g (Panel B) Threshold Levels Grouped by Corresponding Ranges of Aerial Survey Total Counts with and without Samples from the BCCA**




Note: Error Bars Represent 95 percent Exact Binomial Confidence Limits.

**Figure K-6. Proportion of Cs-137 Samples Exceeding the 3.1 pCi/g (Panel A) and the 6.2 pCi/g (Panel B) Threshold Levels Grouped by Ranges of Corresponding Aerial Survey Total Counts with and without Samples from the BCCA**

**Table K-3. Summary of Numbers and Proportions of Cs-137 Samples Exceeding Threshold Levels within Ranges of Aerial Survey Total Counts**

| Data Group | Vclass | N | Number Exceeding Threshold Levels | | | | Proportion Exceeding Threshold Levels | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1.05 pCi/g | 1.5 pCi/g | 3.1 pCi/g | 6.2 pCi/g | 1.05 pCi/g | 1.5 pCi/g | 3.1 pCi/g | 6.2 pCi/g |
| Full Data Handling Group | Less than 5,000 | 192 | 8 | 4 | 3 | 2 | 0.042 | 0.021 | 0.016 | 0.010 |
| Full Data Handling Group | 5,000 to 8,000 | 369 | 12 | 10 | 7 | 5 | 0.033 | 0.027 | 0.019 | 0.014 |
| Full Data Handling Group | 8,000 to 16,000 | 22 | 17 | 16 | 14 | 14 | 0.773 | 0.727 | 0.636 | 0.636 |
| Full Data Handling Group | Over 16,000 | 49 | 46 | 44 | 41 | 35 | 0.939 | 0.898 | 0.837 | 0.714 |
| **Total** | All Samples | 632 | 83 | 74 | 65 | 56 | 0.131 | 0.117 | 0.103 | 0.089 |
| No BC Control* | Less than 5,000 | 80 | 8 | 4 | 3 | 2 | 0.100 | 0.050 | 0.038 | 0.025 |
| No BC Control* | 5,000 to 8,000 | 41 | 12 | 10 | 7 | 5 | 0.293 | 0.244 | 0.171 | 0.122 |
| No BC Control* | 8,000 to 16,000 | 12 | 8 | 8 | 7 | 7 | 0.667 | 0.667 | 0.583 | 0.583 |
| No BC Control* | Over 16,000 | 30 | 27 | 25 | 23 | 19 | 0.900 | 0.833 | 0.767 | 0.633 |
| **Total** | All Samples | 163 | 55 | 47 | 40 | 33 | 0.337 | 0.288 | 0.245 | 0.202 |

* The BCCA is more densely sampled than other areas, so its 469 samples were excluded in the "No BC Control" data group to investigate sensitivity of estimates to the BCCA samples.

n = number of surface soil samples collected for Cs-137 analysis

**Table K-4. Estimated Logistic Regression Model Coefficients and Odds Ratios Associated with an Increase of 1,000 in Gross Counts**

| Threshold Level | Data Subset[a] | Parameter | Parameter Estimate[b] | Standard Error | Wald Chi-Square | Pr > ChiSq | Odds Ratio[c] | LCL 95 | UCL 95 |
|---|---|---|---|---|---|---|---|---|---|
| Greater than 1.05 pCi/g | All Data | Intercept | -8.8528 | 0.9808 | 81.5 | <0001 | | | |
| | | Gross Counts | 0.0010 | 0.0002 | 41.1 | <0001 | 2.7 | 2.3 | 3.2 |
| | No BCCA | Intercept | -5.1493 | 0.9605 | 28.7 | <0001 | | | |
| | | Gross Counts | 0.0007 | 0.0002 | 16.9 | <0001 | 2.0 | 1.7 | 2.3 |
| Greater than 1.5 pCi/g | All Data | Intercept | -9.6915 | 1.0807 | 80.4 | <0001 | | | |
| | | Gross Counts | 0.0011 | 0.0002 | 42.3 | <0001 | 2.9 | 2.5 | 3.5 |
| | No BCCA | Intercept | -6.2979 | 1.1749 | 28.7 | <0001 | | | |
| | | Gross Counts | 0.0008 | 0.0002 | 17.1 | <0001 | 2.2 | 1.8 | 2.7 |
| Greater than 3.1 pCi/g | All Data | Intercept | -8.0775 | 0.7590 | 113.3 | <0001 | | | |
| | | Gross Counts | 0.0007 | 0.0001 | 55.9 | <0001 | 2.1 | 1.9 | 2.3 |
| | No BCCA | Intercept | -6.1397 | 1.1020 | 31.0 | <0001 | | | |
| | | Gross Counts | 0.0007 | 0.0002 | 16.5 | <0001 | 2.0 | 1.7 | 2.3 |
| Greater than 6.2 pCi/g | All Data | Intercept | -7.4997 | 0.6431 | 136.0 | <0001 | | | |
| | | Gross Counts | 0.0006 | 0.0001 | 74.6 | <0001 | 1.9 | 1.7 | 2.0 |
| | No BCCA | Intercept | -6.3855 | 1.1387 | 31.4 | <0001 | | | |
| | | Gross Counts | 0.0007 | 0.0002 | 16.8 | <0001 | 2.0 | 1.7 | 2.3 |

a. The "All Data" subset included all Cs-137 samples from the Central Plateau, River Corridor, and north of the Columbia River with geographic coordinates, and that were associated with gross counts less than 20,000.

b. Parameter estimates are the estimated intercept and slope coefficients of the logistic regression model based on maximum likelihood.

c. The Odds Ratio is the change in odds associated when comparing locations with gross counts that differ by 1,000. The odds that soils exceed threshold levels double (i.e., increase by approximately a factor of 2) for each increase of 1,000 gross counts in the aerial surveys.

LCL 95 = 95% lower confidence limit UCL 95 = 95% upper confidence limit

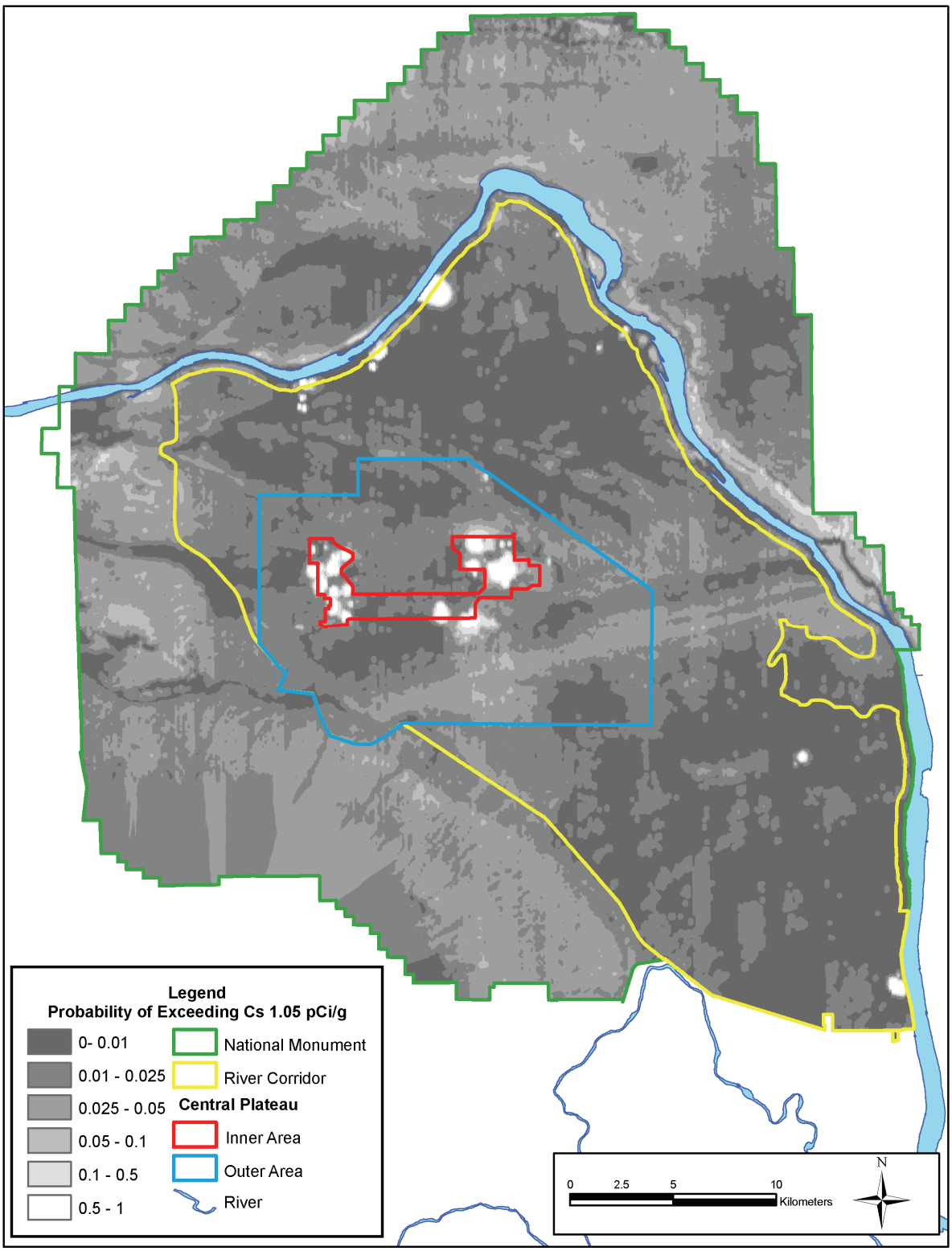



**Figure K-7. Modeled Probability that Soil Cs-137 Exceeds 1.05 pCi/g in the Hanford Site**

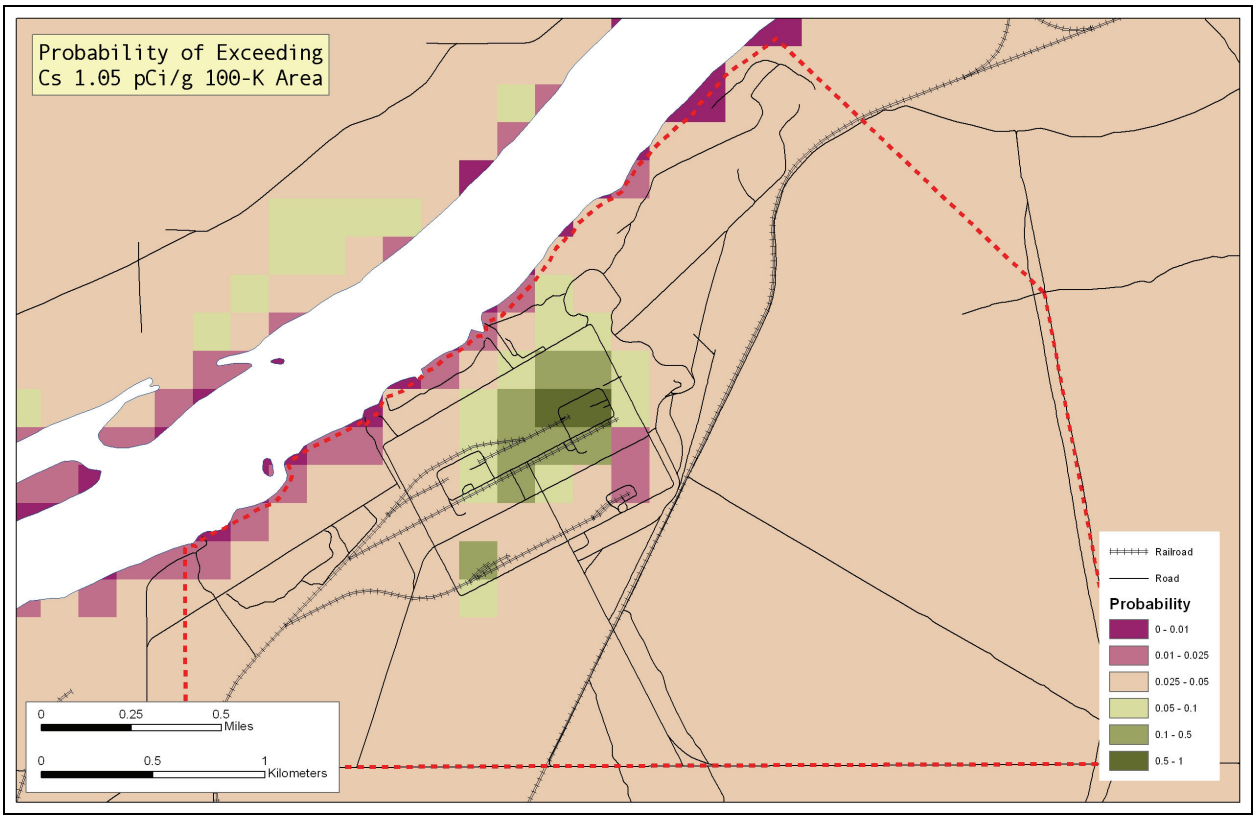



**Figure K-8. Modeled Probability that Soil Cs-137 Exceeds 1.05 pCi/g in the 100-K OU**

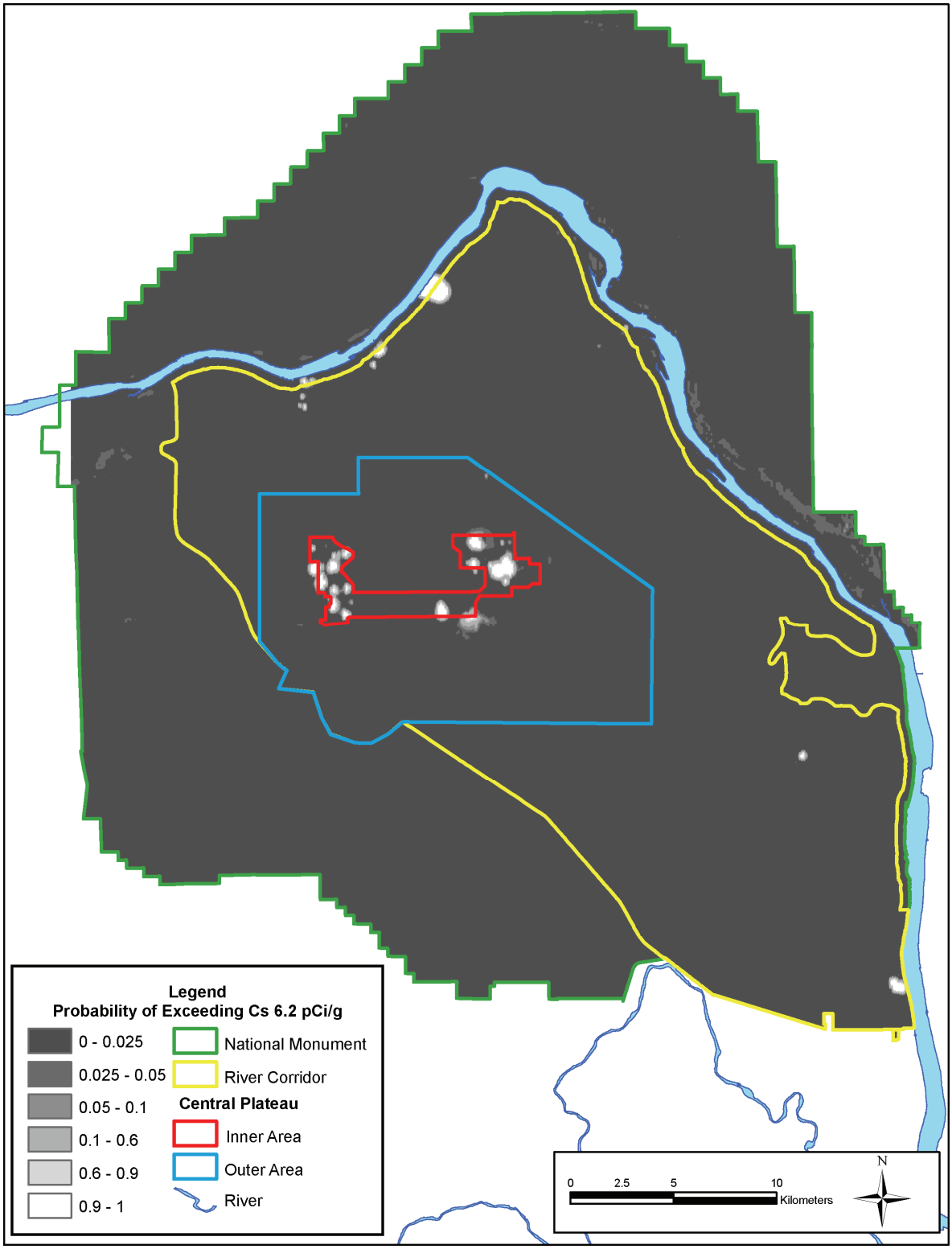



**Figure K-9. Modeled Probability that Soil Cs-137 Exceeds 6.2 pCi/g in the Hanford Site**

## K3.3 Orphan Sites Evaluation

The 100-K OU was addressed by a combination of three separate OSE reports including all of the 100-K OSE, *100-K Area Orphan Sites Evaluation Report* (OSR-2008-0003), parts of Segment 1 OSE, *100-F/IU-2/IU-6 Area – Segment 1 Orphan Sites Evaluation Report* (OSR-2009-0002), and Segment 4 OSE, 100-F/IU-2/IU-6 Area – *Segment 4 Orphan Sites Evaluation Report* (OSR-2011-0001). Sixteen orphan sites (new discovery sites) were identified through the 100-K OSE, six of which are within the 100-K Exclusion Area. There was concern that the six exclusion area sites were physically separated far enough from their associated facilities that they might get overlooked during facility demolition activities and therefore were identified as orphan sites. The information on these sites was provided to CHPRC for completion of the TPA-MP-14 process. TPA-MP-14 discovery site evaluation checklists were completed for each of the 10 orphan sites identified through 100-K evaluation located outside the exclusion area.

# K4 Conclusions

Multiple lines of evidence were reviewed to evaluate conditions in the 100-K nonoperational area (and the River Corridor more generally) based on potential release and transport mechanisms. Surveillance and monitoring programs, in combination with the OSE, have comprehensively identified all waste sites within the 100-K. In addition, the surveillance and monitoring programs, in combination with studies conducted as part of the HEDR, have demonstrated that emissions to the air either from windblown dust or from stack emissions have not impacted nonoperational area soils with radionuclides. The surveillance and monitoring programs also have verified that biointrusion has not resulted in a spread of contamination into the nonoperational areas.

Statistical analysis of the geographical distribution of waste sites based on man–made features and topography describes the likely locations of waste sites near the 100-K. The results from this analysis reinforce the findings from the OSE, which has systematically identified the remaining waste sites within 100-K. Statistical analysis of the distribution of radionuclide concentrations observable from aerial surveys has confirmed that the probability of detecting elevated radionuclide concentrations in nonoperational area soils is very small.

Based on the evaluation of these multiple lines of evidence, the probability of identifying waste sites or contaminant dispersal from Hanford Site operations in 100-K nonoperational areas is considered negligible.

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